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AN INTERNATIONAL METHODOLOGY FOR AN ASSESSMENT OF SOIL DEGRADATION AND GEOREFERENCED SOILS AND TERRAIN DATABASE

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INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

An International Methodology for an Assessment of Soil Degradation and Georeferenced Soils and Terrain Database[1]

by

L.R. Oldeman[2]

1 INTRODUCTION

The intense and increased pressure on land and water resources, leading to degradation and pollution of those resources, and leading to a partial or complete loss of the productive capacity of the soil calls for an approach that strengthens the awareness of users of these resources on the dangers of inappropriate management and at the same time strengthens the capability of national soil/land resources institutions to deliver reliable, up-to-date information on land resources in an accessible format to a wide audience.

Although soil degradation is recognized as a serious and widespread problem, its geographical distribution and the total areas being affected is only very roughly known. Sweeping statements that soil erosion is undermining the future prosperity of mankind do not help planners, who need to know where the problem is serious and were not (Dregne, 1986). The World Association of Soil Conservation stressed the point that, while water and wind erosion have severely impaired land productivity in many countries of the world, maps showing where erosion has reduced long-term productivity are virtually non-existent at the continental, national or regional scale. Such maps are needed to enable planners and donor agencies to make wise decisions on the allocation of scarce resources (WASC, 1989).

This feeling was also expressed by the United Nations Environment Programme (UNEP). This organisation expressed the need to produce, on the basis of incomplete knowledge, a scientifically credible global assessment of soil degradation in the shortest possible time. "Politically it is important to have an assessment of good quality now instead of having an assessment of very good quality in 15 to 20 years from now" (ISSS, 1987).

The project: Global Assessment of Soil Degradation (GLASOD), which was formulated by UNEP, was coordinated by the International Soil Reference and Information Centre (ISRIC) in close cooperation with a diverse group of more than 200 soil scientists and environmental experts worldwide and with expert advice from members of the International Society of Soil Science (ISSS), the Winand Staring Centre for Integrated Land, Soil and Water Research (SC/DLO) and the Food and Agricultural Organization (FAO). The first section of this paper will briefly describe the methodology developed for the preparation of a Global Map of the Status of Human-induced Soil Degradation. Some results derived from this map will also be discussed.

The GLASOD map serves as a tool to strengthen the awareness of policy-makers and decision-makers of the dangers resulting from inappropriate land and soil management. It can lead to a basis for the establishment of priorities for action programmes, in particular for rehabilitation in areas affected by human-induced soil degradation.

The GLASOD map cannot however assess the vulnerability of the land resources to soil degradation processes and thus assist policy-makers and resource managers to prevent the occurrence of soil degradation. For this a comprehensive information system on soil and terrain resources is needed. The World Soils and Terrain Digital Database -SOTER- is an internationally endorsed land resource information system, which can store, at different levels of detail, soil and terrain attributes in such a way, that these data can be assessed, combined, and updated, immediately and easily and can be analyzed from the point of view of potential land use, in relation to food requirements, environmental impact, and conservation. "Only through the development and application of such techniques -SOTER- can we catalyze the required breakthrough in land resource use,

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which is essential to halt and reverse the current degradation of land resources in developing countries (Higgins, 1990, pers.comm.). The second part of this paper describes the SOTER methodology and briefly discusses the implementation strategies for such a world wide Georeferenced Soil and Terrain Database.

2 GLOBAL ASSESSMENT OF SOIL DEGRADATION

In order to achieve the ambitious goal to prepare and publish a world map on the status of human-induced soil degradation within a time frame of three years a large group of soil scientists throughout the world was asked to give their expert opinion on soil degradation in their particular geographic region. In order to ensure uniformity in reporting and delineating on maps the seriousness of various soil degradation processes a simplified geographic base map was provided and general guidelines were developed for the assessment of the status of human-induced soil degradation (ISRIC, 1988). The cooperators were asked to indicate on the map regions where the balance between the attacking forces of climate and the natural resistance of the terrain against these forces has been broken by human intervention, resulting in a decreased current and/or future capacity of the soils to support life. The present status of soil degradation was to be characterized by the degree to which the soil is presently degraded and by the percentage of the mapped area that is affected by soil degradation. Only soil degradation occurrences which took place since 1945 were to be considered. Also the kind of physical human intervention that has caused soil deterioration had to be indicated.

2.1 The Topographic Base Map

UNEP requested the preparation of a wall chart on global soil degradation at a 1:10 million scale, which could be conveniently displayed on an office wall, in conference centres, in classrooms, etc. A base map on which the various continents would be displayed with as less distortion as possible was selected. While this topographic base map (Mercator Projection) had as additional advantage, that the three map sheets -Asia and Oceania; Africa and Europe; the America's- could be interchanged as desired, the variation in scale (1:15 M at the equator; 1:10 M at 48° latitude; 1:5 M at 70° latitude) is a serious disadvantage when areas displayed on the map are to be interpreted as actual surface areas. However actual surface areas could be calculated once the map units were digitized and linked to a Geographic Information System, capable of converting Mercator Projection into 'equal area' projection.

2.2 Soil Degradation Assessment

Soil degradation is defined as a process that describes human-induced phenomena which lower the current and/or future capacity of the soil to support human life. The GLASOD map does not indicate the present and/or future rate of degradation processes and the potential hazards that may occur under human influence. It delineates the present status of human-induced soil degradation, which can be defined by the type, the degree, and the areal extent of the degradation process. Excluded are soil degradation processes, that have occurred in the past as a result of geologic events or under past climatic conditions. However the map indicates those areas where natural erosion has lead to extreme conditions (salt flats, rock outcrops, moving dunes, deserts). In many parts of the world human-induced soil degradation occurred at various times in the past, but subsequently the land surface has come to equilibrium with the causes of soil degradation (e.g. much of the rangelands in Australia has eroded seriously in the past, but has now become stable again). The GLASOD map takes only into account soil degradation events that took place in the post second world war period, very much related to the human population explosion and the increasing demands of that population for higher living standards.

2.2.1 Soil degradation types

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 biomass 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 which lowers the current and/or future capacity of the soils to produce goods or services.

Two categories of soil degradation processes are recognized. The first group relates to displacement of soil material. The two major soil degradation types in this category are soil erosion by water forces or by wind forces. The second group deals with soil deterioration in-situ. This can either be a chemical or physical soil degradation process.

2.2.1.1 Water erosion (W)

The displacement of soil material by water can have several negative consequences. The removal of part of the usually fertile topsoil reduces the productive capacity of the soil, while in extreme cases the rooting depth can become restricted for agricultural crops. Although measurements of crop yield reductions caused by soil erosion are difficult, mainly because over time farmers may substitute increasing amounts of fertilizers to compensate for the loss of the natural fertility of the soil, studies in the U.S.A. have established relationships between soil erosion and reduced crop yield (Batie, 1983). In fragile soils with a low structure stability run-off water may lead to rapid incision of gullies, eating away valuable soils and making the terrain eventually unsuitable for farming. The GLASOD approach distinguishes two forms of water erosion:

1. *Loss of Topsoil (Wt).* This form of water erosion is generally known as surface wash or sheet erosion. It occurs almost everywhere, under a great variety of climatic and soil conditions and land uses. Loss of topsoil is often preceded by compaction and/or crusting resulting in a decrease of the infiltration capacity of the soil.
2. *Terrain deformation (Wd).* Although the total area affected by rills and gullies is far less compared to loss of topsoil its effects are more spectacular and more easy to observe in the field. Control of active gullies is difficult and restoration is almost impossible.

2.2.1.2 Wind erosion (E)

The displacement of soil material by wind is nearly always caused by a decrease of the vegetative cover of the soil, either due to overgrazing or to the removal of vegetation for domestic use or agricultural purposes. It is a wide-spread phenomenon in arid and semi-arid climates. In general, coarse textured soils are more vulnerable to wind erosion than fine-textured soils. Three types of wind erosion are recognized by GLASOD:

1. *Loss of topsoil (Et),* defined as a uniform displacement of the topsoil.
2. *Terrain deformation (Ed),* defined as an uneven displacement of soil material, leading to deflation hollows and dunes. Although mapped separately, this type of wind erosion may be considered as an extreme form of loss of topsoil.
3. *Overblowing (Eo)* is defined as the coverage of the land surface by wind-carried particles. In contrast to off-site effects of water erosion, this off-site effect of wind erosion occurs on relative large areas and is mappable. Overblowing may seriously influence the infrastructure (road, rail roads), buildings and waterways, and may cause damage to crops.

2.2.1.3 Chemical degradation (C)

Chemical degradation of the soil does not refer to cyclic fluctuations of the soil chemical conditions of relatively stable agricultural systems, in which the soil is actively managed to maintain its productivity, nor to gradual changes in the chemical composition as a result of soil forming processes. The following chemical degradation processes are distinguished:

1. *Loss of nutrients and/or organic matter (Cn).* Loss of nutrients is a common phenomenon in countries with low-input agriculture. It occurs if agriculture is practiced on poor or moderately fertile soils, without sufficient application of manure or chemical fertilizers. The rapid loss of organic matter of the topsoil after clearing of the natural vegetation is also included.
2. *Salinization (Cs)* is defined as a change in the salinity status of the soil. It can be caused by improper management of irrigation schemes, mainly in the arid and semi-arid regions covering small areas. Salinization may also occur if seawater or fossil saline groundwater intrudes in coastal regions or in closed basins with aquifers of different salt content when there is an excessive use of groundwater. Finally, salinization takes place where human activities lead to an increased evapotranspiration in soils on salt-containing parent material or with saline groundwaters.
3. *Acidification (Ca)* may occur in coastal regions upon drainage/oxidation of pyrite-containing soils. Acidification is also caused by over-application of acidifying fertilizers. In both cases the agricultural potential of the land is reduced.

4. *Pollution (Cp)*. Many types of pollution can be recognized, such as industrial or waste accumulation, excessive use of pesticides, acidification by airborne pollutants, excessive manuring, oil spills, etc. This form of soil degradation is generally restricted to heavily industrialized nations with high population densities, although the effect of acidification by airborne pollutants may lead to deposits at considerable distance from its source.

2.2.1.4 Physical degradation (P)

Within the category of physical degradation, three different types are identified:

1. *Compaction, crusting and sealing (Pc)*. While compaction of the soil is usually caused by the use of heavy machinery, sealing and crusting of the topsoil occurs if the soil cover is not sufficiently protected from the impact of raindrops. In particular, soils low in organic matter with poorly sorted sand fractions and appreciable amounts of silt are vulnerable.
2. *Waterlogging (Pw)*. Human intervention in natural drainage systems may lead to flooding by river water and submergence by rainwater. It should be noted that the construction of paddy fields is not included in this category as it is considered an improvement of the terrain for wetland rice cultivation.
3. *Subsidence of organic soils (Ps)*. This phenomenon is caused by drainage and/or oxidation of organic soils. It is only identified on the map if the agricultural potential is negatively affected.

2.2.2 Miscellaneous terrain types

Human-induced soil degradation is widespread throughout the world, but large areas are not affected by human intervention because the land is either unsuitable for agricultural activities (climatic, topographic and soil constraints) or poorly accessible. On the GLASOD map, two categories of land are recognized without human-induced soil degradation.

2.2.2.1 Stable terrain (S)

The stable terrain is subdivided in three categories depending on the type of human intervention or its absence:

1. *Stable terrain under natural conditions (SN)*. Absence of any kind of human intervention because the type of land, the climatic conditions or the accessibility is not suitable for living or for agricultural activities. Large portions in northern Canada, northern Europe and the former U.S.S.R. are included, but also large parts of the Himalaya and Andes mountains, as well as certains portions of the rainforests in South America and Africa.
2. *Stable terrain with a permanent agricultural land use (SA)*. If agricultural land is well managed, no soil degradation will occur and productivity levels will not decrease.
3. *Terrain stabilized by human intervention (SH)*. With the growing awareness of the dangers of soil degradation, efforts to conserve this precious natural resource are growing. Examples of conservation practices are reforestation, terracing, gully control, improved water management.

2.2.2.2 Wastelands

Historic or recent natural processes have rendered these terrain into unused wastelands. There is no appreciable vegetative cover or agricultural potential. The GLASOD map recognizes in this group active dunes (D), deserts (A), salt flats (Z), rock outcrops (R), arid mountain regions (M), and ice caps (I).

It should be noted that these miscellaneous terrain types are identified on the GLASOD map, only if the mapping unit does not include any form of human-induced soil degradation. This implies that even if a mapping unit has an infrequent occurrence of a certain type of soil degradation, the whole mapping unit is coloured according to that type of soil degradation, although the vast majority of the land in that mapping unit may be stable, or may include wasteland.

2.2.3 *The degree of soil degradation*

In the GLASOD approach, the degree to which the soil is presently degraded is related in a qualitative manner to the agricultural suitability of the soil, to its declined productivity, to its possibilities for restoration to full productivity and in relation to its original biotic functions. The following four degrees of soil degradation were specified:

1. Light. The terrain has a somewhat reduced agricultural suitability, but is suitable in local farming systems. Restoration to full productivity is possible by modifications of the management. Original biotic functions are largely intact.
2. Moderate. The terrain has a greatly reduced productivity, but is still suitable for use in local farming systems. Major improvements are required to restore the terrain to full productivity, which are beyond the means of local farmers in developing countries. Original biotic functions are partially destroyed.
3. Strong. The terrain has virtually lost its productive capacity and is not suitable for use in local farming systems. Major investments and/or engineering works are required to rehabilitate the terrain, which are often beyond the means of national governments in developing countries. Original biotic functions are largely destroyed.
4. Extreme. The terrain is unreclaimable and beyond restoration. It has become human-induced wasteland. Original biotic functions are fully destroyed.

These general descriptions are qualitative and judgements made by the experts in the field are subjective. Some more quantitative tools are provided in the guidelines to support these estimates. They are given as Annex 1 for the degree of soil degradation due to water erosion, wind erosion, salinization and nutrient decline.

2.2.4 *The relative extend of soil degradation*

At the chosen scale of the GLASOD map it will not be possible to separate each type of soil degradation as individual events. The experts were asked to give their best estimate of the frequency of occurrence of each type of soil degradation within each mapping unit as a percentage of the surface area affected. The following five categories were defined:

1. Infrequent: up to 5 % of the mapped terrain is affected
2. Common: 6 to 10 % of the mapped terrain is affected
3. Frequent: 11 to 25 % of the mapped terrain is affected
4. Very frequent: 26 to 50 % of the mapped terrain is affected
5. Dominant: more than 50 % of the mapped terrain is affected

2.2.5 *Causative factors of soil degradation*

The concept of human-induced soil degradation implies by definition a social problem. No person will intentionally destroy this precious natural resource. But increasing pressure on the land, the increased desire for better living conditions, and higher standards of living, the search for land to survive etc. etc., have resulted in some kind of physical human intervention that has caused the soil to degrade. The GLASOD approach distinguishes the following types of causative factors:

1. *Deforestation or removal of the natural vegetation (f)*. Clearing of the land for agricultural purposes, large scale commercial forestry, road construction, urbanisation.
2. *Overgrazing (g)*. Actual overgrazing of the vegetation may not only lead to vegetation degradation, but can cause soil compaction, wind and water erosion.
3. *Agricultural activities (a)*. This includes a wide variety of agricultural practices, such as insufficient or excessive use of fertilizers, use of poor quality irrigation water, improperly timed use of heavy machinery, absence of anti-erosion measures on land susceptible to water and wind erosion, etc.
4. *Overexploitation of the vegetation for domestic use (e)*, e.g. for fuel needs, fencing, etc. There is not a complete removal of the vegetation but the remaining vegetation does not provide sufficient protection against soil erosion or sealing and crusting of the topsoil.
5. *Bio-industrial and industrial activities (i)*. These causative factors are directly related to the soil degradation type 'soil pollution'.

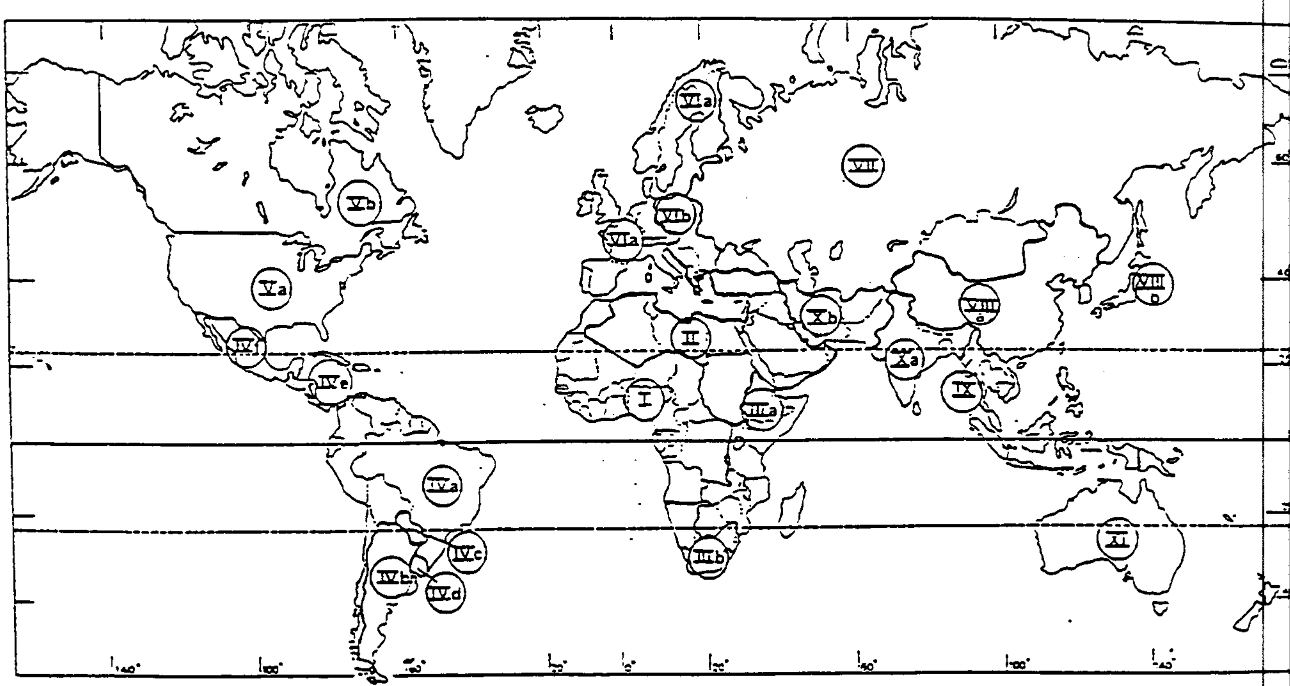
2.2.6 Recent past rate

Recognition of the average rate of soil degradation should be estimated in relation to changes in population densities; intensification of mechanization, fertiliser use, etc. during the last 5 to 10 years. Since recent past rate is not very clearly defined the reliability is limited. Only two categories are shown by symbols on the map (medium and rapid).

2.3 Methodology

2.3.1 Operational methods

In order to achieve the ambitious goal to prepare and publish a world map of the status of human-induced soil degradation within a time frame of three years it was not feasible to request individual nations to prepare soil degradation maps of their own country. As soil degradation phenomena transcends national boundaries the world was divided into 21 regions (see Figure 1). Regional correlators -institutes or individual experts- were designated and requested to give their best estimate on types of soil degradation, its degree, relative extent and causative factor for each physiographic unit, delineated on the basic topographic map. They were asked to prepare their reports in close collaboration with national soil experts in their region. These reports consist of a physiographic map and a matrix table, as illustrated in Figure 2.



I : West + Central Africa
II : North Africa + Arab countries + Turkey
III^{a} : East and South East Africa
III^{b} : Southern Africa
IV^{a} : South America
IV^{b} : Argentina
IV^{c} : Paraguay
IV^{d} : Uruguay
IV^{e} : Central America
IV^{f} : Mexico.
V^{a} : USA
V^{b} : Canada.
VI^{a} : West + South + North Europe
VI^{b} : East + Central Europe
VII : USSR + Mongolia
VIII^{a} : China, North Korea
VIII^{b} : Japan, South Korea
IX : Southeast Asia
X^{a} : Indian Subcontinent
X^{b} : Iran + Afghanistan + Pakistan
XI : Australia + N. Zealand + P. New Guinea + S. Pacific

Figure 1: GLASOD Regions

GLASOD MATRIX TABLE

Map unit : D25
Country 1 : Kenya
Country 2 :
Country 3 :
Area(km2) : 16900

Physiography : Upland, undulating to rolling (dom)
Plateau, undulating (inc)
Soil : AC , clay, deep (ass)
FR , clay, deep (ass)
Geology : Metamorphic rock
Precipitation (an.mean) : 500-900 mm
Temperature (mean) : 21-23 degr.C
Population density : Medium to high
Land use : Mixed farming
Vegetation : Grassland

General remarks :

DEGRADATION CHARACTERISTICS

Type	Caus	Degr	Rate	Ext	Remarks
Wt	g	3	3	4	Caused by sealing, Pk occurs in same area
Wd	g	3	3	2	On steeper slopes
Pk	g	1	1	1	No Wt yet
SN				5	

GLASOD MATRIX TABLE

Map unit : D26
Country 1 : Kenya
Country 2 : Tanzania
Country 3 :
Area(km2) : 42100

Physiography : Plain, undulating (dom)
Hills, steep (inc)
Soil : FRr, clay, deep (dom)
LPe, shallow (inc)
Geology : Metamorphic rock
Precipitation (an.mean) : 200-700 mm
Temperature (mean) : 23-29 degr.C
Population density : Low to medium
Land use : Pastoralism
Vegetation : Bush/shrubland

General remarks : Large area occupied by Tsavo national park, no degradation. Taita hills: heavy erosion in past, now stabilized by conservation practices

DEGRADATION CHARACTERISTICS

Type	Caus	Degr	Rate	Ext	Remarks
Wd	g	3	1	1	On footslopes around hills, now stabilized
Wt	g	1	1	4	Result of Pc in same area
Eo	g	1	1	3	
SH				2	Taita hills, stabilized by cons. practices (SHc)
SN				4	

Figure 2: Examples of two matrix tables, provided by the regional correlators (from Hakkeling, 1989).

In the mean time procedures were developed for the final preparation of the GLASOD map. Through a fruitful cooperation with the Staring Centre in Wageningen the 21 different maps and complementary tables were compiled and comments from the regional cooperators were, whenever possible, incorporated to ensure that the final GLASOD map was the best possible approximation of the global status of human-induced soil degradation. The final draft version was then sent to national soil institutions throughout the world for their comments and acceptance. Only then the final version of the map was prepared.

2.3.2 The Legend

Several concepts were developed for the legend of the GLASOD map, keeping in mind that the main objective of the map was to create awareness on the seriousness of soil degradation in a global perspective among policy-makers, decision-makers and the general public. At the same time however, the map should provide information in sufficient detail on the various aspects of soil degradation, as reported by the regional correlators.

Although the matrix tables accompanying the regional map sometimes listed several types of soil degradation, occurring in the same mapped unit, only a maximum of two types are indicated on the map. Four colours were selected to represent the four main types of soil degradation (bluish green for water erosion; yellowish brown for wind erosion; red for chemical degradation; pink for physical degradation). The colour of the mapped unit was determined by the dominant degradation type occurring in the unit.

The seriousness of soil degradation is an expression of the combination of the degree and the relative extent. Since four degrees are specified and five categories of relative extent are given, a total of 20 combinations are possible. These 20 combinations (see Figure 3) were then assembled in four groups. Each group is given a different shade of the colour of the degradation type. A serious drawback of this grouping is that for example a high severity may indicate a strong degree of degradation occurring infrequently, but also a light degree of degradation occurring frequently. However degree and relative extent of each degradation type is always given on the map by a number combination.

Other symbols, like the causative factors and the recent past rate are indicated as symbols in each mapping unit.

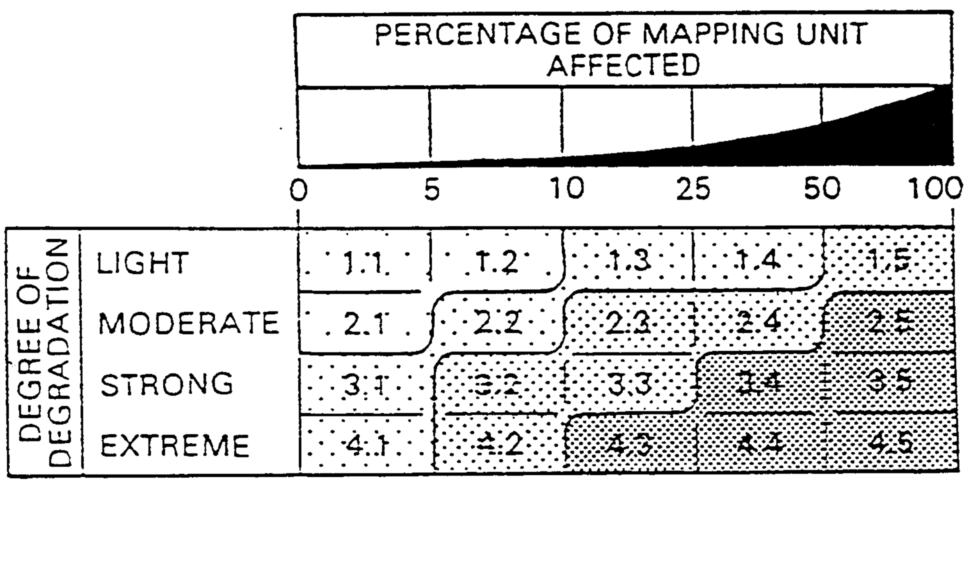


Figure 3. Severity classes of human-induced soil degradation.

2.4 The extent of soil degradation

Since the surface area of each mapped unit on the GLASOD map can be calculated separately once the map was digitized, an estimate can be made of the area within each mapped unit that is affected by human-induced soil degradation. Although the mapped scale of the GLASOD map does not allow to make areal estimates on a country-by-country basis, statistics for the world and for continents can be given. A summarized data set is given in Table 1. In this table Asia is split up in South East Asia, which includes the following countries: Bangladesh, Bhutan, Brunei, China, India, Indonesia, Kampuchea, Korea DPR, Korea Rep., Laos, Malaysia, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand, and Vietnam. The remaining countries of Asia are grouped under W. Asia.

Table 1 The extent of the status of human-induced soil degradation by type, degree and causative factor for the world and major continents or regions, expressed in million hectares.

	World	Asia	SE Asia	W. Asia	Africa –	S. America	C. America	N. America	Europe	Oceania
Degradation Type										
Water	1094	440	322	118	227	123	46	60	114	83
Wind	548	222	88	134	187	42	5	35	42	16
Nutrient decline	135	14	10	4	45	68	4	- -	3	+
Salinization	76	53	17	36	15	2	2	-	4	1
Pollution	22	2	1	1	+	-	+	-	19	-
Acidification	6	4	4	0	2	-	-	+	+	-
Compaction	68	10	+	10	18	4	+	1	33	2
Waterlogging	11	+	+	0	+	4	5	-	1	-
Subsidence org. soils	5	2	2	0	-		-	-	2	-
Total	1965	747	444	303	494	243	63	96	218	102
Degradation Degree										
Light	749	295	151	144	173	105	2	17	60	96
Moderate	910	344	214	130	192	113	35	78	144	4
Strong	296	108	79	29	124	25	26	1	10	2
Extreme	9	+		+	5	-	-		4	+
Causative factors										
Deforestation	579	298	219	79	67	100	14	4	84	12
Overgrazing	678	198	67	131	243	68	9	29	48	83
Agric. mismanagement	552	204	157	47	121	64	28	63	64	8
Overexploitation	133	46	-	46	63	12	11	-	1	-
Industrial Activities	23	1	1	0	+	-	+	+	21	+

The summation of the surface areas of all GLASOD mapped units leads to a total land area of 13013 M ha (million hectares), which compares favourably with FAO's estimate of 13069 M ha (FAO, 1990a). Human-induced soil degradation worldwide has affected 1965 M ha or 15% of the total land area. The total land area however includes large portions of the earth that are not influenced by men. A more realistic figure would be to consider the total area under agriculture, permanent pasture and under forest and woodland. These are the areas that are most likely affected by human-induced soil degradation. Based on FAO statistics this land surfaces is around 8735 M ha, of which 22% is degraded as a result of human intervention.

Water erosion is the most important type of soil degradation (55%) followed by wind erosion (28%), nutrient decline (7%), salinization (4%) and compaction (3%). In all continents water erosion is the most important type of soil degradation, except for West Asia and Africa, where water and wind erosion are of almost equal importance. In South America nutrient decline is more important than wind erosion. Almost 50% of the land that is affected by salinization is located in West Asia, while it occupies almost equal areas in South East Asia and Africa. Compaction is a major type of soil degradation in Europe (50% of the compacted soils worldwide). Although pollution is worldwide a type of soil degradation occupying only 22 M ha, it is important to note that 19 M ha of these polluted soils are located in Europe. Over 300 M ha -about the size of India- is degraded to such an extent that restoration to its original productivity can only be achieved through major investments. This terrain has virtually lost its productive capacity. Around 40% of this strongly degraded land is located in Africa, while 25% is found in South East Asia. A much larger portion -910 M ha- has a moderate degree of soil degradation. This terrain is characterized by a serious decline in productivity, but can be restored. If no efforts are undertaken to rehabilitate this moderately degraded land, one may fear that a major portion will further deteriorate to the point where it may become unreclaimable. Around 25% is found in South East Asia, 20% in Africa.

Overgrazing of the pasture land, mismanagement of the agricultural land, and deforestation of the forest and woodlands are the major causes of soil degradation. Overgrazing is of particular importance in Africa and West Asia, deforestation is of serious concern in South East Asia and South America, while agricultural practices have affected the soils negatively on all continents, but particularly in large areas in South East Asia and Africa. Overexploitation of the vegetative cover is mainly a problem in West Asia and Africa. Industrial activities are of obvious importance in Europe.

Further details on areas by type and by degree for the various continents can be found elsewhere (Oldeman, Hakkeling and Sombroek, 1991; Oldeman, 1992).

2.4.1 The extent of soil degradation in South East Asia

Some more detailed information on human induced soil degradation in South East Asia is given in Table 2.

Table 2 Human-induced soil degradation in South East Asia (expressed in million hectares).

Type	Light	Moderate	Strong	Total	(%)
W Water Erosion	**86.8**	**176.0**	**58.4**	**321.2**	**72**
Wt Loss of topsoil	62.8	154.5	36.2	253.5	57
Wd Terrain deformation	24.0	21.5	22.2	67.7	15
E Wind Erosion	**49.8**	**24.3**	**14.5**	**88.6**	**20**
Et Loss of topsoil	41.6	9.4	-	51.0	12
Ed Terrain deformation	8.2	6.0	14.5	28.7	6
Eo Overblowing	-	8.9	-	8.9	2
C Chemical Degradation	**12.8**	**12.9**	**5.8**	**31.5**	7
Cn Nutrient decline	4.1	4.7	1.0	9.8	2
Cs Salinization	8.3	5.0	3.4	16.7	4
Ca Acidification	0.4	2.3	1.2	3.9	1
Cp Pollution	-	0.9	0.2	1.1	(+)
P Physical Degradation	**1.5**	**1.0**	**0.2**	2.7	**(1)**
Pc Compaction	0.4	-	-	0.4	+
Pw Waterlogging	0.4	-	-	0.4	+
Ps Subsidence org. matter	0.7	1.0	0.2	1.9	(1)
Total	150.9 (34%)	214.2 (48%)	78.9 (18%)	444	100

The total land surface of South East Asia is around 1850 M ha. Land, that is not used as agricultural land, permanent pastures or has a forest/woodland vegetation, occupies around 650 M ha. This particularly relates to so-called non-used wasteland. These areas (dark grey on the GLASOD map) are mainly found in China and along the border between India and Pakistan.

Water erosion is by far the most important type of human-induced soil degradation. The total area affected by water erosion is around 320 M ha, which implies about 17% of the total land surface of South East Asia, or around 72% of the total area affected by soil degradation. Water erosion is a problem in all countries in South East Asia, being particularly serious along the West Coast of India, North and North East Thailand, in major parts of Vietnam, in South East China and in parts of Central and East Java. The major type of water erosion is loss of topsoil (more than 250 M ha). It is also significant to note that more than 50% of the area affected by water erosion is characterized by a moderate degree and almost 20% has even a strong degree of water erosion. Figure 4 illustrates a thematic map of human-induced water erosion in Southeast Asia.

Wind erosion in South East Asia affects about 90 M ha, or around 5% of the total land surface. This type of soil degradation is mainly found in northern China, as well as in some parts of Pakistan, characterized by a much drier climate. Loss of topsoil is the dominant type of wind erosion. In contrast to water erosion more than 50% of the area affected by wind erosion has a light degree and only 25% is moderately degraded.

The areas, affected by chemical degradation represent relative small areas, covering around 30 M ha in South East Asia. Salinization occupies within this category the largest proportion. This type is found in Pakistan, North East India, North East China, South Burma, South East Thailand, along the East coast of Malaysia, in Kalimantan and the East coast of Sumatra. Areas affected by acidification, occurring in coastal regions upon drainage on pyrite-containing soil, cover "only" 4 M ha. This category of chemical degradation is specifically significant for South East Asia (see Table 1). These areas are mainly found in the Mekong delta in South Vietnam, along the coast of the Malaysian peninsula, while the South coast of Kalimantan is also seriously affected by acidification. Soils, affected by pollution are only identified in West Korea and in Malaysia. More than 50% of the soils affected by chemical degradation are moderately to strongly degraded.

The major type of physical degradation is subsidence of organic soils, caused by drainage and/or oxidation. Note that this type of soil degradation is only recognized if the agricultural potential of the land is negatively affected. The affected area occupies only 1.9 M ha. It is found along the coast of East Malaysia and Brunei, in South Kalimantan and in the Mekong delta.

The GLASOD map identifies five types of human intervention that have caused the soils to degrade. Deforestation, defined as the removal of the natural vegetation of stretches of land for agricultural purposes, commercial forestry, road construction, or urban development, is the major cause of soil deterioration. The information derived from GLASOD indicates that about 50% of the soils affected by soil degradation has as major cause deforestation, while about 35% of the degraded soils are the result of some kind of agricultural mismanagement. This can be related to insufficient use of fertilizers, leading to nutrient decline; shortening of the fallow period in shifting cultivation; absence of anti-erosion measures, leading to water erosion; use of poor quality irrigation water, leading to salinization. Overgrazing of pasture land is the major cause of soil degradation in the remaining 15% of the degraded portion of the land. This cause is restricted to areas in India, Pakistan and China.

2.5 Conclusion

The GLASOD map and the derived statistics on human-induced soil degradation should be considered as a first attempt to arrive at a global picture of the status of human-induced soil degradation. The methodology is subjective and based on a qualitative expert estimate of the present conditions of the status of the soils. There is an urgent need to follow-up these estimates by more detailed studies and a better quantification of the status of soil degradation.

Since the map was first published in 1990, ISRIC has received many comments, both supporting the results as well as criticizing details of the map. At the same time, many requests were received for more detailed information on the status of soil degradation for specific countries. We have categorically denied such requests, since GLASOD was not meant for providing these details. Last year the Group of Soil Conservation experts of the Council of Europe requested to prepare an up-date of the European section of GLASOD.

The objective of this Expert Consultation to identify a common methodology for the collection of land degradation data leading to the establishment of updatable national and regional land degradation databases may want to apply as a first approximation the methodology developed for GLASOD, but at a more detailed resolution. An alternative approach, which has been developed lately is the concept of a georeferenced soil and terrain digital database. This will be the topic of the following chapter.

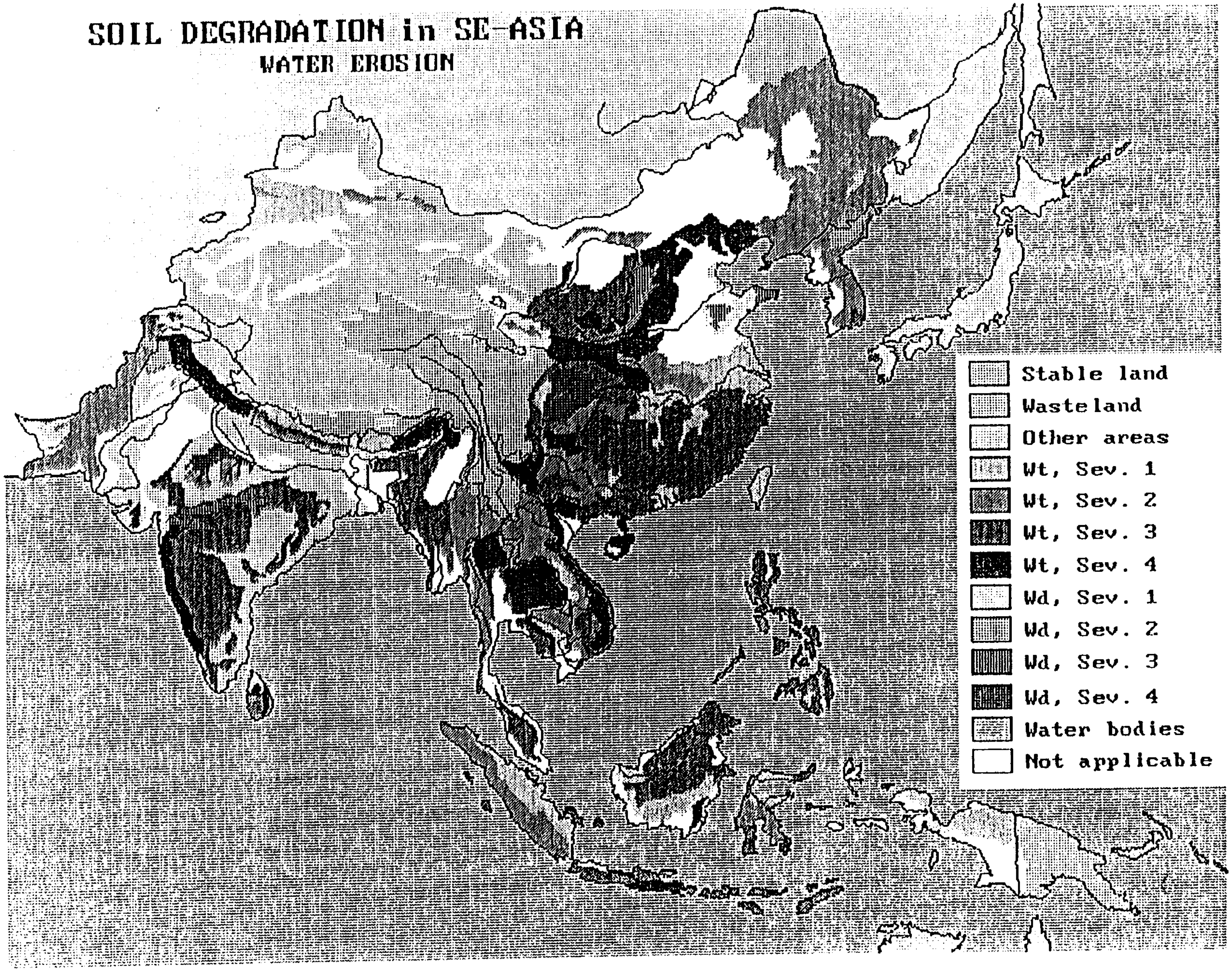


Figure 4 Human-induced water erosion in South East Asia.

3 A GEOREFERENCED SOIL AND TERRAIN INFORMATION SYSTEM

The development of an internationally accepted georeferenced system capable of providing accurate, useful and timely information on soil and terrain resources is a prerequisite for policy-makers, decision-makers, resource managers and for the scientific community at large in their assessment of the productive capacity of soils, of the status, risks and rates of soil degradation, and of global change.

The environmental links between soils, food crops and water supplies mean that if soils are degraded or polluted, there is every likelihood that food chains and drinking water will also be affected. Quantification of processes of soil degradation (and pollution) requires that researchers have access to compatible and uniform databases linked to a Geographic Information System, which include data layers on climate, landform, soils and land cover.

In 1985 a provisional working group was established under the auspices of the International Society of Soil Science (ISSS) "to consider the feasibility and desirability of developing a World Soils and Terrain Digital Database (SOTER)" (Sombroek, 1984; ISSS, 1986). After endorsement of SOTER at the International Congress of Soil Science in Hamburg (1986), an ad-hoc expert meeting was convened by the United Nations Environment Programme (UNEP) in Nairobi (ISSS, 1987) to discuss the implementation of SOTER. This meeting concluded, that SOTER would provide the necessary ingredients to make quantitative assessments of the rate and risk of soil degradation at sufficient detail for national and regional planning. Based on recommendations of this expert meeting UNEP requested ISRIC to develop a methodology for small scale digital map and database compilation of soil and terrain conditions and to test the methodology in pilot areas in South and North America. The results were discussed at the 14th International Congress of Soil Science in Kyoto. ISRIC was encouraged to continue the coordination of activities related to SOTER.

The SOTER methodologies were further refined and discussed at various international workshops. Early 1993 the Procedures Manual for the Development of Global and National Soil and Terrain Digital Databases was jointly published by FAO, ISRIC, ISSS and UNEP (Van Engelen and Wen, 1993), thus giving the SOTER approach international endorsement. Also the World Resources Institute indicated that "SOTER, which plans to use properly structured ground assessments to create a geo-referenced database on baseline soil and terrain conditions over the next 10 to 15 years -if funding becomes available- would be invaluable for local and national planners and to those seeking to set priorities for global action and environmental assistance" (WRI, Cal.Tech., 1992).

3.1 Implementation of SOTER

SOTER activities are presently being implemented in Uruguay and major parts of Argentina. In addition to a SOTER coverage of the whole territory of Uruguay and over 400.000 km^2 of Argentina at the SOTER reference scale of 1:1 M., SOTER will also be applied in two areas of 7000 km^2 at a scale of 1:100,000. Early 1993 a SOTER project has been implemented for the Republic of Kenya and will include also an assessment of the status and risk of soil erosion in Kenya. Hungary has submitted a project document for a SOTER database of Hungary at a scale of 1:500,000, which will most probably be implemented early 1994. In cooperation with the Institute of Soil Science of the Academia Sinica a project proposal has been submitted for the development of a georeferenced soil and terrain database for two areas of about 40.000 km^2 each in South East China.

In close cooperation with national soil research institutions in South and Central America, FAO and ISRIC are implementing the development of a SOTER framework for the whole continent at a scale of 1:5 M. Requests for implementation of SOTER from national soil research institutions have been received from many countries in Africa, South America, and Asia. The following sections will discuss the justification, objectives, characteristics, the mapping approach, the database attributes of SOTER, and its relevance to soil degradation.

3.2 Justification of SOTER

The urgent need for a global inventory of the Earth's natural resources has been expressed by many international research organisations and policy-making agencies. While there have been substantial advances in our understanding of environmental processes, and also a consensus has emerged that all forms of development must be sustainable, there are still important gaps in our knowledge of how to assess adequately the impact of environmental damage. "The world's environmental database is incomplete and of variable quality" (UNEP, 1992). One of the recommendations from a meeting on desertification, land degradation and the Global Environment Facility (GEF) was, that the collection and dissemination of environmental data and environmental monitoring is a major priority for effective action (UNSO/UNDP, UNEP, 1992). The World Resources Institute (Washington) and the California Institute of Technology (Pasadena) stressed that in order to manage our planet's environment rationally we need a sound understanding of environmental processes, an accurate measure of baseline conditions of the Earth's natural resources, and an efficient system for monitoring and reporting changes in resource conditions (WRI, Cal.Tech., 1992). Sombroek (1992) stated that the many international initiatives of the modelling of the effects of an environmental change in combination with population growth in the developing countries are in dire need of sound ground-truthed and up-to-date spatial databases on agroclimatic conditions; on basic landform-soil relationships; on water resources and agro-hydrology; on present-day land cover and land use; on status and hazard of land degradation.

There is no doubt that what is needed at global level also applies at national and regional level. Rural development planning in developing countries is increasingly dependent upon reliable soils information. The history of agricultural development projects during the past decades is replete with examples of how the results might have been more positive if accurate and timely information about the land and water resources had been available to the planners. This contradicts the fact, that at the same time in many countries new or updated soil maps have become available. Every new soil survey report published in a country is more advanced, complex and technically more difficult than previously published reports. However, the majority of potential users of soils and terrain information are not technically trained in soils. The consequences are that these users either will not or cannot extract the specific information they need from a modern soil survey report. Purnell (1992) stated that there is a need for more reliable and more timely information about soils. This information must be more accessible and intelligible to non-soil scientists: "Clear language, free from jargon does not come easily to soil surveyors, but soil survey reports are of no value if not read". One of the main obstacles to the exchange of scientific data and to the effective transfer of technology is the lack of standardization in describing and recording data for soils and terrain resources. The SOTER procedures manual provide an internationally accepted form of standardization of quantifiable soil and terrain attributes, stored in a versatile database management software system.

3.3 Objectives and characteristics

The overall objective of SOTER is to utilize emerging information technology to produce a World Soil and Terrain Digital Database, containing digitized map unit boundaries in a GIS and their attribute database in a Relational Database management System (RDBMS). This integrated system will hold the data necessary for improved mapping and characterization of world soil and terrain resources, and for monitoring changes therein. SOTER is structured to provide a comprehensive framework for the storage and retrieval of uniform soil and terrain data that can be used for a wide range of applications at different scales. It will contain sufficient data to allow information extraction at a resolution of 1:1 Million, both in form of maps and as tables. SOTER will be compatible with global databases of other environmental resources. The system will be amenable to updating; "old" datasets can be saved as files for monitoring purposes. SOTER will be accessible to a broad array of international, national, and regional environmental specialists through the provision of standardized resource maps, interpretative maps and tabular information essential for the development, management and conservation of environmental resources. Finally the system will be transferable to and useful for national database development at larger scales from 1:1 Million to 1:100,000 (Oliveira and Van den Berg, 1991).

3.4 The SOTER mapping approach

The general approach adopted by SOTER is to screen all existing soil and terrain data in a georeferenced area and to complement the terrain information with remote sensing where necessary. Basic to the SOTER approach is the mapping of areas of land -SOTER units-, with a distinctive pattern of landform, surface form, slope, parent material and soils. Each SOTER unit thus represents one unique combination of terrain and soil characteristics. The SOTER mapping approach resembles in many aspects physiographic soil mapping, although stronger emphasis is placed on the terrain-soil relationships as compared to what is commonly done in traditional soil mapping.

3.4.1 SOTER differentiating criteria

The differentiating criteria are applied in a stepwise manner, each step leading to a closer identification of the land area under consideration. The main criterion for separating SOTER units at the highest level of differentiation is physiography: the major landforms are identified and quantified based on the dominant gradient of their slopes and their relief intensity. Areas falling within a similar land form are further segregated according to their lithology or parent material. These terrain units possesses one or more typical combinations of surface form, meso relief, parent material aspects and soil. These differentiating criteria form the basis for dividing the terrain units into terrain components. The complexity of the occurrence of terrain components does not always allow individual mapping at the reference scale of 1:1 M. In such cases the information related to non-mappable terrain components is stored in the attribute database only.

The final step in the differentiation of the terrain is the identification of soil components within the terrain components. The criteria used for separating soil components are based on the diagnostic horizons and properties as formulated by FAO. At the SOTER reference scale soils must in general be characterized to the subunit level following the rules of the FAO revised legend (FAO, 1988). For soils, characterized according to Soil Taxonomy (Soil Survey Staff 1975, 1990, 1992) the FAO subunit level corresponds roughly to the subgroup level of Soil Taxonomy. Soil components can, in addition to diagnostic horizons and properties, also be separated according to factors that have potentially restricting influence on land use or that may affect land degradation.

As with terrain components, soil components can be mappable or non-mappable. At a scale of 1:1 M a terrain component is likely to comprise a number of non-mappable soil components (compare soil associations or soil complexes in traditional soil mapping). Figure 5 illustrates the relations between SOTER units and their composing parts and major separating criteria.

3.4.2 SOTER mapping approach at different scales

The SOTER methodology has been developed for applications at a scale of 1:1 M. However the methodology is also intended for use at both smaller and larger scales. The attributes of terrain, soil and other units as used by SOTER are hierarchically structured to facilitate the use of the procedures at other scales. For the compilation of smaller scale continental and global land resource maps and associated data tables, the methodology was tested by FAO for the preparation of the physiographic base for a future update of the Soil Map of the World (Eschweiler, 1993; Wen, 1993). As a systematic and highly organized way of mapping and recording soil and terrain data, the SOTER methodology can be extended to include reconnaissance level inventories, at scales between 1:1 M and 1:100,000. With an increase in resolution the highest level constituents of a SOTER unit will gradually lose importance and may disappear altogether at a scale of 1:100,000. At that scale, terrain alone may not offer sufficient differentiating power. Conversely, the lower part of the SOTER unit will gain in importance with more detailed mapping. SOTER units will become delineations of soil entities, with the information on terrain becoming incorporated in the soil attribute file.

3.5 SOTER database attributes

Two types of data are present in the SOTER database. The geometric component, indicating the location and topology of SOTER units, is stored in that part of the database that is handled by GIS software. The attribute component, describing the non-mappable SOTER unit characteristics is stored in a separate set of attribute

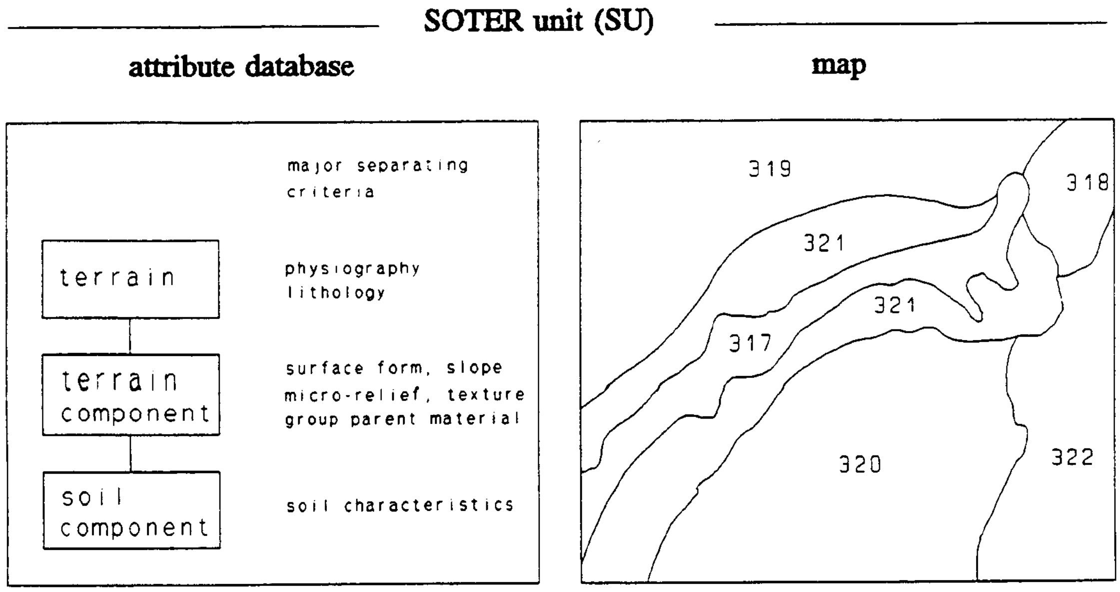


Figure 5 Relations between a SOTER Unit and their composing parts and major separating criteria.

files, handled by RDMS software. The two types of data components are linked by a label, unique for each SOTER unit. The geometric database contains information on the delineations of the SOTER unit. It also holds data from the base map (such as roads, towns, hydrological network, administrative boundaries). As base map SOTER uses the 1:1 M Operational Navigation Charts (ONC) and their digital version, the Digital Chart of the World (DMA, 1992). The attributes of the terrain and terrain components are either directly available or can be derived from other parameters during the compilation of the database. Soil attributes are taken from a representative soil profile. Where possible SOTER will rely on a selection of reference profiles made by the original soil surveyors. These reference soil profiles are preferably stored in a national soil profile database. The full list of non-spatial attributes of a SOTER unit is given in Table 3. It should be noted that the attributes for soil horizons are distinguished in mandatory and optional attributes. Mandatory attributes are those considered essential for any realistic interpretation of the soil component of a SOTER unit. In cases where mandatory data are not available, expert estimates are to be used for attributes of the representative profile (directly measured and estimated values will be stored separately!).

3.6 SOTER Source Materials

Basic data sources for the construction of SOTER units are topographic, geomorphological, geological and soil maps. All soil maps, that are accompanied by sufficient analytical data for soil characterization, preferably using the revised FAO-Unesco legend (FAO, 1988) can be used. Larger scale maps can be used if they cover sufficiently large areas. Information from these maps can support source materials at smaller scales.

SOTER map sheets at scale 1:1 M will cover large areas, often including more than one country. Thus correlation of soil and terrain units may be required. If no maps of sufficient detail exist for a certain area, it may still be necessary to obtain information from smaller scale maps, provide that some additional field work is carried out (where necessary in conjunction with satellite imagery). Some extra analytical work may have to be carried out to complement existing soil and terrain information. It must be stressed that SOTER is based on existing soil and terrain information and that it specifically excludes new land resource surveys within its programme.

Table 3. Non-spatial attributes of a SOTER unit.

TERRAIN

1 SOTER unit_ID
2 year of data collection
3 map_ID
4 minimum elevation
5 maximum elevation
6 slope gradient
7 relief intensity
8 major landform
9 regional slope
10 hypsometry
11 dissection
12 general lithology
13 permanent water surface

TERRAIN COMPONENT

14 SOTER unit_ID
15 terrain component number
16 proportion of SOTER unit
17 terrain component data_ID

TERRAIN COMPONENT DATA

18 terrain component data_ID
19 dominant slope
20 length of slope
21 form of slope
22 local surface form
23 average height
24 coverage
25 surface lithology
26 texture group non-consolidated parent material
27 depth to bedrock
28 surface drainage
29 depth to groundwater
30 frequency of flooding
31 duration of flooding
32 start of flooding

SOIL COMPONENT

33 SOTER unit_ID
34 terrain component number
35 soil component number
36 proportion of SOTER unit
37 profile_ID
38 number of reference profiles
39 position in terrain component
40 surface rockiness
41 surface stoniness
42 types of erosion/deposition
43 area affected
44 degree of erosion
45 sensitivity to capping
46 rootable depth
47 relation with other soil components

PROFILE

48 profile_ID
49 profile database_ID
50 latitude
51 longitude
52 elevation
53 sampling date
54 lab_ID
55 drainage
56 infiltration rate
57 surface organic matter
58 classification FAO
59 classification version
60 national classification
61 Soil Taxonomy
62 phase

HORIZON (* = mandatory)

63 profile_ID*
64 horizon number*
65 diagnostic horizon*
66 diagnostic property*
67 horizon designation
68 lower depth*
69 distinctness of transition
70 moist colour*
71 dry colour
72 grade of structure
73 size of structure elements
74 type of structure*
75 abundance of coarse fragments*
76 size of coarse fragments
77 very coarse sand
78 coarse sand
79 medium sand
80 fine sand
81 very fine sand
82 total sand*
83 silt*
84 clay*
85 particle size class
86 bulk density*
87 moisture content at various tensions
88 hydraulic conductivity
89 infiltration rate
90 pH H_2O*
91 pH KCl
92 electrical conductivity
93 exchangeable Ca^{++}
94 exchangeable Mg^{++}
95 exchangeable Na^{+}
96 exchangeable K^{+}
97 exchangeable Al^{+++}
98 exchangeable acidity
99 CEC soil*
100 total carbonate equivalent
101 gypsum
102 total carbon*
103 total nitrogen
104 P_2O_5
105 phosphate retention
106 Fe dithionite
107 Al dithionite
108 Fe pyrophosphate
109 Al pyrophosphate
110 clay mineralogy

3.7 Associated Data

For many of its applications SOTER data can only be used in conjunction with data on other land-related resources. Therefore the SOTER database includes separate files on climate, vegetation and land use. The climate file is in the form of point data from existing climate stations, that can be linked to SOTER units through GIS software. Vegetation and land use data are provided at the level of SOTER units. It should be stressed, that for specific applications, information on these associated data should be obtained from specialized databases.

3.8 SOTER and Soil Degradation

Soil degradation phenomena can be observed and described in the field, particularly those related to the displacement of soil material. These visible signs of erosion are entered in the SOTER database in the soil component file. The characterization of the erosion or deposition type follows the guidelines for soil profile description of FAO (FAO, 1990), although the coding is slightly adopted:

N: no visible evidence of erosion
S: sheet erosion
R: rill erosion
T: tunnel erosion
P: deposition by water
W: water and wind erosion
L: wind deposition
A: wind erosion and deposition
D: shifting sand
Z: salt deposition
U: type of erosion unknown

The area affected by the above mentioned erosion follows the same classes as described for GLASOD (see 2.2.4), and is related to the frequency of occurrence of the erosion type. The degree of soil erosion follows the guidelines for soil classification of FAO (1990b), which is similar to those described in GLASOD (see 2.2.3).

S: slight. Some evidence of loss of surface horizons. Original biotic functions largely intact.
M: moderate. Clear evidence of removal or coverage of surface horizons. Original biotic functions partly destroyed.
V: severe. Surface horizons completely removed (with subsurface horizons exposed) or covered up by sedimentation of material from upslope. Original biotic functions largely destroyed.
E: extreme. Substantial removal of deeper subsurface horizons (badlands). Complete destruction of original biotic functions.

Physical soil degradation phenomena which can be observed in the field are surface sealing and crusting. SOTER describes the sensitivity to capping, which is expressed as the degree in which the soil surface has a tendency to capping and sealing (FAO, 1990b).

N: none. No capping or sealing observed.
W: weak. The soil surface has a slight sensitivity to capping. Soft or slightly hard crust less than 0.5 cm thick.
M: moderate. The soil surface has a moderate sensitivity to capping. Soft or slightly hard crust of 0.5 cm thick or more, or hard crust less than 0.5 cm thick.
S: strong. The soil surface has a strong sensitivity to capping. Hard crust of 0.5 cm thick or more.

Other types of soil degradation, like nutrient decline, loss of organic material, salinization, acidification, pollution can only be assessed on the basis of measured attributes from undisturbed soil profiles in comparison with measured values from disturbed profiles. The electrical conductivity of saturation extract itself is not enough to determine whether salinization has occurred. Salinization is considered as the relative change over a number of years in the salinity status of the soil (see Annex 1).

The SOTER database contains sufficient terrain and soil attributes as well as subfiles on climate and land cover/land use parameters to assess the vulnerability of the soil to soil degradation. Algorithms can be used to assess the hazards of soil degradation. A programme has been developed for water erosion assessment applied to SOTER (Van den Berg, 1992). This Soil Water Erosion Assessment Programme (SWEAP) facilitates the use of the SOTER database for water erosion hazard risk prediction. SWEAP consists of two parts: (1) the menu and (2) the model. The menu part is an interface between the user and the model. The user can define the boundary conditions that must be taken into account to run the model: where to find the input data in SOTER; where to send the output file results; which erosion model is to be used; for which scenario the calculations are to be made.

The model part consists of two erosion risk assessment models: SLEMSA (Soil Loss Estimation Model for Southern Africa; Elwell and Stocking, 1982; Stocking *et.al.*, 1988) or USLE (Universal Soil Loss Equation; Wischmeyer and Smith, 1978). The intention of SWEAP is not to present another model for erosion hazard assessment, but to take advantage of existing models as a tool for the assessment of erosion risks and to be used with SOTER. The aim was to optimize the balance between refinement of the equations in the models and the available information. The extent to which the results will be accurate depends mainly on the variability of factors related to erosion within SOTER units, terrain components and soils, as well as on the temporal variability of these factors. SWEAP was tested with the SOTER database for a pilot area in North America (South West Canada and North West U.S.A.). Simultaneously algorithms developed by Shields and Coote (1989) were used to generate maps of the rate and risk of soil degradation due to wind erosion, water erosion and salinization. The results of those two independent assessments of water erosion risk were consistent.
The SOTER database, which contains information on the actual status of water erosion and attributes which can be used to estimate water erosion risk provide a unique opportunity for making an objective validation.

4 CONCLUSION

Soil degradation is a dynamic process, which is conditioned by a certain arrangement of terrain and soil parameters and climatic factors and is enhanced by human action. An assessment of soil degradation hazard should therefore be complemented by a socio-economic database, which contains information on population dynamics, dominant land use and land management, existing infrastructure etc. Such a database should be georeferenced like SOTER. While SOTER can assess the potential risks -vulnerability- of soils to degradation in their specific physiographic and climatic setting, human behaviour determines the actual rate of these processes. The methodologies to describe the present status of human-induced soil degradation combined with the methodology for the development of a georeferenced soil and terrain database with internationally accepted standards will provide policy-makers, decision-makers and resource managers important tools to reverse the current trends of soil degradation in developing and industrialized countries and to implement a programme for soil conservation and sustainable use of the land.

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ANNEX 1

Guidelines for the assessment of the degree of soil degradation due to water erosion, wind erosion, salinization and nutrient decline (ISRIC, 1988).

Degree of present degradation due to water erosion

1) *Slight:* in deep soils (rooting depth more than 50 cm): part of the topsoil removed, and/or with shallow rills 20-50 m apart.
   in shallow soils (rooting depth less than 50 cm): some shallow rills at least 50 m apart.
   in pastoral country the groundcover of perennials of the original/ optimal vegetation is in excess of 70%[1].
2) *Moderate:* in deep soils: all top soil removed, and/or shallow rills less than 20 m. apart or with moderately deep gullies 20-50 m. apart.
   in shallow soils: part of topsoil removed, and/or shallow rills 20-50 m apart.
   in pastoral country: groundcover of perennials of the original/ optimal vegetation ranges from 30% to 70%[1].
3) *Severe:* in deep soils: all topsoil and part of subsoil removed, and/or with moderately deep gullies less than 20 m. apart.
   in shallow soils: all topsoil removed: lithic or leptic phases or with exposed hardpan.
   in pastoral country: groundcover of perennials of the original/ optimal vegetation is less than 30%[1].

Degree of present degradation due to wind erosion.

1) *Slight:* in deep soils: topsoil partly removed and/or with few (10-40% of the area) shallow (0-5 cm) hollows.
   in shallow soils: very few (10% of the affected area) shallow (0-5 cm) hollows.
   in pastoral country: groundcover of perennials of the original/ optimal vegetation is in excess of 70%[1].
2) *Moderate:* in deep soils: all topsoil removed; and /or with common (40-70% of the area) shallow (0-5 cm) or few (10-40% of the area) moderately deep (5-15 cm) hollows.
   in shallow soils: topsoil partly removed and/or few (10-40% of the area) shallow (0-5 cm) hollows.
   in pastoral country: groundcover of perennials of the original/ optimal vegetation ranges from 30%-70%[1].
3) *Severe:* in deep soils: all topsoil and part of subsoil removed and/or with many (70% of the area) shallow (0-5 cm) or common (40-70% of the area) moderately deep (5-15 cm) or few (10-40% of the area) deep (15 cm) hollows/blowouts.
   in shallow soils: all top soil removed: lithic or leptic phases or with exposed hardpan.
   in pastoral country: groundcover of perennials of the original/ optimal vegetation is less than 30%[1].

Degree of present degradation due to salinization.

Salinization should be considered as the relative change over the last 50 years in salinity status of the soil, the latter being defined as follows:

non-saline:	electrical conductivity less than 5 dS/m; E.S.P. < 15%; pH < 8.5
slightly saline:	electrical conductivity 5-8 dS/m; E.S.P. < 15%; pH < 8.5
moderately saline:	electrical conductivity 9-16 dS/m; E.S.P. < 15%; pH < 8.5
severely saline:	electrical conductivity more than 16 dS/m; E.S.P. < 15%; pH < 8.5

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[1]Known maximum coverage of perennials under good management as practiced during some time in the past.

The present degree of human-induced salinization can now be identified as a change in salinity status as follows:

1) *slight:* from non-saline to slightly saline; from slightly to moderately saline, or from moderately saline to severely saline.
2) *moderate:* from non-saline to moderately saline, or from slightly saline to severely saline.
3) *severe:* from non-saline to severely saline.

Degree of present degradation due to nutrient decline

Criteria to assess the degree of present degradation are the organic matter content; the parent material; climatic conditions. The nutrient decline by leaching or by extraction by plant roots without adequate replacement is identified by a decline in organic matter, P, CEC (Ca, Mg, K).

1) *slight:* Cleared and cultivated grassland or savannas on inherently poor soils in tropical regions. Cleared or cultivated formerly forestland in temperate regions on sandy soils, or in tropical (humid) regions on soils with rich parent materials.
2) *moderate:* Cleared and cultivated grassland or savannas in temperate regions, on soils high in inherent organic matter, when organic matter has declined markedly by mineralization (oxidation). Cleared and cultivated formerly forested land on soils with moderately rich parent materials in humid tropical regions, where subsequent annual cropping is not being sustained by adequate fertilization.
3) *severe:* Cleared and cultivated formerly forestland in humid tropical regions on soils with inherently poor parent materials (soils with low CEC), where all above-ground biomass is removed during clearing and where subsequent crop growth is poor or non-existent and cannot be improved by N fertilizer alone.
4) *extreme:* Cleared formerly forested land with all above ground biomass removed during clearing, on soils with inherently poor parent materials, where no crop growth occurs and forest regeneration is not possible.