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AN INTERNATIONAL METHODOLOGY FOR SOIL DEGRADATION ASSESSMENT AND FOR A SOILS AND TERRAIN DIGITAL DATABASE (SOTER)

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INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

An International Methodology for Soil Degradation Assessment and for a Soils and Terrain Digital Database (SOTER)[1]

by
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1 INTRODUCTION

Intense and increasing pressure on land and water resources throughout the world have been shown to lead to land degradation and pollution, as well as decreasing biological productivity and declining bio-diversity. The initial calls by soil scientists for these problems to be addressed seriously has since been taken up by many national governments and international organisations culminating in the need for an approach that:

- strengthens the awareness of the users of these resources, as well as scientists and decision makers about the dangers of inappropriate management;

- enhances the capability of national resource institutions to collect and deliver reliable, up-to-date information on these resources in an accessible format to a wide audience;

- encourages monitoring of changes taking place in these resources in order to identify, halt and remedy their deterioration. This not only applies to soils, land and water, but also to soil cover and other biological resources.

The soil is a natural resource, non-renewable in the short term or very difficult to renew and expensive either to reclaim or to improve following erosion, by water and wind forces, or by physical or chemical degradation *in situ.* Soil degradation in the arid, semi-arid, and dry subhumid regions mainly from adverse human impact has been identified as a global problem since the 1970s. Although soil degradation is recognized as a serious and widespread problem, its geographical distribution and total areas being affected is only very roughly known.

The sustainable use of the land, so strongly advocated by the United Nations Conference on Environment and Development (UNCED) held at Rio de Janeiro in 1992 in its AGENDA 21, is an important but poorly defined concept. At the centre of the concept, but rarely mentioned by non-soil scientists, lies the soil which is a vital part of the intricate web of interactions between human beings and the natural environment. In order to understand these interactions and effectively to be able to use the land on a sustainable basis, it is essential that maximum use is made of existing knowledge about soils and the present status of human-induced soil degradation.

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

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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.

GLASOD has been regarded as a suitable approach, although further refinement is required (Thomas D.G.G. and N.J. Middleton, 1994). According to IFPRI (International Food Policy Research Institute), GLASOD is one of the most cited studies in recent literature on the extent of global soil degradation (Yadar, S. and S. Scherr, 1995).

The GLASOD database and map cannot assess the vulnerability of the land resources to soil degradation processes and thus assist policy makers and research managers to prevent the further deterioration of the soil and water resources. The SOTER programme stores at different level of detail, soil and terrain attributes in such a way, that these data can be assessed, combined, updated and analyzed from the point of view of potential land use, in relation to food requirements, hazards of soil degradation, environmental impact and conservation. According to FAO, the required breakthrough in land resource use, which is essential to halt and reverse the current degradation of land resources can be catalyzed through the development and application of methodologies such as SOTER.

The first part of this paper discusses the GLASOD methodology and results with special emphasis on the status of soil degradation in North Africa and West Asia. The second part describes the SOTER methodology and the possible uses of this database to further clarify the hazards of soil degradation in the drylands and the effect of soil degradation on food production.

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 Definition of Soil Degradation

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. In GLASOD 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.

2.3 Soil Degradation Assessment

2.3.1 Soil degradation types

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.

2.3.1.1 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.

2.3.1.2 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.

2.3.1.3 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 practised 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.

2.3.1.4 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.

2.3.2 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.

2.3.2.1 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 certain 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.

2.3.2.2 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.

2.3.3 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.

Changes in soil and terrain properties (e.g. loss of topsoil, development of rills and gullies, exposure of hardpans in the case of erosion) may reflect the occurrence and intensity of soil degradation but not necessarily the seriousness of its impacts on (overall) productivity of the soil. Removal of a 5 cm layer of topsoil has a greater impact on a poor shallow soil than on a deep fertile soil. Therefore, it would be better to measure the degree of degradation by the *relative* changes of the soil properties: the *percentage of the total topsoil* lost, the *percentage* of total nutrients and organic matter lost, the *relative decrease* in soil moisture holding capacity, changes in buffering capacity, etc. In future assessments of the degree of soil degradation emphasis will be placed on the impact of soil degradation on productivity.

A significant complication in indicating productivity losses caused by soil degradation is the variety of factors that may contribute to yield declines. Falling productivity can seldom be attributed to a single degradation process such as erosion, but may be caused by a variety (and/or combination) of factors, like erosion, fertility decline, improper management, drought or waterlogging, quality of inputs (seeds, fertilizer), pests and plagues, etc. However, if one considers a medium to long term period (10-15 years), large aberrations resulting from fluctuations in the weather pattern or pests will be levelled out.

Soil degradation also can be more or less *hidden* by the effects of various management measures such as soil conservation measures, improved varieties, fertilizers and pesticides. It should be realized that part of these inputs is used to compensate for the productivity loss caused by soil degradation, for instance application of fertilizers to compensate for lost nutrients. In other words, yields could have been much higher in the absence of soil degradation (and/or costs could have been reduced). Therefore productivity should be seen in relation to the amount of inputs.

A first, simple approximation for assessing the degree of soil degradation will be the level of production increases or decreases in relation to the level of management improvements. If one finds a small increase in productivity despite major management improvements we consider the degree of soil degradation as light. If there is a small decrease in production, despite major improvements in management, the degree of soil degradation is strong, etc.

2.3.4 The relative extent 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

2.3.5 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'.

2.4 The Extent of Soil Degradation

The surface are of each digitized mapped unit on the GLASOD map was calculated separately. Since each mapped unit is characterized by the extent, degree and causes of soil degradation estimates 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 (see 2.1) does not allow to make country-by-country estimates, statistics for the world and for continents can be presented. A summarized data set is given in Table 1.

In this table the area "North Africa and West Asia" is highlighted and includes the following countries: "Morocco, Algeria, Tunisia, Libya, Egypt, Turkey, Lebanon, Israel, Syria, Jordan, Iraq, Iran, Saudi Arabia, N. Yemen, S. Yemen, Bahrain, Oman, Kuwait, Qatar, U.A.Emirates, and part of Pakistan and Afghanistan (see fig. 1).

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	**N.Africa + W.Asia**	Africa	S. America	C. America	N. America	Europe	Oceania
Degradation Type									
Water	1094	440	**84.1**	227	123	46	60	114	83
Wind	548	222	**145.2**	187	42	5	35	42	16
Nutrient decline	135	14	**6.3**	45	68	4	-	3	+
Salinization	76	53	**46.9**	15	2	2	-	4	1
Pollution	22	2	**0.3**	+	-	+	-	19	-
Acidification	6	4	-	2	-	-	+	+	-
Compaction	68	10	**3.6**	18	4	+	1	33	2
Waterlogging	11	+	**0.1**	+	4	5	-	1	-
Subsidence org. soils	5	2	-	-		-	-	2	-
Total	1965	747	**286.5**	494	243	63	96	218	102
Degradation Degree									
Light	749	295	**142.8**	173	105	2	17	60	96
Moderate	910	344	**113.7**	192	113	35	78	144	4
Strong	296	108	**29.6**	124	25	26	1	10	2
Extreme	9	+	**0.4**	5	-	-		4	+
Causative factors									
Deforestation	579	298	**52.7**	67	100	14	4	84	12
Overgrazing	678	198	**152.0**	243	68	9	29	48	83
Agric. mismanagement	552	204	**49.1**	121	64	28	63	64	8
Overexploitation	133	46	**32.3**	63	12	11	-	1	-
Industrial Activities	23	1	**0.4**	+	-	+	+	21	+

Worldwide soil degradation has affected 1965 million ha or 15% of the total land area. A more realistic figure would be to consider the total area under agriculture, permanent pasture and under forest and woodland. These are the areas most likely affected by human-induced soil degradation. Based on FAO statistics (FAO, 1990a), this land surface is around 8735 M ha, of which 22% is affected by soil degradation. For the region "North Africa + West Asia" an estimated 280 M ha or 23% of the total land area is affected by soil degradation. However a major portion of the total land area in this region is classified as "other land", including deserts, moving dunes, salt flats and bare rock formations. The total area under agriculture, permanent pasture and forest and woodland is around 380 M ha. This implies that about 74% of the vegetated land is affected by soil degradation.

Worldwide 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. However in "North Africa + West Asia" region, wind erosion alone accounts for 51% of the area affected by soil degradation, followed by water erosion (29%) and salinization (16%), nutrient decline (2%) and compaction (1%).

The geographical distribution of soil degradation in the region "North Africa + West Asia" is as follows: Wind erosion is particularly serious in Libya, the northern part of Saudi Arabia (Loss of topsoil), while terrain deformation is severe in parts of Syria, Iraq, Iran and Afghanistan. Water erosion is a serious problem in Morocco, Tunisia, Turkey, Iran, Yemen and Oman and in some parts of Syria, Jordan and Afghanistan. Salinization problems are most pronounced in Iraq, the Nile delta of Egypt, certain parts of Algeria and major parts of Iran. Loss of nutrients finally is identified along the coastal areas of Turkey, in the northwestern part of Syria and along the Mediterranean coast in Algeria. Also Southern Yemen is affected by a serious nutrient decline problem. Compaction is only identified in Iraq, while waterlogging is a problem in the Nile delta.

Worldwide about 38% of the degraded soils is affected to a light degree, 46 % has a moderate degree, while around 15% is seriously degraded. In the region "North Africa + West Asia" around 50% of the degraded soils is lightly affected, 40% is moderately affected and 10% strongly affected.

The GLASOD methodology recognizes five different types of human intervention that results in soil degradation. Worldwide agricultural mismanagement, deforestation and overgrazing are the dominant causative factors each affecting soil degradation for around 30%. In the region "North Africa + West Asia" the dominant causative factor leading to soil degradation is overgrazing (53%), followed by deforestation (18%), agricultural mismanagement (17%) and overexploitation of the vegetative cover (11%).

Further details on areas by type, degree and causative factors of soil degradation can be found elsewhere (Oldeman *et al.*, 1991; Oldeman, 1992).

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. In 1992 the Group of Soil Conservation experts of the Council of Europe requested to prepare an up-date of the European section of GLASOD.

An expert consultation of the Asian network on problem soils, which convened under the auspices of the Regional Office for Asia and the Pacific of FAO, recommended to adopt the GLASOD approach as the common methodology in identifying soil degradation types, degrees and causes. Network nodal institutions were asked to initiate actions for the preparation of national soil degradation maps, based on existing data at a scale of 1:5 Million or larger and using as template a physiographic map of Asia at scale 1:5 Million utilizing methodologies as outlined in the SOTER manual (FAO, 1994). Based on these recommendations, ISRIC prepared a project proposal for the execution of a South and Southeast Asian Soil Degradation Assessment (ASSOD), which was implemented under a financial agreement with UNEP early 1995 in close cooperation with FAO and the Asian Network of Problem Soils.

The Centre for Environment and Development for the Arab Region and Europe (CEDARE) has now decided through its Land Resource Development Programme for the 1995/1996 biennium, to implement a comprehensive programme for the assessment and monitoring of soil degradation. The objective of the Regional Workshop on Assessment and Monitoring of Land Degradation is to identify a common methodology for the collection of land degradation data leading to the establishment of updatable national and regional land degradation databases. Such an information system is urgently needed. It is a direct answer to recommendations of many chapters of Agenda 21, formulated at the United Nations Conference on Environment and Development, and more in particular to the recently formulated Desertification Convention.

3 A GEOREFERENCED SOILS AND TERRAIN INFORMATION SYSTEM

The development of an internationally accepted georeferenced soils and terrain database, 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.

3.1 Justification

To meet future world food needs, reduce poverty and at the same time protect the environment calls for a massive international effort, in which the development of user-friendly information on the productive capacity of soils, its vulnerability to degradation and its resilience is crucial. The dominant focus of investigations in soil science up to now has been on agricultural production. The nature of most investigations has been appropriate and the quality high; however, the research does not seem to have adequately benefitted those whom it is supposed to help, particularly in the Developing Countries. Research in soil science needs to be broadened to emphasize food security, alleviation of poverty and hunger, and the protection of natural resources. The significance of this research is that it must take place against a continually growing world population which will make ever-increasing demands upon the soil to provide food for its support (Pinstrup-Andersen & Pandya Lorch, 1994).

At the end of the 15th World Congress of Soil Science, held in Acapulco, Mexico, in July 1994, a declaration was adopted in which it is stated that 'Soil science has a crucial role to play in realizing sustainable land use systems that satisfy the needs of an evermore global society'. Soil scientists should cooperate in research teams with scientists in other disciplines, such as agronomy, ecology, biology, engineering, economy and sociology. This is not only needed in pressing global issues such as those related to climatic change or global warning, but also at a national level. A holistic interdisciplinary approach that is dynamic and process-oriented is a pre-requisite for lasting results. An important issue in this approach is the contact between the natural and social sciences (Anon 1992; Catizzone and Muchena, 1994; Bridges and Catizzone, 1995).

At the 31st General Conference of the International Federation of Agricultural Producers (IFAP), held in Istanbul, Turkey in May 1994, it was stated that farmers' organisations should identify and implement achievable solutions towards a more environmentally friendly and sustainable land use for the future (Anon, 1994). It is stressed that the combination of sustainability and environmentally sound development is not a task which farmers can achieve alone, it will require dialogue and partnership with many different sectors of society. This will require closer working links between international and national agricultural research establishments and the farming community in order to ensure that the needs of farmers are correctly addressed. Adequate research should be undertaken, and the needs of small-scale resource-poor farmers should especially be taken into account.

Although gains in productivity and global agricultural production have been and will probably continue to rise, an increased efficiency in the use of soil and water resources is a pre-requisite for the achievement of sustainable agriculture and rural development. The global demands for food, water, housing and development will escalate if the projection that the world's population will exceed 10 billion in 2050 is correct. An improved resource management is only possible if the relevant environmental factors are known and a natural resource base is available.

International agencies such as the World Resources Institute, the World Bank, UNEP, FAO, CGIAR and IGBP have expressed the need for a quantified basic information on land and soil resources. Over the last decade, significant changes have affected the collection, interpretation and dissemination of soil survey data. The most important advances resulted from the incorporation of new technologies developed for remote sensing and information handling. Also, efforts have been made by soil scientists to quantify and standardize soil information and data, but in the process dependence on technology also has increased the degree of complexity and abstraction of soil survey operations. This increased complexity of soil information and information systems may satisfy the scientific community, but will not necessarily provide the kinds of data required by land resource managers and decision-makers. They need to have the possibility of readily accessing soil and terrain data sources through point and geo-referenced databases in order to quantify the productive capacity of soils. This is necessary at one level to obtain a better understanding about the risks and rate of soil degradation and at another level to better quantify processes of global change.

The Soils and Terrain Digital database (SOTER), aims to provide such information which can be used to assess the productivity of land, to provide a basis for its sustainable use, to monitor the effects of soil degradation, and to help in the development of action plans for conservation of productive soils or rehabilitation of degraded soils at global or national levels (Oldeman and Van Engelen, 1992).

3.2 Development of SOTER methodologies

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 -now also in Spanish and French- 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).

3.3 Implementation of SOTER

SOTER databases at scale 1:1 million have been established for the whole territory of Uruguay, for the Republic of Kenya and for over 400.000 km^2 of Argentina. For selected areas SOTER databases at scale 1:100.000 were also developed in Uruguay and Argentina. In Hungary a SOTER database at scale 1:500.000 has been prepared.

In close cooperation with national soil research institutions in South and Central America, UNEP, FAO and ISRIC are implementing the development of a SOTER framework for the whole continent at a scale of 1:5 M. Presently, SOTER databases are available for Mexico, Cuba, Venezuela, Brazil (south of 18° latitude), Uruguay and Argentina. Contracts with other Latin American countries are being established.

Late 1994 a project document was signed between UNEP and the Arab Center for the Studies of Arid Zones and Drylands (ACSAD) for the establishment of Soils and Terrain Database (MESOTER) for Jordan and Syria at scale 1:500.000 in close cooperation with the Soils Directorate of the Syrian Ministry of Agriculture and Agronomic Reform and the Jordanian National Soil Survey and Land Use Project. Early 1995, a project proposal has been submitted to the European Union for the establishment of a Comprehensive Land Resources Information System for Sustainable Agriculture and Environmental Protection for the Rif and Pré-Rif region of Morocco by the Institut Agronomique et Vétérinaire Hassan II and ISRIC. Also the National Research Centre of Egypt has developed a project proposal for the establishment of a Soils and Terrain Digital Database for Land Resources of Egypt.

3.4 SOTER 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).

3.5 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.

3.5.1 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 2 illustrates the relations between SOTER units and their composing parts and major separating criteria.

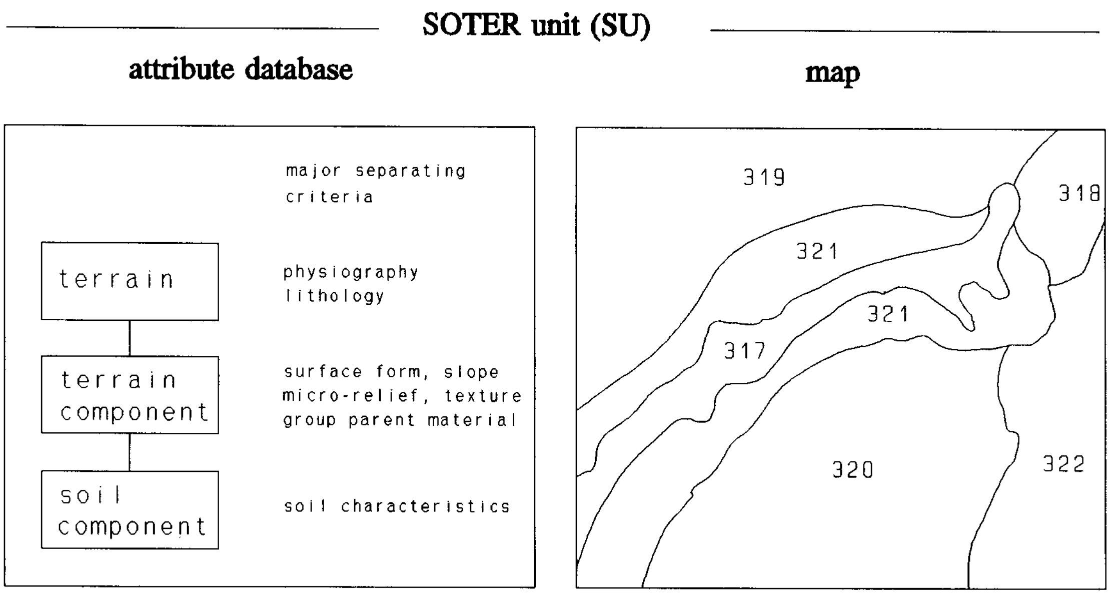

Figure 2 Relations between a SOTER Unit and their composing parts and major separating criteria.

3.5.2 *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.

3.6 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 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 2. 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!).

3.7 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 2. 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

3.8 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.

3.9 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, 1990b), although the coding is slightly adopted:

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

The area affected by the above mentioned erosion follows the same classes as described for GLASOD (see 2.3.4), 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 2.3.3).

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.

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.

In a smiliar approach a programme is under development at ISRIC to utilize existing models and algorithms in connection with attributes of the SOTER database to assess the risk of wind erosion and salinization.

3.10 SOTER and crop suitability

The Automated Land Evaluation System (ALES), developed by Rossiter and Van Wambeke (1993) will permit the identification of the suitability of terrain units for broadly defined land uses as put forward by planners. A procedure was developed for physical land evaluation in accordance with FAO's Framework for Land Evaluation, applying ALES, the Automated Land Evaluation System and using SOTER data at 1:1 M. The system was tested in West Kenya, but validation in other areas with SOTER or other data is needed. In future two more technology levels and more land utilization types will be incorporated into the evaluation model. The results of the evaluation are to provide relative suitabilities of SOTER units for the defined land utilization types, based on evaluator's judgement.

As a follow-up, a quantified land evaluation of potentially suitable terrain units will be attempted using a crop growth simulation model. With the resulting quantitative information on expected production and the inputs needed, the economic suitability can be evaluated by ALES.

With specific regard to Africa, an increased food production through the development of small-scale irrigation schemes could be planned with the use of an inventory such as SOTER. Methods for Sustainable Agriculture and Rural Development (SARD) have recently been put forward. Together with the International Scheme for the Conservation and Rehabilitation of African Lands (ISCRAL), adopted by FAO in 1990, these worthwhile activities should be based on reliable inventories of natural resources.

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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