CSFD
Les dossiers thématiques

Issue 8

A LAND DEGRADATION ASSESSMENT AND MAPPING METHOD

A standard guideline proposal

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CSFD
Comité Scientifique Français de la Désertification
French Scientific Committee on Desertification

Les dossiers thématiques du CSFD Issue 8

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French Scientific Committee on Desertification

The creation in 1997 of the French Scientific Committee on Desertification (CSFD) has met two concerns of the Ministries in charge of the United Nations Convention to Combat Desertification. First, CSFD materializes the will to involve the French scientific community versed in desertification, land degradation, and development of arid, semi-arid and sub-humid areas, in generating knowledge as well as guiding and advising the policymakers and stakeholders associated in this combat. Its other aim is to strengthen the position of this French community within the international context. In order to meet such expectations, CSFD is meant to be a driving force regarding analysis and assessment, prediction and monitoring, information and promotion. Within French delegations, CSFD also takes part in the various statutory meetings of the organs of the United Nations Convention to Combat Desertification: Conference of the Parties (CoP), Committee on Science and Technology (CST), Committee for the Review of the Implementation of the Convention. It also participates in meetings of European and international scope. It puts forward recommendations on the development of drylands in relation with civil society and the media, while cooperating with the DeserNet International (DNI) network.

CSFD includes a score of members and a President, who are appointed *intuitu personae* by the Ministry for Higher Education and Research, and come from various specialities of the main relevant institutions and universities. CSFD is managed and hosted by the Agropolis International Association that gathers, in the French city of Montpellier and Languedoc-Roussillon region, a large scientific community specialised in agriculture, food and environment of tropical and Mediterranean countries. The Committee acts as an independent advisory organ; it has neither decision-making powers nor legal status. Its operating budget is financed by contributions from the French Ministries of Foreign and European Affairs and for Ecology, Energy, Sustainable Development and Sea, as well as the French Development Agency. CSFD members participate voluntarily to its activities, as a contribution from the Ministry for Higher Education and Research.

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Foreword

Mankind is now confronted with an issue of worldwide concern, i.e. desertification, which is both a natural phenomenon and a process induced by human activities. Our planet and natural ecosystems have never been so degraded by our presence. Long considered as a local problem, desertification is now a global issue that affects us all, including scientists, decision-makers, citizens from both the South and North. Within this setting, it is urgent to boost the awareness of civil society to convince it to get involved. People must first be given the elements necessary to better understand the desertification phenomenon and the concerns. Everyone should have access to relevant scientific knowledge in a readily understandable language and format.

Within this scope, the French Scientific Committee on Desertification has decided to launch a new series entitled *Les dossiers thématiques du CSFD*, which is designed to provide sound scientific information on desertification, its implications and stakes. This series is intended for policy makers and advisers from the North and South, in addition to the general public and scientific journalists involved in development and the environment. It also aims at providing teachers, trainers and trainees with additional information on various associated disciplinary fields. Lastly, it endeavours to help disseminate knowledge on the combat against desertification, land degradation, and poverty to stakeholders such as representatives of professional, nongovernmental, and international solidarity organisations.

These *Dossiers* are devoted to different themes such as global public goods, remote sensing, wind erosion, agroecology, pastoralism, etc., in order to take stock of current knowledge on these various subjects. The goal is also to set out ideological and new concept debates, including controversial issues, to expound widely used methodologies and results derived from a number of projects, and lastly to supply operational and intellectual references, addresses and useful websites.

These *Dossiers* are to be broadly circulated, especially within the countries most affected by desertification, by e-mail, through our website, and in print. Your feedback and suggestions will be much appreciated! Editing, production and distribution of *Les dossiers thématiques du CSFD* are fully supported by this Committee thanks to the backing of relevant French Ministries and the French Development Agency. The opinions expressed in these reports are endorsed by the Committee.

Richard Escadafal
President of CSFD
IRD Research Director at the Center
for the Study of the Biosphere from Space

Preamble

Land degradation diminishes or destroys the soil's production capacity. This major problem is undermining the future of our planet, which is being altered by humans to an increasing extent—especially in developing countries—due to the ever increasing population pressure (forecasts indicate that there will be 9 billion inhabitants in 2050). It is therefore not surprising that this issue is the focus of substantial scientific research. Hence, the French Academy of Sciences, in collaboration with the French Academy of Moral and Political Sciences and the French Society of Agriculture, has in recent years been involved in publishing science and technology reports on the functioning of the human-altered biosphere*.

Such degradation is inherent to the location of land on the Earth's surface (soil is actually the Earth's living skin), so it is in direct contact with natural atmospheric elements, and with various actions related to the most common human interventions (agriculture, livestock production, pastoral farming and road, airport and housing development, etc.). These latter interventions have long facilitated human life on Earth, but they can also be responsible for soil loss (erosion) or degradation due to an underlying modification of the physical, chemical and biological properties of the soil. Otherwise, the soil may simply be immobilized (buildings).

The degradation potential is also clearly related to the nature of the soil. Soil is above all known to be an unconsolidated material made up of three types of overlapping constituents: the skeleton (minerals, plant debris), plasma (clay-humus) and living organisms (roots and soil mesofauna)—interactions between these elements maintain the soil's coherence and give it a certain degree of stability.

This is, however, not always the case when there is an absence of **plasma****, organic material or mesofauna (e.g. coarse mineral and desert soils), or—often in relation with the onset of and increasingly longer and more severe dry season—because of the lack of interactions, leading to plasma-skeleton dissociation, which ultimately causes marked soil textural differentiation (e.g. transformed tropical ferruginous soils in the Sudanian zone).

It is understandable that any natural or human-induced action that inhibits plasma production or alters links between the different soil phases on the Earth's surface will trigger land degradation. This process is even more marked when the soil is highly vulnerable, when the climate has a heavier impact (in dryland areas, this can create a desertlike environment), when human pressure is more accentuated, or when the action lasts longer.

For the future of humanity, it is thus essential to have a clear picture of degradation phenomena and ways to rehabilitate land that still has a capacity to be restored. It is important to be able to assess the actual land degradation situation, especially in order to facilitate efficient management of current development operations, while also providing a reference point for future initiatives taken by human societies. This was Pierre Brabant's quest, by proposing a method for assessing and mapping land degradation based on a composite index that will hereafter facilitate land conservation policymaking. This proposal has already generated excellent results in Africa (Togo) and Southeast Asia (Vietnam), and even better future results can be expected with its application in other regions worldwide.

The French Scientific Committee on Desertification, in its *Les dossiers thématiques* collection, has already alerted decisionmakers concerning erosion and natural environment restoration issues, the importance of investing in arid environments and the role of scientists. The Committee should be commended for focusing on the importance of land and soil, which are currently disregarded in large-scale international discussions—these are often too specifically oriented towards the climate, biodiversity and forests, whereas it would be crucial to investigate these different issues as a whole.

Georges Pédro
French Academy of Sciences
Lifetime Honorary Secretary
of the French Society of Agriculture

* Cycles biogéochimiques et écosystèmes continentaux. RST N°27.2007-Démographie, climat et alimentation mondiale -2010 (in press) – Gestion des sols et services écosystémiques (in preparation) – Published science and technology reports (EDP Sciences – Paris).
** Terms defined in the Glossary *(page 48)* are highlighted in blue and underlined in the text.

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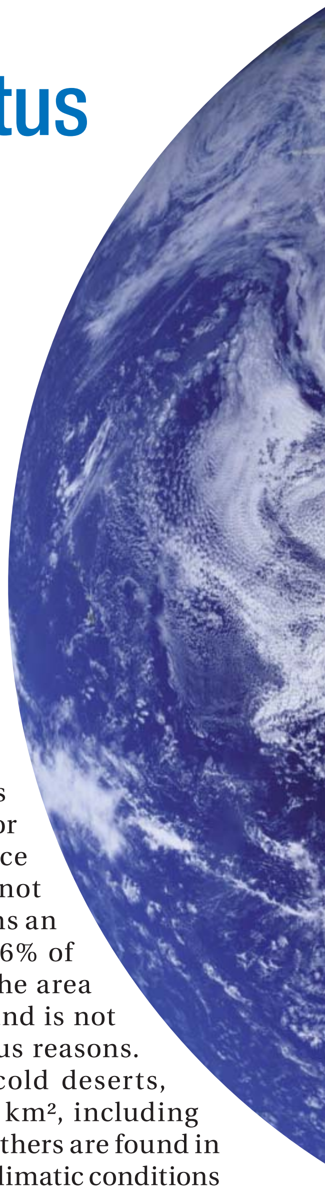
An essential assessment of the current land degradation status



LAND—A PRECIOUS FINITE RESOURCE

Edouard Saouma, former Director General of the Food and Agriculture Organization of the United Nations (FAO), stated in 1996: "*Land is the World's most precious resource. It is not, however, appreciated for its true value. Because of the high prices obtained for gold, petroleum, mineral ore and precious stones, land is treated as mere dirt.*"

Land is an essential resource for humans because it generates enough food to feed 6.8 billion inhabitants on Earth. However, it is also a scarce resource, with 30 million km² of arable land currently available, which is only 5.8% of the Earth's surface!

Land resources are being constantly depleted because of high population growth and the negative effects of human activities (overexploitation of land, pollution, etc.)—2 ha of land were available per inhabitant in the World in 1900 as compared to less than 0.5 ha in 2010…

Land is a nonrenewable resource on the human timescale. A hundred thousand years are necessary for just a single metre thick layer of **arable land** to form from rock in temperate countries, whereas this land can be eroded down to the bedrock within just 25 years (i.e. one human generation) in case of substantial erosion.

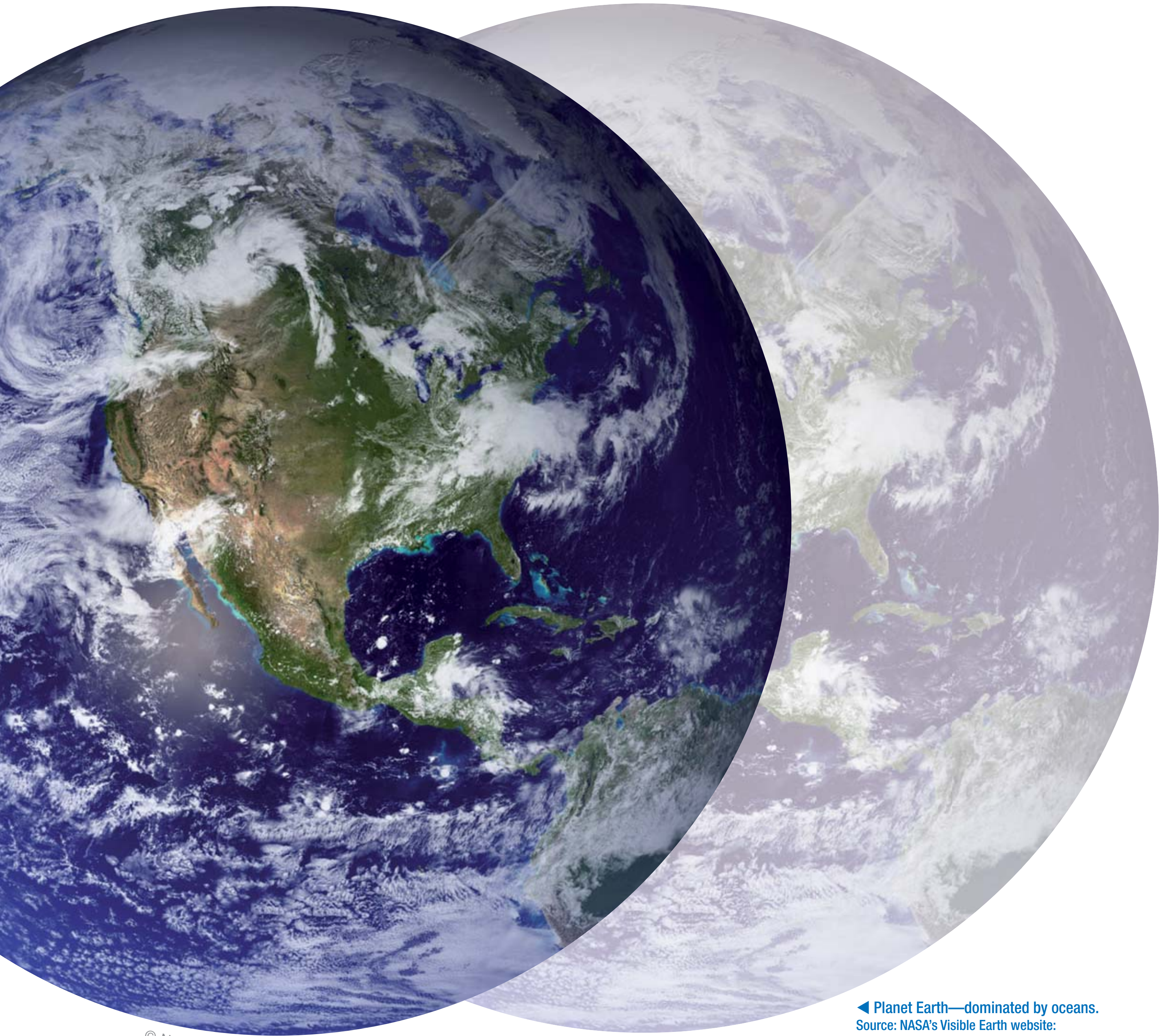
Land is not a commodity like petroleum, water or mineral ore. It is a living resource that cannot be transported from one place to another (one 2 m thick hectare of land weighs 30000 t!). It therefore has to be exploited right where it is, and under the prevailing climatic conditions.

ARABLE LAND—PRESERVATION IS VITAL

Oceans and glaciers, sometimes hundreds of metres thick, account for three-quarters of the Earth's surface (510 million km²). Emerged land not covered by permanent glaciers spans an area of 134 million km², or only 26% of the Earth's surface, i.e. 245 times the area of France. Much of this emerged land is not exploitable or productive for various reasons. Some emerged areas are hot or cold deserts, covering a total area of 18 million km², including 7.7 million km² just for the Sahara. Others are found in high mountain regions under harsh climatic conditions with steep slopes. Moreover, freshwater lakes occupy 1% of the total emerged land area. This means that there is only 120 million km² of exploitable land, which is less than a quarter of the Earth's surface (Pédro, 1985).

A third of this exploitable land (45 million km²) is not arable. In some cases, the climate is too dry, such as in part of the Sahel, and there is not sufficient rainfall for crops to complete their growth cycle. Some of this land can still be used for extensive grazing. In other cases, the climate is too cold and the ground is frozen throughout much of the year, e.g. in the northernmost parts of North America and Siberia, where the natural forests are sometimes logged. In some areas, the soil layer is too thin, humid or infertile to be cultivated.

The total arable land area is thus not more than 33 million km², from which 3 million km² have to be subtracted because the land is extremely degraded and unsuitable for cultivation (ISRIC-UNEP, 1991). Highly fertile arable land—such as that found in the Mekong River delta or the volcanic soils on the island of Java—only accounts for 1.6% of the total emerged land area.



◀ Planet Earth—dominated by oceans.
Source: NASA's Visible Earth website:
http://visibleearth.nasa.gov

Note these figures: humanity currently has access to around 30 million km² of arable land to feed everyone under the economic conditions prevailing at the outset of the 21st century. This represents around a quarter (23.5%) of all exploitable emerged land, which is the equivalent of only 55 times the area of metropolitan France. According to FAO (2000), 45% of all arable land on Earth is being utilized. The remainder is lying fallow or under natural vegetation cover, mainly in Equatorial regions, including the Congo and Amazon forest zones. **Arable land** is thus a not very widespread natural resource that is nonrenewable on the human timescale. **It is vital for humanity to preserve this resource.**

▼ Land resources worldwide

	Millions of km²
Total surface area of the Earth	510
Oceans, seas, permanent glaciers	376
Emerged land, including:	134
• Unexploitable land	14
• Exploitable land, including:	120
Nonarable land	87
Arable land	**33**

M. Savy © IRD

▲ Crop fields around Bogande, Gnagna province, Burkina Faso.

> FOCUS | **Land and soil— two overlapping concepts**

The ‘land’ concept is broader than the ‘soil’ concept, with soil being the main constituent in the land concept:

Land is the “*part of the Earth’s surface that encompasses all natural components that are normally stable or have predictable cyclical dynamics, and are located above and below this surface. These components include the soil, atmosphere and climate, surface patterns, the original soil material, water, fauna, vegetation, the results of present and past human activities, as they have significant impacts on the current and future use of land by humans*” (Brabant, 1991).

Soil is the “*product of the alteration, reshaping and organization of the top layers of the Earth’s crust under the effects of living organisms, the atmosphere, and energy exchanges that occur there*” (Lozet & Mathieu, 1990).

AND YET...

Most States consider that their arable land resources are nondepletable and that their preservation is not a priority. These national land resources are, however, nonrenewable and therefore precious. Moreover, land is not considered important in the eyes of the media. For instance, a special 162-page dossier published in December 2009 by the French daily newspaper *Le Monde*—entitled *Bilan Planète* (Earth assessment)—included a CD-ROM entitled *Les enjeux du développement durable* (sustainable development challenges) along with 50 maps. Only a half page of this document was devoted to the status of soils in Africa. A few comments mentioned the possibility of long-term leasing of arable land in Africa and Asia by highly populated countries with foresight, or petroleum-producing countries with huge financial resources. Land resources and desertification were not mentioned on any of the 50 maps. Hence, there is a clear lack of interest in this vital natural resource for humankind. This shortcoming could partially be explained by land specialists’ lack of communication.

SOIL—AN EXTREMELY THIN COATING OVER EMERGED LAND

One of the key themes of the International Year of Planet Earth (2009) was soil—'Soil, Earth's living skin'—which is actually thin and fragile.

The Earth could be compared to an 80 mm diameter orange coated with a 4 mm thick peel. One function of this peel is to protect the fruit. Emerged areas on Earth are also covered with a 'skin', i.e. soil, with a mean thickness of 2–3 m, but sometimes only 0.2 m, over a mean global diameter of 6 371 km.

In relative terms, this Earth's skin is around 100 000-fold thinner than an orange peel! It is also much thinner than our human skin, for which we take so much care. However, this ultrathin and fragile Earth's 'skin' supports life on Earth, while also providing a substrate for manmade buildings. Hence its functions are absolutely vital for humankind.

© P. Brabant

▲ Togo, Dayes region. A thin soil (0.5 m) overlying hard and relatively unalterable bedrock (quartzite and schist).

▶ Togo, Dayes region. This very thin soil (0.2 m) can completely erode away within less than 10 years if precautionary antierosion measures are not taken with respect to its exploitation.

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THE SEVEN MAIN FUNCTIONS OF SOIL

Soil has seven essential functions. Six of these have a positive impact on agriculture and the environment, whereas the seventh function can sometimes have a negative impact.

- **Soil provides a substrate for plants and buildings.** This is the main function of soil since it enables rooting of grass and tree species. The soil depth required depends on the physiology of the plant. Otherwise, many buildings are built on soil, not on bedrock. These buildings may collapse when there is a landslide or lateral sapping erosion.

- **Soil is a source of plant nutrients.** Soil has a storage capacity for different elements, e.g. calcium, magnesium, potassium, sodium, nitrogen, phosphorus and trace elements. This capacity varies with the quantity of organic matter, and with the quantity and type of clay in the soil. The soil gradually releases these elements and they thus become available to plants, which absorb them through their roots.

- **Soil is a temperature regulator.** Daily and annual air temperature variations are greatly diminished below the soil surface, which is a particularly important feature in arid regions.

- **Soil is a water reservoir**. It has a water storage and gradual replenishment capacity. It thus provides plants with a relatively steady water supply between rains or during a drought period. This storage capacity varies between soil types depending on the particle size, mineral composition and porosity.

- **Soil is a biological purifier.** The soil macrofauna and microfauna activity decomposes organic manure (plant waste, dung, straw and other crop residues), thus recycling the soil nutrients they contain. This activity can also to some extent transform and lead to the absorption of pollutant residues and pathogens.

- **Soil sequesters carbon.** Soils on Earth sequester around 1 500 billion t of carbon. This is threefold more than the quantity stored in terrestrial biomass and twofold more than that in the atmosphere. This has a marked impact on greenhouses gases such as carbon dioxide (CO_2) and methane (CH_4), and thus on global warming (hypothesis put forward by the Intergovernmental Panel on Climate Change and a number of scientists).


J.-L. Janeau © IRD

■ **Soil stores toxins** from various sources—agricultural, industrial, etc.—which are taken up by clay, organic and hydroxide fractions. Heavy metals, dioxin, radioactive elements and other products can thus persist in soil for many years after being contaminated. This function can have negative impacts on agriculture and the environment.

The seven above-described functions are mainly related the agricultural usage of soil. Soil also fulfils other functions, such as:

■ Soil provides a source of construction material in areas where solid rocks are scarce. This includes laterite for road and airport runway construction, and clay which has been used for centuries for building houses and making pottery.

■ Soil is a burial place for most of the 85 billion humans who have lived since the origin of humankind.

■ It has provided a shelter for fighters during wars ever since weapons with a high destruction capacity have been used (Crimean War in 1855, and especially since 1914). "*Land is more important for soldiers than for anyone else*" (Remarque, 1956).

■ Finally, it is a conservatory of prehistoric and historic human activities—soil contains remains from all ages (charcoal, pottery, etc.) thus enabling the dating of these activities.

EROSION, DEGRADATION, DESERTIFICATION—TERMS THAT SHOULD NOT BE CONFUSED

Land degradation has dramatically increased worldwide over the last 60 years because of population growth and industrial development. It is essential to note, however, that desertification, erosion and land degradation are three distinct processes that should not be confused.

Erosion and degradation—two different processes

Erosion occurs when all or part of the soil is carried a variable distance off its original site via water, wind, gravity or even farming tools and human development projects. Erosion is an irreversible process when soil is carried down rivers towards the sea.

Degradation *stricto sensu (s.s.)* occurs when the land is degraded at the original site without soil movement or loss. Degradation *s.s.* thus concerns the physical, chemical and/or biological properties of the soil. The processes involved are generally reversible, e.g. **acidification** of land.

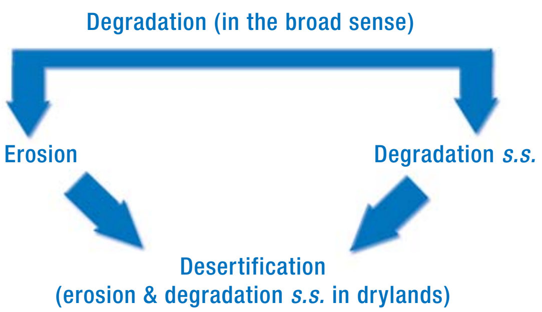
Desertification: a special case of erosion and degradation *s.s.*

Desertification is a process involving erosion and/or degradation *s.s.* that occurs in **environments under low rainfall conditions.** According to Article 1 of the United Nations Convention to Combat Desertification (Paris, 1994), desertification means *"land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities."*

Wind erosion is the main type of erosion, but desertification can also be the result of water erosion, physical and chemical soil degradation *s.s.*, such as **salinization** and **aridification**. Desertification often corresponds to situations in which the respective responsibilities of the climate and human activities are hard to determine.

▲ Soil erosion in South Africa.

Details of the erosion and degradation *s.s.* processes are not described in this document. Interested readers may also refer to the many specialised documents available when seeking more detailed information on these processes, land husbandry, and land degradation prevention and **restoration** (De Noni *et al.*, 2009; Roose, 1994).



> FOCUS | Concerning land degradation...

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Land degradation "*is a process that **diminishes or destroys** the agricultural—crop or livestock—and forest production capacity of land. It is induced by human activities or can be a natural phenomenon aggravated by the effects of human activities.*" (Brabant, 2008).

This degradation can have the following impacts:

- relatively marked deterioration of one or several of the seven main soil functions;
- disappearance of soil;
- transformation of soil for a nonagricultural use;
- soil pollution, making the affected areas unexploitable, or they may still be exploited but with major constraints for agricultural usage.

Degradation first affects the soil—the main land constituent. When soil degradation reaches a certain degree of severity, other land constituents are then also gradually affected, i.e. the type and density of the natural vegetation, nutrient reserves, soil fauna, crop yields, the type of exploitation and **land use**. The topsoil reflectance could also be added to this list. This parameter is used in satellite image interpretation to identify and monitor land degradation patterns on Earth. Soil reflectance is quickly modified when the soil becomes eroded or degraded. Erosion, along with different types of physical degradation (e.g. crusting, compaction and **aridification**) or chemical degradation (e.g. **salinization**), can thus be detected on satellite images, whereas they are generally less easy to detect visually in the field.

▲ Burkina Faso. Highly degraded land. Only a few thorny shrubs are present.

> FOCUS| GLASOD: the Global Assessment of Human-induced Soil Degradation programme

The aim of this programme, which was initiated by the United Nations Environment programme (UNEP) and implemented by the World Soil Information foundation (ISRIC), was to present a world land degradation map at the World Congress of Soil Science in Kyoto in 1990, and then at the Rio Summit in 1992. The GLASOD world map is not a synthesis of information culled from national land degradation maps. Most countries did not have such maps at that time. This original map was drawn up between 1987 and 1990 by compiling existing data and the findings of a few field surveys carried out in 1988 and 1989.

The procedure was as follows: continents were subdivided into 21 regions each containing several countries. A national representative (generally from the national soil service) was to provide data on the country, based as closely as possible on the ISRIC guidelines for drawing up the map. These guidelines provided a list of indicators (e.g. degree of degradation), but without describing how they should be determined. A regional coordinator then pooled the national data, streamlined them prior to sending them to ISRIC. This latter foundation then pooled data from all regions and drew up a world map (scale 1/10 000 000) using a conventional manual mapping method. The original paper version completed in 1990 and disseminated in 1991 was then digitized. In 1992, a series of calculated digital data accompanied the publication of the second map derived from the original one.

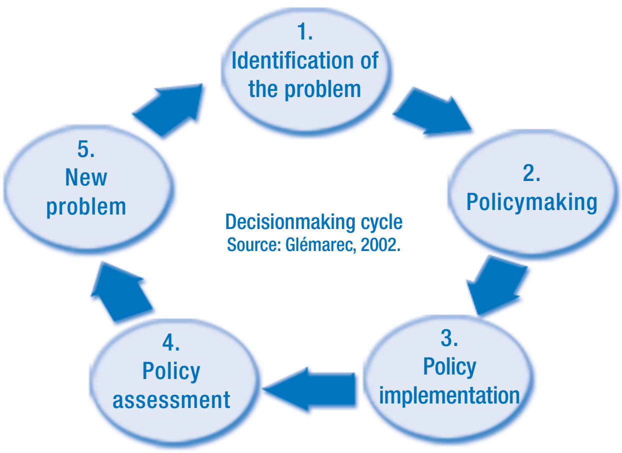
Pierre Brabant, author of the present *Dossier* and Coordinator of the West and Central African region (25 countries), noticed the difficulties involved in carrying out such work in such a short amount of time with scant resources. The national representatives had just a few months—a year at most—to present their results. It can be readily understood that African countries, especially politically volatile ones, had a hard time fulfilling this task within the required timeframe. The method was based mainly on expertise, sometimes with reference to the ISRIC guidelines. Finally, the work involved compiling data on the land degradation status (which were sparse 20 years ago), locally supplemented with a few recent observations.

Between 1992 and 1998, this author also drew up land degradation maps on a national scale for Togo, and on a provincial scale for Vietnam. He noted substantial differences with the results that had been published by GLASOD. This map did, nevertheless, outline the global land degradation trends, so one of the main objectives had thus been achieved. GLASOD coordinators then critically analysed the results and determined the scope for using the map and data calculated from the digital version. They also put forward relevant recommendations for future initiatives of this type. Unfortunately, the digital map was widely utilized by various authors and institutions without taking the variability in the quality of the information inherent to this map into account.

From GLASOD, 1988 & ISRIC-UNEP, 1991.
For further information: www.isric.org/UK/About+ISRIC/Projects/Track+Record/GLASOD.htm
Or www.fao.org/landandwater/agll/glasod/glasodmaps.jsp

LAND DEGRADATION ASSESSMENT AND MAPPING—A FIRST STEP TOWARDS COMBATING DESERTIFICATION

Land degradation assessment and mapping is an essential step before implementing any land degradation prevention, **restoration** and land protection policies. In the longer term, such initiatives facilitate field assessment of the results and impacts of implementing these policies. One major constraint to date has been the lack of streamlined international land degradation assessment procedure that would enable comparison of assessments carried out in different countries and at different times.



Decisionmaking cycle
Source: Glémarec, 2002.

A tentative global land degradation assessment

A world map of human-induced soil degradation was published by the Global Assessment of Human-induced Soil Degradation programme (GLASOD) in 1991. It was funded and implemented by the United Nations Environment Programme (UNEP) in collaboration with World Soil Information (ISRIC). This provided a first approximation of the degradation status.

However, the map had to be drawn up within a very short timeframe, so the guidelines proposed by ISRIC (GLASOD, 1988) for carrying out this work could not be applied in all countries. Moreover, these guidelines were not sufficiently straightforward or detailed, so there were marked between-country differences in the assessments. This mapping initiative was still worthwhile, despite the incomplete and heterogeneous results.

▲ Togo, Central Region. Hoed mounds of earth for yam growing. This cropping practice results in the displacement of high quantities of soil, which can then be gradually carried down slopes by gravity.

Assessment findings not very representative of the field situation

Assessments of the degree of degradation—or stage of severity—have sometimes been underestimated or (more often) overestimated, whereas the extent of degradation was often overassessed. According to FAO (1992), *"assessments of the extent of land degradation and/or their production can be highly exaggerated. This is due to governments or sectoral interests in soil conservation."*

These erroneous estimates could also be explained by the subjectivity of field observers. For instance, trend evaluators' attention tends to be attracted by clearly visible types of erosion such as water erosion (e.g. ravines) or wind erosion (e.g. dunes). In contrast, the degradation of physical soil properties—which is a substantial constraint with respect to land productivity—is generally underevaluated since it is not directly visible in the field. Laboratory measurements or tests are usually required to measure this type of degradation. This is why the percentage of land affected by physical degradation, according to GLASOD, was only 4% of all land on Earth, which is certainly an underestimate.

A proposed streamlined human-induced land degradation assessment method

The main aim of this *Dossier thématique du CSFD* is to disseminate a land degradation assessment and mapping method. **This method can be queried on a CD-ROM (Brabant, 2008), which was published by the French *Institut de recherche pour le développement* (IRD) and produced by the Cartography section of the IRD Information and Communication Service*.** There are, of course, also other land degradation assessment and mapping methods.

This land degradation assessment method meets some of the GLASOD programme guidelines concerning the types, degree and extent of degradation. It still strives to improve the assessment procedure by perfecting the indicators, defining them more accurately and fully describing the course followed in the procedure from data collection to drawing up maps and developing databases. The assessment guidelines are based on as reliable as possible indicators that could be applied in all countries and climatic zones, especially arid and semiarid areas with a high risk of desertification, and on different scales—from farm to country-wide—and on highly variable types of land. These guidelines could obviously be further improved.

This streamlined procedure is designed to facilitate assessment comparisons between countries and periods, and thus ultimately to produce a second enhanced and more reliable version of the world map of human-induced soil degradation.

The assessments require reliable analyses based on field observations. It is thus necessary to: (1) accurately describe the different types of degradation, and (2) to quantify the degree and extent of each type using relevant indicators through targeted application of recent observation techniques (satellite imaging and global positioning system, **GPS**) that can be used on a global scale.

* For further information: www.cartographie.ird.fr/degra_PB.html

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E. Roose © IRD

◀ Senegal. Onset of sand encroachment in an intensive groundnut growing area where the arable layer is already degraded, thus facilitating wind erosion.

▼ Intensive deforestation in Côte d'Ivoire.

The assessment method described in this *Dossier* involves assessment of the current status and causes of land degradation. It is not aimed at evaluating future degradation risks. Assessments of the current status are based on field observations and measurements whereas modelling is required for risk assessments. The status, as evaluated here, is the result of the direct and indirect impacts of present and past human activities: agricultural, mining, industrial and other activities. Moreover, degradation status assessments are mainly related to agricultural land use.

… for various users with different aims

"*Nevertheless, whoever the end user of the knowledge produced by the scientific community, an efficient communication is indispensable to make such information understandable and within the reach of everyone.*" (Bied-Charreton & Réquier-Desjardins, 2007)

The results of this method are presented in the form of a land degradation map based on a single composite degradation index that is easy to use and interpret—even by nonscientists. This map is accompanied by a database managed through a geographical information system (GIS) that contains all data required for drawing up and using this map.

These products and results are targeted for several users' groups whose objectives may differ: (1) politicians and decisionmakers, (2) technicians, farmers and operators, (3) scientific staff.

Rather than being restricted to a small group of specialists, the results should be readily usable by decisionmakers so as to facilitate the implementation of policies aimed at preventing degradation or restoring degraded land. **Gaining insight into the degradation status, i.e. identifying the problem, is the first phase in the decisionmaking cycle, and essential for the follow-up.** The media should also be able to use the results in the form of public awareness presentations.

The synoptic document (map and booklet, see next chapter) could interest politicians and decisionmakers wishing to gain insight into the land degradation severity, extent and locations prior to making decisions and taking potential initiatives for land **restoration**, preservation, etc. This significant, composite and easy to interpret document can help these decisionmakers assess the land degradation status in a province, country or region based on a single degradation index that is highlighted by a specific colour on the map. This index indicates areas where the land degradation status is satisfactory, worrisome or critical. Decisionmakers can then make decisions according to the socioeconomic, budgetary, or even electoral setting. This synoptic document could also interest the media and international organizations such as the United Nations.

The assessment procedure can be easily implemented by agents responsible for carrying out land degradation assessments and mapping in any country or region worldwide using the proposed standard guidelines. The complementary indicators *(see page 34)* are designed to help engineers, operators and other technicians responsible for implementing land degradation control operations in areas selected by decisionmakers.

▲ A thorny tree remaining on highly degraded land in Burkina Faso.

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Development of the composite land degradation index

▲ Cameroon, Maroua region. Vast gullying sheet erosion area extending several hundreds of metres. The ravined soil is not more than 1 m thick. The slope of the already aridified ravined plateau is less than 2%.

The assessment and mapping method described in this *Dossier* is based on a composite land degradation index which is used to draw up land degradation maps of studied areas. This index is calculated according to three main indicators: (1) the **type** of degradation, (2) the **extent** of the identified type of degradation in the area, and (3) the **degree** of degradation.

> FOCUS | **Indicators and indices:**
tools for measuring or assessing a status

An **indicator** is a parameter, or value derived from parameters, which points to, provides information about and describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value.

An **index** is a set of aggregated or weighted parameters or indicators that describes a situation.

Source: OCDE, 1994.

FIRST INDICATOR: TYPES OF DEGRADATION

Thirty-six degradation types and subtypes have been identified and can be the focus of an assessment. They are classified in three main categories: (1) erosion, (2) degradation *s.s.* and (3) 'other' degradations. All of these types are induced or aggravated by human activities. The degradation subtypes (total of 26) that can occur in desertification risk areas are indicated in brown in the following table. Each type and subtype is represented by an internationally recognizable symbol (e.g. Ws for 'water sheet erosion').

The 10 subtypes most commonly encountered in areas affected by desertification (brown shading in the table) are sheet erosion, linear erosion, **deflation**, **silting**, dune formation, soil surface crusting, **aridification**, soil nutrient deficit, **salinization** and **alcalinization**.

Readers wishing to gain insight into and identify each of these subtypes in the field should refer to the fact sheets provided in the CD-ROM (Brabant, 2008); each fact sheet consists of 14 items to help field staff for land degradation identification and assessment (definition, rating, etc.).

▼ List of land degradation types and subtypes and their symbols

The symbols, types and subtypes are given in brackets.

Category	Type	Subtype
Erosion	**Water erosion** (W for Water)	Sheet erosion (Ws, s for sheet)
		Linear groove, rill and small gully erosion (Wd, d for deformation)
		Linear gully erosion (Wg, g for gully)
		Landslides and sudden subsidence (Wl, l for landslide)
		Urban erosion* (Wu, u for urban)
		Coastal sea erosion (Wm, m for marine)
		River bank erosion (Wb, b for bank)
	Wind erosion (E for Eolian)	**Deflation** (Ew, w for wind)
		Silting (Es, s for *sand*)
		Dune formation (Ed, d for *dune*)
	Plough and mechanical erosion (M for Mechanical)	Plough erosion due to cropping practices (Mp, p for practice)
		Surface scraping during land clearing (Mc, c for clearing)
Degradation *(stricto sensu)*	**Physical degradation** (P for Physical)	Reduction in the **humus** layer (Pt, t for thickness)
		Destabilization of aggregates and the soil structure (Ps, s for structure)
		Soil surface crusting (Pc, c for crusting)
		Compaction, caking and hardening (Ph, h for hardening)
		Aridification (Pa, a for aridification)
		Submersion or stoppage of submersion (Pw, w for waterlogging)
		Soil subsidence (Pl, l for lowering)
	Chemical degradation (C for Chemical)	Soil nutrient deficit (Cn, n for nutrient)
		Excess soil nutrients (Ce, e for excess)
		Acidification (Ca, a for acidification)
		Salinization (Cs, s for salinization)
		Alcalinization (Ck, k for alkalinization)
		Various pollutions *(pro parte)* (Cp, p for pollution)
	Biological degradation (B for Biological)	Reduction in soil **organic matter** content (Bm, m for organic matter)
		Reduction in soil **macrofauna** quantity (Bq, q for quantity)
		Reduction in macrofauna biodiversity (Bd, d for biodiversity)
Other degradations (D for Diverse)	**Urbanization and other construction projects** (Dc, c for construction)	
	Open pit and quarry mining (Dm, m for mining)	
	Radioactive pollution (Dr, r for radioactivity)	
	Degradation due to wars and conflicts (Dw, w for war)	Presence of antipersonnel mines (Dw-m, m for mine)
		Presence of explosive remnants of war (Dw-e, e for explosive)
		Land deformation due to bombing (Dw-b, b for bomb)
		Massive defoliant sprays (Dw-d, d for defoliant)
		Use of depleted uranium munitions (Dw-u, u for uranium)*

In brown shading: the 10 most common subtypes in areas affected by desertification.

In brown: the 26 degradation subtypes that can occur in desertification risk areas.

* Gully erosion in peripheral nonasphalted parts of towns in developing countries.

** Depleted uranium munitions were extensively deployed during conflicts in the Balkans, Irak, Koweit and Afghanistan, mainly by NATO, coalition and US troops. The very fine depleted uranium debris settled on and contaminated the ground after explosion of these weapons.

> FOCUS | **The working scale issue**

To determine the extent of land degradation, the first issue is the scale and its impacts on the observation method and density, assessment period, cost and clear presentation of the results.

Large scales (e.g. 1/10 000) are suitable for small areas of not more than 100 km². Small scales (1/100 000, 1/200 000, 1/500 000) can be used for large areas such as an entire province or country. It could be said that scale problems may be overcome by using GIS and digital data, but this is only partially true. A land degradation map originally drawn up on a 1/10 000 scale can be reduced to a 1/100 000 scale. This is acceptable because there is no loss of accuracy or clarity because of the use of GIS.

However, the reverse is not true. In addition, the same strategy is not used for assessing a 10 km² catchment basin and an entire country with an area of 300 000 km². The time and budget required are inevitable constraints. The method therefore has to be tailored to the area of the field to be assessed. This determines the baseline working scale and finally the working cost, with the aim of obtaining the best ratio between the cost and quality of the results.

SECOND INDICATOR: THE EXTENT OF DEGRADATION

Once the type of degradation has been identified, it is necessary to determine its extent, which is defined as *"the area of land subjected to a given type or subtype of degradation in a specific area"* (Brabant, 2008). The extent of degradation is a quantitative indicator that is expressed as a percentage of the studied area.

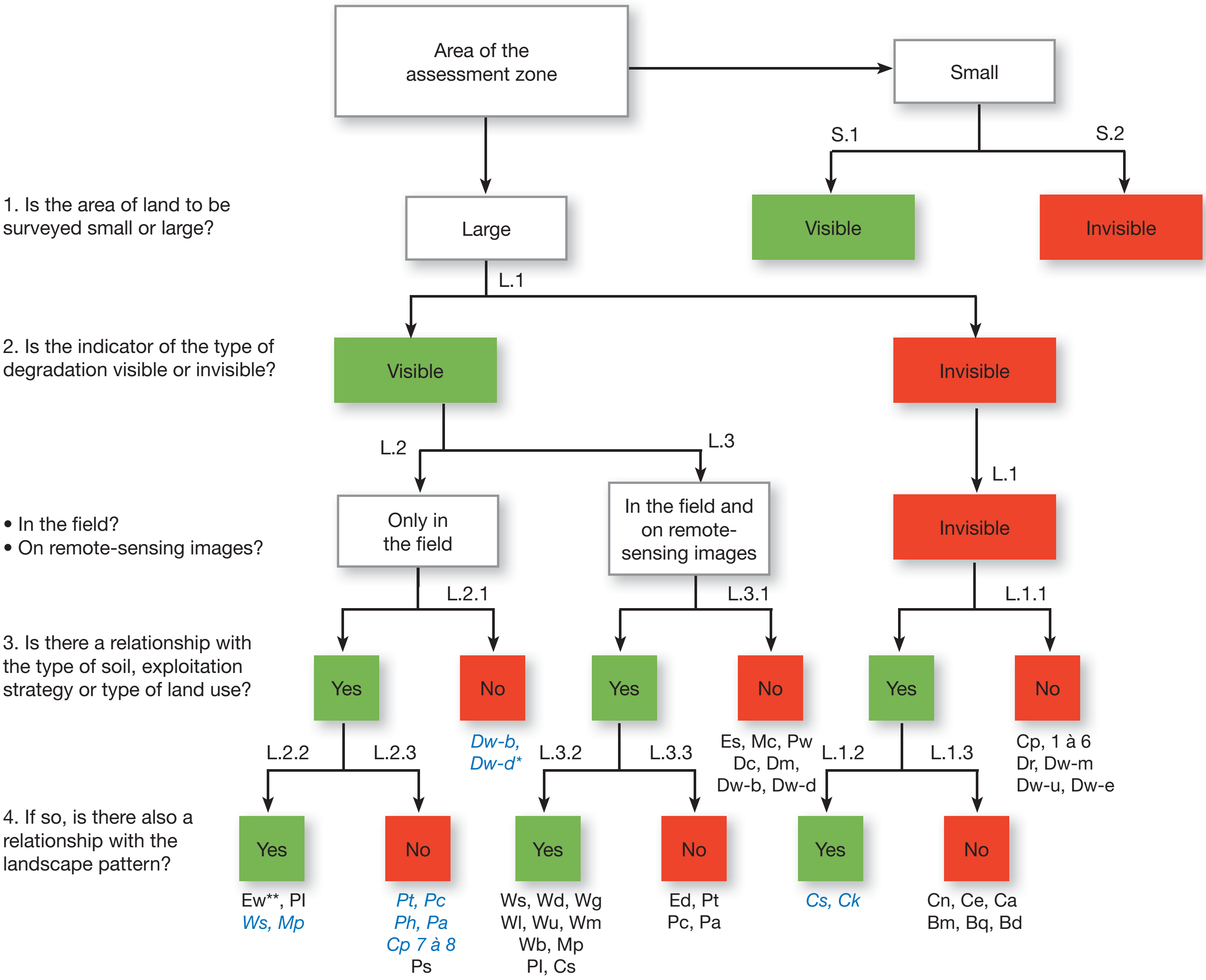
The extent indicator must be known in order to be able to implement land management policies. Its cost of course varies according to the type of degradation, as well as the area being assessed.

How can the extent of degradation be determined?

This procedure involves three operations:
❶ measuring the extent of degradation in a landscape by visual monitoring or on remote-sensing images;
❷ locating and mapping the observations;
❸ calculating the area involved.

Five questions can be asked to assess the extent of degradation:
❶ Is the area of land to be surveyed small or large?
❷ Is the type of degradation visible to the naked eye or not? In the field and/or on remote sensing images?
❸ Is the type of degradation always invisible or does it only become visible when the there is a high degree of degradation (e.g. **salinization** becomes visible when it reaches an advanced stage)?
❹ Is the type of degradation related to the type of soil, exploitation strategy or kind of **land use** (rainfed cropping, irrigated cropping, grazing, etc.)?
❺ Is the type of degradation related to the landscape pattern (peaks, slopes, plains, etc.)?

The procedure to be used can be selected on the basis of the answers to these questions. The following figure provides a key to facilitate assessment of the extent of degradation according to the answers to the previous questions.



▲ Key for assessing the extent of various degradation subtypes (Source Brabant, 2008)
L: large area • S: small area
* The symbol is in *italics* (blue) when the type or subtype has a low to medium degree of degradation; it is thus invisible or visible only in the field.
** The symbol is in normal type (black) when the type or subtype has a high to very high degree of degradation; it is thus visible in the field or in the field and on the images.

Assessment of the extent of degradation in a small land area

A small area (around 1–100 km²) may correspond to a farm, a group of farms, a small catchment, a district or any other similar-sized territorial entity. A systematic field survey can be carried out to be able to directly determine the extent of a given type of degradation. Two situations are then possible:

▪ **The types of degradation are visible in the field and on images** *(see above figure, S.1)*. This is the simplest situation, which involves pinpointing areas in the field affected by the type of degradation, transferring the observations on a large-scale map, and then calculating the degraded area to determine its extent. The visual observations can be supplemented by the use of large-scale (1/5 000 to 1/20 000) aerial photographs, by a fly-over, and by the interpretation of available high-resolution satellite images. GPS can be used to accurately locate the observations. This concerns all subtypes of water, wind and mechanical erosion, physical degradation *s.s.*, solid waste pollution and other degradations.

▪ **The types of degradation are not visible in the field or on images** *(see above figure, S.2)*. In this situation, field measurements and tests are required depending on the type of degradation concerned, or field samples can be collected for laboratory analyses after drawing up a sampling plan to facilitate statistical analysis of the results. These operations can be prepared or supplemented by surveys of farmers and inhabitants to determine the cropping practices, the history of the land plots and obtain information on armed conflicts that have taken place in the region. This concerns subtypes of chemical and biological degradation *s.s.*, chemical and radioactive pollution and degradation resulting from conflicts.

> FOCUS | Extent of degradation: what can be done when the type of degradation is invisible?

This is the main problem in determining the extent of degradation. The best way to solve it is to carefully exploit and refer to the baseline data so as to determine what data is related to the concerned type of degradation. The available baseline data concerns the actual natural environment and socioeconomic setting (maps, archival images, field data, etc.). These data are then analysed by making deductions or putting forward hypotheses, which are then verified in the field. Here are four examples on the use of baseline documents to illustrate this practice:

① Land cover and **land use** indicate exploited and unexploited areas and types of usage that could induce a type of degradation. For instance, irrigated rice growing can be conducive to soil compaction to around 30 cm depth, or salinization, but not **aridification** or crusting. Rainfed cropping on slopes can induce sheet or plough erosion, but not compaction, etc.

② The soil type also provides indications. Planosols and Vertisols are sensitive to aridification whereas ferruginous soils (CPCS, 1997) are vulnerable to sheet erosion, structural destabilization and crusting. Peaty soils are subject to subsidence. It is thus important to know the sensitivity of each soil category to different types of degradation.

③ Cropping practices, which are identified on the basis of statistics and farmer surveys, provide an indication on the use of fertilizers, pesticides, irrigation water quality and on farmers' knowledge concerning degraded areas according to crop yields.

④ Historical data supplied by inhabitants or obtained from archives can reveal whether, for instance, guerrilla troops have buried antipersonnel mines in different sectors.

It is still important to be aware of problems that may arise when a type of degradation is not visible in the field or detectable on remote sensing images. In such situations, the extent of degradation can be just as well assessed on the basis of expertise as it can by accurate measurements at the current state of assessment techniques.

▲ Togo, Maritime Region. Erosion grooves turning into rills in a cassava field planted on *Terres de Barre*.

Assessment of the extent of degradation on a vast land area

Assessments of areas over 100 km² concern districts, provinces, regions or entire countries. The land can no longer be gridded because of the high cost and time required to obtain results. A procedure must therefore be adopted to determine the extent of degradation—this involves first outlining the physiographic units and then thoroughly studying selected test sites in these units (see next chapter).

The results obtained at these test sites are then transposed to the entire area covered by the physiographic units, while analysing remote sensing images and conducting field surveys to confirm the relevance of the transposition hypotheses. Satellite images and aerial photographs are widely used when there are visible types of degradation.

The most important parameter is the fact that a subtype is visible or, conversely, invisible on the images. In the former case, the work takes

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▲ Togo, Maritime Region. Small gully erosion in a maize field after a single 80 mm rainfall.

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considerably less time and the reliability is better. There are nine (out of 36 identified) readily identifiable subtypes, irrespective of the degree of degradation. There are 23 such subtypes when there is a relatively severe degree of degradation. It is quite likely that this number will increase as the performance of satellite-borne sensors increases.

The figure on page 17 indicates subtypes that are invisible (L.1), only visible in the field (L.2), and visible in the field and on images (L.3).

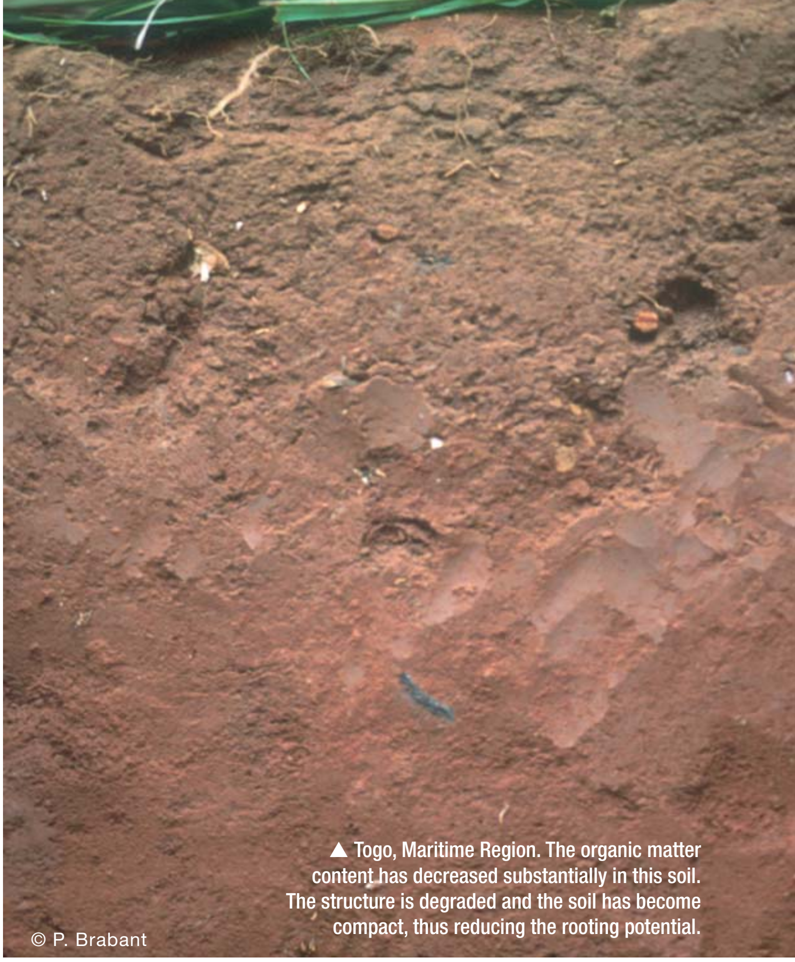
Five extents of degradation classes

Five extent classes are selected according to the concerned percentage. Class 5, for instance, means that over 75% of the area of the concerned physiographic unit (e.g. an irrigation plain) is affected by **salinization**. The intervals of limits between extent classes can of course be modified according to field requirements, the area to assess and the work scale. It is nevertheless recommended that not more than five classes be formed so as to facilitate development of the degradation index *(see page 24)*.

▼ Extent classes for a type of degradation.

Extent class	Extent rating	Limits of extent classes for a degradation subtype in the concerned area (in % of the field area)
1	Very low	< 5 %
2	Low	5 – 25 %
3	Medium	25 – 50 %
4	High	51 – 75 %
5	Very high	> 75 %

▲ Togo, Maritime Region. Example of a relatively undegraded soil in a flat area on the *Terres de Barre* plateau. Thick topsoil humus layer with a high organic matter content.



▲ Togo, Maritime Region. The organic matter content has decreased substantially in this soil. The structure is degraded and the soil has become compact, thus reducing the rooting potential.

THIRD INDICATOR: THE DEGREE OF DEGRADATION

The degree of degradation, which is a qualitative indicator*, is the severity reached by a given type of degradation in a specific field area. For instance, consider a simple situation: a crop field has lost 1 cm of arable soil layer (originally 20 cm thick) via water-induced sheet erosion. Here the degree of degradation is considered to be low. However, the degree is considered to be high or very high if the eroded soil layer is as much as 15 cm. This type of assessment is not always as easy for all degradation subtypes.

Two methods for assessing the degree of degradation

Recall that the degree is assessed with respect to an agricultural land use based on the following assumption—the higher the degree of degradation, the lower the agricultural yield of the land. In some cases, this leads to an increase in the negative environmental impacts (e.g. off-site effects of water erosion). The yield may even drop to zero if the land has another usage (in the case of urbanization), if soil has been carried away by erosion, or if major chemical or radioactive pollution has made this land unexploitable.

* A qualitative indicator is not the result of a calculation or of an accurate measurement. It is an expert's estimation and the results are expressed by adjectives. The degree of degradation can thus be ranked as very low, low, etc. Conversely, a quantitative indicator can be measured and is expressed in numerical values (ha, %, etc.).

▪ **The first method** involves identifying soil properties that are markers of its degree of degradation and that could have a negative impact on crop yields. These markers should be as easy to observe, measure or estimate as possible so that an observer would be able to assess the degree of degradation as objectively as possible. For instance, these markers could be the gully density, the reduction in the thickness of the **humus layer**, soil compaction, acidity as determined by pH measurements, excess salt levels, the presence of **aridification** indicator plants, etc.

The impact of the degree of degradation on yields when comparing undegraded land and relatively degraded land should be determined with reference to the same level of inputs. For instance, conventional rainfed crops with a low level of **inputs** with periodic fallowing.

This first method thus determines, upstream, the degree of degradation of soil functions that could induce yield reductions.

▪ **The second method** is based on the assumption that a reduction in yields or in the level of **land suitability**, for a given type of use, indicates that the land is degraded. Schematically, it could be considered that this method deduces that the land is variably degraded as a function of the noted loss of productivity. This has been used, for instance, to assess the degradation status of land in South and Southeast Asia within the framework of the Soil Degradation in South and Southeast Asia

(ASSOD) programme (ISRIC, 1995) partly based on the GLASOD guidelines. According to these guidelines, "*the current degree of soil degradation (degree of severity or degradation severity) is assessed in relation to changes in agricultural land suitability relative to the loss of productivity and, in some cases, of its biotic functions.*"

The drawbacks of this second method are twofold. First, the information required for the assessment can sometimes be scarce and doubtful. The reference data is often derived from agricultural statistics. The productivity level is also not always only directly related to the degree of land degradation, i.e. it can also be linked to the agricultural practices or to the plant varieties used. "*The experience and knowledge of experts in the region are required to eliminate other factors from this assessment which could have contributed to the decrease in yield, such as poor crop management*" (FAO-UNEP, 1994). The question also arises as to whether to assess the actual productivity of the main studied type of land use with its input level or the potential productivity involving different input levels.

This second method requires expertise, which comes with the risk of being subjective. Hence, the first method seems preferable, especially considering the problems of reliability of the available data. This is the choice that was made for the method presented in this *Dossier*.

Difficulty in implementing a streamlined approach

Determination of the degree of degradation is the hardest of all operations involved in characterizing the degradation status. This was also a major constraint with respect to uniformizing global work on the land degradation status in the GLASOD programme. The results presented were often heterogeneous since assessments of the same degree of degradation varied between countries because of the highly different ecological settings, and sometimes because of the subjectiveness of evaluators' assessments due to the lack of standard nomenclature on this topic (Brabant, 1997). *"Although land degradation may be clearly perceptible in the field, it is easier to describe than to quantify"* (BDPA-SCETAGRI, 1992).

Six basic principles for assessing the degree of degradation

❶ **Parameters for assessing the degree of degradation vary according to the type of degradation.** There is no common globally applicable rule. For instance, the standards differ for determining the nutrient deficit for plants in the arable layer and the land **salinization** severity level.

❷ **The degree of degradation may be dependent on or independent of the land type**. There are often relationships between the degree of degradation and the type of land or land use. However, in some cases, these two factors are completely independent. For instance, accidental chemical or radioactive soil pollution does on depend on the soil type but rather on its location, i.e. its distance from the pollution source.

❸ **The soil thickness is an important variable to consider in the 'erosion' category.** Let us consider a situation in which 1 cm of the arable soil layer is lost yearly as a result of severe water erosion (i.e. 30 cm in 30 years). The extent of degradation will not be the same if the soil thickness is 50 cm or 300 cm. Then how can the soil thickness be integrated in the degree of degradation and in the composite index? The value of the degree of degradation indicator ranges from 1 to 5 *(see table on the next page)*. The indicator value is increased by one point for soils 50–100 cm thick and by two points for soils less than 50 cm thick, while not going any higher than the maximum value of 5 in both cases.

❹ **Some soils are more sensitive than others to a given type of degradation.** For instance, a clayey soil is much more susceptible to salinization than a very sandy soil because the exchange capacity of this former soil has a high sodium ion retention capacity. It can thus have a higher degree of salinization than a sandy soil under the impact of the same type of usage.

❺ **The degree of degradation sometimes depends on the initial conditions.** Let us consider a situation concerning two cultivated soils with a surface pH of 4.5. One is a humid tropical forest soil with an original pH of 5.0, while the other is a savanna soil with an original pH of 6.8. There is acidification in both cases. However, the degree of **acidification** is higher in the second soil than in the first one because the initial conditions differed due to the type of soil.

❻ **The degree of degradation is assessed in a conventional farming situation with a low level of inputs and an equivalent level of inputs between degrees of degradation.** This is the most common type of agricultural land use worldwide, especially in tropical developing countries. The loss of land productivity in developed countries resulting from a certain degree of degradation can be temporarily obscured when there is a high chemical fertilizer input in an intensive subsidized agriculture setting. However, degradation of the physical soil properties will eventually occur, along with environmental damage, especially with respect to the water quality.

> EXAMPLE | Degree of degradation classes proposed for water-induced sheet erosion

The following table describes a situation of water-induced sheet erosion. A similar table has been drawn up for most identified subtypes (Brabant, 2008). The main parameter that indicates the degree of degradation is first determined. Here it involves a reduction in the thickness of the arable **humus** layer, which is commonly called **topsoil**. Other variables that could directly or indirectly impact the degree of sheet erosion are then listed (variable classified in alphabetical order).

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▲ Togo, Maritime Region. High sheet erosion on slightly sloped land. The soil humus layer has been eroded. Residual white sand with the underlying clayey and reddish layer becoming exposed and hardened as it dried.

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▲ Cameroon, Garoua region. Sheet erosion that has striped away the arable humus layer. The sandy whitish underlying layer is exposed.

Main parameter	Reduction in the thickness of the **humus layer**
Variables	• Density of stones on the soil surface • Land productivity level • Landscape pattern • Land value • Major kind of land use and land tenure system • Natural vegetation status • Rainfall, distribution and intensity • Rural population density • Soil surface roughness and degree of surface fauna activity • Thickness of the humus layer • Topsoil status • Type of soil and topsoil

Class	Degree of degradation rating	Indicators
1	Zero to very low	Natural erosion marks which vary according to the soil type and field conditions. The land is generally uncultivated and under natural vegetation cover or located in a protected area, without human activities.
2	Low	Reduction in the thickness of the humus layer less than 1/5 the total thickness in uncleared soil; a few sand deposits are noted on the leeward side of obstacles in the field (clumps of grass, stones). Local accumulation of fine fractions in small field depressions. Very little or no obvious decrease in productivity.
3	Medium	Reduction in the thickness of the humus layer over 1/5 and less than 1/3 the total thickness. Clumps of grass partially uprooted; accumulation of fine sand and silt on the soil surface at sites conducive to such deposits. Some surface crusting on less than 10% of the field. Substantial decline in productivity (around 25%).
4	High	Reduction of almost half of the thickness of the humus layer. Substantial uprooting of clumps of grass. Tree and shrub roots exposed below the root collar. Many sand and silt deposits on low parts of the field. Substantial crusting on the soil surface. Bare areas without natural vegetation sometimes on 10–25% of the surface area of the field. As much as 50% decrease in productivity.
Threshold		
5	Very high	Reduction of almost 3/4 of the humus layer. This layer may disappear in some areas, sometimes in a large part of the field. Tree and shrub roots exposed for several centimetres or decimetres. Marked reduction in natural vegetation cover. Large bare areas. Abundant sand deposits (fine and coarse) in the lowest parts of the field and along drainage routes. Substantial crusting. Highly reduced grass cover. Bare areas sometimes on over half of the field area. Over 75% decrease in productivity. Land often abandoned.

Source: Brabant, 2008.

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▲ Cameroon, Maroua region. Gully formed in a landscape with a very slight slope (1%) with a black clayey Vertisol.

Five degree of degradation classes

The degree of degradation can gradually vary from very low to very high. Distribution classes between these levels have to be established. Five classes were established for each degradation type in reference to several physical and socioeconomic parameters or the crop yield level. Most of these parameters were selected on the basis of surveys carried out in tropical areas in Africa and Asia, and sometimes in South America, over the last decades.

Degradation threshold: values above which land restoration becomes very expensive

For most of the described subtypes, there is a threshold (indicated by a thick line in tables, as in the example hereafter). This threshold is essential to determine. "*Even when there is an international consensus on an ideal environmental indicator, it is still hard to define tolerable (ecologically) thresholds. However, all of the advantages of environmental indicators depend on the quality of these thresholds*" (Glémarec, 2000).

The threshold is associated with land **restoration** possibilities and depends on the type of degradation concerned. It is generally located between classes 3 and 4 or between classes 4 and 5. The cost of land restoration when the degree of degradation is above the threshold is 10- to 100-fold higher than for land with a degree under the threshold. Passing this threshold leads to a quantitative increase in the economic cost of restoration and also in the loss of crop productivity induced by the degree of degradation.

In most cases, it can be considered that **the threshold is passed when the land restoration cost after degradation by private activities is too expensive for the land user and has to be covered by the community.** Here is a typical example: intensive agriculture and intensive indoor pig production in French Brittany, which are practiced by a very small part of the population, has such a negative pollution impact on the soil, inland water and coastal sea water that work to improve the situation has to be managed by the European Commission, the French federal government, regions, departments, and thus the community.

▼ Five degree of degradation classes

Soil thickness > 100 cm		Soil thickness 50–100 cm		Soil thickness < 50 cm	
Reference class	Degree rating	Equivalent reference class	Degree rating	Equivalent reference class	Degree rating
1	Very low	2	Low	3	Medium
2	Low	3	Medium	4	High
3	Medium	4	High	5	Very high
4	High	5	Very high	5	Very high
5	Very high	5	Very high	5	Very high

COMPOSITE LAND DEGRADATION INDEX

Once the three main indicators are determined, they are combined to form a single composite index.

Formation of the index from three main indicators

The extent and degree of degradation are divided into classes that are given a value ranging from 1 to 5. By definition, the subtype has no numerical value and is represented by its symbol. The extent value (1–5) and the degree value (1–5) are thus totalled, while weighting the degree value according to the soil thickness if necessary. This gives a composite numerical index that is identified by a degradation value ranging from 1 to 5 and by a colour, as indicated in the table below.

By convention, a different colour is given to each index value. The redder the colour the more the land is degraded, and the greener the colour the less it is degraded. Neutral shades (grey or white) indicate land that is not affected by degradation, **protected land**, stabilized or improved land.

Presentation of the results—are map representations useful?

Should a map be drawn up or not? In fact, it is not always necessary to draw up land degradation maps since a database containing a broad range of information is available and maps can be produced from this database to fulfil specific needs. This, however, only applies for technicians because decisionmakers, funding agents and especially politicians would be unable to extract relevant information from such a complex database. Simple maps with a range of suitable colours would still facilitate the transmission of synoptic information.

The results could be presented and utilized at three different levels:

❶ **First level:** a single map showing zones degraded to various degrees or undegraded and having two attributes—an index and a corresponding colour—to give decisionmakers a glimpse of the land status in a region or country.

❷ **Second level:** the symbol of the dominant degradation subtype is added to the index number and to the colour. For instance, a red zone with the index 4 and symbol Cs indicates that the land is highly degraded by **salinization**. This information level can be suitable for decisionmakers who are aware of the fact that it is very expensive to conduct operations to restore saline land.

❸ **Third level:** it is recommended for technicians and scientists to enquire about the complementary indicators *(see page 34)*, to query the database containing detailed information on each zone on the map, or to examine the details of the assessment procedure *(see page 26)*.

▼ Drawing up a composite land degradation index

Number of combinations of **extent** (bold) and *degree* (italic) indicators	Total value of the extent-degree combination	Degradation status index rating	Value of the composite degradation status index
1+*1*	2	Very low*	1
1+*2*/**2**+*1* **1**+*3*/**2**+*2*/**3**+*1*	3 4	Low	2
1+*4*/**2**+*3*/**3**+*2*/**4**+*1* **1**+*5*/**2**+*4*/**3**+*3*/**4**+*2*/**5**+*1*	5 6	Medium	3
2+*5*/**3**+*4*/**4**+*3*/**5**+*2* **3**+*5*/**4**+*4*/**5**+*3*	7 8	High	4
4+*5*/**5**+*4* **5**+*5*	9 10	Very high	5

* This could be described as 'Zero to very low', which corresponds to a level of natural erosion, or of natural erosion very slightly aggravated by human activities.

> FOCUS | **Several types of degradation present in the same area**

Some degradation subtypes are mutually exclusive. For instance, subsidence and **aridification** (in the former case, there is excess water in the soil and in the latter there is a deficit). Moreover, dune formation and **alkalinization** cannot coexist, i.e. dune soils are very sandy whereas alkalinization occurs in soils with a high clay content.

Conversely, other subtypes such as sheet erosion and rill or gully erosion can coexist at the same site. There are around 60 possible associations between two or even three subtypes (Brabant, 2008). Water-induced sheet erosion is involved in the highest number of associations. Note also that the radioactivity and degradation due to wars can be associated with all other subtypes. They occur on all types of land—arable, exploitable or not, protected or stabilized—and land degradation due to such activities has no spatial or intensity limits.

The problem is to know how to aggregate this in the composite index. Should the dominant degradation subtype only be considered, or also the other main associated subtypes? In what proportion? With what extent and degree?

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▲ Cape Verde islands. Example of a very high stone concentration on the soil surface under the effects of deflation and water erosion.

In this case, it could be considered that the extent and degree of the dominant degradation subtype determines the value of the index. The characteristics of the associated subtypes are only indicated in the database, but not on the map (otherwise it would be too complicated). When their extent and degree are known, they can be added to the database attributes.

How can undegraded land and undegradable zones be taken into account?

The **protected land** or land improved by human activities categories should also be indexed because they can serve as a **reference status** for future assessments. They are divided into three categories (GLASOD, 1988):

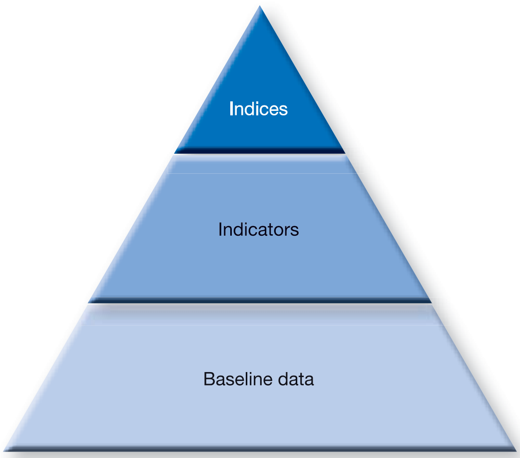
- Uninhabited zone that is naturally stabilized, mainly by vegetation (e.g. natural tropical forests): this type is potentially susceptible to degradation if the natural balance is upset.
- Protected and uninhabited zone (forest reserve, National Park, land reserve).
- Zone that is stabilized or improved by human activities:
  - by bunds in irrigation rice fields;
  - by terraces in rainfed agriculture;
  - by reforestation, by permanent crops;
  - by polderization.

Areas that are undegradable or not considered in assessments are lands on which there have never been human activities, on which there were human activities very long ago, or on which there are currently no human activities that could damage the land. These include mobile dunes, natural nonarable salt flats, rock outcrops, uninhabited deserts, glaciers and inland waters, e.g. lakes, ponds, dam lakes, water reservoirs, etc. There are generally no zones that have been degraded by human activities in these nine categories, except in special cases, e.g. pollution by long half-life radioactive material (chemical or radioactive) that may still be active after several decades.

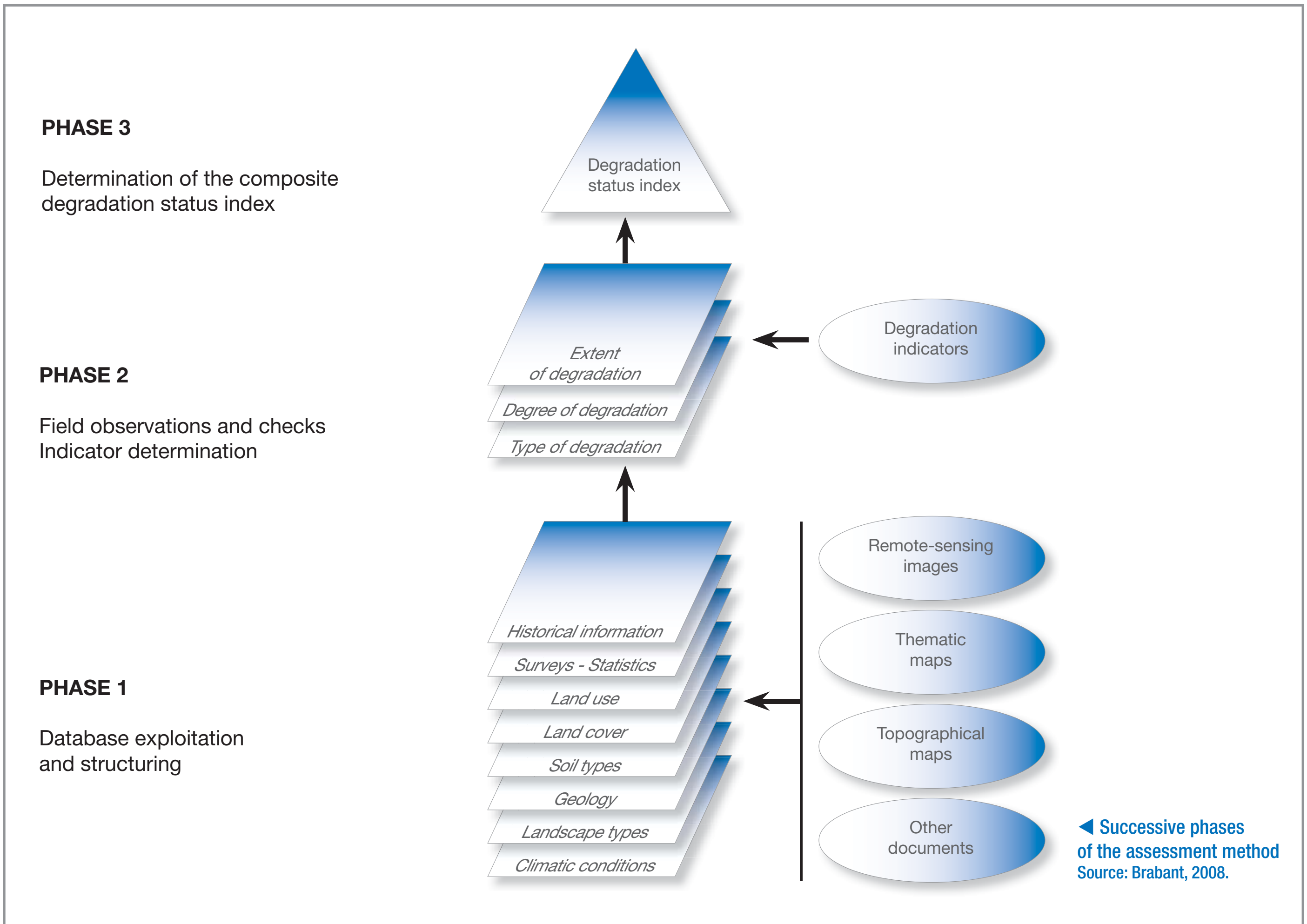
A method for assessing human-induced land degradation

This chapter describes the sequence of various practical operations that are conducted successively from baseline data collection to presentation of the results. They are intended for people involved in programmes for assessing the land degradation status within a country, province, or any other geographical entity.

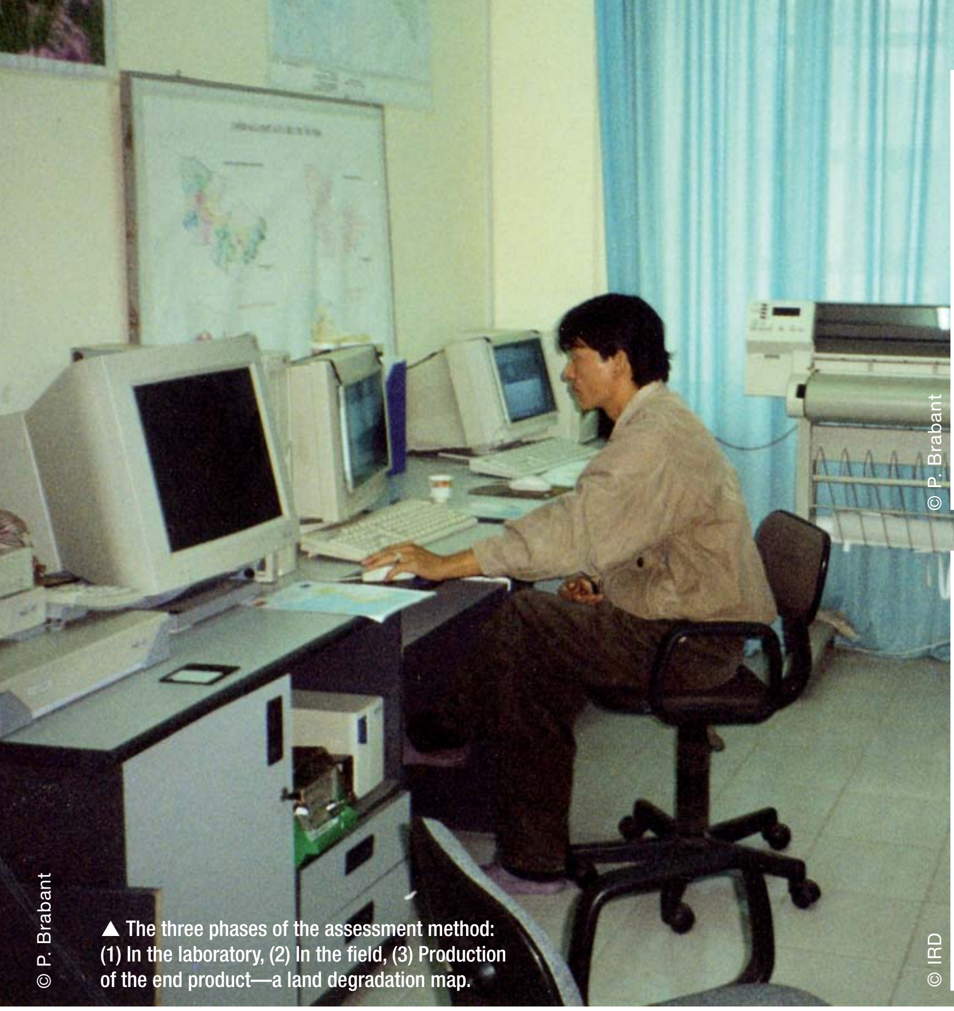
The assessment method includes three successive activity phases. The figures on this page indicate that the information is gradually integrated from the baseline data to development of the index.



▲ The information pyramid
Source: Braat, 1991, cited by Glémarec, 2002.



◄ Successive phases of the assessment method
Source: Brabant, 2008.



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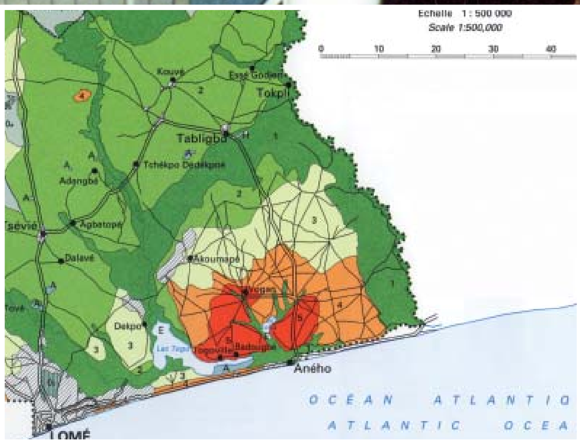

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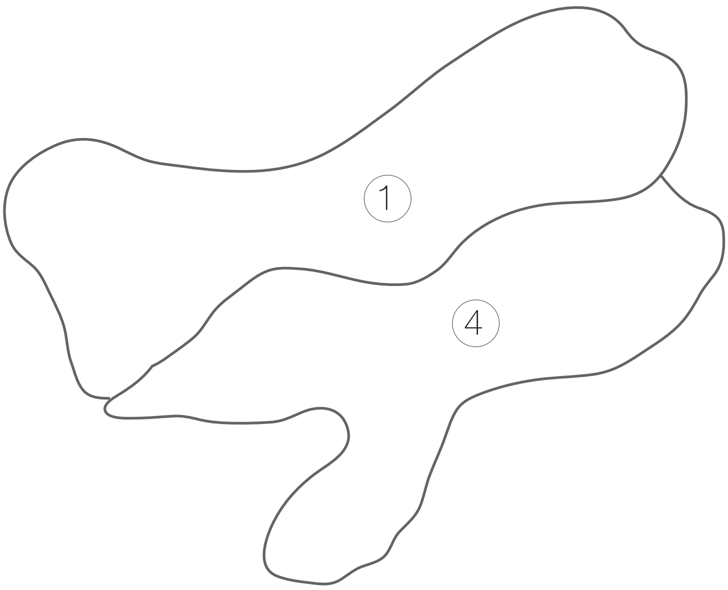
▲ The three phases of the assessment method: (1) In the laboratory, (2) In the field, (3) Production of the end product—a land degradation map.

PHASE 1. EXPLOITATION OF EXISTING DATA ON THE NATURAL ENVIRONMENT AND HUMAN ACTIVITIES

This first laboratory phase involves three successive operations. The aim is to collect information (operation 1), to divide the area to be assessed according to the physical parameters (operation 2), and according to the land use (operation 3).

Operation 1. Collection of baseline documents

These documents include topographical maps, archival and current records on climatic conditions, geological maps, soil maps and works, land cover and **land use** maps, information on rural population distributions and densities, statistical data on agricultural production, historical data and any other useful documents. Looking for satellite images and aerial photographs captured during the most suitable period of the seasonal cycle is also a key activity in this operation.



▲ Outlining physiographical units from physical baseline data.
The numbers 1 and 4 represent polygons within the physiographical units.

Operation 2. Exploitation of baseline documents to outline the physiographical units

This is the most important operation: outlining the boundaries of physiographical units in study areas. **The formation of physiographical units from reliable baseline data is the basis of all land assessment procedures.**

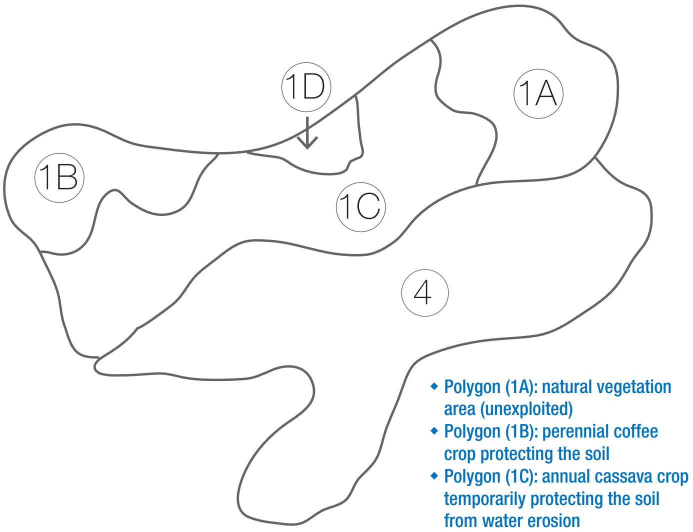
During this operation, undegraded and undegradable protected areas are also indexed: rock outcrops, inland waters, land and forest reserves, natural parks, etc.

Once the physiographical units are outlined over the entire land area to be assessed, they are transferred to hardcopy or digitized topographical maps and represent polygons on the provisional maps.

▲ Satellite images. Northern Cameroon, satellite image of Maroua region. SPOT image (15/01/87) – Infrared colour composite image. Resolution 20 m – pale grey and whitish areas indicate degraded land.

Operation 3. Initial processing of remote-sensing images

These images are used to identify the main current kinds of land use (protected areas, wastelands, and forest, urbanised and cropped areas, etc.) and sometimes the land-use system (perennial, annual and irrigated crops, etc.). Human activities can modify the natural degradation and induce a type, extent and degree of degradation, which may differ depending on the kind of exploitation and **land use**. A polygon defined during operation 2 can thus be subdivided into several secondary polygons depending on the human activities involved. This operation is carried out for all polygons of each physiographic unit.



▲ Subdivision of polygon 1 of physiographical unit 1 into four secondary polygons according to human activities

> FOCUS | Physiographical units and polygons

A physiographical unit is defined as “*a land zone having the same type of landscape, the same geological substrate, the same soil or association of soils under similar climatic conditions. Such units are supposed to react to natural agents and to a specific human activity by a certain relatively uniform level of degradation over its entire area*” (Brabant, 2008). For instance this reaction will differ between an uneven hilly area on a granite substrate with a thin soil (polygon 1), and on a slightly sloped alluvial area with a deep soil (polygon 4). Physiographical units are sometimes not related to a degradation agent, e.g. in situations of accidental radioactive or chemical soil pollution.

Physiographical units become polygons when plotted on a topographical map. A polygon is defined as “*a relatively vast area of land that is delineated on a map by a closed outline and identified by a colour, an icon or a number corresponding to a legend unit*” (Brabant, 1991). Each physiographical unit can be formed by a single polygon—which is uncommon—or several polygons dispersed in the field.

Results of phase 1: a provisional map with polygons delineated and identified in physiographical units

This provisional map is essential for carrying out the field work in the second phase. The following features should be represented on this map:

■ roads, because the habitat—and thus the exploited sectors—is often focused in the vicinity of entrance roads used to carry out the field work;

■ drainage pathways because some types of erosion often occur along them.

PHASE 2. IDENTIFICATION OF THE THREE INDICATORS AT THE TEST SITES

The aim of this second phase is to determine the degradation indicators in the previous mapping units and to subdivide these units, if necessary, according to the values of these indicators. This is the field work phase, which includes two operations.

Operation 1. Determining the degradation subtypes and their extents and degrees

Large surface areas cannot be entirely surveyed, so test sites are selected in the physiographical units delineated during phase 1. Observations on these three indicators are carried out and validated by remote-sensing image interpretation. If the study area is small (under 100 km²), a systematic field survey is possible without implementing the test site procedure.

Operation 2. Transposing the results obtained at the test sites

After the image interpretations are validated, the results obtained at the test sites are transposed to other similar physiographical units. This enables considerable savings in field work time. Here are three recommendations for conducting this second operation:

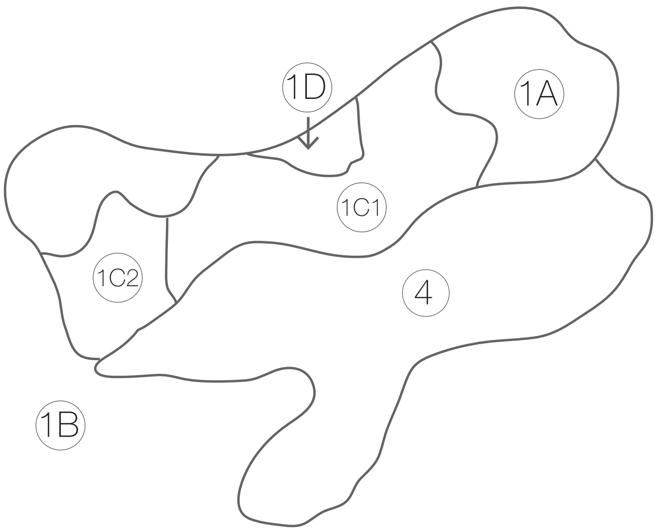
❶ Field work at the test sites should be simultaneously focused on the three main indicators (type, extent, degree) because the field surveys are very expensive and time consuming. Hence, several surveys on the same site should be avoided as much as possible. The observations are supplemented by surveys of land users when necessary. Trips between test sites also provide an opportunity to conduct observations.

❷ Field validations and image interpretations should be very carefully done in order to avoid making serious errors.

❸ The results of the observations carried out at test sites should be transposed to all polygons in a physiographical unit. When there is uncertainty about the reliability of the transposition, a second field check could be required. The use of **GPS** and the future European ***Galileo*** system are very helpful for locating test sites and for other observations.

Results of phase 2: subdivision of polygons according to the degree of degradation

The provisional maps drawn up in phase 1 include polygons, with each one characterized by physical properties and the type of exploitation or **land use**. At the end of phase 2, information on polygons is supplemented by adding the three main degradation indicators, i.e. the type, degree and extent. Additional polygons could then be formed by subdividing certain polygons on the phase 1 provisional map according to the degree and extent class. The map derived from phase 2 thus encompasses the first two levels of the information pyramid (baseline data and indicators).



▲ Results of phase 2
Here polygon 1C of the provisional map is subdivided into two polygons (1C1 and 1C2), because the field survey during phase 2 revealed that the degree of degradation was higher in the sector covered by 1C2 because of the presence of small erosion gullies.

Polygon number	Dominant type of degradation (symbol)	Degree of degradation class	Extent of degradation class
Physiographical unit 1			
1A	Water erosion (Ws)	1	1
1B	Water erosion (Ws)	2	1
1C1	Water erosion (Ws)	3	3
1C2	Water erosion (Wd)	4	3
1D	Urbanization (Du)	5	5
Physiographical unit 2			
4	Water erosion (Ws)	3	3

PHASE 3. CALCULATION OF THE COMPOSITE LAND DEGRADATION INDEX

The aim is to calculate the degradation index for each polygon and to transfer it onto the map. This phase, which is mostly carried out in the laboratory, involves three operations.

Operation 1. Calculating the composite index for each polygon

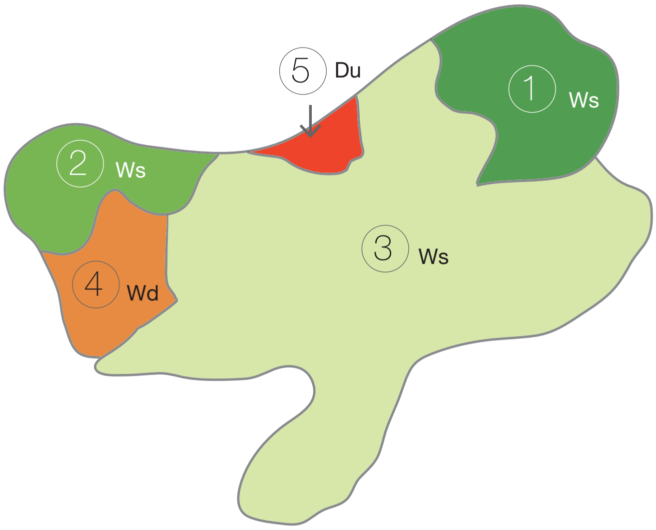
The three main indicators (type, degree, extent) attributed to each polygon are combined to obtain a composite index. This index indicates the land degradation status in the concerned polygon. A few final indicator field checks are sometimes necessary, especially if there is any doubt concerning the validity of the remote-sensing image interpretations for a specific sector.

Operation 2. Drawing up the final map

The final map is drawn up by transferring the composite index into each polygon on the map derived from phase 2. During this operation, the polygons—which are overlapped on the map and have the same index—can be pooled.

Operation 3. Compiling a database

When working in digital mode, a GIS-managed database is compiled that describes each polygon on the map with attributes (identifier, degradation, reference of the topographical map, of aerial photographs, satellite images, environment, etc.). When working in analog mode, the map is prepared for printing and the information chart is drawn up.



▲ Results of phase 3, operation 2
The two polygons 1C1 and 4 delineated during phase 2 are pooled into a single polygon. They have the same degradation index (3). However, information on the indicators and on other attributes of these two polygons (1C1 and 4) is kept separately in the database.

Results of phase 3: a hardcopy map or database indicating the field zoning

Each identified zone is represented by a polygon, which is characterized on the map by a degradation index (1 to 5), along with a colour gradient ranging from green for undegraded or relatively undegraded zones (index 1) to red for the most degraded zones (index 5). The symbol of the dominant degradation subtype can be added in the polygon. Each polygon is also characterized by a high number of attributes that are indicated in the database.

▼ Degradation index represented in each polygon by a value and colour

Polygon number	Drawing up the index (degree + extent)	Ranking the degradation status (symbol of the dominant degradation type)	Degradation status index value	Colour
1A	1 + 1 = 2	Very low (Ws)	1	
1B	2 + 1 = 3	Low (Ws)	2	
1C2	4 + 3 = 7	High (Wd)	4	
1D	5 + 5 = 10	Very high (Du)	5	
1C1	3 + 3 = 6	Medium (Ws)	3	
4	3 + 3 = 6	Medium (Ws)		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▲ Senegal. Ripplemarks. Typical appearance of land during the sand encroachment process.

PRESENTATION AND USE OF THE ASSESSMENT RESULTS

The modes for data storage and presentation of the results should be selected prior to beginning the work, i.e. analog or digital mode. The planning of the laboratory and field activities, budget and working period will generally depend on this choice.

Analog mode

The baseline documents, in printed form, are examined in the standard way. The complexity of the analysis increases as the number of documents increases. The distribution of types, extents and degrees of degradation observed in the field is manually transferred to the hardcopy topographical maps. The final map containing degradation status indices is then drawn up manually.

■ **Drawbacks:** A good staff expertise level is essential; the map has to be remade when updating; analysis of the results is limited.

■ **Advantages:** The work can be quickly carried out at relatively low cost. The analog mode is usually suitable when the land area to assess is small and rapid results are required. The final map represents a land zoning pattern in which each polygon on the map is identified by a degradation index and colour. The indicators can be represented in the polygons by a symbol if this does not reduce the clarity of the map.

■ **End users:** This mode of presenting the results is suitable for decisionmakers and some users for which all baseline data and full details on the indicators used for developing the index are unnecessary. Such users just want to get a general overview of the situation and pinpoint priority sectors.

The GLASOD world map was prepared and edited in analog mode, despite the fact that it covered a vast area, because of the very short publishing timeframe and technical constraints. It was digitized following publication, which then made it possible to print the entire map or parts of it on different scales and to quickly perform statistical analyses on some indicators.

> FOCUS | **What can be done when no baseline data are available?**

■ Remote-sensing images are essential. It would not be realistic to try to assess large land areas within a suitable timeframe and cost without recent or quite recent coverage via satellite images or aerial photographs.

■ Topographical maps are essential for locating observations. Full coverage topographical maps are available for all countries worldwide. However, all countries do not have access to topographical maps that have been digitized on different scales. In some cases, by default, it is possible to use small-scale digital topographical maps that can be obtained at a reasonable price from several data suppliers.

■ Soil maps and geological maps are the most useful thematic maps. Their absence can sometimes be partially offset by an analysis of satellite image. Land cover and **land use** maps, which are often obsolete when they are not recent, can be appropriately replaced by an analysis of satellite images.

Digital mode

All phase 1 baseline documents, information acquired during phase 2 on indicators and data generated in phase 3 are digitized in a GIS-managed database. There is one requisite condition—all of these data stored in the database have to be accurately geolocated. This requires digitization of topographical maps on a scale that is suitable for the size of the area to be studied. This can be a major constraint, since many developing countries, especially in Africa, do not yet have access to these digitized topographical maps.

■ **Drawbacks:** The main drawback is the absence of already digitized topographical maps and a suitable scale. If topographical maps have to be digitized, this is a long and costly operation which would substantially increase the programme budget. Skilled personnel are also necessary to manage the GIS.

■ **Advantages:** The digital mode has more advantages than the analog mode because it enables:

• storage of many baseline documents in the form of information layers;
• many types of analysis during phase 1 by cross-comparison of these various digital data layers;
• quick calculation of areas and statistical analyses;
• direct integration of satellite image analysis results in the database;
• digitization of results on indicators;
• cross-comparison of information on indicators and automatic determination of the composite index;
• printing of final maps with the index and colour of each polygon, as well as any other maps, e.g. maps of degradation types, low or high degrees, sectors in which the degradation rate is high, etc.;
• printing of maps on different scales, while remaining compatible with the working scale;
• querying of the database to obtain answers to many questions through cross-comparison of various information layers;
• partial or complete document updates at low cost;
• providing requestors, ranging from politicians to researchers, with suitable answers to their questions.

THE ASSESSMENT METHOD IMPLEMENTATION COST

It is hard to come up with an accurate and reliable figure for all situations because of the many different parameters involved. The cost generally ranges from €1 to 2/km² of studied area (excluding salaries). The assessment is valid for around 25 years before a map update is necessary. This period can be as high as 30–35 years in cases of partial updates in selected sectors. The implementation cost partially depends on:

• Whether the assessment is done in a developed or developing country, e.g. the technical facilities are often greater in the former, but the service costs are lower in the latter.
• The area to be surveyed and the working scale, with a gradual reduction in cost per km² for an increase in area (economy of scale).
• The quantity, quality and type of baseline documents—the presence or absence of already digitized topographical maps is an important parameter.
• The training level of personnel involved in the project.
• The nature and density of the road and navigable river systems for carrying out the field work.
• Whether the land heterogeneity and climatic conditions are suitable or not for remote-sensing image acquisition.

> FOCUS | Cost of carrying out the work: implementation of the method in Togo

The cost of the land degradation status map for Togo (56 895 km²), which was developed from 1992 to 1994 by IRD at the request of the Togolese government (Brabant *et al.*, 1996), was around €100 000 (excluding staff salaries), or €1.75/km² (funding: French Ministry of Cooperation). The scientific team of the project included four people. The field observation density was, on average, one observation per 4 km², or one observation per cm² of the topographical map used in the field (scale 1/200 000). The final map, derived from the database, was published at 1/500 000 scale, i.e. a format suitable for representing the entire country on a single 120 x 60 cm sheet of paper. Bilingual explanatory notes (in French and English) were included with the map. The database was not disseminated.

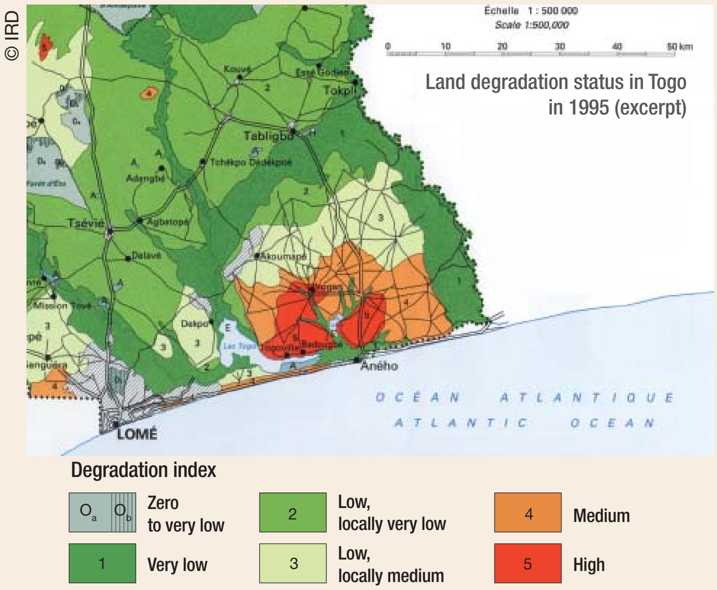
The total map of Togo includes 610 polygons of various sizes (3-4 km² to 200-300 km² in regions that were not or only slightly degraded), which is a relatively small number. For instance, the protected sectors of the *Parc de la Kéran* and the *Réserve de l'Oti*, which are adjoining, cover a continuous area of 3 100 km² which is represented by a single polygon, thus explaining the low number of polygons. The main results (concerning the 1992-1993 period) are as follows:

▪ Lands with index 1 and 2 accounted for 62.7% of the total area of Togo, **protected areas** and inhabited areas 14.8%. Overall, this means that 77.5% of the total area was undegraded or only slightly degraded (43 672 km²).

▪ Lands with index 5, i.e. highly degraded, only represented 1.6% of the total area (923 km²) in four zones:
① in the far northwestern part of the country, north of Dapaong, under a semiarid climate with a long dry season: highly populated and cultivated Moba **land system**;
② in the northeastern part, under a subhumid climate with a long dry season: populated and highly cultivated Tamberma land system, east of Kandé;
③ in Kara region, close to the previous area, in the densely populated Kabié and Losso land systems with a climate comparable to the previous area;
④ in the far southeastern part, along the coasts, under a climate with a shorter dry season: land system overexploited for commercial cassava cropping.

▪ Moderately degraded lands were located on both sides of the international road between the coastal city of Lomé and Burkina Faso northwards along the central road of the country.

▪ Vast lands undegraded or only slightly degraded were further from the central road; they extended towards the border with Ghana to the west and Benin to the east.



▪ Protected lands (83 areas overall) were substantial and covered 14.8% of the total area (8 317 km²): national parks, wildlife reserves, protected forests.

The results are indicated for each of the five regions, which are comparable to provinces, and totalled for the entire country. Another result derived from this assessment is the land cover map which can be extracted from the database. The major cause of the high land degradation was the shortening of fallowing times due to the lack of space in the land systems, and the shortage of fertilizers and organic amendments and, finally, the overexploitation of land systems concerned by the activities of a high-density rural population. The mean national population density was 84 inhabitants/km² in 1994 and 70 inhabitants/km² in rural areas. In highly degraded areas, the rural population density was sometimes as high as 300 inhabitants/km². The mean national density reached 103 inhabitants/km² in 2008.

Let us compare the land degradation status map of Togo published by IRD (Brabant *et al.*, 1996)* with that derived from the GLASOD programme (1992)** for the same country. According to the IRD map, highly degraded land accounted for 1.60% of the total area of the country (923 km²). According to the GLASOD map, severely degraded land and very severely degraded lands covered 23.7% of the country (13 470 km²). Considering the extent of this disagreement, it would be essential to conduct a national assessment on a suitable scale while adopting common assessment guidelines that are clear and easy to apply, with the aim of obtaining more reliable results that would be comparable between different countries worldwide.

Source: Brabant *et al.*, 1996.

* IRD land degradation status map for Togo available online at: www.cartographie.ird.fr/sphaera/carte.php?num=376&pays=TOGO &iso=TGO
** GLASOD map available online at: www.fao.org/landandwater/agll/glasod/glasodmaps.jsp

Complementary indicators to determine the land degradation status

Six other indicators supplement the three main indicators described previously. These complementary indicators should be especially useful for teams responsible for programmes to combat land degradation and desertification.

These six complementary indicators are: the degradation rate and trend, the natural susceptibility of soils and their resilience capacity, the historical background, the degradation causes and off-site effects. The population density may also be an interesting factor. Insight into these indicators could be very useful, for:

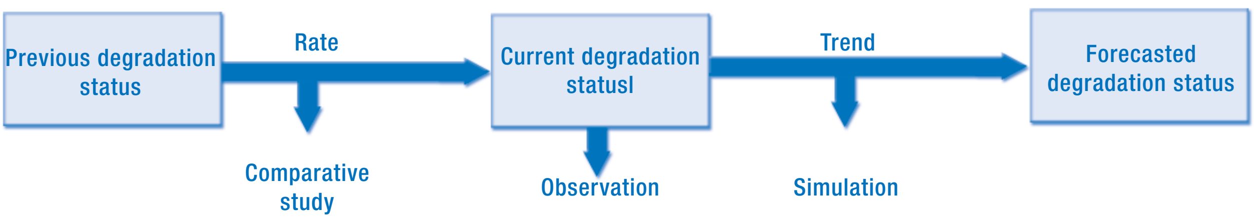
- supporting decisionmaking and guiding initiatives to be taken to halt or reduce land degradation;
- assessing the impact of land degradation control policies;
- determining past to recent land degradation patterns;
- facilitating risk determination.

THE LAND DEGRADATION (OR IMPROVEMENT) RATE

This is defined as *"the difference between two land statuses during a specific period and in a delineated zone"* (Brabant, 2008). This rate increases as the difference increases. When the status is increasingly degraded, this is the degradation rate. When it is less and less degraded, this is the improvement or **restoration** rate. When there is no change, the rate is zero, and this is stability.

When there is a problem of degradation involving natural conditions and human activities, the rate is measured in years or decades (e.g. for water-induced sheet erosion or **deflation**). When only human activities are involved, the rate is measured in days or months (e.g. urbanization, mining, or land pollution due, for instance, to an industrial nuclear [Tchernobyl] or chemical [Seveso] accident).

To assess this rate, it is necessary to know the previous degradation status and then to compare it to the current status, in line with the above definition.



▲Degradation dynamics—rate and trend

▲ Agrarian setting. Periurban vegetable cropping (tomato) in Ouagadougou, Lac de Loumbila, Burkina Faso.

Knowing the previous land degradation status

The search for this previous status is often difficult. Land degradation inventories have only recently been carried out in various countries because the issue was not considered a priority until the 1990s. There is therefore a real information gap on the topic. Recent assessments carried out systematically on large surface areas are scarce and were even scarcer in the past. Finally, the results are often heterogeneous due to the lack of a standard procedure.

Procedures used in the past

Some procedures are based on measurements and field tests, e.g. monitoring soil loss (t/ha/year) for water erosion processes. The major drawback is that this generally only concerns one subtype—water-induced sheet erosion.

Other procedures are based on the interpretation of agricultural statistics, e.g. crop yield variations. The drawback of these procedures is that the available information is sporadic, fragmented or only concerns limited areas in small catchments of a few hectares or, more often, experimental plots of a few dozens of square metres. It is thus risky to extrapolate such results to large areas because the land is often irregular. Moreover, the use of agricultural statistics is not always reliable because there is no systematic causal relationship between the decline in productivity and the degree of land degradation. Other parameters—technical, economic or political—can interfere. Under these conditions, the reliability of assessments carried out by these procedures, as well as comparisons between two successive statuses, could be questioned.

Proposed procedure: comparison of two successive land degradation statuses

This involves comparing two land assessments carried out on the same land at two different dates using a similar method based on physical observations. Each unit identified in a database or on a map is qualified by indicators and an index. The difference between index values highlights the degradation pattern in the concerned sector over the time period considered. This reveals the land degradation (or improvement) rate. It is the ideal situation. This rate assessment could now be undertaken in Togo since a land degradation status map was drawn up in 1994 (Brabant *et al.*, 1996). It would also be possible in Cameroon, which was the focus of an assessment in 1975 (Brabant & Gavaud, 1986; Gavaud *et al.*, 1977). However, this ideal situation is still uncommon because of the lack of past assessments in most countries.

To bridge this gap, a default solution is to query baseline documents that exist on the concerned area, interpret remote-sensing images, and conduct field surveys of local inhabitants and administrative staff who could provide information on the status of the sites in the past. The probable previous degradation situation is then deduced for a given time and then compared to the current status. Let us just focus on the last 60 years, which is equivalent to two long fallows in a **recurrent cultivation** system with two generations.

This projects us to the 1950s, a period that corresponds to the time when land degradation began accelerating worldwide.

This solution has one drawback, i.e. land degradation assessments before 1975 were scarce and mapping even more so. The only world assessment was conducted by the GLASOD programme in 1990. The GLASOD map was drawn up on a very small scale (1 cm² = 10 000 km² in the field) and thus cannot serve as a **reference status** for studies on a province scale, or even less on a district scale. Finally, the solution for assessing the rate is to compare the current degradation status with a previous so-called 'reference status'.

How can the reference status be determined?

The reference status is defined as *"that of lands in their natural state, i.e. never having been exploited, or at least not within the last 60 years, or exploited and having reached a known degradation status"* (Brabant, 2008). Documents for determining this status are therefore required. Four periods within which documents can be sought and used to characterize this status were thus defined:

- **Before 1950.** Historical data must be referred to, along with surveys of elderly inhabitants, despite their subjectivity. The knowledge and expertise of elderly people who have surveyed the lands in these regions is also interesting. Moreover, it is possible to refer to available archival aerial photographs of many regions worldwide which were taken between 1940 and 1950 by military services.

- **From 1950 to 1980.** Aerial photographs taken by civilian institutions (in France by the *Institut Géographique National*, IGN) are reliable reference documents for this second period. Old aerial photographic coverage is available in archives in most countries. Systematic aerial photographic coverage operations were systematically conducted by colonizing countries around 1950 to facilitate topographical mapping operations. The quality is not as high as on current photographs, but they give a good idea of the land cover and vegetation cover status, which is a good indicator for assessing the land status. In 1975, the first Landsat Earth observation satellite images became available. Some declassified military satellite monitoring images taken during the 1960s can also be useful (e.g. Corona satellites).

- **From 1980 to 2010.** Reference documents are recent satellite observation images with global coverage. These images are increasingly numerous and accurate. This represents a major technical progress. Older images can be found in archives and consulted free of charge or for a small fee. Excellent quality colour aerial photographs of this period may also be used. Land degradation status maps are available for some countries, but they often just cover a part of the area, such as in Kenya (UNEP, 2009) and Cameroon (Gavaud *et al.*, 1977, Brabant & Gavaud, 1986).

> EXAMPLE | Reference statuses available for Togo and Cameroon

In Togo, the first reliable reference status document was published in 1996 (Brabant *et al.*, 1996). This land degradation status map* was drawn up on the basis of findings of field studies carried out between 1992 and 1994 and processing of Landsat and SPOT images. This will serve as a reference status document for a new assessment to be carried out in the 21st century.

In northern Cameroon, between the 8th parallel N and Lake Chad, a detailed inventory of the land degradation status was conducted on the basis of observations collected in a 1974-1975 field survey covering an area of 82 500 km² (Brabant & Gavaud, 1986). This inventory could serve as a reference status document if it were updated now, 35 years later. This could be a highly interesting example for semiarid and subhumid zones in Africa, north of the Equator, where there is a high risk of desertification.

* Map available online at (PDF format): www.cartographie.ird.fr/sphaera/carte.php?num=376&pays=TOGO&iso=TGO

▲ Togo, Plateau Region. Sapping erosion along a gully under a layer of hardened laterite. The laterite collapses in large blocks, which then have to be removed from the land.

DEGRADATION TRENDS

The degradation trend is defined as "*the reasonably foreseeable short-, medium- or long-term variation in the land status (degradation, stability or improvement) in a specific zone under the impact of human activities.*" (Brabant, 2008)

This trend is assessed by taking the current degradation situation as reference status. It is thus a future projection. The aim is to predict changes in an area as a function of several parameters or possible scenarios: past degradation rate, changes in major kinds of land use, modification in types of land-use and cropping practices, implementation or not of soil conservation measures, areas selected to become reserves, increase in built-up sectors, population growth, climatic or other risks, socioeconomic and political setting—this latter aspect is more unpredictable. Three trends are proposed: degradation increased, stable or reduced.

HISTORICAL PATTERNS

The types of degradation, induced by the action of natural agents such as water and wind, have existed for thousands of years, but at low intensity. This intensity has sharply increased over the last century, especially in the last 60 years, under the effect of human activities (human population explosion, industrial and agricultural development, globalization). However, other types of degradation not involving natural agents have also appeared or have sharply intensified in recent times (within the last 50–60 years) because of excessive fertilizer inputs, intensive land clearing, high urbanization, chemical and radioactive pollution, and war-related constraints. The following table indicates the seven main historical periods.

▼ Succession of periods based on the history of Western Europe.
The limits between periods and the names of these periods can differ for other World regions: Asia, North America, South America, India, Australia.

	Successive periods from –5000 years to present	Period name
1	Before – 5000	Prehistorical
2	– 5000 to – 2000	Very ancient
3	– 2000 to + 400	Ancient
4	400 to 1800	Preindustrial
5	1800 to 1950	Industrial – European expansion
6	1950 to 2000	Recent
7	After 2000	Actual

> EXAMPLE | Assessment of the land degradation trend in Togo

This land degradation trend simulation for an entire country was based on the degradation status published in 1996 (Brabant *et al.,* 1996), which is considered as the reference status. It could also apply for each province or any other sector delineated on the map. Togo covers a 56 895 km² area, including 51 000 km² of arable land. There were 1.44 million inhabitants in 1958, 2.7 million in 1981 and 4.8 million in 1995, for a density of 84 inhabitants/km².

The area of moderately to severely degraded land (indices 3 to 5) concerned 15% of the country in 1994, including 1.60% of severely degraded land (index 5). The estimated degradation rate was slow between 1950 and 1994. The six following hypotheses were selected to simulate the potential degradation status in 2035, i.e. 41 years after the 1994 assessment:

- The major kind of land use will be rainfed agriculture with a low to medium level of **inputs**, a sedentary habitat, and shorter and shorter fallowing periods as the population pressure increases.
- The annual rate of increase in degraded lands will remain steady.
- At least two-thirds of currently protected land in national parks and natural reserves will remain protected.
- The urban area will increase by 0.25%/year.
- The improved and stabilized land area will increase by 0.1%/year.
- Population growth will continue at an annual rate of 3% (the United Nations predicts that there will be 9.4 million inhabitants in Togo in 2025, or 163 inhabitant/km²). Hence the number of inhabitants will reach 13 million in 2035 (or 228 inhabitants/km²). In fact, these projections are probably overevaluated since the Togolese population was around 5.9–6 million at the beginning of 2010.

When taking the UN population projections into account, the simulations indicate that the total percentage of degraded land will rise from 15% of the country in 1994 to 42% in 2035, including 16% of highly degraded land with very little agricultural potential. The arable land area would thus be 35 700 km² after subtracting highly degraded land, urban areas, rural housing areas, reserves and submerged land. In 2035, each inhabitant will thus have access to 0.25 ha of land for subsistence, as compared to 1 ha in 1994 and 0.8 ha at the beginning of 2010.

Based on the hypothesis of a slowdown in population growth from the beginning of this century, the number of inhabitants would be 7.5 million in 2025 (132 inhabitants/km²) and 9 million in 2035 (158 inhabitants/km²). The proportion of **arable land** available per inhabitant would thus be 0.39 ha in 2035. The key factor thus seems to be the population growth rate.

In conclusion, the report recommends implementing a prevention policy right now. If this is not done, land degradation will accelerate and **restoration**—which is absolutely essential—will be expensive. This could have a heavy impact on the national budget of Togo and serious socioeconomic consequences.

Source: Brabant *et al.*, 1996.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▲ An excellent tropical soil (Vertisol) formed on a basaltic substrate, which is not very susceptible to degradation and erosion, in a flatland area. Kenya.

SUSCEPTIBILITY OF SOILS TO DEGRADATION AND THEIR RESILIENCE

The susceptibility is defined as "*the degree of resistance of a soil to an unfavourable (or favourable) impact of a human activity on its main functions*" (Brabant, 2008). The soil degradation (or improvement) rate is higher in highly susceptible soils. For instance, a clayey soil is much more susceptible to **salinization** than a sandy soil due to irrigation using salt-laden water.

The resilience of a soil is "*the period of time necessary for a soil to get back its original functions once the human activity that led to its degradation has stopped*" (Brabant, 2008). The soil regenerates under natural conditions but repair practices can be implemented to activate this **restoration** process. The shorter the recovery period, the higher the resilience and the faster the soil gets back its original functions. This capacity can vary substantially depending on the type of soil and degradation. A high susceptibility to a type of degradation is often associated with low resilience. Stocking & Murnaghan (2001) proposed to combine these two properties (susceptibility and resilience) to define the soil degradation 'vulnerability' concept. The most vulnerable soils are the most susceptible to degradation and the hardest to restore. This is the case for tropical ferruginous soils (CPCS, 1967): tropical Lixisols, Luvisols, Acrisols and Alisols, according to the FAO World Soil Classification given in the legend of the FAO Soil Map of the World. Conversely, the least vulnerable soils are the least susceptible to degradation and are easily restored, e.g. Vertisols and fersiallitic soils (Vertisols and Cambisols, under the FAO classification).

Studies should be conducted to enhance knowledge (currently insufficient) on the degree of susceptibility and resilience of soils, which has a considerable impact on the duration and cost of restoration projects. This would also be useful for determining a soil vulnerability range (from 1 to 5), which could be integrated in the composite land degradation index.

CAUSES OF LAND DEGRADATION

The human-induced causes are technical, social, economic and political, but only those that could concern desertification are listed below.

Here are a few of the technical causes:
- deforestation and clearing, overexploitation of vegetation for domestic uses;
- late and uncontrolled bush fires;
- overgrazing and trampling by livestock;
- inappropriate agricultural practices such as:
  - an absence of soil conservation measures where they would be necessary;
  - continuous cropping without fertilizer or amendment inputs;
  - exportation of harvest residue and reduced manuring;
  - poorly managed irrigation or use of water that is unsuitable for irrigation (too salt-laden);
  - excessive shortening of the fallowing period;
  - use of very heavy machinery.

▲ Togo, Central Region. Off-site effect of water erosion. This bridge was destroyed by heavy flooding in a highly eroded catchment. The area served by the bridge could be cut off for months or years.

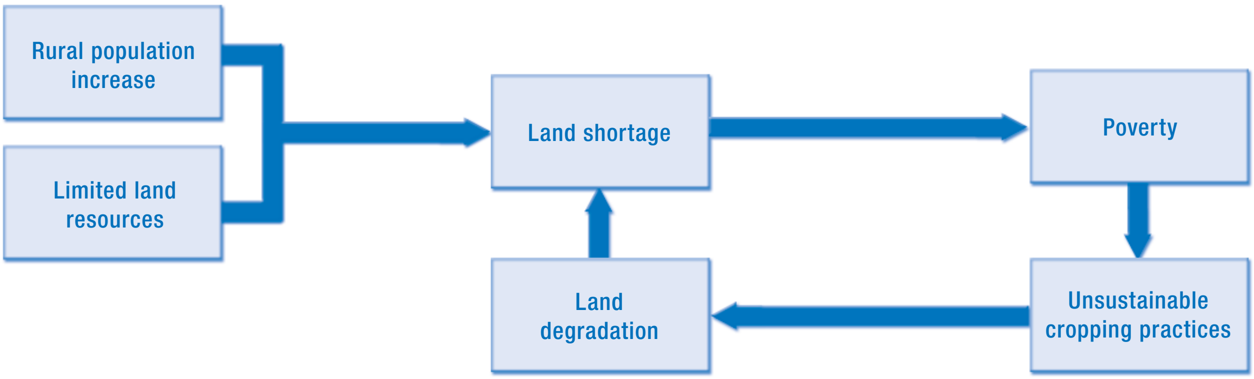
Here are some of the social, economic and political causes (in alphabetical order):

- armed conflicts, insecurity and rural population movements;
- economic pressure and market commodity price volatility;
- high population growth and saturation of the agricultural area;
- the nature of land rights, legislation on resource use;
- the poverty of farmers and the lack of investment capacity;
- the shortage of land, leading to their overexploitation or exploitation of marginal areas.

These socioeconomic aspects can be represented (see figure below) as a causal chain.

OFF-SITE EFFECTS

The off-site effects are consequences of land degradation. They occur at various distances from degraded sites and they are usually unsuitable for human activities, but sometimes they are suitable. The effects are usually associated with erosion because there is movement of soil material, which is transported by water, wind or gravity a varying distance from the



▲Causal chain involving the population, land resources and degradation
Source: FAO, 1984.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erosion site. These off-site effects sometimes have socioeconomic consequences such as the destruction of houses, bridges, roads and other building via mudslides, and can result in loss of human lives. The monetary cost of these off-site effects should be included in the land degradation cost, but this is seldom done.

Here are a few examples of physical off-site effects specific to desertification:
■ lowering of water tables and water shortages;
■ abrasion of plants by sandstorms;
■ abrasion of metallic structures by sandstorms;
■ accumulation of sand and pebbles which can be used for construction (positive effect);
■ aerosols hampering air, land, river and maritime circulation;
■ blocking of roads by sand encroachment;
■ deposition of aerosols containing nutrients for plants (positive effect);
■ silting over young plantlets;
■ sand and mud siltation in dam reservoirs (Rémini, 2000), waterways, irrigation canals and estuaries;
■ dune encroachment over fertile land.

Here are some socioeconomic off-site effects:
■ abandonment of land in conflict zones and outmigration towards refugee camps;
■ increase in the landless population and use of marginal and fragile land;
■ population growth and shorter fallowing periods;
■ increase in labour time and input quantities;
■ unreasonable community cost for degraded land restoration, polluted water treatment and repairing damaged infrastructures;
■ degradation of living conditions and standards and outmigration to urban centres;
■ rural outmigration to urban centres within the country, to other countries in the region, or to other countries elsewhere in the world;
■ loss of arable land and increased use of other land due to increased land pressure, and concomitant social unrest;
■ reduction in land value;
■ social unrest resulting from land-use competition, sometimes leading to conflicts—declining resources and resource distribution, population growth.

According to the World Resources Institute, the link between security (worldwide) and environment is becoming increasingly obvious. Of all resources, land and water are considered to be the focus of most conflicts.

POPULATION DENSITY AND LAND DEGRADATION

This indicator can be added to the six others, especially since it is essential data and relatively reliable in most countries. Is rural population density a land degradation indicator? It could theoretically be considered that the higher this density, the more the land is exploited and the greater it is degraded. Actually this relationship is even more complex because several factors are involved:

■ **The soil type** determines the natural fertility of land, its susceptibility to degradation and its resilience, as well as the threshold beyond which an exploitation strategy or given type of land use is no longer sustainable.
■ **The climatic conditions**—temperature, especially rainfall—impacts the major type of land use and the degradation conditions.
■ **Farmers' behaviour** also has an influence because a farmer will only modify his exploitation strategy when he notices that land degradation has led to a significant decrease in production. Farmers are sometimes late in reacting, which can give rise to critical situations such as increased soil salinization.
■ **Political and economic constraints**—a change in land tenure system, an rise or drop in agricultural commodity prices on the world market can also affect the relationship between population density and land degradation. This can lead to exploitation intensification or, conversely, to land abandonment.

Examples of the relationship between population density and land degradation

Very low population density (< 10 inhabitants/km²) – Low land degradation

This is the case for rainfed slash-and-burn **shifting cultivation** where farmers do not settle in one place. A substantial land area is utilized but the land is not degraded. This type of cultivation is no longer possible when there are more than 10 inhabitants/km² because there would not be enough available land. This land-use strategy has almost completely disappeared throughout the world.

Moderate population density (< 40 inhabitants/km²) – Moderate land degradation

When the population increases and people settle, then slash-and-burn **recurrent cultivation** is implemented without any or only scant amounts of **inputs**. Much of the **land system** is fallowed for long periods (20–30 years). This naturally restores soil fertility. A land system with a 20- to 30-fold larger area than the area cropped each year is required for fallowing under this land-use strategy. In this situation, the population density can be as high as 30–40 inhabitants/km² depending on the soil type. When the density is higher, pressure on the land becomes too great, while the available land area and fallowing periods decline. The soil fertility is no longer restored, so crop yields inevitably decrease due to soil degradation. As soil conservation measures are seldom applied under this type of land-use system, it degrades and is no longer sustainable. This leads to a crisis and a land-use change is then necessary.

High population density (40–250 inhabitants/km²) – High to severe land degradation trend

In this situation, intensive rainfed cultivation is practiced with very little or no fallowing. This change in land-use strategy involves application of inputs (manure, fertilizer, amendments). Erosion and degradation may be substantial since soil conservation techniques are generally seldom applied. Hence, there is a threshold—which varies according to the type of land—that corresponds to the maximum production capacity of the land for this type of exploitation. Beyond this capacity, this intensive rainfed cultivation system is no longer sustainable because of high degradation and reduced crop yields, thus giving rise to a crisis. Part of the population will then abandon their land or remain living at low income on the land. A dynamic part of this population may modify their land-use strategy to ensure their survival.

Very high population density (250–400 inhabitants/km²) – Moderate land degradation trend

Under this land-use strategy, soil and water conservation techniques are implemented, such as terrace and water retaining reservoir construction, reforestation, etc. A very high amount of work is necessary to ensure the sustainability of this system. Soil conservation investments hamper degradation. The rural population density may be as high as 400 inhabitants/km² or more, as in India, southeast Asia and China. In this situation, there is also a threshold, which is determined by the soil type and climatic conditions. Beyond this threshold, production no longer increases and degradation tends to increase, thus again giving rise to a crisis. Population numbers are excessive, which can prompt outmigration, or otherwise inhabitants may remain living on the land in poverty.


▲ Aerial view of a Togolese village in a region with a high population density.
© P. Brabant

Sometimes governments intervene to control the population growth, e.g. in China, or to move part of the excess population to other regions within the country, e.g. in Indonesia (transmigration programme).

And two other specific examples…

Low density population exploiting the land – High land degradation

This is the situation in developed countries where subsidized intensive agriculture is practiced. There are very few rural farmers, i.e. under 6% of the total population. Intensive use of fertilizers and pesticides is high. This system has a sustainability threshold because of physical soil degradation, toxic chemical pollution of soil, and high water pollution in rivers and coastal marine environments. This land-use strategy is fostered by politicians, high government subsidies and public funding of pollution management operations. This kind of intensive production has been ongoing over the last 50 years or so, but seems to have reached its limit as a result of the environmental damage induced. New cropping techniques are now being developed, e.g. direct seeding mulch-based cropping systems with crop rotations to reduce pollution (Raunet & Naudin, 2006). **Land restoration** can be long (several decades) and very expensive.

Very high rural population density – Low land degradation

This situation may be found in developing countries where the rural population density is very high, sometimes up to 1 000 inhabitants/km², but land degradation is low. This concerns alluvial delta regions and areas with fertile volcanic soils in the tropics. The land-use system is irrigated cropping on flatlands, or on slope terraces. Delta soils are fertilized naturally each year during river flooding. This system has prevailed for centuries, sometimes millennia, as in China and India. The corollary of this sustainability is the extreme poverty of the population, because each family lives off a very small tract of land. This explains the current outmigration trend, with part of this population moving to peripheral urban areas or to other countries abroad. Despite the fact that it is not highly degraded, this land-use system also has a threshold capacity because of the pesticide pollution problem that has arisen over the last few decades.

Gaining insight into land resources to enhance their management

Land is our common resource. It is spatially limited and essential for all living organisms. Along with water and plant and animal resources, it is a life support for all men and women. It is nonrenewable on the human historical scale and it degrades as a result of human activities, etc. It is not a commodity like mining and petroleum resources. It should therefore be utilized efficiently according to local climatic conditions and needs. It has recently become a strategic resource for some countries seeking to lease land in other countries.

Despite this importance, land is too often overlooked by governments and the media. Clearly, issues associated with land degradation are currently not a priority in industrialized countries, where it is obliterated by massive **input** applications in agricultural systems based on subsidies, the domination of large hypermarket purchasing centres and pollution from numerous sources, despite the negative environmental impacts. Moreover, they are not any more a priority in developing countries where socioeconomic problems are so hard to manage that issues concerning land degradation—and generally natural resources—are disregarded. However, 75% of humankind lives in these developing countries, with three-quarters of these people working in the agricultural sector. Land is a highly vital resource for these people, generating food and income.

RESULTS USEFUL FOR DECISIONMAKERS ON DIFFERENT SCALES …

The global arable land area was 2 ha/inhabitant in 1900 and is now just 0.4 ha/inhabitant in 2010. Otherwise vast uncultivated areas can still be found. It is thus essential to gain insight into local, national and global land resources so as to be able to recommend crucial measures for land protection, prevention and **restoration** initiatives. A decisionmaking cycle is thus required *(see diagram, page 10)*.

The first step of this cycle is to identify the problem. This is essential for implementing and evaluating land management policies. This identification process involves determining how much land is degraded, nondegraded or improved, which is the main aim of the assessment method presented in this *Dossier*. How many hectares of land are degraded? What types of degradation are involved? What is the extent and severity of this degradation in the landscape?

The conclusions presented in the present *Dossier* show that such assessments can be carried out using detectable or measurable indicators that can be implemented by technicians. The indicators are then combined into a composite land degradation index. This index can be utilized by politicians and decisionmakers. This method can be applied to various natural or administrative spatial entities, and in different climatic environments.

The results obtained by this method could help fulfil some of the objectives of the United Nations

G. Mandret © Cirad

▲ Sapa rice terraces—an example of improved and well managed land, thus substantially reducing erosion risks. Sapa region, Vietnam.

Convention to Combat Desertification, especially national objectives of countries affected by desertification which are obliged to conduct regular assessments of the land degradation status.

These results could be useful on local and subregional scales to be able to regularly determine the impacts of land degradation control operations and initiatives designed to improve cropping and livestock production systems. They could also be used to develop a **global indicator**, i.e. the *arable land availability per inhabitant*. Rural and urban populations are concerned since both consume food produced by the land. This availability is expressed in hectares of nondegraded, improved or degraded land under a certain threshold. This indicator could be applied on different geographical scales, e.g. a province, country, region or even globally. It could be adjusted according to the agroecological zone (FAO-IIASA, 2000) in which the land is located. At a given **input** level, a hectare of land located in a temperate area actually does not have the same production capacity as a hectare of land located in a humid tropical area. In the former case, for instance, because of the short vegetative growth period (around 180 days), there can only be one yearly cereal harvest, whereas in the latter case two annual cereal harvests are possible on a hectare of land since the growth period lasts over 300 days.

This indicator could be easily and quite reliably controlled through a population census, and also on the basis of satellite images, which considerably facilitate land degradation and desertification monitoring. The value of this global indicator was 0.42 ha/inhabitant in the world in 2009, whereas it was 2.0 ha/inhabitant in 1900. At most, it will be 0.29 ha in 2050, for a total world population of 9.2 billion people. It was 1 ha in Togo in 1992, 0.35 in Vietnam in 1997 and 0.32 in Thai Nguyen province, northern Vietnam.

… AND FOR AN AGGRESSIVE SUSTAINABLE LAND MANAGEMENT POLICY

Application of this assessment method is not hampered by scalar or spatial technical constraints, but rather by political and budgetary concerns. There must be political willingness to give priority to land management and to fund the first step of this process, which involves assessment of the land degradation and desertification status. The mean assessment cost is around €1-2/km², depending on the type of field access problems involved. Other CSFD *Dossiers* have also shown that it is possible and cost-effective to invest in **restoration** of natural capital and agriculture in arid regions.

Obviously, this is not the sole method available for assessing land degradation and the area available per inhabitant. This considerable methodological contribution should be correlated with methods developed by institutions like FAO, via its Land Degradation Assessment in Drylands (LADA) programme, or by many national research institutes in affected countries, generally in collaboration with partner institutes in developed countries, such as the French *Institut de recherche pour le développement* (IRD) and the French Agricultural Research for Development (CIRAD).

For further information…

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Glossary

Acidification: An increase in the degree of acidity in the topsoil and sometimes in the underlying layers. The soil solution pH is thus below 5.5.

Aerosol: Windborne deflation-derived dust, with particle sizes ranging from less than 5 µm to 80 µm. The finest particles can be uplifted several kilometres in altitude and carried several thousands of kilometres before being deposited on the ground.

Alkalinization: A process in which high quantities of sodium salts are bound to clay in the soil, and the soil solution pH is highly alkaline, i.e. over pH 8.6. These conditions are very unsuitable for the growth of most crops because of the high soil sodium content, compactness and low permeability resulting from this alkalinization.

Antipersonnel mine: An explosive mine that is buried just under the soil surface or concealed on the surface. It will explode under the weight of a human or animal of equal weight. Such landmines may remain active for several decades.

Arable land: Land that is—or could be—manually or mechanically ploughed, sown, and then laid bare by the harvesting of crops, and which can then be resown, or which is—or could be—planted with perennial food crops and other crops. This land is located in areas where, because of the favourable climatic conditions, one or several crops can be harvested in an annual seasonal cycle.

Aridification: This is the degradation of soil moisture conditions due to a reduction in soil porosity and permeability. The soil-climate thus becomes drier than the surrounding atmosphere. This markedly alters the soil's water reservoir function. It is very hard to restore aridified land—the process is sometimes irreversible under the climatic conditions that prevail in the vicinity of such lands.

ASSOD Programme: A programme that was carried out by ISRIC in collaboration with UNEP and FAO. The aim was to determine the extent of land degradation in South and Southeast Asia resulting from human activities. The mapping assessment was done on a 1/5 000 000 scale and the results were published in 1997, and covered 17 countries in this region.

Current land suitability: A land state in which the properties fulfil the conditions required for a specific usage without any land improvement.

Deflation: Sand, loam, clay and organic matter particles are lifted from the soil surface by the wind and carried a variable distance from the source area.

Galileo: The European navigation satellite system that provides geospatial positioning with global coverage, similar to the American GPS. It indicates the latitude, longitude and elevation of any point on Earth.

Geographic information system: A GIS combines techniques and methods for capturing spatially referenced data, for coding this information in vector or matrix form, organizing it in databases, in addition to various other treatments and processes that are implemented to tailor this information to specific applications. A GIS is designed to provide environmental planners and managers with information required for decisionmaking (Glémarec, 2002).

GPS: The satellite-borne global positioning system that is managed by the US military services. It indicates the latitude, longitude and elevation of any point on Earth.

Humus layer: Top soil layer that contains the most organic matter. It has a relatively dark appearance due to the presence of this organic matter, or humus. It is commonly called 'topsoil'.

Improved land: Land that has benefitted from favourable cultivation practices that have increased its fertility level along with its plant, livestock or forest production capacity.

Input: See **Input level**.

▲ Harvesting maize cobs in Togo.

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Input level: A classification to differentiate farming systems and define them according to the inputs and technology used. There are three main levels:

- **Low level:** Little use of machinery and material inputs such as chemical fertilizers, selected seeds and pesticides. This level often corresponds to conventional cultivation practiced by farmers in least developed countries.
- **Medium level:** Cultivation techniques enhanced by inputs to boost crop yields, but without achieving maximum yields or economic benefits, as expressed in monetary terms. These methods are implemented by farmers who follow the advice of extension services, but who also have technical know-how and/or some limited financial resources.
- **High level:** Cultivation methods involving the use of fertilizers at maximum economic benefit, herbicides and pesticides, applied using the most advanced techniques, with tailored machinery, to obtain peak yields and economic benefits, as expressed in monetary terms. These methods are implemented by farmers who are able to handle advanced technology and have high financial resources.

Land degradation reference status: The predegradation status of land which has not been used or cultivated for 60 years, or which has reached a known state of degradation following its usage. This is the state of the land at time T0, which serves as a reference for assessments in comparison with the actual status. This facilitates calculation of the mean degradation rate.

Land improvement: Modification of a land system or other land through a human intervention in order to make it more suitable for a specific type of farming or other use.

Land system: A natural and consistent geographical unit that is relatively amenable to being used in the same way over its entire area (e.g. rainfed agriculture, irrigated farming, tree growing) (Brabant, 1991).

Major kind of land use (of a land system): How a land system is generally utilized, e.g. rainfed cropping, irrigated cropping, extensive grazing, etc. (Brabant, 1991).

Micromorphology: Technique used by soil scientists which involves observing an undisturbed soil sample under a polarizing microscope. Various spatial relationships between soil skeleton and plasma constituents can thus be described, while determining the types of empty spaces (soil porosity) occupied by water or air.

Nonarable rangeland or forestland: Emerged land with an excessively thin soil layer or located in an area with too dry or cold climatic conditions. It cannot be ploughed or produce annual, multiannual or perennial crops. The natural vegetation thus prevails, but it can be grazed by livestock (e.g. in the Sahel) or be reforested (in cold areas in the Northern Hemisphere).

Organic matter: Organic material—mainly of plant but also animal origin—which is transformed into humus.

Plasma: This micromorphology term refers to fine mineral (clay) or organic (humus) soil constituents, as well as relatively soluble constituents (carbonates). Plasma is associated in different ways to coarse mineral particles in the soil (sand)—this fraction is called the 'skeleton'.

Potential land suitability: A land state in which the properties fulfil the conditions required for a specific usage after one or several land improvement operations (Brabant, 1991).

Protected land: Land that cannot, under administrative regulation, be used or occupied, or whose usage is controlled so as to (theoretically) keep it from being degraded as a result of human activities.

Qualitative assessment: An assessment whose results are expressed by adjectives, e.g. the average suitability of land for a given type of land use.

Quantitative assessment: An assessment whose results are expressed by numerical values, and which can be of the following types:
- **geographical,** if the numerical values refer to areas (ha, km²);
- **agricultural,** if the numerical values refer to crop yields or some type of agricultural production per surface unit;
- **socioeconomic,** if the numerical values refer to profits or monetary expenditures.

Recurrent cultivation: A cultivation practice whereby a farmer clears a plot, crops it for 4-7 years, and then leaves it fallow so as to allow the land to recover its fertility naturally for a certain period, i.e. a maximum of 30 years in the tropics. At the end of this period, the plot is cleared again and cultivated—this is the beginning of a new cycle. The farmer's habitat is permanent. Note that the expression 'shifting cultivation' is sometimes wrongly used when referring to recurrent cultivation.

Remote-sensing image: Photographical plotting (aerial photography, satellite image, radar image) of data acquired by aircraft or satellite onboard cameras resulting from various types of radiation or from the reflectance of the Earth's surface. The data can be stored and used in digital form.

Salinization: The concentration of soluble salts (especially sodium) within the soil to a level which is excessive for most plants.

Shifting cultivation: A cultivation practice whereby a farmer clears a plot, crops it for 2-4 years, and then fallows it for an indefinite period—he then moves to another location to clear a new plot. The farmer's habitat is temporary since the land is only cultivated for 2-4 years. A vast land area with a low population density are required for shifting cultivation.

Silting: The ground is covered with a layer of windborne sand (minimum 10 cm thick), corresponding to a sand mass of around 2 000 t/ha.

Soil and land restoration: All initiatives applied to degraded soils or lands that will enable them to recover the main functions that they had prior to being disturbed by human activities. They are applied to soils and lands which, despite being degraded, still have a sufficient degree of resilience.

Soil macrofauna: Soilborne invertebrates, at least 90% of which are discernible without magnification.

Topsoil: The common name of the soil surface layer and which has the highest humus content and is generally darker than the underlying layers.

Type of land use: A specific way in which land is used under a farming strategy. Cotton and lowland rice cropping are two different types of land use within under the same farming strategy, i.e. rainfed agriculture (Brabant, 1991).

Unexploitable land: Emerged land located in an area with climatic conditions that are too dry or cold for agricultural production (crops or livestock) or forest production. Such lands are found in deserts, cold northern and southern regions and in high mountain areas.

► Abundant earthworm castings on nondegraded land in northern Cameroon.

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List of acronyms and abbreviations

ASSOD	Soil Degradation in South and Southeast Asia
CESBIO	Center for the Study of the Biosphere from Space, France
CIRAD	Agricultural Research for Development, France
CSFD	French Scientific Committee on Desertification
DIC	*Délégation à l'Information et à la Communication* (IRD, France)
FAO	Food and Agriculture Organization of the United Nations, Italy
GIS	Geographic information system
GLASOD	Global Assessment of human-induced Soil Degradation
GPS	Global Positioning System
IGN	*Institut Géographique National*, France
IRD	*Institut de recherche pour le développement,* France
ISRIC	World Soil Information (formerly International Soil and Reference Information Center), Netherlands
LADA	Land Degradation Assessment in Drylands
SPOT	French Earth observation satellite
UNEP	United Nations Environment Programme

Abstract

Arable land is a vital resource for humankind. Cultivation of this land generates food to meet the daily needs of the world's population. This land is limited and the area is constantly shrinking—2 ha/inhabitant in 1900 versus 0.4 in 2010—due to the impact of human activities and population growth. Arable land is not a naturally renewable resource on the time scale of human evolution and is invaluable as it cannot be manufactured. This land therefore has to be properly managed. It is thus essential to understand the actual land degradation status so as to be able to draw up protection, restoration and/or sustainable management policies.

In 1990, the results of the first global land assessment were incomplete because of a lack of common assessment procedure. This CSFD *Dossier* describes a streamlined land degradation assessment method that can be applied on different spatial scales—farm to country—and in all climatic zones in worldwide.

The type, extent and degree (or severity) of land degradation are the three main indicators selected. When pooled, they represent a degradation index rating that is displayed in a simple way on maps that can be readily used by politicians, decisionmakers and the media. Complementary indicators are useful for staff responsible for implementing land degradation control initiatives in areas earmarked by decisionmakers: degradation rate and trend, historical background, soil sensitivity and resilience, possible causes, off-site effects, and rural population density.

The results obtained could contribute to meeting the objectives of the United Nations Convention to Combat Desertification, especially through national objectives in countries affected by desertification that must regularly report on land degradation.

Keywords: Human activities, land degradation, assessment method, indicators, degradation index, mapping, environment, desertification

Résumé

La terre cultivable est une ressource vitale pour l'humanité. Son exploitation permet de nourrir chaque jour la population mondiale. Sa superficie, limitée, est en constante diminution—2 hectares par habitant en 1900 contre 0,4 en 2010—du fait des impacts des activités humaines et de la croissance démographique. La terre cultivable n'est pas renouvelable naturellement à l'échelle de temps humaine et elle est irremplaçable car personne ne peut en fabriquer. Il convient donc de bien la gérer. Ainsi, connaître l'état actuel de dégradation des terres est indispensable pour définir des politiques de protection, de restauration et/ou de gestion durable.

Une première évaluation mondiale de l'état des terres, réalisée en 1990, a produit des résultats incomplets à cause d'un manque de procédure commune d'évaluation. Ce *dossier du CSFD* décrit une méthode harmonisée pour déterminer l'état de dégradation des terres, qui est applicable à différentes échelles spatiales—depuis l'exploitation agricole jusqu'à un pays tout entier—et dans toutes les zones climatiques du monde.

Trois indicateurs principaux sont retenus : le type, l'extension et le degré de dégradation. Une fois regroupés, ils constituent un indice synthétique de dégradation qui est représenté de manière simple sur des cartes facilement exploitables par les politiciens, les décideurs et les médias. Des indicateurs complémentaires sont utiles au personnel chargé de mettre en œuvre les actions de lutte contre la dégradation dans les zones sélectionnées par les décideurs : vitesse et tendance de la dégradation, historique, sensibilité et résilience des sols, causes possibles, effets hors-site, densité de population rurale.

Les résultats obtenus peuvent contribuer à atteindre certains des objectifs de la Convention des Nations Unies sur la lutte contre la désertification, particulièrement les objectifs nationaux des États affectés par la désertification qui doivent faire régulièrement l'état de la dégradation des terres.

Mots clés : Activités humaines, dégradation des terres, méthode d'évaluation, indicateurs, indice de dégradation, cartographie, environnement, désertification

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2: Togo, Maritime Region.
Rill erosion in a maize field after a single 80 mm rainfall.
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3: An example of highly degraded land (index 5). Thai Nguyen province, Vietnam.
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