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Land Degradation Neutrality: An Evaluation of Methods

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Land Degradation Neutrality: An Evaluation of Methods

by

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Abstract

In many parts of the world the quality of land is decreasing, thereby limiting its capacity to provide the manifold goods and services humanity depends on for existence. It is estimated that the health and livelihoods of an estimated 1.5 billion people are currently threatened through the negative impacts of land degradation.

Alarmed by the Sahelian drought in the early 1970's, the global community made first attempts to determine and map the extent of land degradation in the world's drylands. Until today, several more efforts have been made to assess state and trends in global land and soils. Over time, the scope widened from drylands to total terrestrial land, and definitions of land degradation moved from production-based aspects to the evaluation of ecosystem goods and services, and the inclusion of economic and socio-cultural dimensions.

Main assessment methods applied were expert opinion (through questionnaires), modelling, and remote sensing (through satellite imagery). The results varied substantially, depending on the conceptual framework used, total area analysed, parameters chosen for analysis, and methodologies applied. Uncertainties aside, most experts agree that at this point in time some 20-25% of terrestrial surface area are affected by land degradation.

It is somewhat sobering that it has so far not been possible to conciliate expert-based knowledge ("bottom-up") with remote sensing information ("top-down"). Both approaches have their strengths and weaknesses, and would ideally need to be combined for an ultimate global assessment. Since 1990 there has been no more truly global, land based assessment, which is in stark contrast to the demand for such data.

Hopes are growing that the Sustainable Development Goals (SDGs) in general, and the target of Land Degradation Neutrality (LDN) in particular, will soon generate sufficient momentum for a universally agreed conceptual framework, and an up-to-date analysis of global land degradation. This could be the beginning of a global monitoring effort to better understand trends of soil degradation and improvement over time.

Land degradation is a global issue with local solutions. Therefore, a concerted global effort on the post-2015 development agenda should also include the many promising SLM technologies and approaches that are already applied. This would help empower the global community to learn from each other, and contribute to building resilience at local, national, and regional levels.

This document portrays the major land and soil degradation assessments of the past and critically evaluates their results. Another section is devoted to the various methodologies that can be applied, including their strengths and weaknesses. It finally explores promising potential corner stones of future assessments, with particular reference to the SDG target of Land Degradation Neutrality.

Despite the numerous challenges involved, the document is making the case *for* global assessments of land and soil quality. And it suggests that besides an agreed conceptual framework it is awareness, respect for complexity and diversity, an ecosystem approach and last but not least adequate funding that will make future endeavours a success.

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Acronyms

ASSOD	Soil Degradation in South and Southeast Asia
CBD	United Nations Convention on Biological Diversity
CIESIN	Center for International Earth Science Information Network
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-Ecological Zones
GEF	Global Environment Facility
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographical Information System
GLADA	Global Assessment of Land Degradation and Improvement
GLADIS	Global Land Degradation Information System
GLASOD	Global Assessment of Human-Induced Soil Degradation
GLII	Global Land Indicator Initiative
GLOBIO	Global Biodiversity Model
GPFLR	Global Partnership on Forest Landscape Restoration
GSP	Global Soil Partnership
IASS	Institute for Advanced Sustainability Studies
ICSU	International Council for Science
IFPRI	International Food Policy Research Institute
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre of the European Commission
LADA	Land Degradation Assessment in Drylands
LDN	Land Degradation Neutrality
LDSF	Land Degradation Surveillance Framework
MA	Millennium Ecosystem Assessment
MDG	Millennium Development Goal
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Production
PAGE	Pilot Assessment of Global Ecosystems

PBL	Netherlands Environmental Assessment Agency
RUE	Rain Use Efficiency
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
SOLAW	State of the World’s Land and Water Resources for Food and Agriculture
SOC	Soil Organic Carbon
UNCCD	United Nations Convention to Combat Desertification
UNCOD	United Nations Conference on Desertification
UNEP	United Nations Environment Programme
USD	US Dollars
WAD	World Atlas of Desertification
WOCAT	World Overview of Conservation Approaches and Technologies
WWF	World Wide Fund for Nature

Executive Summary

Land degradation has been termed the ‘silent emergency’ as its increasing negative impacts currently threaten the health and livelihoods of an estimated 1.5 billion people, but only one global, land-based assessment of it has been performed so far. Consequently, the Rio+20 document “The Future We Want” highlights that member states “recognize the need for urgent action to reverse land degradation.

This document portrays the major land and soil degradation assessments of the past and critically evaluates their results. It looks into the various methodologies than can be applied, including their strengths and weaknesses. It finally explores promising potential corner stones of future assessments, with particular reference to the Sustainable Development Goal (SDG) target of Land Degradation Neutrality (LDN).

Chapter 2 reviews existing global assessments on land and soil degradation. Key contents are:

- Alarmed by the Sahelian drought in the early 1970’s, the global community made first attempts to determine and map the extent of land degradation in the world’s drylands. The so-called UNCOD assessment in 1977 found that 75% of global drylands were threatened by desertification. Accuracy of this and similar early assessments was low, and figures were later considered too high. This is mainly because not much experience with the issue existed at the time, and field data were missing to help distinguish between areas actually or potentially (“at risk”) affected by land degradation.
- The UNEP-funded project Global Assessment of Human-induced Soil Degradation (GLASOD) was conducted between 1987-1990 and mapped the type, extent, degree, rate and main causes of degradation based on expert knowledge. It found that approximately 15% of the terrestrial land surface - or about one-third of the land used for agriculture - were affected by some form of soil degradation. Since its publication, GLASOD attracted considerable criticism mainly targeted at the expert-based methodology and the potential subjectivism and misjudgement involved.
- The World Overview of Conservation Approaches and Technologies (WOCAT) database was created in the mid-1990s to demonstrate the “good news” side of things, i.e. of SLM measures that are already being applied all over the world. This database is still in use today and could play an important role in future land degradation assessments.
- From 2001-2005, the Millennium Ecosystem Assessment (MA) set out to evaluate the degree to which ecosystem services within the various systems, on which human societies depend, are sustainable, given the many environmental stresses they face. Unfortunately the analysis did not extend to the degradation of land and soils; the only system considered in this respect were the global drylands of which 10-20% were found to be affected by desertification.
- In 2006, the global component of the GEF-funded Degradation Assessment in Drylands project (GLADA) aimed at providing an up-to-date, quantitative and reproducible land degradation assessment. Analysing remotely sensed trends in “greenness” of the earth’s surface GLADA found that nearly one quarter (24%) of the world’s land area was undergoing degradation in the period 1981-2003. It also found that land degradation is not primarily associated with farming, and mainly occurs outside the drylands (22% in drylands vs. 78% in humid areas). The use of remotely sensed greenness as a proxy for land degradation has been criticised, and there is consensus that a groundtruthing component will be needed in future assessments.

- Following up on LADA/GLADA, a Global Land Degradation Information System (GLADIS) has been set up by FAO. Whereas GLADA had solely focused on the production function of land, GLADIS looked into an ecosystems' capacity to deliver all kinds of goods and services, also including 'Soil Health', 'Water quantity', 'Biodiversity', 'Economic Services', and 'Social services'. By showing results for these dimensions along the axes of a radar diagrams, the status and/or trend of a system can be illustrated. Combining various sources of information, GLADIS produced global maps of the biophysical status of land, the biophysical land degradation process, classes of land degradation, and land degradation impact. The differentiated approach and output of GLADIS not only portrays the complexity of the land degradation phenomenon, but also forces people to be clear about what data it is that they want. As a product, GLADIS faces multiple challenges concerning data quantity and quality, the biggest issue remaining the general lack of global data with sufficient detail and resolution.
- The main characteristics of the past global assessments on land and soil degradation can be summarised as follows:

Name of assessment	Global Assessment of Human-Induced Soil Degradation (GLASOD)	Millennium Ecosystem Assessment (MA)	Global Assessment of Land Degradation and Improvement (GLADA)	Global Land Degradation Information System (GLADIS)
Duration	1987-1990	2001-2005	2006-2009	2009-2011
Budget (mio. USD)	0.3	approx. 17	0.6	?
Lead organisation	ISRIC-World Soil Information	Collaborative (UNEP coordinated)	ISRIC-World Soil Information	FAO
Methodologies applied	Expert opinion	Desktop study (review)	Remote sensing	Desktop study (GIS, indices)
Main land degradation estimate	~15% of global terrestrial surface affected by soil degradation	10–20% of drylands affected by desertification	24% of the world's land area undergoing degradation in 1981-2003	9% of terrestrial surface area is scoring very low in terms of biophysical status, 31% low, 21% moderate, and 19% high
Website	http://www.isric.org	www.millennium assessment.org/	http://www.isric.org	http://www.fao.org

- There are several upcoming analyses and assessments in the field. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), e.g., has proposed to conduct a global thematic assessment on land degradation and restoration. Additional efforts are the third edition of the World Atlas of Desertification (WAD), the Status of the World Soil Resources report of the Global Soil Partnership, or UNCCD World Land Outlook report. All of these are expected to be desktop studies and not likely to involve a substantial amount of groundtruthing.

Chapter 3 characterises the main approaches used to map global land degradation. And it highlights how this and similar information is needed to put land degradation data into context. Key contents are:

- Expert-based or "qualitative" assessments: When the idea of a global-scale assessment of land degradation was born during the second half of the 20th century, the most straightforward approach involved the compilation of national datasets, and the consultation of experts. This has a number of advantages, e.g. it captures the "accumulated" knowledge of an expert that ideally reaches over several decades, rather than just a snapshot in time; it assesses all aspects of degradation – causes, types, degrees and extents – at multiple scales; and it provides a relatively quick overview for national and regional planning, including the identification of hot spots for further study. The biggest challenge with qualitative assessments is their potentially subjective character. Besides, qualitative assessments are time-consuming and need substantial harmonisation. Expert judgements cannot be tested for consistency, and findings cannot be reproduced for unvisited sites, so that temporal or spatial comparisons are more difficult. Improvements for future expert-based assessments have been formulated, e.g. relating qualitative statements to quantitative measures of land degradation, increasing consistency of statements through participatory workshops, or using a digital elevation model to derive more uniform and reliable mapping units.
- Remote-sensing-based assessments: since the turn of the millennium environmental monitoring has been increasingly relying on remote sensing. The incentives are manifold: it is a relatively cheap and rapid method of acquiring up-to-date information over a large geographical area in a homogeneous way; it is the only practical way to obtain data from inaccessible regions; and resulting data can be processed using a PC, then combined with other geographic layers in a GIS. However, they are not direct samples of the phenomenon, so must be calibrated against reality through some sort of groundtruthing; distinct phenomena can be confused if they look the same to the sensor, leading to classification error; phenomena which were not meant to be measured can interfere with the image and must be accounted for; and the resolution of satellite imagery is too coarse for detailed mapping.
- Modelling approaches: The modelling of land degradation is a means of combining field measurements with remote sensing information. In the spatial domain this helps to predict soil/land or degradation information from measurement locations to those areas that could not be assessed, thus allowing for areal information, and mapping. In the temporal domain, modelling can help to project present data into the future and thus elucidate trends or develop risk scenarios. Various forms of soil degradation have been modelled at larger scales in the past, although efforts were mostly restricted to cropland, and there to the threat of soil erosion. Generally, our understanding of the land degradation processes is insufficient to formulate theoretically founded laws that can be used to construct a conceptual model. The Dutch Environmental Assessment Agency (PBL) is currently looking into including global soil degradation information into their GLOBIO model, thus allowing a modelled global analysis of how land degradation impacts on the various ecosystem services for the first time.
- As there is currently no single approach available to assess and monitor global land and soil degradation, a combination of approaches is required to tackle the challenge. This is inherent to the multi-dimensional, multi-scale, transitional, multi-perspective, and multi-actor nature of land degradation, and is not likely to change in the foreseeable future. The real challenge therefore is to find reproducible, globally applicable ways in which the various scales can be bridged, applying all of the above methodologies.

- In the past 40 years not one but many answers have been provided to the one big question of how much land is degraded globally. But mapping land degradation on a global level has definitely advanced, and much of the confusion surrounding its spatial extent could be reduced if estimates were interpreted according to the conceptual and methodological framework under which they were produced. Taking time to reflect upon the various "dimensions" of an assessment may help avoid blindly jumping onto the next effort considered the silver bullet in global land degradation assessment.
- Most importantly, the conceptual framework has to be looked at. Definitions of the term "land degradation" have been changing substantially over time, moving from an initial emphasis on productive capacity of soils to the holistic concept of goods and services provided by ecosystems. The decision what to assess will affect how it is being assessed, i.e. the indicators selected in the process, or the for/against bottom-up and/or to-down approaches.
  A global authoritative effort to define the various dimensions of ecosystem degradation, thereby clearly defining the terms used and standardising efforts to quantify it, is still badly needed as a basis for internationally consistent approaches. The establishment of an Intergovernmental Platform for Land and Soil, as advocated by UNCCD, could be a great step forward in the right direction.

Chapter 4 is exploring the motivation for global land degradation assessments; and it is looking ahead and bundles the lessons learnt from previous endeavours in order to define a set of promising elements for future land degradation assessments at global level. Key contents are:

- Global land and soil data are a prerequisite for informed decision-making. It is generally accepted that major global challenges such as land degradation, global food production, water quality and quantity, climate change or biodiversity decline are all connected to soil quality. Vice versa – and that is the positive side of the medal – they could all be addressed at the same time through proper soil management.
- Intensified development reduces the potential of the environment to support it. Because of this environment-development linkage, considerable time, effort and money have to be continuously invested into exploring and understanding the "land degradation system", assess and monitor the impact of land and soil degradation at the global scale, and initiate concrete action to prevent and mitigate worst affected areas.
- The costs of inaction are huge, and growing. Connecting harmonised land and soil data to economic analyses would enable economic evaluation at the national or macro level. This could help capture ecosystems' changing capacities to provide goods and services to people, and contribute to a more systematic analysis of the costs and benefits of changes in land-use practices. Economic valuation and associated knowledge management systems are considered a powerful tool in the design of inequitable and efficient instruments or policies to foster SLM.
- Hopes are growing that the Sustainable Development Goals (SDGs) in general, and the target of Land Degradation Neutrality (LDN) in particular, will generate sufficient momentum for a universally agreed conceptual framework, and an up-to-date analysis of global land degradation. Although it appears extremely ambitious to achieve a fully land degradation neutral world within 5 years from now, this could be the beginning of a global monitoring effort to better understand trends of soil degradation and improvement over time. The LDN concept has already triggered a rich, vibrant discourse and provoked refreshing discussions.
- As a basis for LDN, an appropriate assessment of degradation would be crucial. This must be based on good theoretical framework including clear scope and universally agreed definitions before being implemented. As soil evaluation is done by people, who have ideas about how

soils ought to be used and for what ends, the term “degraded” may be inappropriate or only be applicable to a situation where land or soil cannot fulfil any of its functions anymore. Especially in view of the concept of LDN there will also be a need to not only assess the negative side of the equation (i.e. what’s degrading) but the ecological restoration/land and soil conservation side, too. An innovative and at the same time extremely valuable element of future global assessments could be the registration and documentation of SLM methodologies and approaches (e.g. through WOCAT International) that have proven beneficial effects in terms of the target indicators selected.

- In terms of methodology, there is a need for a global approach that uses standardized methods and an integrated bottom-up technique that starts at the local level. At the same time it should make use of latest techniques for data collection, interpolation and interpretation. For a comprehensive all “dimensions” of land degradation will have to be captures: its causes, types, degrees (intensity), and extents. Expert observations and judgements should be supported by objective criteria that are measured in the field and can describe various land degradation indicators. A promising, innovative way to collect large amounts of groundtruthing data could be through the use of mobile phones. ISRIC as the ICSU-accredited World Data Centre for soils would be the ideal instance to collect, harmonise and store such locally generated information. Locally collected information on the state of land and soil could be aggregated by using land quality indices. To be able to bridge the gap to the global level, a larger research programme would urgently be needed that could work on matching high-resolution satellite data with well-described and standardised field point measurements.
- Where it comes to indicators, the selection very much depends on how degradation or improvement have been defined in the first place. There is not 1 indicator alone that could act as an ultimate proxy for land degradation or improvement. A balance will have to be struck between a situation where too many indicators make the assessment unmanageable and cost-prohibitive, and a situation where a too narrowly defined set does not allow for the detail of insight required. Therefore, integrative indicators that can cover various vital processes at the same time should be preferred. An indicator system that lives up to the target of LDN would require a biophysical component. Soil-based parameters are a straightforward choice. As a “3D archive” soils represent the cumulative result of past management, and at the same time determine the options for future land use scenarios. Looking at the state of soil therefore is the ultimate ‘reality check’ to help analyse if an SLM technology or approach is sustainable or rather destructive. The dynamics of soil organic carbon (SOC) content are a good example for such an indicator. Not only is it at the nexus of soil chemical, physical and biological processes; it is also influenced by land management, and significant changes can be detected within a couple of years. Also, it relates to the CO_2 parameter of the climate change community.
- Under the LDN policy schemes, data collection should not be a one-off event but ongoing in order to enable a regular update regarding the status of land degradation at local, regional, and global levels (“monitoring”). There currently is no global database that supports this effort. If as part of the post-2015 development process a network for worldwide monitoring and global assessment of land and soil change finally becomes established, it will be straightforward to take the first round of assessments as a baseline reference.
- A global land & soil assessment would be facilitated if the following conditions would be met more often: Awareness on soils and land; establishment of a science-policy interface and “lobby” for soils; respect for complexity of subject; acceptance of the ecosystem approach; respect for cultural diversity; more scientists in the role of knowledge-brokers; and last but not least adequate funding.

1 Introduction

Degradation of land and soil is the ‘silent emergency’ (Dowdeswell 1998). It is an emergency because its increasing negative impacts threaten the health and livelihoods of an estimated 1.5 billion people (Bai et al. 2008a). And it can be considered largely silent as no truly global, land-based assessment of it has been performed since 1990.

Signs are increasing that this is about to change. As a successor to the Millennium Development Goals (MDGs) negotiations are underway for a set of Sustainable Development Goals (SDGs) to which the nations of the world will subscribe and live up to in the period 2015-2030. The goal of Land Degradation Neutrality (LDN) in particular addresses the need to maintain – and where possible – restore land and soil quality. Also, awareness is increasing that by addressing and reverting land degradation other major economic, ecological and environmental challenges can partly be tackled at the same time.

Realising that this is a good point in time to look back on past global assessments of land and soil degradation to draw on the lessons learnt, the German Federal Environmental Agency (UBA) has commissioned ISRIC-World Soil Information to compile a survey report on the topic. The aim is not only to look back on past global efforts, but also to critically analyse the various technologies applied, and discuss this in view of future global assessment and monitoring of land and soil on the post-2015 development agenda.

Chapter 2 of the document will highlight land and soil degradation assessments as a saga that has now been spanning 40 years. The focus is on all major global assessments conducted, and includes a section on upcoming initiatives. Efforts that only cover part of the terrestrial land surface area have not been considered. Chapter 3 consists of two major parts, the first being technical in nature and discussing pros and cons of the major technologies applied; based on this, the second part will show how important it is to put existing figures not only into their “technical” context, but also consider the overall framework and its multiple implications for correctly interpreting the respective outcomes. Finally, Chapter 4 makes the case for global assessments as such, and explores a set of corner stones recommended for such efforts, including promising framework elements, methodologies, and indicators.

In its present form, the survey report cannot be exhaustive. But it is hoped that it allows for both, a thorough overview of past efforts, and an understanding of what would be required to make future land and soil degradation assessments a success.

2 Review of global assessments on land and soil degradation

2.1 GLASOD

2.1.1 Towards a first global assessment

The onset of efforts to map land degradation at global level can be located in the 1970s. The acute drought years in the Sahelian region of Africa from 1968 to 1973 drew worldwide attention to the large-scale and trans-boundary problems of desertification and human survival in drylands. A first assessment on the state and change of the world's drylands was presented during the 1977 UN Conference on Desertification (UNCOD). Based on expert judgements, the area threatened, at least moderately, by desertification was found to be 3,970 Mha[1] or 75.1% of the total drylands, excluding deserts. Of those, 350 Mha (9%) were considered very severely, 1,840 Mha (46%) severely, and 1,780 Mha (45%) moderately affected by desertification hazard. UNCOD also made estimates on annual rates of land degradation (arid and semiarid areas only): 0.125 Mha/yr in irrigated lands, 2.5 Mha/yr in rainfed croplands, and 3.2 Mha/yr in rangelands, yielding a total of 5.825 Mha/yr (UNCOD 1977).

As a follow-up to the UNCOD, Mabbutt (1984) in collaboration with UNEP launched another assessment of desertification status and trends. It was based on desertification questionnaires sent to all countries affected, and subsequent regional aggregation of results with the help of UN regional commissions and updated UNCOD documents. It was noted that the information provided was "patchy and often unsatisfactory" and attributable to the general failure of countries to conduct the required assessments, but also to the lack of simple methodologies for desertification assessments over larger areas. Overall, Mabbutt (1984) arrived at global desertification status figures that were similar to the desertification risk figures proposed by UNCOD (1977), with the area of significantly desertified land constituting 75% of all productive land in the world's drylands. In another effort, Dregne & Chou (1992), e.g., used anecdotal evidence, research reports, expert opinion and local experience to derive degradation estimates for drylands, but in retrospect admitted that "accuracy was still low" (Dregne 2002).

The pre-GLASOD figures are nowadays no longer considered as reliable sources of information (Safriel 2007), and their findings have largely been discarded as too pessimistic (Nelson 1988, Reynolds & Stafford-Smith 2002) for two main reasons: the lack of experience with the issue at the time, and missing field data as the basis for these assessments. No sharp line has in the beginning been drawn between areas actually undergoing land degradation (current status) or being potentially affected ("at risk"), mainly because very little field data or experience were available at the time (Dregne 2002). There also were – and still are – difficulties in defining what exactly constitutes land degradation or desertification, and which indicators should be used to measure the state, and change of land. This again has implications on the degradation severity categories to be defined and used for mapping.

Nelson (1988) has pointed out another factor why initial figures might have been overestimates. The time of Mabbutt's (1984) survey was at the end of a severe and prolonged drought in Africa, which could have affected the judgement of African officials. After reviewing other studies in the land degradation literature, Nelson concluded that the evidence with respect to the rate, extent, and severity of land degradation around the world is "extraordinarily skimpy".

Probably the most decisive shortcoming until the late 1990's was that land degradation assessments focused on the drylands only. Although these cover a substantial 40% of the terrestrial land surface

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[1] 1 Mha = 1 million hectares = 0,01 million km^2 = 10,000 km^2; this is approximately the area of ¼ of the Netherlands, so 1,000 Mha would be 250 times the Netherlands.

area and contain one third of the world’s population, land degradation outside the drylands was largely neglected.

2.1.2 Methodology and results of GLASOD

The Global Assessment of Human-induced Soil Degradation (GLASOD) set out to assess soil degradation beyond the drylands. Using the “provisional methodology” for the assessment and mapping of desertification originally developed for the UNCOD, the UNEP-funded project compiled a soil degradation database for the period 1987-1990 (Oldeman et al. 1991, Oldeman & van Lynden 1996). The status of soil degradation was mapped within loosely defined physiographic units (polygons), based on the judgement of about 300 experts worldwide, following semi-quantitative criteria. The type, extent, degree, rate and main causes of degradation have been compiled into a global map at a scale of 1:10 million, and documented in a downloadable database [2].

GLASOD found that 1,964 Mha - roughly 15% of the terrestrial land surface, or about one-third of the land used for agriculture - were affected by some form of soil degradation (Table 1). The project provided estimates of the degree of soil degradation: Out of the total degraded land worldwide (1,964 Mha), a light degree, implying a somewhat reduced productivity of the terrain but manageable in local farming systems, was identified for 38% of all the globally degraded soils (749 Mha). A somewhat larger percentage (46%) had a moderate degree of soil degradation. This portion of the earth surface, 910 Mha, was considered as having a greatly reduced productivity, and major improvements often beyond the means of local farmers in developing countries required to restore productivity.

Table 1: Soil degradation degree by region inside the drylands (“Susceptible”)[3] and outside (“Others”); all data in Mha.

Region	Aridity zone	Light	Moderate	Strong	Extreme	Total degraded	Total non-degraded
Africa	Susceptible	118.0	127.2	70.7	3.5	319.4	966.6
	Others	55.7	64.6	52.8	1.7	174.8	1504.8
Asia	Susceptible	156.7	170.1	43.0	0.5	370.3	1301.5
	Others	137.8	174.2	64.6	0.0	376.6	2207.6
Australasia	Susceptible	83.6	2.4	1.1	0.4	87.5	575.8
	Others	13.0	1.6	0.8	0.0	15.4	203.5
Europe	Susceptible	13.8	80.7	1.8	0.0	99.4	200.3
	Others	46.7	63.8	8.9	0.0	119.4	531.4
North America	Susceptible	13.4	58.8	7.3	0.0	79.5	652.9
	Others	5.5	53.7	19.5	0.0	78.7	1379.8
South America	Susceptible	41.8	31.1	6.2	0.0	79.1	436.9
	Others	63.0	82.4	18.9	0.0	164.3	1087.2
World	Susceptible	427.3	470.3	130.1	7.5	1035.2	4134.0
	Others	321.7	440.3	165.5	1.7	929.2	6914.3
Total		**749.0**	**910.6**	**295.6**	**9.2**	**1964.4**	**11048.3**

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[2] The GLASOD dataset can be downloaded from http://isric.org/projects/global-assessment-human-induced-soil-degradation-glasod [Accessed: 12.11.2014]

[3] Following the UNCCD usage of terms, hyperarid drylands such as deserts are not considered “susceptible” to desertification, and “susceptible” therefore refers to the remaining three dryland zones (dry-subhumid, semi-arid, and arid).

Source: Middleton & Thomas (1997)

More than 340 Mha of this moderately degraded terrain was found in Asia and over 190 Mha in Africa. Strongly degraded soils were found to cover an area of 296 Mha worldwide, of which 124 Mha in Africa and 108 Mha in Asia. These soils were estimated to be not any more reclaimable at farm level and only restorable through major engineering measures. Extremely degraded soils – considered "irreclaimable and beyond restoration" – covered approx. 9 Mha worldwide, of which over 5 Mha was located in Africa.

Looking at the types of soil degradation, 55.6% of the area experiencing soil degradation was reported as damaged by water erosion, 27.9% by wind erosion, 12.2% by chemical, and 4.2% by physical deterioration[4] (Middleton & Thomas 1997). The above findings represent the cumulative effect of all previous soil degradation damage "since 1950" but probably since much earlier (Hurni et al. 2008).

Although GLASOD made no distinction for different land use types or ecosystem classifications, some indication can be derived from the causes of land degradation mentioned (Table 2): overgrazing (34.5%), deforestation and removal of the natural vegetation (29.5%), agricultural activities (28.1%), overexploitation of vegetation for domestic use (6.8%), and (bio)industrial activities (1.1%). GLASOD has found that 53% of soil degradation is occurring within the drylands, highlighting that soil degradation is by no means restricted to drylands alone (Oldeman et al. 1991).

Table 2: Main causes of soil degradation by region in susceptible drylands and other areas (in Mha).

Region	Aridity zone	Overgrazing	Deforestation	Agricultural activities	Overexploitation	(Bio)industrial	Total degraded	Total non-degraded
Africa	Susceptible	184.6	18.6	62.2	54.0	0.0	319.4	966.6
	Others	58.5	48.2	59.2	8.7	0.2	174.8	1504.9
Asia	Susceptible	118.8	111.5	96.7	42.3	1.0	370.3	1301.5
	Others	78.5	186.3	107.6	3.8	0.4	376.6	2207.5
Australasia	Susceptible	78.5	4.2	4.8	0.0	0.0	87.5	575.8
	Others	4.0	8.1	3.2	0.0	0.1	15.4	203.5
Europe	Susceptible	41.3	38.9	18.3	0.0	0.9	99.4	200.2
	Others	8.7	44.9	45.6	0.5	19.7	119.4	531.4
North America	Susceptible	27.7	4.3	41.4	6,1	0.0	79.5	652.9
	Others	10.2	13.6	49.1	5.4	0.4	78.7	1379.8
South America	Susceptible	26.2	32.3	11.6	9.1	0.0	79.1	436.9
	Others	41.7	67.8	51.9	2.9	0.0	164.3	1087.3
Total		**678.7**	**578.6**	**551.6**	**132.8**	**22.7**	**1964.4**	**11048.3**

Source: Middleton & Thomas (1997)

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[4] Chemical deterioration encompasses loss of nutrients and/or organic matter, salinization, acidification, and pollution; physical deterioration contains compaction/sealing/crusting, waterlogging, and subsidence of organic soils.

There has been some confusion on GLASOD results, with significantly higher, "UNCOD-style" degradation values of up to 74% of dryland area circulating in the literature. This is because during the production of the GLASOD world map of global soil degradation, the mismatch between ground sampling scale and map unit scale had to be bridged. For cartographic reasons, each polygon which is not 100% stable would show as degraded, even if only 1 to 5% of the polygon was actually affected on the ground. Looking at the map only therefore gives a visually exaggerated impression of the extent of degradation (Safriel 2007, Engel-di Mauro 2014).

2.1.3 Follow-up assessments and evaluation of GLASOD

Soon after the publication of GLASOD the need for a more detailed and more country-specific degradation assessment became apparent. In 1993, the members of the Asian Network on Problem Soils recommended the preparation of a qualitative assessment for South and Southeast Asian at a scale of 1:5 million. The study, named Soil Degradation in South and Southeast Asia (ASSOD), was commissioned by UNEP to ISRIC and carried out 1995-1997 in close co-operation with FAO and national institutions in 16 countries. The assessment was carried out using a physiographic base map, compiled according to the SOTER methodology[5], and a slightly modified GLASOD methodology (van Lynden & Oldeman 1997). Water erosion is (like in GLASOD) the most widespread degradation type, covering 21% of the total land area in the region (46% of the total degraded area), followed by wind erosion (9% of the total area, 20% of all degradation). Various subtypes of chemical degradation (11% of the total or 24% of the degraded area) and physical degradation (affecting about 4% of the total area or 9% of the total degraded area) also occur in most countries, mostly with light to moderate impacts. A new element in ASSOD was the link between impact on productivity and management level: a large increase in production would e.g. have a lesser degradation impact where level of management is also high, and the worst case scenario being low-level management of unproductive land. The relative extent of three levels of management per country presented a rather varied picture, which at the same time illustrated that information on management levels may not be fully adequate for the entire region.

Several other attempts have been made to build upon, and extend the GLASOD data set. The SOVEUR project (Mapping of soil and terrain vulnerability in Central and Eastern Europe, 1997-2000) elaborated procedures for a geo-referenced assessment of the status of human-induced land degradation, with particular attention to issues of soil pollution, and an assessment of the vulnerability of soils to delayed-pollution (Batjes 2000). Using data derived from the GLASOD assessment, Crosson (1997) calculated the cumulative on-farm productivity loss due to soil degradation since World War II at the global level. Average productivity losses on the total area of land in crops and permanent pastures were between 4.8% and 8.9%. Based on the worst case scenario, Oldeman (1998) later singled out the data for cropland alone (12.7% productivity lost), and for pasture land (3.8%).

The Pilot Assessment of Global Ecosystems (PAGE) used the GLASOD data as a foundation and combined them with a newly calculated global area of agriculture (IFPRI calculation using CIESIN 2000). The PAGE results suggested that human-induced degradation since the mid-1900s is more severe than estimated by the GLASOD. Over 40% of the PAGE agricultural extent coincided with the GLASOD mapping units that contained moderately degraded areas, and 9% coincided with mapping units that contained strongly or extremely degraded areas (Wood et al. 2000). The PAGE further hypothesised that a state of strong or extreme degradation implied that soils would be very costly or infeasible to rehabilitate to their original (mid-1900s) state, and that land degradation is estimated to have reduced overall global crop productivity by around 13%.

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[5] For details see http://www.isric.org/projects/soil-and-terrain-database-soter-programme [Accessed: 12.11.2014]

In order to go beyond the "soil-centred" approach of GLASOD, UNEP (1991) intersected GLASOD data with an ICASALS (International Centre for Arid and Semiarid Land Studies, Texas Tech University) map of major land uses. They concluded that some 2,600 Mha, mainly in rangelands, are impacted by vegetation degradation not recorded in GLASOD, bringing the total extent of drylands experiencing some kind of degradation up to nearly 70%. In face of the "visual exaggeration" on GLASOD map as mentioned in the previous section, it must be considered that both the PAGE as well as the UNEP-ICASALS assessment are overestimates of the actual area affected by land degradation on the ground.

Since its publication, GLASOD attracted considerable criticism (Safriel 2007), that was mainly targeted at the expert-based methodology which necessarily includes a degree of subjectivism and possible misjudgement, or – in the worst case – vested interests of institutions or corporations. It is also important to note that the expert-based degradation estimates reflect human-induced changes only and are thus primarily related to managed land rather than the entire terrestrial surface. The GLASOD study also focused on soil degradation largely related to soil erosion with only little mention of other forms of land degradation—namely, loss of vegetation (for example, deforestation) and biodiversity (Nkonya et al. 2011). Diverse types are represented as if they could be separable from each other, and there is neither information on how to treat multiple forms of degradation over the same area nor on how these processes interact and affect changes in soil properties (Engel-di Mauro 2014).

In an effort to evaluate the GLASOD findings with the help of new GIS data to delineate and define the characteristics of GLASOD map units, Sonneveld & Dent (2009) tested the consistency and reproducibility of the expert judgements at the time. Although acknowledging what has been achieved on a global level in short time, they concluded that the expert assessments were not very reliable. Experts were found to be only moderately consistent in assigning soil degradation classes to similar sites and the authors speculated that the different conceptualization of the degrees of degradation among experts might be one of the main reasons for this. They also delineated improvements for future expert-based GLASOD-style assessments:

- Reduce subjective interpretations: give a quantitative interpretation to the qualitative assessments by relating their ordered classes to a quantitative measure of land degradation;
- Make qualitative assessments more consistent and more operational by discussing them in plenary sessions with the experts involved;
- Establish a common procedure for establishing physiographic mapping units by using a detailed global digital elevation model (in GLASOD, the experts were given a free hand with this)
- Reduce the impact of outliers generated by "special sites" unknown to the entire group by including specific factors that account for those particular locations.

Set up as an awareness raising tool in the first place, GLASOD showed the "damage done" and thus focussed on the "bad news" side of things. This on the other hand helped in the mid-1990s to trigger the establishment of the World Overview of Conservation Approaches and Technologies (WOCAT) database[6], a growing compilation of SLM approaches and technologies. Lately renamed WOCAT-International, it is still in use today and might also play an important role in future land degradation assessments (see sections 4.2.1 . and 4.2.2).

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[6] The WOCAT databases can be accessed through https://www.wocat.net/ [Accessed: 20.02.2015]

2.2 Millennium Ecosystem Assessment

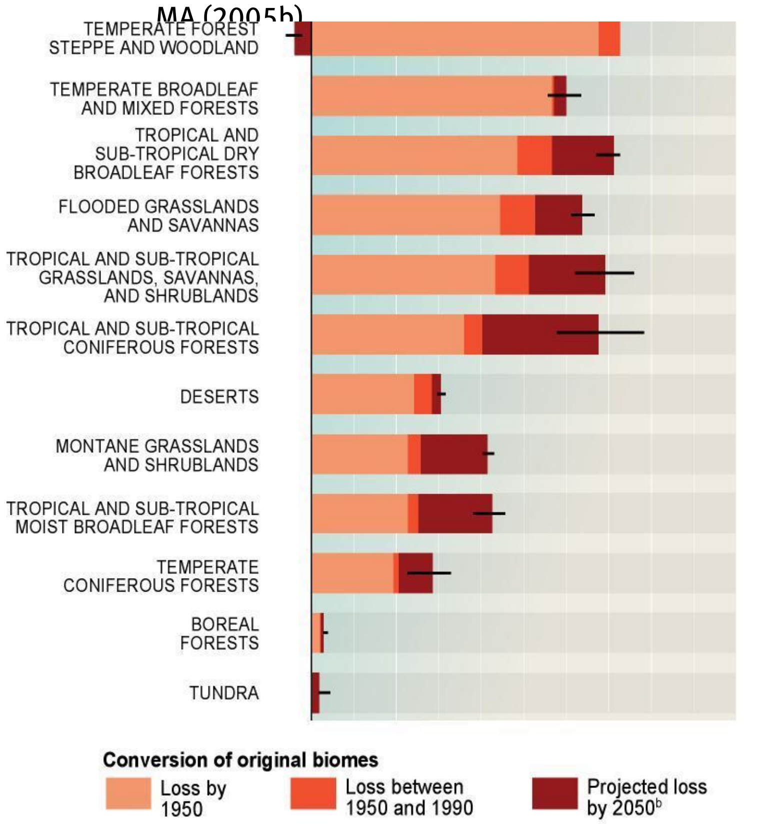
2.2.1 Widening the scope of land degradation assessments

ASSOD had done the first step towards a more holistic assessment of land degradation by trying to include information on land management levels. Through taking into account not only the state of the land but also the drivers that are impacting on the existing conditions it is hoped that insight into the nature and speed of future changes can be gained. The Millennium Ecosystem Assessment (MA), a global desk study to which more than 1,000 experts have contributed, defined a number of “systems” as reporting units, rather than “ecosystems” to consequently show the linkages between ecosystems and human well-being (MA 2005a). The aim was not to generate new primary knowledge but to evaluate the degree to which ecosystem services within these systems, on which human societies depend, are sustainable, given the many environmental stresses they face (Lepers et al. 2005). As a consequence, global land degradation has not been in the focus of the MA and a detailed analysis of land degradation has only been performed for one of the systems, the “Dryland Systems”. However, the impressive amount of overall information assembled and the MA’s crucial role in facilitating new assessment technologies justify its inclusion in this compilation.

2.2.2 Results of the MA

The MA showed that more than two-thirds of the area of two of the world’s 14 major terrestrial biomes and more than half of the area of four other biomes had been converted by 1990, primarily to agriculture and livestock production systems (Figure 1).

Figure 1: Extent of conversion of terrestrial biomes by 1950, 1990, and as projected for 2050; this is using “pristine” ecosystem conditions without human influence as a baseline; source: MA (2005b).



[a] A biome is the largest unit of ecological classification that is convenient to recognize below the entire globe, such as temperate broadleaf forests or montane grasslands. A biome is a widely used ecological categorization, and because considerable ecological data have been reported and modeling undertaken using this categorization, some information in this assessment can only be reported based on biomes. Whenever possible, however, the MA reports information using 10 socioecological systems, such as forest, cultivated, coastal, and marine, because these correspond to the regions of responsibility of different government ministries and because they are the categories used within the Convention on Biological Diversity.

[b] According to the four MA scenarios. For 2050 projections, the average value of the projections under the four scenarios is plotted and the error bars (black lines) represent the range of values from the different scenarios.

The nature of these data is indicative only, as the MA authors themselves pointed out that despite a rapid expansion in the availability of data and information on ecosystems, no systematic examination of the global status and trends in land cover had been conducted yet (MA 2005d). Also, it can be discussed in how far conversion from a natural state to cultivated land represents degradation or not. This is just one of the issues which have to be resolved for setting up future frameworks for global land degradation as outlined in Chapter 4.

The MA analysed land degradation in drylands in particular. In a partial-coverage assessment of desertification prepared for the MA in 2003, Lepers et al. (2005) combined partially overlapping regional data sets with remote sensed land “greenness” data. Taking vegetative cover and its net primary productivity (NPP) as a proxy for the state of the soil, a time series of satellite images of remotely sensed reflectance from live vegetation – measured as a Normalized Difference Vegetation Index (NDVI) – was used as a proxy indicator of land degradation. Based on this approach, Lepers et al. (2005) found that 10% of global drylands (including hyper-arid areas) were degrading during the period 1981-2000 (MA 2005c). Having reviewed the available data on dryland degradation, the MA drylands section underscored the need for better assessment given the limitations and problems with each of the underlying data sets. They concluded that the actual extent of desertified area may lie somewhere between the figures reported by GLASOD and the 2003 MA study. This would mean that some 10–20% of drylands – or 600 and 1,200 Mha - would already be affected by desertification (MA 2005c).

Especially in the context of the MA it must be pointed out that assessments based on remotely sensed greenness focus solely on the production function of land, while decreases in some provisioning and most supporting, regulating and cultural services are not taken into account. Thus, NPP as a proxy for land degradation is likely to be on the conservative end of estimates on global ecosystem degradation. In recognition of this, the Millennium Ecosystem Assessment (MA) analysed a set of 24 ecosystem services and concluded that approximately 60% (15 out of 24) of the services examined were found to be degraded or were being used unsustainably, including freshwater, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests.

As broad as the MA assessment has been, it did not extend to examine the costs of land degradation or the costs and benefits of the prevention of loss of ecosystem services or the rehabilitation of degraded ecosystem services (Nkonya et al. 2011). The authors of the MA restricted their findings to the general statement that the full costs of ecosystem services degradation are difficult to measure, but that the available evidence demonstrates that they are substantial and growing (MA 2005b).

2.3 GLADA

2.3.1 Remote sensing as a basis for global assessment of land degradation and improvement

In spite of the criticisms on GLASOD - or maybe due to those - no funds were made available to finance an update and getting a better and more scientifically sound approach. The Millennium Ecosystem Assessment for instance did still use GLASOD results to make its estimates of land degradation. This situation lasted until 2006 when the Global Environmental Facility (GEF) funded the FAO program Land Degradation Assessment in Drylands (LADA) which set out to tackle the assessments at three levels of detail. Its global component, GLADA, aimed at providing an up-to-date, quantitative and reproducible land degradation and improvement assessment.

In the GLADA project, land degradation is defined as a long-term decline in ecosystem function and measured in terms of net primary productivity. The remotely-sensed normalised difference vegetation index (NDVI) is used as a proxy. The GLADA assessed global land degradation and improvement by analysis of trends of climate-adjusted NDVI making use of Global Inventory Modeling and Mapping Studies (GIMMS)[7] data (Bai et al. 2008a, b). Drought effects were screened using rain–use efficiency (RUE) estimated from the ratio of the annual sum NDVI to annual rainfall. Areas where biomass productivity depends on rainfall variability were identified as those with a positive relationship between NDVI and rainfall; in these areas, below-normal rainfall is reflected in below-normal NDVI and, usually, increased RUE; where there is decreasing NDVI but steady or increasing RUE, loss of productivity is attributed to drought and these areas are masked. Where both NDVI and RUE decline, something else is happening and these areas are included in the next stage of analysis together with the areas where production is not limited by rainfall. Similarly, energy-use efficiency, the ratio of NDVI and accumulated temperature is used to screen trends driven by rising temperatures. To provide a more tangible measure of land degradation, NDVI was translated into NPP by correlation with MODIS NPP data for the overlapping period from 2000, yielding a globally consistent dataset that could then be intersected with land use and/or land cover data to estimate changes for each major ecosystem type. Numerous studies have identified a strong relationship between NDVI and net primary productivity (NPP), one of the indicators of the state of land degradation (Yengoh et al. 2014).

2.3.2 Results of GLADA

According to their analysis of Bai et al. (2008a), nearly one quarter (24%) of the world's land area was undergoing degradation in the period 1981-2003; this is equivalent to 3,510 Mha of terrestrial land surface area. The areas most affected were tropical Africa south of the Equator, Southeast Asia, South China, North-central Australia, drylands and sloping-lands of Central America and the Caribbean, Southeast Brazil, the Pampas and the boreal forests (Bai et al. 2008a) (Figure 2).

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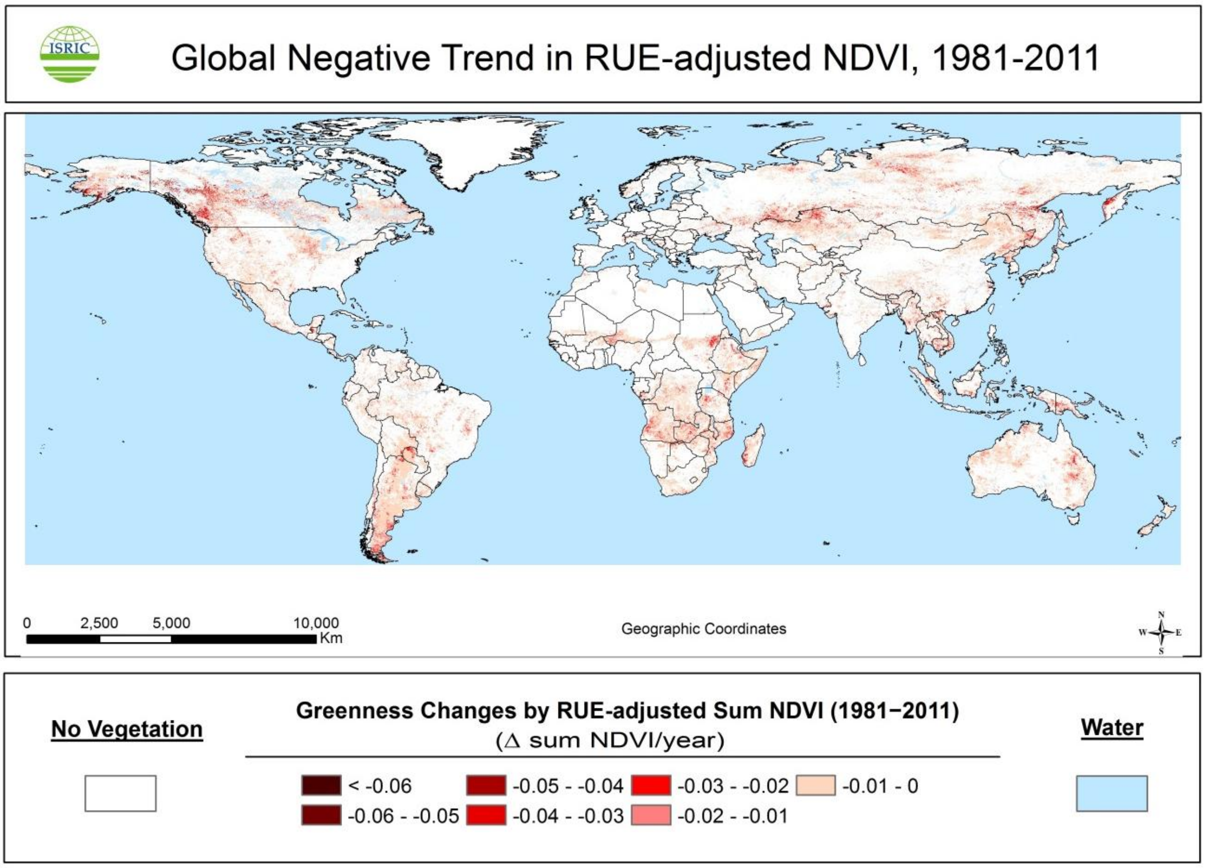
[7] The GIMMS NDVI data can be accessed through http://glcf.umd.edu/data/gimms/ [Accessed: 20.02.2015]

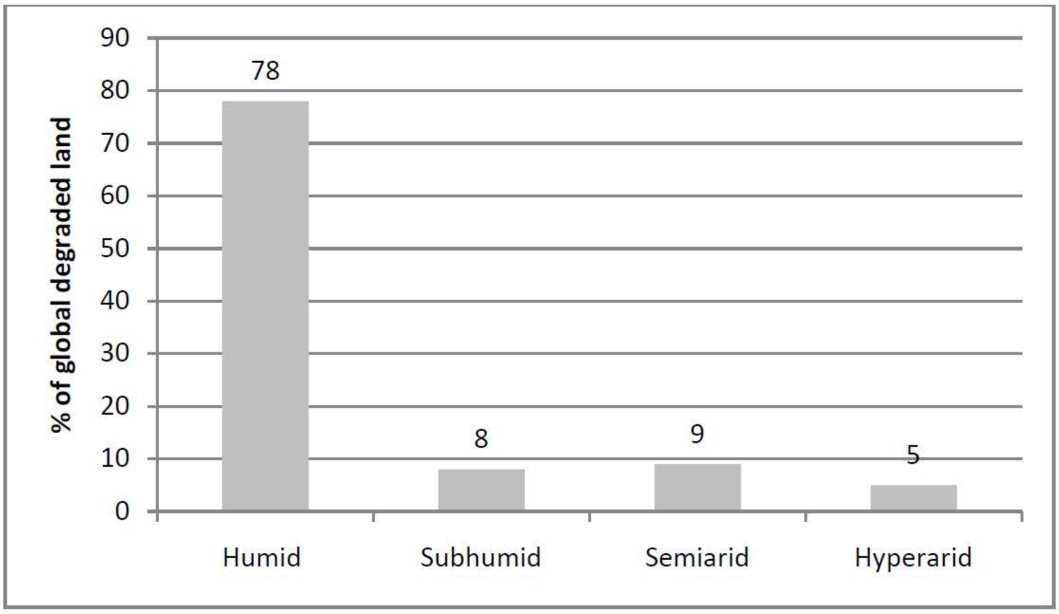
Figure 2: Proxy assessment of global land degradation (updated to 2011); source: Bai & Dent (2015)



Some 1.5 billion people depend directly on the degrading area. In terms of C fixation, degrading areas represent a loss of net primary production (NPP) of $9.56 \text{x} 10^{8}$ tonne C relative to the mean NPP over the period 1981–2003, that is $9.56 \text{x} 10^{8}$ tonne C not removed from the atmosphere, equivalent to 20% of the global CO_2 emissions for the year 1980. The analysis also indicated that about 16% of the land area showed improvement.

The authors found that there is little correlation between land degradation and the aridity index: 78% of degradation by area was in humid regions, 8% in the dry sub-humid, 9% in the semi-arid and 5% in arid and hyper-arid regions (Figure 3).

Figure 3: Degraded area as a percentage of total global degraded land area across agroclimatic zones, GLADA, 1981–2003; source: Bai et al. (2008b), adapted by Nkonya et al. (2011).



Integrating remotely sensed degrading areas with FAO global land use systems (FAO 2008) the authors also analysed the data with respect to land use. For agricultural land, the GLADA found that 22.2% were degrading, equal to 17.6% of total land degradation observed. Thus it concludes that land degradation is not primarily associated with farming. Degradation was over-represented in forests, with 46.7% of degrading land covered by forest, although broadleaved and needle-leaved forest together occupied only 29.3% of the land. The GLADA also noted that, counter-intuitively, the proportion of degradation in the various forest categories was very similar: declining net primary production (NPP) was seen across 30% of natural forest and supposedly protected forest, across 25-33% of grazed forests, and 33% of plantations. To explain these findings, the authors assumed that "some of the recorded degradation" reflected clearance for cropland and grazing. They further noted that apart from land degradation as it is commonly understood, high-latitude taiga is subject to catastrophic fires and pest outbreaks that affect huge areas (Bai et al. 2008b).

2.3.3 Follow-up and evaluation of GLADA

In a study similar to GLADA, Le et al. (2014) were identifying the hotspots of land degradation in the world across major land cover types, using global level remotely sensed vegetation index data for a 25-year period (1982-2006). They found that land degradation hotspots cover about 29% of global land area and are occurring in all agro-ecologies and land cover types. Land degradation was found to be especially massive in grasslands, with approximately 3.2 billion people residing in these degrading areas. At the same time, the data indicated that land improvement has also occurred in about 2.7% of global terrestrial land area during the last three decades.

There is an obvious trade-off in GLADA-type assessments between the "cheap and rapid" way to achieve a global dataset on trends in net primary production, and what it can actually tell us about status and trends of land degradation. First of all, data resolution (8 km) is still quite coarse. Opposite to expert assessments, remote sensing does not allow for insights into causes and types of land degradation. Even various degrees of degradation are hard to elucidate. With an emphasis on the production function of land (NPP) alone, the focus is quite narrow from the start. It is also important to understand that the GLADA methodology allows for detecting areas that may have been degrading, but does not allow to analyse what is or was degraded at the time. Thus, it targets the process of land degradation, not the state of land. It does e.g. not support the definition of a global degradation "baseline" required in the context of land degradation targets such as LDNW (see chapters 3.1 and 4.2).

At the core of the GLADA methodology is the discussion in how far NPP or a vegetation index such as NDVI can be taken as a proxy for land degradation, i.e. how human-induced effects on land can be separated from other factors leading to vegetation change, such as e.g. atmospheric fertilisation or natural climatic variation (Le et al. 2014). Yengoh et al. (2014) remarked that there is no simple and straightforward way to disentangle these effects. In GLADA, Rain Use Efficiency (RUE), calculated by dividing NDVI by rainfall, was used to separate human action from natural variation. Le et al. (2014) additionally corrected for atmospheric fertilisation by looking at the NDVI dynamics in "pristine" areas. Sonneveld & Merbis (2013) pointed at a range of other technical issues, such as e.g. the health and age status of the vegetation having an influence on the result, the influence of cloudiness affecting the results, or ground level features like heavy erosion or deforestation not being detected. Wessels (2009) criticized the summation of NDVI over calendar years instead of summing over the vegetation period.

The criticism goes beyond technical issues. By focussing on production, high-biomass production systems (e.g. market-oriented plantations) might show as less degraded than lower-biomass systems such as subsistence farming (Engel-die Mauro 2014), although the latter might be more sustainable. Soil quality cannot be judged from analysing aboveground aspects alone. The larger part of biomass production happens belowground and is not being evaluated. The sudden decrease in total biomass of e.g. a cut down forest area as spotted through satellite imagery would not reflect the largely unchanged level of soil productivity. The other way round, the assumption that more vegetation is automatically better might also not hold true in all cases, especially where considerations go beyond the production function. Based on NDVI analysis alone, a shift from conventional to organic farming could e.g. qualify as soil degradation. Or the biomass observed may be considered a weed by the land users (Engel-di Mauro 2014).

There is consensus that NDVI-based assessments do need a groundtruthing component. According to Nachtergaele et al. (2011b) GLADA provides a general identification of areas of interest for further investigation rather than areas of land degradation. Country-based analysis of the data was made in six LADA countries (Bai and Dent 2007a-f). These countries were asked to verify the results of potential land degradation hotspots indicated by GLADA. Detailed checking of the results as done e.g. in South Africa revealed that only about half of the sites considered as hotspots could be considered as suffering from land degradation as observed on the ground (Pretorius, 2008).

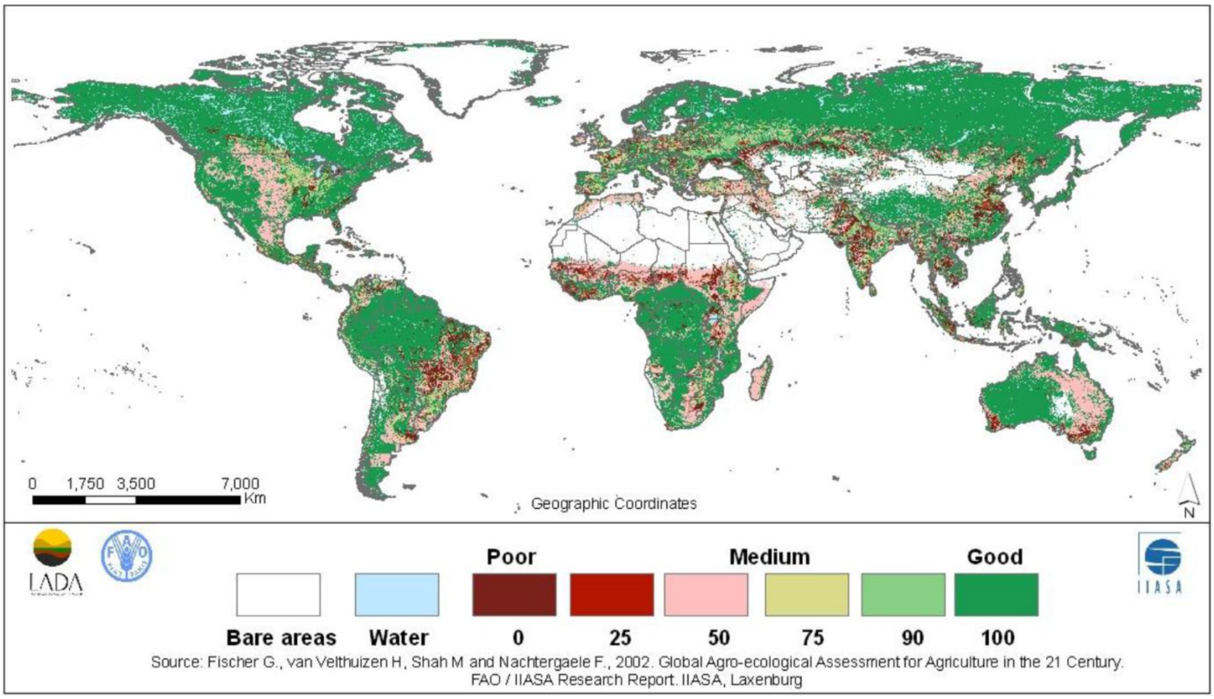
Overall the conclusion seems to be that the results of the GLADA-NDVI study cannot be used as a proxy for land degradation at a global level as a whole (Nachtergaele et al. 2011b). This appears to be irrespective of the fact that a substantial body of peer-reviewed research lends unequivocal support for the use of NDVI time series for studying vegetation dynamics and provides compelling evidence that these data are highly correlated with biophysically meaningful vegetation characteristics that again are closely related to land degradation (Yengoh et al. 2014). As Le et al. (2014) have demonstrated, NDVI-based studies can be helpful to detect *where* degradation magnitude and extent are *relatively* high. This helps to identify degradation hotspots as a basis for prioritizing both preventive investments for the restoration or reclamation of degraded land, and subsequent focal ground-based studies. The authors argue that his degradation hotspots mapping is "different from, indeed not as contentious as, the production of an accurate map of all degraded areas."

2.4 GLADIS

Following up on the LADA/GLADA initiative, a Global Land Degradation Information System (GLADIS) has been set up by FAO and partners (Nachtergaele et al. 2011b). The 'ecosystem approach' (CBD 2000) is at the heart of the GLADIS, and with it the definition of 'land degradation' as the reduction in the capacity of the land to provide ecosystem goods and services over a period of time for its beneficiaries. In this context, 'ecosystem goods' refers to absolute quantities of land produce having an economic or social value for human beings, e.g. animal/crop production, or water quantity/quality. 'Ecosystem services' on the other hand concerns more qualitative characteristics and their impact on the beneficiaries and the environment. Whereas GLADA had solely focused on the production function, GLADIS set out to determine both, the status of ecosystems' capacity to deliver goods and services, as well as the change in this capacity.

Goods and services in question were broken down into six 'tangible', measurable units of 'Biomass', 'Soil Health', 'Water quantity', 'Biodiversity', 'Economic Services', and 'Social services'. To assess the *status*, global data sets of land use and management, climatic conditions, socio-economic conditions etc. were analysed using models to create a 'baseline' condition. For the 'Soil Health' axis the soil quality inventory from the GAEZ study (Fischer et al. 2002) has been used[8]:

Figure 4: Global maps of soil health status for present land use.



Source: Fischer G., van Velthuizen H, Shah M and Nachtergaele F., 2002. Global Agro-ecological Assessment for Agriculture in the 21 Century. FAO / IIASA Research Report. IIASA, Laxenburg

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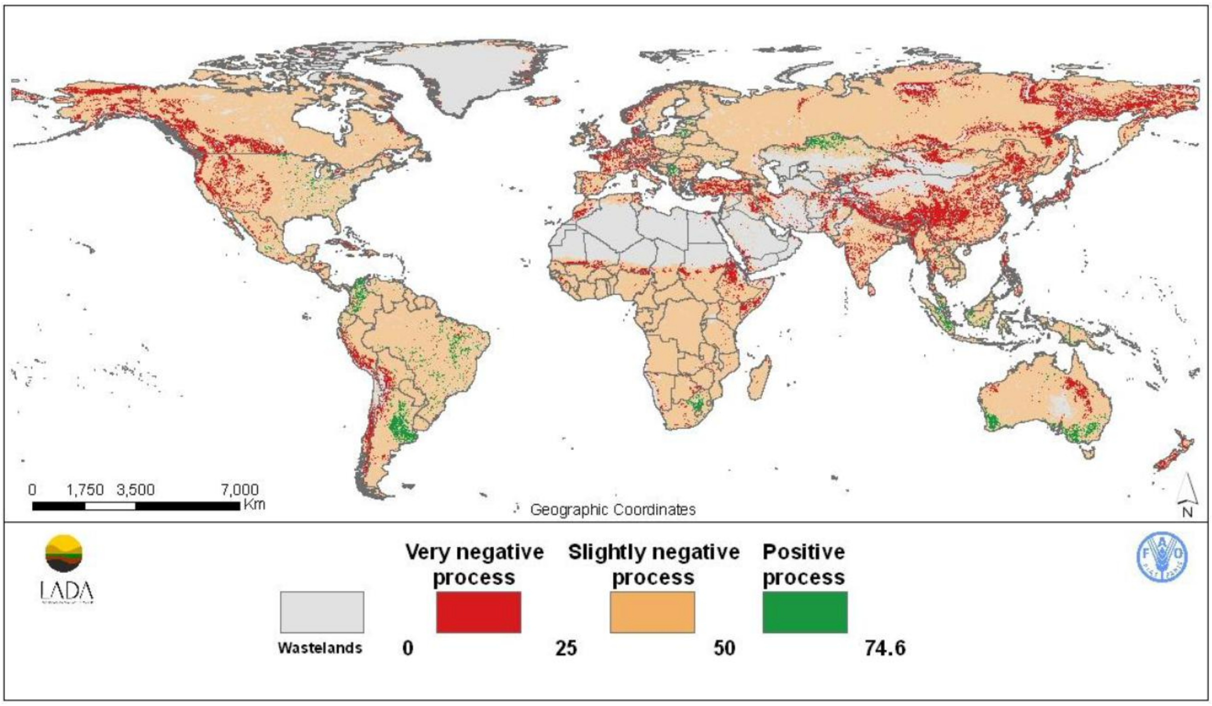
[8] The agro-ecological zones are defined as homogenous and contiguous areas with similar soil, land and climate characteristics. Geo-referenced global climate, soil and terrain data are combined into a land resources database, commonly assembled on the basis of global grids, typically at 5 arc-minute and 30 arc-second resolutions (http://gaez.fao.org).

To assess the *trend* (or process), i.e. the overall long-term tendency of changes in the flow of such benefits, time models were fed with information on pressures. In case of 'Soil Health', this e.g. included estimates on parameters such as water/wind erosion, high livestock and mechanization presence, salinization risks, or soil nutrient mining[9]. Total soil physical and chemical degradation ratings were established, merged to an overall degradation rating, and – together with soil improvement trends – a global map of overall soil health processes derived:

Figure 5: Global map of GLADIS soil health processes; source: Nachtergaele et al. (2011b).



Based on LADA's integrated ecosystem approach methodology, land degradation would not only be based on the results along the Soil Health axis, but would also respect status and process results of the other 5 spheres/axes. For each pixel on the global map this yields six 'status spikes' and six 'trend/process spikes'. In order to make this information visible and understandable, it was decided to process the information into four aggregated land degradation indices:

1. The biophysical *status* of land (Figure 6). This considers the actual state of the biophysical ecosystem factors to provide goods and services (Biomass, Soil, Water, and Biodiversity). The 4 axis have been weighted according to factors based on the main land use. The resulting global map (Figure X) shows approximately 9% of the terrestrial surface as scoring very low (0-24%), 31% low (25-49%), 21% moderate (50-74%), and 19% high (75-100%).
2. The biophysical land degradation *process* (Figure 7). This index considers the overall processes of declining or improving ecosystem services by considering the combined value of each biophysical process (Biomass, Soil, Water and Biodiversity). Also in this case, the 4 axis have been weighted according to factors based on the main land use.
3. The *classes* of land degradation (Figure 9). This combines the *status and process* information of the first to aggregated indices. It therefore describes the overall status in provision of biophysical ecosystem services, including information on the processes of declining biophysical ecosystem

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[9] For more details, please see http://www.fao.org/nr/lada/gladis/gladis_db/help.php

services by considering the combined value of each biophysical axis (Biomass, Soil, Water and Biodiversity). Figure 8 illustrates how the classification was done.

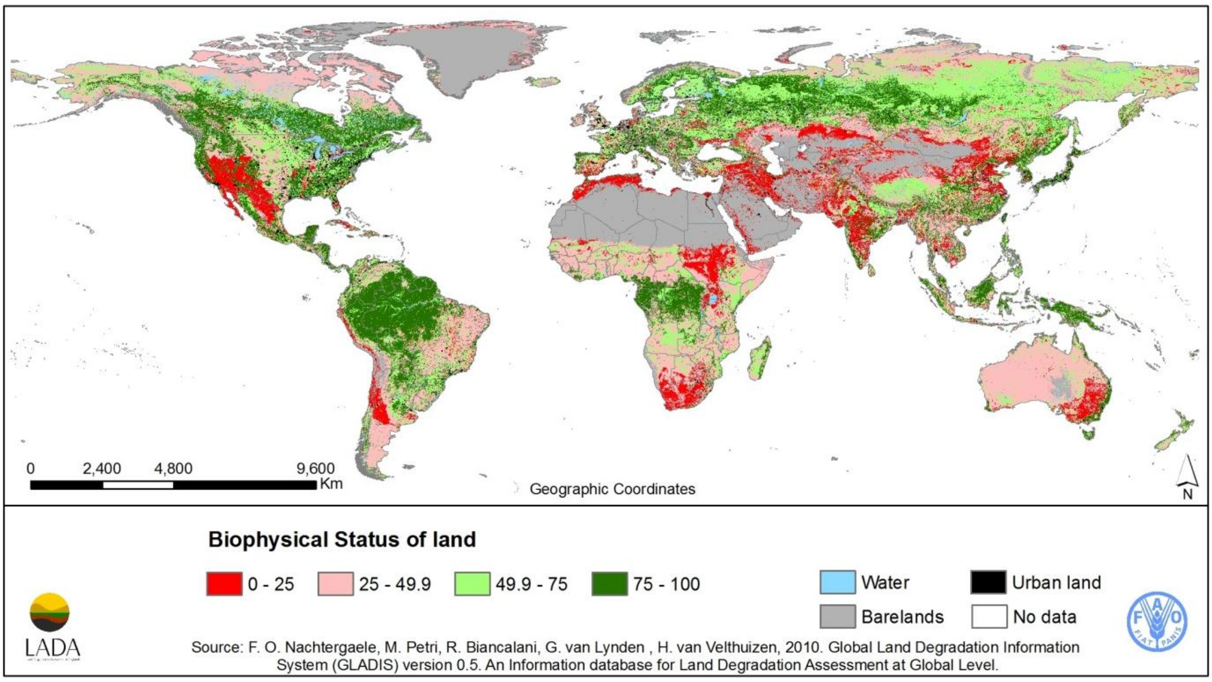
According to this analysis, the following global land area and population is affected by the various land degradation classes:

- Low status, medium to strong (negative) process: 23% of global area, 27.1% of population
- Low status, weak process: 13.5% of global area, 9.1% of population
- Low status, improving process: 3.6% of global area, 1.4% of population
- High status, medium to strong process: 32.3% of global area, 17.5% of population
- High status, stable to improving process: 5.6% of global area, 3.8% of population.

4. Land Degradation Impact Index. This multiplies the results for the land degradation classes with the poverty and population levels to analyse where impacts will be most pronounced. The resulting global map shows that significant effects can be expected even in case of lightly to moderately degraded land (e.g. in India) if the area is densely populated and people have low income. Nachtergaele et al. (2011b) summarize that at continental scale, Africa and Asia are the most impacted by land degradation, while most of Western Europe, North and South America, Australia and the Russian Federation suffer much less.

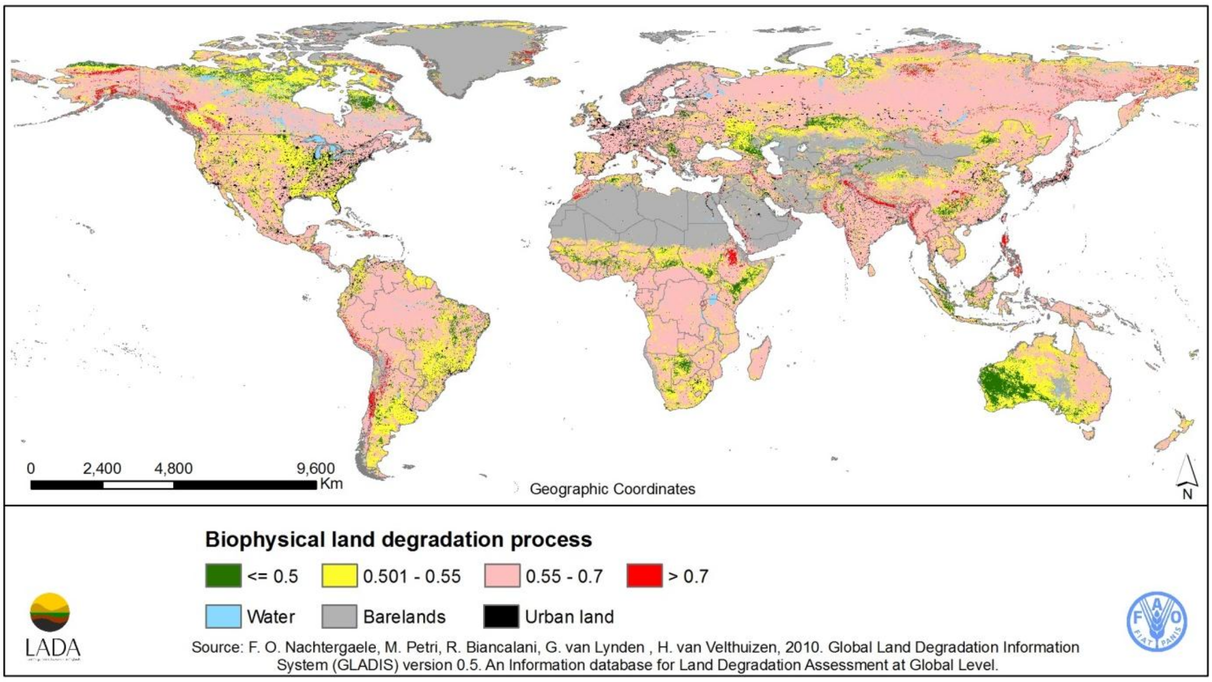
GLADIS has the merits of being the first mapping assessment using an interdisciplinary approach, and a time dimension. The manifold outputs of GLADIS may appear confusing on first sight; but it is indeed the complex nature of land degradation that necessitates this multi-faceted approach. The differentiated approach and output of GLADIS not only portrays the complexity of the land degradation phenomenon, but also forces people to be clear about what data it is that they want.

Figure 6: Global map of GLADIS biophysical status of land; source: Nachtergaele et al. (2011b).



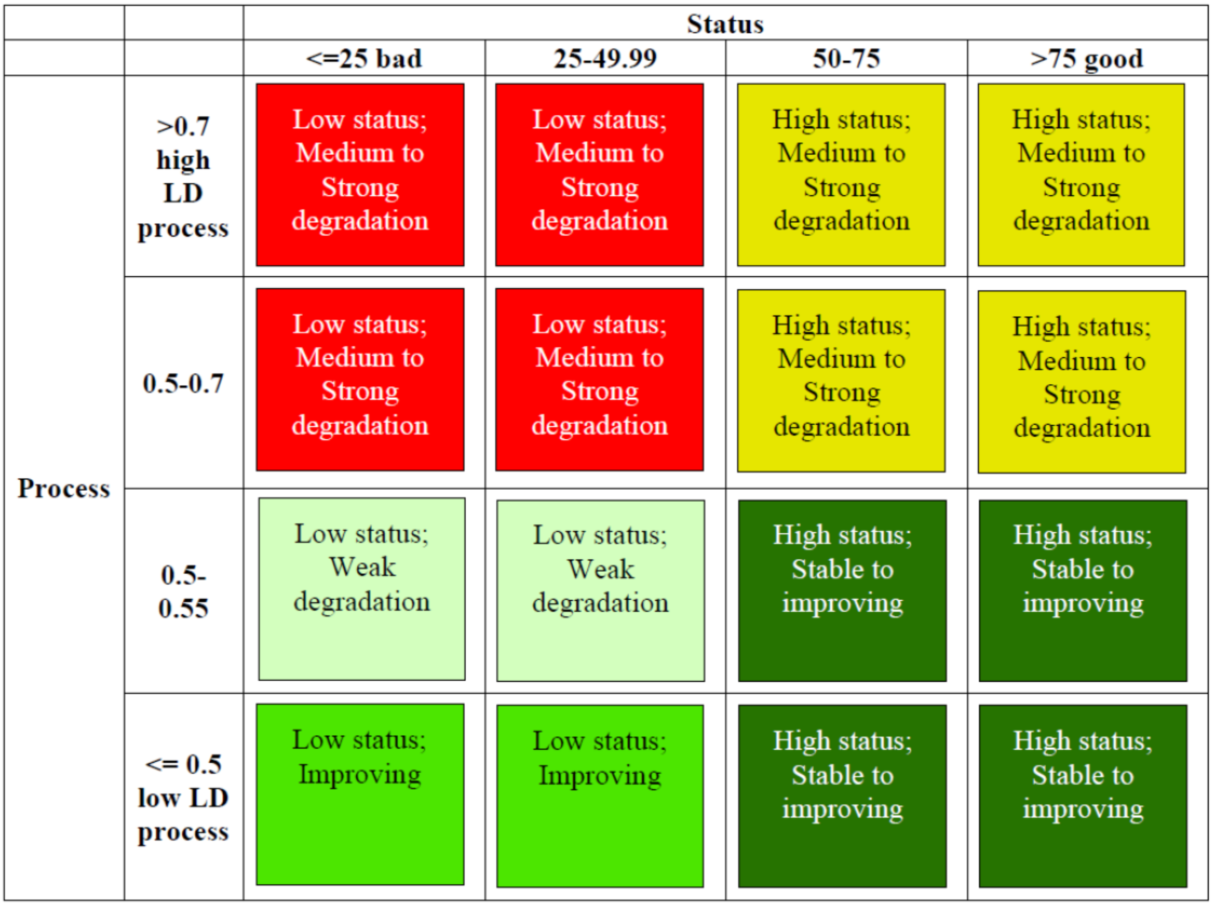
Source: F. O. Nachtergaele, M. Petri, R. Biancalani, G. van Lynden , H. van Velthuizen, 2010. Global Land Degradation Information System (GLADIS) version 0.5. An Information database for Land Degradation Assessment at Global Level.

Figure 7: Global map of GLADIS biophysical land degradation process; source: Nachtergaele et al. (2011b).



Source: F. O. Nachtergaele, M. Petri, R. Biancalani, G. van Lynden , H. van Velthuizen, 2010. Global Land Degradation Information System (GLADIS) version 0.5. An Information database for Land Degradation Assessment at Global Level.

Figure 8: Combination of the Biophysical status index with the Biophysical degradation index; source: Nachtergaele et al. (2011b).



		Status			
		<=25 bad	25-49.99	50-75	>75 good
Process	>0.7 high LD process	Low status; Medium to Strong degradation	Low status; Medium to Strong degradation	High status; Medium to Strong degradation	High status; Medium to Strong degradation
	0.5-0.7	Low status; Medium to Strong degradation	Low status; Medium to Strong degradation	High status; Medium to Strong degradation	High status; Medium to Strong degradation
	0.5-0.55	Low status; Weak degradation	Low status; Weak degradation	High status; Stable to improving	High status; Stable to improving
	<= 0.5 low LD process	Low status; Improving	Low status; Improving	High status; Stable to improving	High status; Stable to improving

Figure 9: Global map of GLADIS land degradation classes; source: Nachtergaele et al. (2011b).

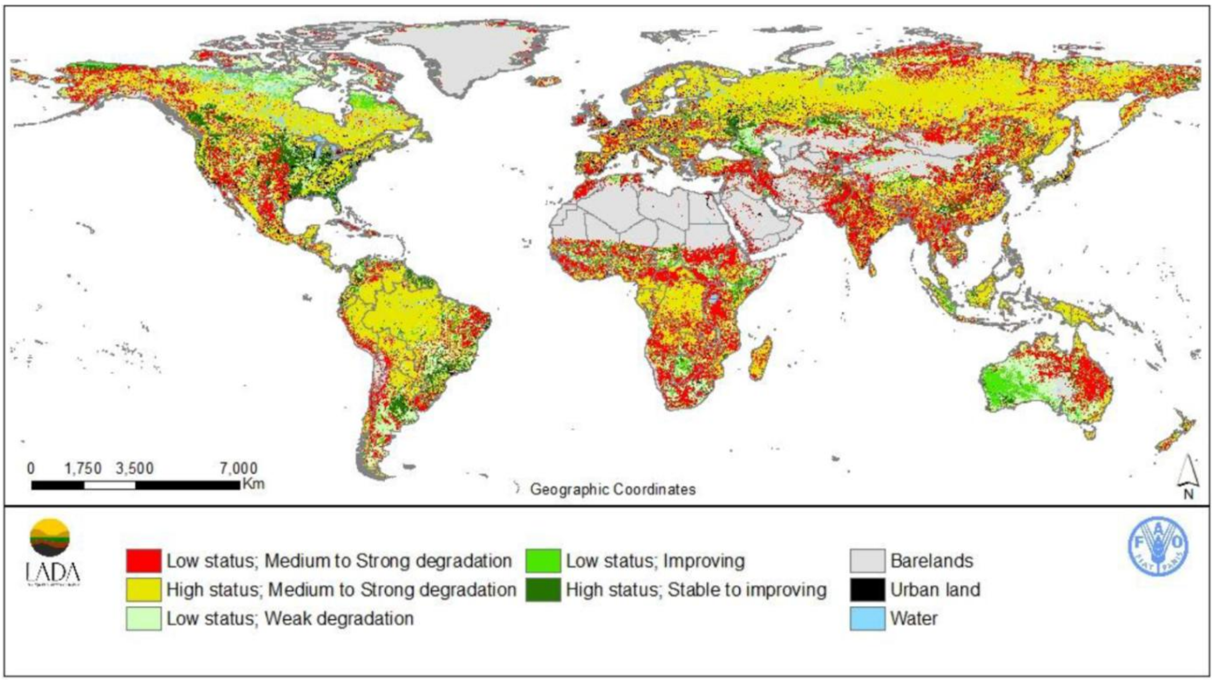
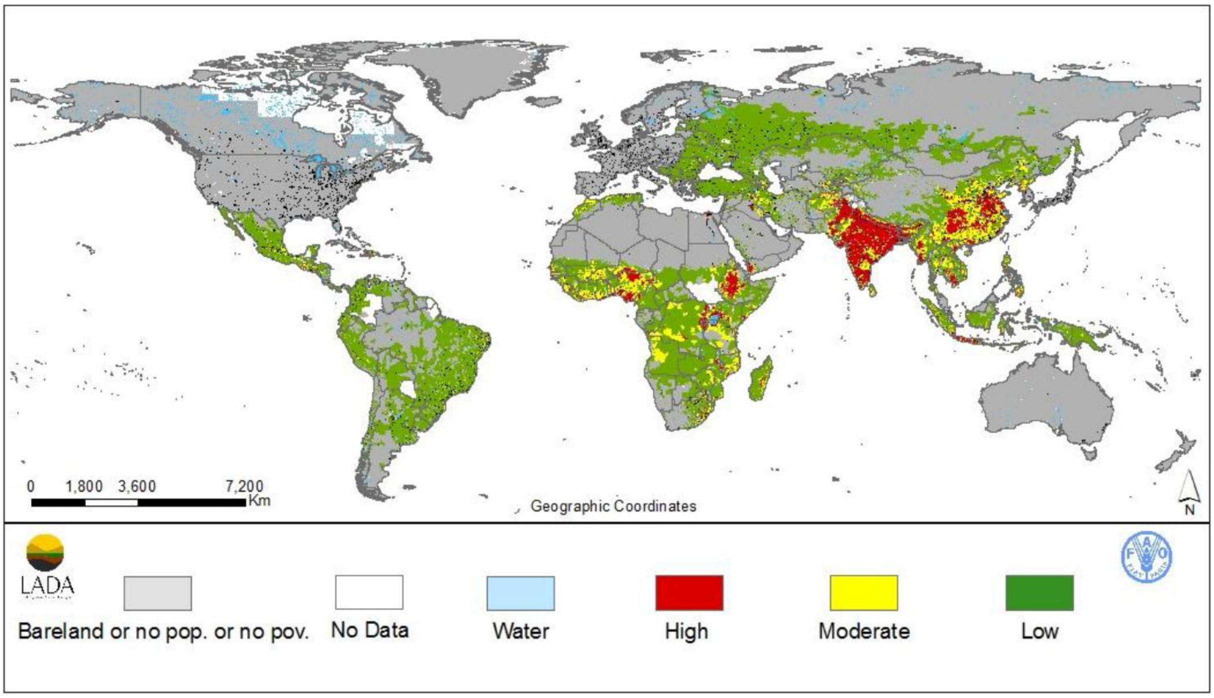


Figure 10: Global map of GLADIS land degradation impact index; source: Nachtergaele et al. (2011b).



The output for status of soil health will be different from trend in biomass production, and this again will differ from impact of land degradation. Emphasizing a close link between land degradation and poverty is one of GLADIS' strengths; combining biophysical as well as socioeconomic determinants offers a broad but not exact view of global hot spots of land degradation (Ngonya et al. 2011).

Like its predecessors, GLADIS faces multiple challenges concerning data quantity and quality. Like in GLASOD a conceptual weakness is the focus on managed land. Soils are not considered degraded when under natural vegetation, but only when used for cropped agriculture or in case of livestock with the potential to reduce the anticipated soil-based goods and services. Further, problem soils and natural soil degradation processes were not taken into account; in areas classified as 'wasteland', e.g., associated soils and their health status or trends were considered irrelevant. The biggest issue remains the general lack of global data with sufficient detail and resolution. The compilation of detailed maps often requires the consolidation and harmonisation of various data sources to finally generate a global product. In GLADIS, maps with resolutions ranging from 30 arc second to country-scale were harmonized to 5 arc minute (9 by 9 km at the Equator). Where certain information only existed on a country basis, this greatly limited the calculation of aggregated indices. Nkonya et al. (2011) criticized that the GLADIS approach of combining multiple indicators into maps lacks a more detailed description of why and how the selected indicators affect land degradation, and of how the generated maps can be interpreted. For example, what are the baselines used, how should categories such as "poor" or "good" soil health be read, etc.

Being aware of these challenges the authors themselves concede that GLADIS results provide a first indication of possible pressures and trends (Nachtergaele et al. 2011b). Being a 'top-down' desktop-study only, the findings would need to be supplemented by some sort of groundtruthing, especially in view of the biophysical land degradation status and process.

2.5 Overview of past global land degradation assessments

The following table provides a synoptic overview of the main global assessments conducted on the topic of land and soil degradation as portrayed in the sections above. Please note that direct comparison of global assessments is restricted due to different subjects assessed, and various methodologies applied. Section 3.2 will be looking into this aspect in more detail.

Table 3: Main characteristics of global assessments on land and soil degradation

Name of assessment	Global Assessment of Human-Induced Soil Degradation (GLASOD)	Millennium Ecosystem Assessment (MA)	Global Assessment of Land Degradation and Improvement (GLADA)	Global Land Degradation Information System (GLADIS)
Duration	1987-1990	2001-2005	2006-2009	2009-2011
Budget (mio. USD)	0.3	approx. 17	0.6	?
Lead organisation	ISRIC-World Soil Information	Collaborative (UNEP coordinated)	ISRIC-World Soil Information	FAO
Methodologies applied	Expert opinion	Desktop study (review)	Remote sensing	Desktop study (GIS, indices)
Main land degradation estimate	~15% of global terrestrial surface affected by soil degradation	10–20% of drylands affected by desertification	24% of the world's land area undergoing degradation in 1981-2003	9% of terrestrial surface area is scoring very low in terms of biophysical status, 31% low, 21% moderate, and 19% high
Website	http://www.isric.org	www.millennium assessment.org/	http://www.isric.org	http://www.fao.org

2.6 Upcoming analyses and assessments of global land degradation

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has proposed to conduct a global thematic assessment on land degradation and restoration[10]. The objective is to assess methodologies for assessing and categorizing land degradation; the global status of, trends in and drivers of land degradation, by region and land cover type, taking account of various knowledge and value systems; the effect of land degradation on biodiversity values, ecosystem services and human well-being; and the state of knowledge of measures to mitigate degradation and restore or recover biodiversity and ecosystem services, by region and land cover type. It is currently in the scoping phase and scheduled to be available by 2017[11].

Besides this intergovernmental effort, there is a number of publications coming up that will contain new or updated information on global levels of land and soil degradation. This includes:

- Third edition of the World Atlas of Desertification (WAD) which is being compiled by the Joint Research Centre (JRC) of the European Commission, in partnership with the United Nations Environment Programme (UNEP); focus will be on changes in land system productive capacity ('99-'13) as evidenced from remotely sensed greenness (NDVI) data; it is also intended to link results to the concept of ecosystem services; tentative date of issue is in 2016.
- GSP Status of the World Soil Resources report; as one of the outputs of the Global Soil Partnership (GSP), this report will show the state of global soil resources set within a framework of ecosystem services, assesses the threats to soil functions and their consequences for these services, and include a series of recommendations for action by policy-makers and other stakeholders; the first edition will be launched on 5 December 2015, with updates scheduled in 5-year intervals (FAO 2014).
- UNCCD Global Land Outlook (GLO) report; this is currently in the concept phase, and details of potential scope and contents of this work are not available at this moment in time.

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[10] http://www.ipbes.net/work-programme/objective-3/45-work-programme/459-deliverable-3bi.html [Accessed: 12.02.2015]

[11] http://www.ipbes.net/images/documents/plenary/third/working/3_7/IPBES_3_7_EN.pdf [Accessed: 12.02.2015]

3 Synopsis of approaches to map land degradation at global level

3.1 Characteristics of the main approaches in mapping global land degradation

3.1.1 Expert-based assessments

When the idea of a global-scale assessment of land degradation was born during the second half of the 20th century, the most straight-forward approach involved the compilation of national datasets, and the consultation of experts. National data as an information source can be tricky in a global context, mainly because they do not exist equally everywhere, and are not necessarily comparable where they do exist. This is because sampling, handling, analysis and interpretation may be biased.

Degradation assessments relying on the perception of experts are potentially subjective, and therefore also termed "qualitative" assessments. They are having a number of advantages over purely quantitative, data-driven assessments (van Lynden et al. 2004, Caspari et al. 2014):

- They allow to assess all aspects of degradation – causes, types, degrees and extents – at multiple scales, with (theoretically) no restriction to resolution;
- They represent "accumulated" knowledge of an expert that ideally reaches over several decades, rather than just a snapshot in time; qualitative indicators that an expert may choose provide richness and intuitive understanding that numerical data cannot convey;
- They can provide a relatively quick overview for national and regional planning;
- They enable identification of hot spots and bright spots (problem areas and examples of effective responses) for further study;
- They constitute a good tool for awareness raising;
- Their data requirements are limited: adequate expert knowledge, though preferably supported by hard data, is sufficient.

The biggest challenge with qualitative assessments is their potentially subjective character. Against this it can be argued that by its very nature, degradation assessment is qualitative, since the term "degradation" implies a loss of value. In this sense, the assessment of degradation is a value judgement. Perception of that value is also depending on the user of the land: the land qualities important for a farmer are very different from those of importance for a construction engineer (van Lynden et al. 2004). Further disadvantages of qualitative assessments are:

- Method for collecting and harmonising expert opinion is laborious and time-consuming, thus expensive;
- A general lack of hard supporting data;
- Expert knowledge and associated existing data may not always be up to date;
- Expert judgement cannot be tested for consistency;
- Findings cannot be reproduced for unvisited sites, so that temporal or spatial comparisons are more difficult.

Sonneveld & Dent (2009) tested the consistency and reproducibility of the GLASOD expert judgements in an effort to evaluate the qualitative findings with the help of new GIS data to delineate and define the characteristics of GLASOD map units. Although acknowledging what has been achieved on a global level in short time, they concluded that the expert assessments were not very reliable. Experts were found to be only moderately consistent in assigning soil degradation classes to similar sites and the authors speculated that the different conceptualization of the degrees of degradation among experts might be one of the main reasons for this. They also delineated improvements for future expert-based GLASOD-style assessments:

- Reduce subjective interpretations: give a quantitative interpretation to the qualitative assessments by relating their ordered classes to a quantitative measure of land degradation;
- Make qualitative assessments more consistent and more operational by discussing them in plenary sessions with the experts involved;
- Establish a common procedure for establishing physiographic mapping units by using a detailed global digital elevation model (in GLASOD, the experts were given a free hand with this)
- Reduce the impact of outliers generated by “special sites” unknown to the entire group by including specific factors that account for those particular locations.

3.1.2 Remote-sensing based assessments

Environmental monitoring has since the turn of the millennium been increasingly relying on remote sensing, i.e. the use of aerial sensor technologies to detect and classify objects on Earth by means of propagated signals from aircrafts and satellites. The main incentives for their use in land evaluation are:

- Relatively cheap and rapid method of acquiring up-to-date information over a large geographical area in a homogeneous way;
- It is the only practical way to obtain data from inaccessible regions, e.g. Antarctica, Amazonia;
- At small scales, regional phenomena which are invisible from the ground are clearly visible, e.g. faults and other geological structures. A classic example of seeing the forest instead of the trees;
- Cheap and rapid method of constructing base maps in the absence of detailed land surveys.
- Easy to manipulate with a PC, and combine with other geographic layers in a GIS.

However, they also come with a range of challenges:

- They are not direct samples of the phenomenon, so must be calibrated against reality. This calibration is never exact, a classification error of 10% is excellent;
- They must be corrected geometrically and georeferenced in order to be useful as maps, not only as pictures;
- Distinct phenomena can be confused if they look the same to the sensor, leading to classification error;
- Phenomena which were not meant to be measured can interfere with the image and must be accounted for. Examples for land cover classification: atmospheric water vapour, sun vs. shadow etc.
- Resolution of satellite imagery must be high enough for detailed mapping (e.g. tunnel erosion features) and for distinguishing small contrasting areas. Rule of thumb: a land use must occupy at least 16 pixels (picture elements, cells) to be reliably identified by automatic methods. The higher the resolution, the larger the resulting data sets.

It also has to be noted that a remote sensing measurement – just as the one-off analysis of a soil parameter – just represents a “snapshot” in time in the assessment of an ecosystem. Furthermore, although remote sensing has advanced knowledge of land cover and land use, reliable information on changes is limited as data from different points in time are often not comparable because of changing sensor technology, insufficient ground truthing and a lack of agreement on ecosystem delineations.

In the context of using remotely sensed Normalized Difference Vegetation Index (NDVI) data, e.g., von Braun & Gerber (2012) noted that although the NDVI and related indicators currently provide the only empirical tools for global assessments of land and soil degradation, they have clear shortcomings: In particular, their ground-truthing revealed many (and large) errors, their relationship with actual land and soil degradation was still debated (e.g. Vlek et al. 2010), and their application and treatment in parallel with socio-economic indicators and models hampered by a lack of compatibility in data format and nature. Further, a comprehensive methodology to overcome these issues, such as that outlined in Nkonya et al. (2011), has not yet been applied.

3.1.3 Modelling approaches

The modelling of land degradation is a means of combining field measurements with remote sensing information. It can expand local observations in the spatial as well as the temporal domain. In the spatial domain it helps to predict soil/land or degradation information from measurement locations to those areas that could not be assessed, thus allowing for areal information, and mapping. In the temporal domain, modelling can help to project present data into the future and thus elucidate trends or develop risk scenarios.

Various forms of soil degradation have been modelled at larger scales in the past, although efforts were mostly restricted to cropland, and to soil erosion. Well-known examples include the USLE/RUSLE models, the CORINE methodology, the PESERA soil erosion risk model, or the Water Erosion Prediction Project Model (WEPP). The Netherlands Environmental Assessment Agency (PBL), in cooperation with an international consortium of institutes, is currently looking into including global soil degradation and restoration information into their model train consisting of IMAGE-LPJ, PCR-GLOB WB and GLOBIO models. A comparison of soil properties (topsoil depth, soil depth, soil organic carbon, sand/clay fraction, vegetation cover, water holding capacity/soil moisture) between natural/undisturbed and current state will be used to assess functional change in terms of ecosystem functions such as carbon storage & sequestration, water availability, (protection against) floods & droughts, net primary productivity of biomass, potential suitable area for food production, potential suitable forestry area & fiber production, mitigating climate change, and biodiversity (Stoorvogel 2014). First results of model runs are expected for 2015. For each of the soil properties and ecosystem functions individual maps will be constructed for the undisturbed and current state as well as for different (prevention & restoration) projections in the future up to 2050. The study concerns all terrestrial ecosystems, natural and cultivated. They decided to abandon the term ‘degradation’ for its subjective and badly defined character. Instead they express the outcomes in terms of individual soil property and function change, or function trade-offs, compared to the undisturbed state or targeted state. These metrics can be more easily defined and quantified. So instead of one single ‘degradation’ map, the result will be a set of maps of function and soil property maps.

Otherwise, possibilities have been and still are rather restricted at the global level. Sonneveld & Merbis (2013) attribute this to the following reasons:

- Data paucity of the landscape characteristics constitute a serious problem in land degradation assessment procedures.
- Understanding of the land degradation processes is insufficient to formulate theoretically founded laws that can be used to construct a conceptual model (Nearing & Hairsine 2011).
- The modular approach to calibrate parts of the process in laboratories and in small scale field experiments lacks the overall structure that is needed to build an integrated model that could be upscaled to larger areas. Hence, incorporating data at an ever increasing level of detail in models that were conceptually incorrect cannot lead to a better prediction at larger scales. The use of statistical models to a certain extent overcomes the conceptual problem as the model designers basically concentrate on predicting correct outcomes of the land degradation process and are less concerned about accommodating process knowledge that could be used to explain and arrest land degradation. Yet, these

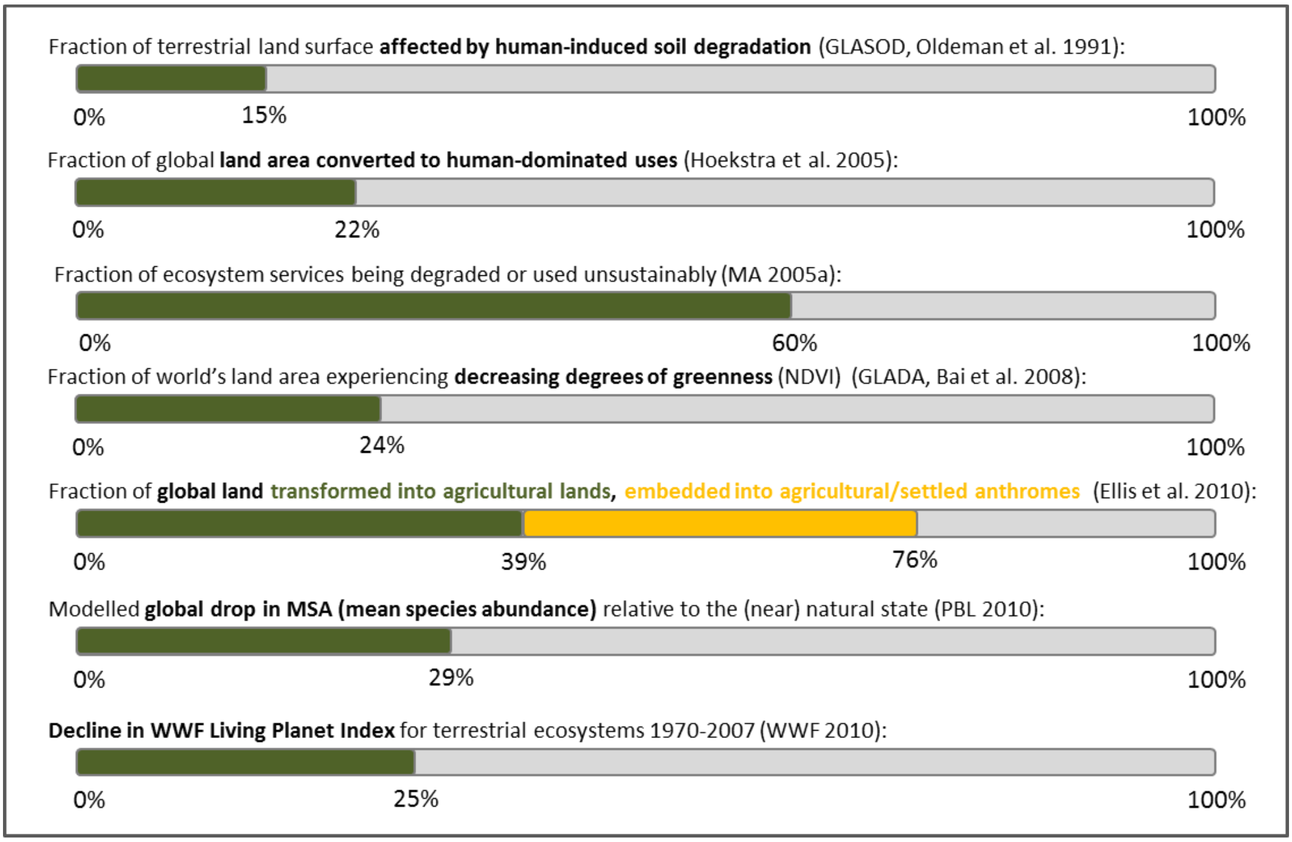
statistical approaches are limited to their calibration domain and cannot be used at other places and, therefore, also disqualify for assessments over larger scales.

As there is currently no single approach available to assess and monitor global land and soil degradation, a combination of approaches is required to tackle the challenge. This is inherent to the multi-dimensional, multi-scale, transitional, multi-perspective, and multi-actor nature of land degradation, and is not likely to change in the foreseeable future. The opposition between expert-based and remotely sensed data is not that strong anyway when considering that local expert knowledge can serve as input for modelling and upscaling using remotely sensed information, and that interpretation of remote sensing data is also driven by experts' choice on methodology and data processing procedures. Rather than creating artificial conflicts between the two ways of collecting and assessing data, the aim should be to use the best data and the best opinion available for the global assessment of ecosystem state and degradation. The real challenge therefore is to find reproducible, globally applicable ways in which the various scales can be bridged, applying all of the above methodologies.

3.2 The evolving concept of land degradation

The previous chapter has shown how in the past 40 years not one but many answers have been provided to the one big question of how much land is degraded globally. And not all the answers have been the same or even similar (Figure 11). Even where the order of magnitude appeared to be similar, the actual distribution and severity of land degradation did rarely matched. Most frustratingly, remote-sensing based assessment do not align with those based on expert judgement. Sonneveld & Merbis (2013) e.g. tested GLADA against LADA and reported that expert assessments are seen to diverge widely from the NDVI-based findings. Kong et al. (2015) compared performance of local ecological knowledge and various satellite imagery based vegetation indices to assess rangeland conditions; they found that remotely sensed data correlated poorly to the field-measured vegetation cover because of the excess spectral noise from the high iron oxide content in the soil.

Figure 11: Synoptic view of outcomes of global land degradation assessments; results are normalised to 100% terrestrial surface area; source: Caspari et al. (2014).



From the above, it would be a simple but unnecessarily fatalistic conclusion that we cannot say anything definite about the extent of global land degradation. It is true that results of global assessments are rarely compatible, and that no reliable, up-to-date estimate is currently available. But it is also true that "mapping land degradation on a global level has definitely made advances" (Nkonya et al. 2011) and that "much of the confusion surrounding the spatial extent of desertification would be reduced if estimates were interpreted according to the conceptual and methodological framework under which they were produced" (Verón et al. 2006). Developing an understanding of the evolving concept of land degradation and its various "dimensions" helps to put data into context and forms the basis for their comparison across various assessments. Taking time to reflect upon both what we have available and what we want in the future may help avoid blindly jumping onto the next effort considered the silver bullet in global land degradation assessment.

It must be acknowledged that we are talking about nothing less than a world-wide task. Whatever is going to be assessed, it has to be done in an agreed and harmonised way across the great diversity of cultures and ecosystems of our planet. And as drivers for land degradation such as e.g. climate change do not respect borders, it has to go beyond those areas where most people live and farm to record and monitor the state and trend of marginal land or natural areas and formerly degraded and abandoned areas, too. We have to keep in mind that by far not all soils are fertile or arable by nature; Lal (1997) described the land resources of the world as finite, fragile, and non-renewable and reported that only about 22% of the total area of the globe is suitable for cultivation and only 3% of the total area has a high agricultural production capacity. Any truly global land degradation framework will have to address the problem of how to valuate "problem soils" where soil characteristics themselves pose problems for their optimal use.

Land degradation processes are highly dependent on a complex interaction between biophysical factors and land use systems, both of which very in space and time (Sonneveld & Merbis 2013). This requires that anthropogenic as well as natural drivers have to be taken into account, and it would not be sufficient in most cases to "just" look at soil characteristics. It also means that land degradation describes both a state and a process. A one-off-assessment like e.g. GLASOD would have to be repeated at regular intervals to guarantee that trends can correctly be captured.

One major reason why this has not been consequently happening is that – besides technological process – the concept of "land degradation" itself has been (and keeps on) changing over time. It has moved from an initial emphasis on productive capacity of soils to the holistic concept of goods and services provided by ecosystems (Nachtergaele et al. 2014). Where a definition explicitly refers to beneficiaries of goods and services, this adds another layer of complexity as the view of beneficiaries may change over time and not all beneficiaries may have the same evaluation of the value of a particular good or service (Nachtergaele et al. 2011a). A recent definition of the term "land degradation" e.g. is: "Land degradation is defined for the purposes of the present note as a long-term decline in biodiversity or ecosystem function or loss of ecosystem services from which land cannot recover unaided" (IPBES 2014).

Irrespective of more comprehensive definitions, some groups are maintaining the productive capacity definition, either in order to guarantee comparability of results (such as current efforts for the 3rd edition of the World Atlas of Desertification[12]) or because it allows for indicators to be defined more easily (such as current efforts towards a post-2015 development agenda). Today more than ever, "land degradation" remains a blurred entity: it is multi-dimensional, multi-scale, transitional, multi-perspective, multi-actor, and above all value-laden. A growing number of people appear to be uncomfortable with the term altogether. Some groups even argue that because of the inherent negative connotation of the term 'degradation' it should not be used any longer, and rather be substituted with the concept of 'functional trade-offs', i.e. losses in functions would be viewed as trade-offs for economic benefits for instance (ten Brink, PBL, pers. comm.).

A global authoritative effort to define the various dimensions of ecosystem degradation, thereby clearly defining the terms used and standardising efforts to quantify it, is still badly needed as a basis for internationally consistent approaches. The establishment of an Intergovernmental Platform for Land and Soil could be a great step forward in the right direction (Hurni et al. 2006, UNCCD 2012).

The outcome of the framework and definition discussion will decisively influence the methodological and technical considerations involved, e.g. on

- the level of assessment: Status and/or trends can be assessed from the micro-scale of genetic diversity, over the meso-scale of species or soil health based indicators, to changes in the provision of ecosystem services at landscape or ecosystem scale.
- the reporting units ("cookie-cutting"): there are various ways that the world's land surface can be divided into a finite number of units and their delineation from each other. This can e.g. be based on political, climatological, biogeographical, or ecological considerations.
- the indicators and thresholds selected: which parameters and thresholds are selected for determining a degradation or improvement of the system in question?
- the baseline: is a baseline against which to measure land degradation required, and if so, what is the baseline taken? A baseline can be anything from a "garden of Eden" scenario (pre-human state of the earth), an arbitrary date chosen (such as e.g. the Living Planet Index starting from 1970), a well-defined and meaningful critical level (of e.g. stability or

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[12] WAD (JRC) definition: loss of biophysical/biological and economic productive capacity of the land (ES equilibrium) that is under use

water holding capacity), to the moment a certain dataset became available. Understanding the various existing baselines is a pre-requisite to comparing degradation figures from different studies.

- the overall assessment strategy: will top-down or bottom-up approaches be user, or both? To what extent will participatory approaches be used?

Existing global land degradation assessments provide an excellent basis for “lessons learnt” in how to best tackle this task. Nkonya et al. (2011) observed that “It seems that the clearer the definition of land degradation, the more precise the assessment and, hence, the mapping of this process.”

Based on the considerations above, the following chapter will highlight promising cornerstones of future land degradation assessments.

4 Exploring a set of promising elements of future land degradation assessments at global level

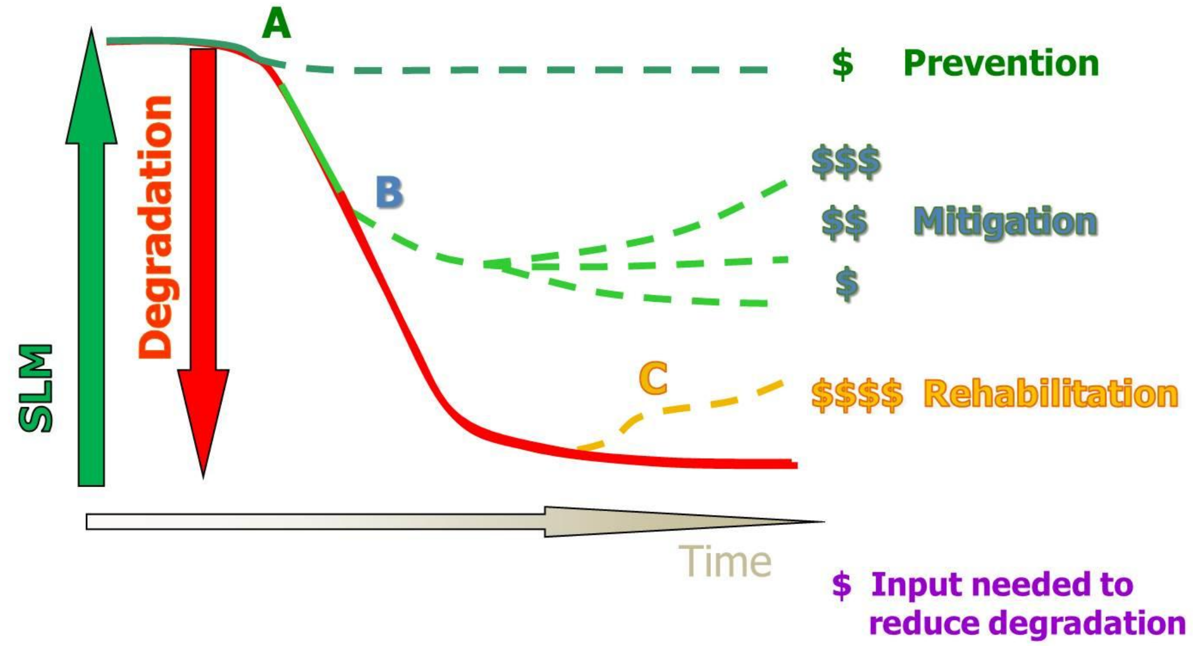
4.1 Making the case for global assessments of land and soil degradation

4.1.1 Global land and soil data as a prerequisite for informed decision-making

There is a widespread consensus that the pressing issues of land and soil degradation are not yet properly and adequately addressed in today's political agenda at global, national and regional level. Why is that? It cannot lie in the fact that soils are irrelevant. At Rio+20, world leaders once more acknowledged that natural capital, in particular land resources are the foundation of our society and economy. And it is generally accepted that major global challenges such as land degradation, global food production, water quality and quantity, climate change or biodiversity decline are all connected to soil quality. Vice versa – and that is the positive side of the medal – they could all be addressed at the same time through proper soil management.

Mankind has to face the fact that development affects the environment, i.e. realise that intensified development tends to reduce the potential of the environment to support it. Although solutions to this dilemma can mostly be found at the local level, the wider consequences are of trans-boundary and trans-disciplinary nature and can often only be tackled at regional or even global level (Safriel 2007). Accepting these environment-development linkages also means that considerable time, effort and money have to be continuously invested into a) exploring and understanding the "land degradation system" to be better able to model it, and b) assessing and monitoring the impact of land and soil degradation at the global scale, and c) concrete action to prevent and mitigate worst affected areas.

Figure 12: The costs of inaction, or: Prevention, mitigation and rehabilitation costs over time; source: Schwilch et al. (2009).



This document argues that because of the trans-boundary and trans-disciplinary nature of the issue there has to be a global dimension to its assessment and monitoring. The absence of one single methodology suited to assess land and soil degradation across the various scales is no excuse to be idle. Increased efforts will have to be made to improve assessment methodologies at all levels, and to better connect these levels with each other. Alternatively, a tiered approach could be used in which framework, methodologies and indicators are chosen separately at each level. A three-tier approach, e.g., could operate at three levels:

- Tier 1: Global level; based on land productivity adjusted for land cover and further stratified by land use; remote sensing based;
- Tier 2: Regional level; based on
  - biodiversity and ecosystem services; data collection and expert opinion as prescribed in the FAO/LADA/WOCAT framework; and
  - socio-economic conditions; based on land tenure security, land conflict, and administrative services;
- Tier 3: Local level; based on field validation, stakeholder evaluation, and crowdsourcing; participatory approaches linked to GIS and land quality index systems.

Because of the challenges with remote-sensing technologies (see section 3.1.2), this can only constitute a temporary “work-around”, though. The costs of inaction are huge, and growing (Figure 12). Connecting harmonised land and soil data to economic analyses would enable economic evaluation at the national or macro level. This could help capture ecosystems’ changing capacities to provide goods and services to people, and contribute to a more systematic analysis of the costs and benefits of changes in land-use practices. Economic valuation and associated knowledge management systems are considered a powerful tool in the design of efficient instruments or policies to foster SLM (UNCCD 2013).

4.1.2 Land degradation assessments in view of the post-2015 development agenda

The concept of land degradation neutrality (LDN) was born out of the United Nations Conference on Sustainable Development (Rio+20) where Member States recognized the need for urgent action to reverse land degradation. LDN proposes a scheme under which the extent of global degraded lands will decrease or at least, remain stable. To enable this type of scenario, the rate of global land degradation should not exceed that of land restoration (Figure 13) (Stavi & Lal 2015).

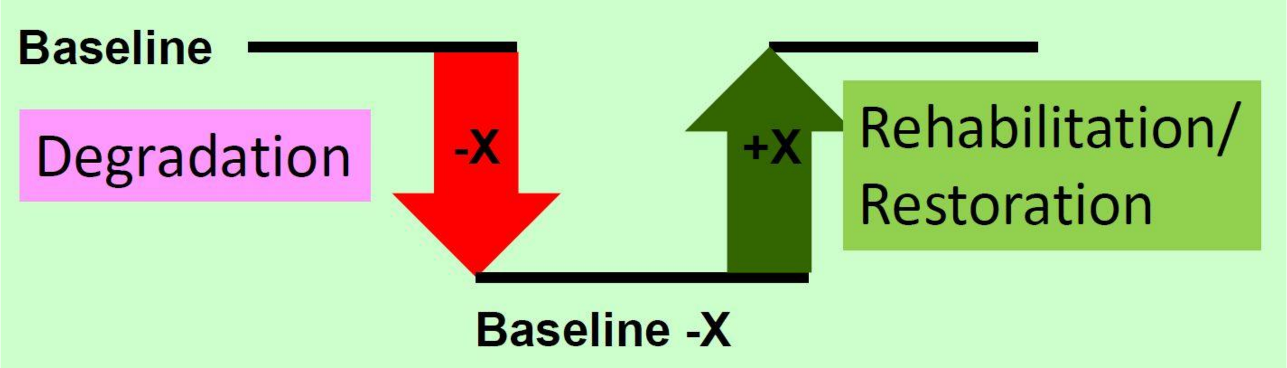
UNCCD has been instrumental in promoting the vision of LDN, and carrying it into the Sustainable Development Goal (SDG) process. In the latest Open Working Group document, the proposed target 15.3 reads as: “By 2020, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation-neutral world.” (OWG 2014). This target is likely going to be reformulated with the target set to 2030 (Sasha Alexander, UNCCD, pers. comm.).

To achieve a land degradation neutral world in 10 or even 5 years from now is an extremely ambitious goal. In their extensive study on the legal and scientific integrity in advancing LDN, Welton et al. (2014) highlighted three key issues that emerge for further consideration:

- How to define and measure land degradation (as well as the success of solutions applied) in scientifically and legally meaningful ways;
- How to successfully pursue "neutrality" as an organizing principle; and
- How to balance local and global, and public and private, in the administration of such a program.

They concluded that past experience does not allow for enthusiastic endorsement of “neutrality”-framed land management programs, and that the best hopes for success will lie in “early, honest conversations that achieve reasonable clarity in program aims, coupled with metrics that accurately capture these aims and a willingness to allow pluralistic experimentation during early stages of implementation.”

Figure 13: Sketch depicting the concept of Land Degradation Neutrality (LDN); strategies to reach LDN are minimising land degradation on the one hand, and offsetting unavoidable land degradation by restoration and rehabilitation efforts on the other hand; source: Ehlers (2014).



Stavi & Lal (2015) confirmed that some challenges related to the mode of data monitoring and management currently remain unresolved; among others how to monitor the dynamic process of land degradation, or how to quantify cost, benefits and impacts of SLM on food security, water availability, and climate change mitigation. Specific attention is currently being given by collaborative efforts such as the Global Land Indicators Initiative (GLII) to identify a set of indicators to be measured under the LDN effort. Although there are hundreds of SLM-related indicators potentially available, the challenge is to identify a restricted set that is generically applicable, gets universally accepted, indicates the essence of degradation processes, is sensitive enough, relevant to policy, easy to understand, draws on existing data and is cost-effective to monitor, can be easily modelled (cause – effect relationships), and is linked to human interventions (to assess the share of causal factors and be able to make projections in the future incl. ex-ante policy assessments).

On the positive side, the LDN concept has triggered a rich, vibrant discourse and provoked refreshing discussions, and keeps on doing so. This is expected to capture the attention of stakeholders at various levels, and breathe new life into land degradation theory and practice (Chasek et al. 2015).

4.2 Corner stones of promising land degradation assessments

There is hope that the LDN mechanism can produce a comprehensive and dynamic report on the state of the world's lands in order to overcome existing gaps in scientific knowledge and to provide policy makers, land managers, and other stakeholders with better information and scientific advice for land management (Stavi & Lal 2015). An appropriate assessment of degradation would be crucial for choosing an application suitable for restoration efforts (Eswaran et al. 2001). As a basis it would require a worldwide, state-of-the-art assessment that captures the state and trends of soil/land/ecosystem development. In fact, assessing the status and trends of soil degradation at the global scale is number 1 item on the World Soils Agenda (IUSS 2002). In this effort, uniform criteria and standard methodology to assess land degradation are of high importance (Stavi & Lal 2015).

But is this ambition realistic, given the manifold challenges outlined in section 3.2, and the fact that formal support for such a product appears to be inversely proportional to overall funding (Engel-di Mauro 2014)? From the above it is obvious that this document cannot aspire to answer all open questions, and that its primary role must be restricted to pointing out corner points or key elements that would constitute a promising future assessment.

4.2.1 Getting the framework right

An important lesson learnt is that any global LD assessment must be based on a good theoretical framework including clear scope and definitions before being implemented. This will avoid falling back into discussions on single elements (definitions, indicators, etc.) during the process. This framework is something that would have to be agreed upon internationally, e.g. through facilitation by organisations such as UNCCD, FAO, UNEP, or WOCAT International. Also, the Global Soil Partnership (GSP) could have a role here.

In view of achieving a land degradation neutral world and considering managed land any assessment would need to answer the question if the business as usual is sustainable, i.e. it must be capable to distinguish ecologically sustainable from destructive forms of land use. The aim would be to know if a system is functional or dysfunctional (John D. Liu, CommonLand, pers. comm.). This approach respects the diversity at the local level, which is important as what counts as a functioning and productive ecosystem can vary, also according to social context. Where systems appear to be obviously degrading, it can be worthwhile to find models for transformational change. The WOCAT database[13], for instance, contains some 500 technologies (measures implemented in the field) and over 200 approaches (implementation strategies) from all over the world, including their evaluation against a comprehensive set of ecological, economic and socio-cultural criteria.

It has been suggested that without a specific reference to a social context it should not be possible to assess if a soil is getting degraded or not because this depends on what a soil is deemed useful for, and by whom, who is affected by changes in soil and how. Soil evaluation is done by people, who have ideas about how soils ought to be used, for what ends. These ideas come from interactions in society, not just from interactions with soils (Engel-Di Mauro 2014). In a framework like outlined above the term “degrading” might be substituted by “functional change”, and “degraded” could describe the end point where a soil cannot fulfil most of its functions anymore, i.e. that physiological needs (of people, animals, etc.) and context-specific objectives (of various stakeholder groups) are being hampered by an undesirable change in local soil characteristics. The advantage of thinking in functions also is that they are well defined, measurable, and socioeconomically relevant.

Especially in view of the concept of LDN there will also be a need to not only assess the negative side of the equation (i.e. what’s degrading) but the ecological restoration/land and soil conservation side, too. An innovative and at the same time extremely valuable element of future global assessments could be the documentation and maybe certification of SLM methodologies and approaches (e.g. through WOCAT International) that have proven beneficial effects in terms of the target indicators selected.

4.2.2 Methodology, or HOW to assess

High-resolution satellite data will remain an attractive way to get an overview of extent and severity of global land degradation. But it is also obvious from the many challenges with interpreting remote sensing imagery (see section 3.1.2) and using biomass production as a proxy of soil quality (see section 2.3.3) that is not suitable by itself to provide the kind of results that are needed. An increasing number of experts therefore lobbies for a bottom-up approach as the starting point. Nkonya et al. (2011), e.g., stress the need for a “global approach that uses standardized methods and a bottom-up technique that starts at the local level, enabling the adaptation of global analysis data to the local level”. Similarly, Nachtergaele et al. (2014) are of the opinion “that to build up a really consistent global assessment of land degradation the only sensible way is to adopt a more comprehensive, integrated and bottom-up approach, e.g. by accelerating and spreading the overall LADA national and local process to a global approach, while at the same time using the latest techniques for data collection, interpolation and interpretation”. Some countries, like China, do already have an elaborate

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[13] http://www.wocat.net

setup themselves, so the challenge will be more about how to integrate these national systems into a globally accepted approach.

A truly global assessment will require some sort of global partnership[14] that guides the collection of required data in a universally agreed, harmonised approach. To elucidate this point, it can be said that the need for "groundtruthing" at the local level inevitable results from:

- the general data paucity of the landscape characteristics; this still constitutes a serious problem in land degradation assessment procedures (Sonneveld & Merbis 2013);
- the fact that remote sensing data are often too coarse and involve a lot of decision-making that might produce "weird" results in the end;
- our insufficient understanding of the land degradation concept, which hampers the formulation of theoretically founded laws that could then be used to construct a conceptual model (Nearing & Hairsine 2011, Sonneveld & Merbis 2013); and
- the likeliness that local land users as the "officially unrecognised soil experts" (Engel-di Mauro 2014) know their land best, and are the ones most directly affected by land degradation.

Ensuring a good understanding of the study site context, including the land management history and current stakeholder priorities, would have to come first. This helps to set the system boundaries, and to define the current status of land degradation and future land degradation risk according to the specific local or regional setting. This analysis, at least to a certain extent, would have to extend to unmanaged land to include historical and current, desired as undesirable soil change in these areas, too.

Ultimately, the following four dimensions are required for a comprehensive assessment of degrading land (Yengoh et al. 2014):

1. Type of degradation - the nature of the process driving decline in land quality or productivity (e.g. drought, salinization, and wind or water erosion);

2. Degree of degradation - classified in degrees of severity (such as 'light', 'moderate', 'strong' and 'extreme');

3. Extent of degradation - the total area affected (as a percentage of the land unit affected); and

4. Causes of degradation - the direct and indirect drivers, mostly man-made (e.g. agricultural practices, overgrazing, deforestation, industrial activities, poverty, land tenure, policies).

Following up on the idea to also assess the effects of restoration at the same time, the equivalent of the above list would be to describe the causes, types, degrees and extents of land and soil improvement. This necessitates a thorough analysis of the SLM measures and approaches applied, and ideally their inclusion in a global database, such as the WOCAT International databases.

Expert observations and judgements should be supported by objective criteria that are measured in the field and can describe various land degradation indicators. An example would be the Land Degradation Surveillance Framework (LDSF) implemented under the Africa Soil Information Service[15]. Another promising, innovative way to collect large amounts of groundtruthing data could be through the use of mobile phones. There are already apps that enable a quick and cost-effective way to cap-

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[14] This could be a task tackled by the Global Soil Partnership (GSP), or the suggested Intergovernmental Panel/Platform on Land and Soil (see section 3.2).

[15] see http://www.africasoils.net/data/ldsf-description [Accessed: 12.02.2015]

ture soil carbon content, for example[16]. ISRIC-World Soil Information is currently working on an extension of the existing SoilInfo App[17] that would allow users to upload measurements of various soil parameters that have been done on the spot. Further, ISRIC as the ICSU-accredited World Data Centre for soils would be the ideal instance to collect, harmonise and store such locally generated information.

The inherent differences among soils, the complexity of environments within which soils exist, and the variety of management practices, complicate the establishment of a specific quality rating against which all soils can be compared. Therefore, an elaborate indexing procedure is needed to enable such comparisons among different soils (Karlen et al. 2003). Locally collected information on the state of land and soil could be aggregated by using land quality indices, such as e.g. the Muencheberg Soil Quality Rating (SQR, Mueller et al. 2007). The precondition is that they have a relationship with land degradation that has been proven across the climatic regimes and major cropping systems of the world.

To finally be able to bridge the gap to the global level, a larger research programme would urgently be needed that could work on matching high-resolution satellite data with well-described and standardised field point measurements, or small map units that are uniform for biophysical factors, land use and characteristics of the socio-economic environment (Sonneveld & Merbis 2013). This would target at making global products more appropriate and acceptable the national scale. The above authors point out that "the challenge is to design adequate statistical tools for a reliable interpolation of land degradation information that makes use of a data set of remotely sensed high resolution observations by means of available ground observations on actual degradation, while conditioning on available geographic information about say, relief, temperature, land use and type of land degradation."

4.2.3 Indicators, or WHAT to assess

A decisive part of methodological considerations is to agree on a set of indicators to be measured to be able to assess the state and trend of the system in question. The selection very much depends on how degradation or improvement have been defined in the first place. Engel-di Mauro (2014) accordingly phrases that "the eco-social context of soil scientists is as important as the soil quality indicators measures."

Given the complexity of the land degradation phenomenon, there is no single indicator that could assess the whole system. A balance will have to be struck between a situation where too many indicators make the assessment unmanageable and cost-prohibitive, and a situation where a too narrowly defined set does not allow for the detail of insight required. Another trade-off is where integrative parameters (e.g. secure tenure of land) could be helpful to cover various aspects at the same time, but might not be precise enough to make a statement on the actual state of land.

The Global Land Indicator Initiative (GLII), a collaborative effort of more than 30 organisations throughout the world founded in 2012, is currently developing a list of 8-10 land indicators that will complement the Post-2015 development agenda (UNHABITAT 2014). In a series of expert group meetings, 4 indicators have been selected as promising:

1. Percentage of women and men, communities and businesses that perceive their land resource and property rights are recognized and protected.

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[16] see http://www.hutton.ac.uk/news/new-soil-carbon-app-scottish-farmers [Accessed: 12.02.2015]

[17] http://soilinfo.isric.org/ [Accessed: 12.02.2015]

2. Percentage of women and men, indigenous people and local communities and businesses with legally recognized evidence of tenure.
3. Extent to which the national legal framework provides women and men equal rights to land resource and property.
4. Extent to which the national legal framework recognizes and protects legitimate land rights and uses derived through a plurality of tenure regimes.

Appropriate land tenure alone is an important precondition but no guarantee for sustainable soil management. An indicator system that lives up to the target of land degradation neutrality would also require some sort of biophysical component. Soil-based parameters are a straightforward choice in the indicator discussion. This is because soils are ubiquitous, their nature and properties (including vital management-related responses) are largely understood, soils tend not to move places (hopefully that is), and have dynamic properties who's change is measureable at reasonable intervals. As a "3D archive" soils represent the cumulative result of past management, and at the same time determine the options for future land use scenarios. Looking at the state of soil therefore is the ultimate 'reality check' to help analyse if an SLM technology or approach is sustainable or rather destructive.

Great care must be taken to ensure the selection of an indicator that is integrative, i.e. able to cover various vital processes at the same time. This will help to reduce the overall number of indicators required, which would be badly needed to keep associated costs low. The dynamics of soil organic carbon (SOC) content are a good example for such an indicator. Not only is it at the nexus of soil chemical, physical and biological processes; it is connected to aspects such as water holding capacity, floods and droughts, productivity, or soil stability and biodiversity. It is influenced by land management, and significant changes can be detected within a couple of years. The beauty of SOC also is that it relates to the CO_2 parameter of the climate change community. Whatever parameter is selected, it is of major importance to properly define it to make sure that is globally captured and interpreted in a similar way. In case of soil organic carbon, the sampling depth, the sampling method, the lab measurement method etc. would have to be recorded to allow for global harmonisation.

As mentioned above, there is not one indicator alone that could act as the ultimate proxy for land degradation or improvement. Therefore a combination of biophysical and socio-economic indicators to cover the land degradation is strongly recommended. Where e.g. remote sensing data suggest land productivity increases, this would have to be cross-checked for potentially undesirable land use/land cover changes and /or concomitant decreases in soil organic carbon contents. Finally, in line with the above suggestion to also consider assessment and monitoring of proven and already applied SLM technologies and approaches, a "systemic indicator" could be used, such as the degree of SLM application at the national level. The idea behind this is that it would measure the "real" implementation and encourage member states to adopt or adjust national policies towards a more sustainable use of land and soil resources.

4.2.4 Monitoring desired and undesirable soil change

It has been emphasised that under the LDN policy schemes, data collection should not be a one-off event but ongoing in order to enable a regular update regarding the status of land degradation at local, regional, and global levels (Stavi & Lal 2015). At this point in time there is no global database that supports this effort, and whereas spatial change in soil properties has been subject of numerous studies, the analysis of temporal dimension of soils and land has not gone beyond some local examples, such as the Rothamstead Broadbalk Long-Term Experiment (BBSRC 2012), or the Calhoun soil-ecosystem study (Richter & Markewitz 2007).

For the examination of trends in the health of soil or land systems, a baseline that all future assessments will refer to is required. The existing global assessments on land degradation as portrayed in section 2 vary greatly in terms of baseline used. Some do not provide baselines at all (e.g. all “one-off” expert-based ones such as GLASOD), others depend on the availability of datasets (e.g. the WWF Living Planet Index starting from 1970), and others imagine a garden of Eden scenario (e.g. the GPFLR 2011 study). If as part of the post-2015 development process a network for worldwide monitoring and global assessment of soil change finally becomes established, it will be straight-forward to take the first round of assessments as a baseline reference. In a next step, a more generic baseline such as natural state could be implemented. When it comes to the formulation of targets, timelines in the not so distant path may help people to better understand the drivers of change and formulate action plans accordingly (Nachtergaele et al 2011b).

4.2.5 Last but not least: What it will also take to be successful

The Rio+20 document “The Future We Want” highlights that member states “recognize the need for urgent action to reverse land degradation. In view of this, we will strive to achieve a land degradation neutral world in the context of sustainable development” (UN 2012). This once more puts the spotlight on the urgency of the land degradation issue. Land degradation neutrality (LDN) as promoted by UNCCD and partners has found entry to the Sustainable Development Goals (SDGs), and it is hoped that alongside with an agreed definition and indicator framework it will remain part of the framework of the post-2015 development agenda.

There is a great chance that this process will create the opportunity to establish new global datasets that are urgently needed. There is no way to currently foretell the shape this will take, but for sure a global land & soil assessment would be facilitated if the following conditions would be met more often:

- Awareness on soils and land: People living off the land tend to have a strong drive to protect and sustainably manage their land assets; efforts have to be increased to raise awareness of the vital functions of land and soil and the destructive consequences of the “cost of inaction” at the level of politicians and decision-makers. In view of the major global challenges such as food production for a growing population, land degradation, biodiversity and climate change all possible efforts have to be undertaken to press for paradigm shift in land stewardship from ‘degrade-abandon-migrate’ to ‘protect-sustain-restore’ (UNCCD 2014). The International Year of Soils 2015 can be an excellent end to this means, as is the message that if land degradation is addressed a lot of economic, environmental and socio-economic issues could be alleviated at the same time. Only if people know the value of something they will start appreciating and protecting it.
- Respect for complexity of the subject: the various existing assessments – and especially their incompatibility with each other – have proven that there is no simple solution to the issue. Working in multi-disciplinary teams will surely be helpful. “Simple” or one-sided frameworks and indicators should be avoided by all means. If necessary, a tiered approach can be used to address the different degrees of complexity and the various levels.
- Acceptance of ecosystem approach: where this is guaranteed, future global efforts will not fall back behind the MA or GLADIS approaches, i.e. will address (eco)systems as their reporting units and look at all relevant services that land and soil provide. This will e.g. be reflected by the choice of indicators: where the emphasis is solely on biomass production (rather than on quality, stability or composition as evaluation criteria) this comes at the expense of a more holistic set of evaluative criteria.
- Respect for cultural diversity: what is considered degraded or who is losing in a win-win situation are aspects that have more answers than could potentially be included in any conceptual framework. Any global assessment must be open to local interpretations of land and soil quality, and be allowed to define and use their own ranking system. If the

outcome is expected to be globally accepted in the end, there is no way around acceptance of local interpretations, and solutions.

- Science-policy interface and lobby for soils: An Intergovernmental Panel / Platform on Land and Soil should be established as a credible and transparent global authority on scientific and technical knowledge on land and soil, including land degradation and desertification. One of its first and foremost tasks would be to provide a globally accepted framework for land and soil assessment.
- Scientists in the role of knowledge-brokers: Rather than advocating technologies and approaches “top-down” style, scientists should accept the challenge to play an intermediate role as knowledge-brokers, e.g. providing input into participatory, bottom-up processes when- and wherever needed.
- Adequate funding: Since the completion of GLASOD in 1990 no harmonised, bottom-up assessment of global land degradation has been conducted. This is in appalling contrast to the necessity of an up-to-date, groundtruthed data set on the state and trend of the world’s soils. On the positive side, new remote-sensing data become increasingly available to tackle the task, and mobile phone-based crowdsourcing of soil data may be a promising way to generate global datasets the cheap(er) way.

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