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# Desertification: Mapping Constraints and Challenges

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**Abstract**

Mapping desertification has proven to be a challenging task. Difficulties derive from its ambiguous definition and the comprehensive integration of various biophysical and socioeconomic indicators that need to be considered in the evaluation process. In the early 1990s, assessments and mapping were based primarily on expert opinions that introduced uncertainties and obvious shortcomings. Later on, with the development of the remote sensing technology and the advancement of the geographic information systems, global mapping became commonplace. Results showed that temporal and spatial scales are crucial components of the mapping and assessment process, but great difficulties arose comparing maps that were developed using different methodologies. Global maps could depict only general trends in desertification caused by human-induced land use changes or climatic variations but proved to be of limited value at local level. On the other side, local studies have problems of extrapolation. This necessitates the performance of mapping at various scales, but only after a methodological approach has been developed that accounts for all the components of the desertification process, allowing upscaling from global to local level and vice versa. Desertification mapping is under way by the World Atlas of Desertification (WAD) 3rd edition. The WAD places particular importance on case studies that document local realities affected by desertification as well as mitigation actions. Finally, concerned efforts must be made to develop and implement sustainable land use planning and land management techniques that arrest and reverse the negative consequences of desertification.



## INTRODUCTION

### What is Desertification?

Desertification is a term widely used by the scientific community and many other stakeholders associated to the United Nations Convention to Combat Desertification (UNCCD), but non-experts often confuse it with naturally occurring deserts.[1] It was first Lavauden[2] who used the term in Tunisia describing it as low rangeland productivity due to inadequate management. However, many researchers credit the French ecologist A. Aubréville[3] who in 1949 applied the term desertification not to drylands, but to the tropical forests of Africa that receive much more rainfall than what conforms the official UNCCD definition. Aubréville noted that the influence of human activities, i.e., cultivation, deforestation, and accelerated erosion, contributed to the process of transformation of tropical forests into savannas and finally into desert-like environments.

It took more than two decades after Aubréville's warnings of desertification before the topic reached the political agenda. This was largely influenced by the impact of extended drought and moving deserts in the West African Sahel in the early 1970s[4] that brought about the United Nations Conference on Desertification in Nairobi in 1977. Two decades later, the UNCCD entered into force reaffirming a previous United Nations Environment Programme's (UNEP)[5] definition of desertification with very slight modifications: *desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities* (UNCCD, Article 1). The UNCCD uses the aridity index, calculated as the ratio between mean annual precipitation to mean annual potential evapotranspiration, to identify the drylands of concern. These areas are characterized by large water deficits, because potential evapotranspiration is much greater than precipitation. The aridity indices in the range of 0.05–0.65 (excluding polar and subpolar regions) identify the arid, semiarid, and dry subhumid zones, likely to be affected by desertification.

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However, criticism has been raised, for instance, about the exclusion of hyperarid areas.[6] On the other hand, even Iceland[7] claims to have desertification problems! No matter the definition, the final outcome of this type of degradation has typically been considered to be either a reduction or a loss of both biological and economic productivity and of environmental quality derived by the complexity of interaction of various biophysical and socioeconomic factors.

The UNCCD definition of desertification has been widely debated over the years. This became even more critical after almost every country in the world signed the Convention, even those not located in the drylands. To overcome this situation and accommodate all the parties of the Convention, a new terminology was introduced by the UNCCD, namely desertification, land degradation, and drought (DLDD), reflecting the subjects the Convention wishes to be responsible for. For instance, Article 2 of Annex V of the UNCCD attempts to broaden the definition of desertification referring to specific conditions in Eastern Europe, mostly covering human-induced soil and land degradation, occurring under climatic regimes that fall outside arid, semiarid, and dry subhumid areas. Land resources in this context include soil, local water resources, and vegetation (or crops), and degradation is an ecological and economic reduction in resource potential, e.g., due to water erosion, wind erosion, a long-term reduction in the diversity of natural vegetation, and salinization and/or sodification. Therefore, in the broadest terms, desertification includes the degradation of land, soil, water, vegetation, and other resources.[8] No matter the definition debate, the main goal of the Convention remains the same, as defined by its Article 2 that emphasizes effective actions as all levels to combat desertification particularly in Africa.[9]

Desertification terminology was greatly enriched after the comprehensive analyses of dryland degradation made by Reynolds, Stafford Smith, et al.[10] and Reynolds, Bastin, et al.[11] and the appearance of dryland development paradigm (DDP) that shed new light on desertification and placed it into a new perspective. The DDP integrated biophysical and human-induced factors in a complex approach based on five principles used to assess the stability or disturbances and malfunctions of the dryland ecosystems. This is particularly relevant for these areas that despite being characterized generally by lower soil fertility and problematic climate (e.g., low rainfall and high evaporation rate) are home to more than one billion people who depend on them for their very survival.[12]

The terminology used to describe resource base degradation creates often confusion, especially for the decision-makers, since no clear indication is made about the differences between soil degradation, vegetation degradation, land degradation, and desertification. However, this last is seldom considered as the final product of degradation and *includes all* of the abovementioned forms despite being used mainly to characterize dryland degradation. Problems are further exacerbated when desertification, mostly a human-induced process, is combined with naturally occurring drought. They both globally cause great losses every year to agricultural production and contribute thus to food insecurity, famine, and poverty and can give rise to social, economic, and political tensions that can cause conflicts, forced migration, and further impoverishment of the local people. UNCCD[9] places special importance to resource base degradation in terms of physical, chemical, and biological deterioration of the land system and its implications to the well-being of affected desertification areas.

Long before, in 1979, United Nations Food and Agriculture Organization (FAO)[13] defined degradation as a process that lowers the current and/or future *capability of soils to produce* (quantitatively and/or qualitatively). Historically, this reflects the main school of thought at that time when *soil degradation* was seen purely as a process identified from the biophysical indicators; it was the domain of soil scientists, and few recognized that *land degradation comprises* many components of the land system, of which soil is only a part.

A further development in the terminology of resource base degradation came after the publication of the Millennium Ecosystem Assessment (MEA)[14] that defined land degradation as *the reduction in the capacity of the land to perform ecosystem goods, functions and services that support the society and development*. MEA deserves credit for the fundamental change in the philosophy of natural resources management that was based since then on ecosystem's functions and services and not on a single component of it, such as the soil.

The Land Degradation Assessment in Drylands (LADA) project funded by the Global Environment Facility, implemented by UNEP, and executed by the United Nations FAO made an important contribution to the study of land degradation in the drylands. LADA operated from 2006 until 2010, and its main objective was to *develop a set of tools and methods to assess and quantify the nature, extent, severity, and impacts of land degradation on dryland ecosystems at a range of spatial and temporal scales*. To achieve this, the project developed its own definition of land degradation that was inspired by the MEA but was slightly changed to reflect the temporal aspect of the process and draw attention to the fact that the value of goods and services are dependent on the stakeholders concerned, and it is therefore a subjective concept.[15] Full definition of land degradation according to LADA[16] is as follows: *The reduction in the capacity of the land to produce ecosystem goods and services and assure its functions over a period of time for its beneficiaries*. Further on, LADA performed also a Global Assessment of Land Degradation (GLADA)[17] and also developed an online Global Land Degradation Information System (GLADIS; http://www.fao.org/nr/lada/index.php?option=com_content&view=article&id=161&Itemid=113&lang=en) that is under improvement.[16] GLADIS based its assessment on the status and trends of biomass, soil health, water quality, biodiversity, economic benefit, and social/cultural benefits showing graphically the results in the so-called radar diagrams.

Following the above considerations, desertification includes all forms of resource base degradation deriving from human-induced activities and climatic adversaries and is expressed by the inefficiency of the dryland ecosystems to maintain economic and ecological functions and to provide goods and services.

## METHODS AND APPROACHES

### Is It Possible to Map Desertification?

#### Initial mapping efforts

The first assessment of the state of human-induced Global Assessment of Soil Degradation (GLASOD) was published in 1991.[18] It surprised both the scientific community and many top environmental decision-makers around the world by estimating that 17% of the 11.5 billion hectares of vegetated land on earth was degraded, largely by erosion, and that 1 in 6 hectares of this land could no longer be cultivated.[19] GLASOD has been debated over the years for its shortcoming, being based on expert opinion and on a mostly qualitative assessment. It produced disputable results and offered poor relationships between soil degradation assessment and policy development and implementation.[20] However, GLASOD deserves credit because it contributed greatly to raising the profile of soil degradation at the highest levels of decision-making and remains the only reference for soil degradation at a global scale. The GLASOD methodology was applied also regionally in Asia,[21] Russia,[22] and Central and Eastern Europe.[23] In 2003, Lal[24] modified GLASOD data and based on information from Oldeman[25] and FAO[26] estimated the extent of various types of soil degradation globally as well as their distribution on continental level (Table 1).

Attempts to map desertification have been made by various authors.[27–32] For instance, Eswaran et al.[33] developed Fig. 1 estimating the vulnerability to desertification based on a reclassification of global climate and soil maps at a 2-minute grid cell resolution. The same authors also correlated soil data with population density and identified that the Indian subcontinent was at a high risk of being affected by desertification[34] due to increased human pressure and unfavorable biophysical indicators that could worsen due to climate change.

#### The advent of remote sensing (RS) and geographical information systems (GIS)

After the GLASOD experience, all other global assessments of desertification have been mainly based on RS technology and GIS applications. GLADA integrated a range of indicators obtained from RS data with existing global data sets and models to identify degrading areas or regions where degradation may have been reversed. Otherwise, this methodology is known as “hot spot” and “bright spot”. The main indicators used in the assessments were net primary productivity (NPP), rainfall use efficiency (RUE), aridity index, rainfall variability, and erosion risk. Furthermore, these indicators were interpreted on the basis of the global land use systems (Fig. 2) and another series of specific indicators typical for a given area such as land cover, urban and protected areas, livestock pressure, irrigation, crops, temperature and thermal regime, rainfall regime, dominant soils and terrain slope, population density, and poverty level.

The remotely sensed normalized difference vegetation index (NDVI) is used as a proxy, and its deviation from the norm serves as an indicator of land degradation and improvement if other factors that may be responsible (climate, soil, terrain, and land use) are accounted for. Rainfall effects may be accounted for by RUE (i.e., NDVI per unit of rainfall) and residual trends of NDVI such as temperature effects by energy use efficiency (derived from annual accumulated temperature). Land degradation is indicated by a declining trend of climate-adjusted NPP and land improvement by an increasing trend. Translation of NDVI to NPP could enable the economic appraisal of land degradation,[14] and one of



**Table 1** Estimates of global extent of soil degradation by different processes.

| Region | Total land area (M ha) | Total degraded area (M ha) | Total degraded area (%) | Water erosion (M ha) | Wind erosion (M ha) | Physical degradation (M ha) | Chemical degradation (M ha) |
|---|---|---|---|---|---|---|---|
| Africa | 2,964 | 494 | 17 | 227 | 186 | 19 | 62 |
| Asia | 3,085 | 749 | 24 | 441 | 222 | 12 | 74 |
| South America | 1,753 | 243 | 14 | 123 | 42 | 8 | 70 |
| Central America | 108 | 63 | 58 | 46 | 5 | 5 | 7 |
| North America | 2,029 | 96 | 5 | 60 | 35 | 1 | — |
| Europe | 2,260 | 218 | 10 | 114 | 42 | 36 | 26 |
| Oceania | 849 | 102 | 12 | 83 | 16 | 2 | 1 |
| World | 13,048 | 1,965 | 15 | 1,094 | 548 | 83 | 240 |

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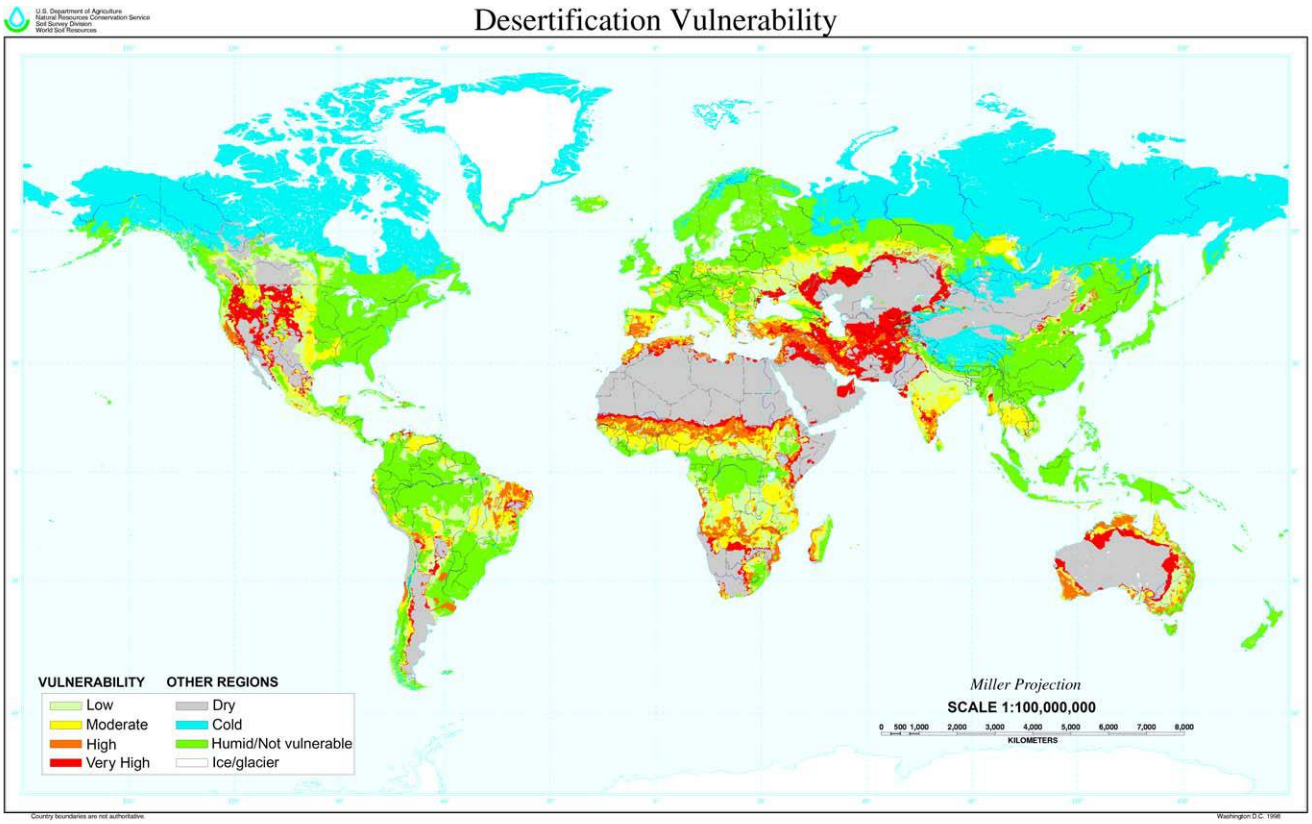


**Fig. 1** Desertification vulnerability based on soil and soil climate data.

such results is shown in Fig. 3. Based on this methodological approach and data provided for the period 1981–2006 deriving from the Global Inventory Modeling and Mapping Studies NDVI database, Bai et al.[35] reported that 23.54% of the earth is degraded and 1.5 billion people were affected over this period. As the focus in studies such as these and, e.g., GLASOD is different, it is very hard to spatially compare these to deduct what happened to land degradation at global scale within a given period.

Fig. 4 is a most challenging one produced by LADA. It describes the overall status in provision of biophysical ecosystem services and the processes of declining these services by considering the combined value of each biophysical axis (biomass, soil, water, and biodiversity). Data show that 32% of land globally is in areas with high provision of biophysical goods and services status, but with medium to strong degradation processes, while a large part of the global population (27%) lives in areas with a low status and a medium to strong degradation trend.[36]

## The new world atlas of desertification (WAD)

A new initiative to develop, publish, and establish an online digital new WAD[37] is coordinated by the European Commission (EC) and UNEP. The WAD endorses a new approach that relies on up-to-date information on the combined biophysical and socioeconomic situation in order to provide a convergence of evidence of potential on-going land degradation processes. Cause–effect analysis of possible land degradation sources also identifies trade-offs and hence offers routes for solutions, such as sustainable land management (SLM) options. WAD intends to be a global updatable reference on where land degradation processes are ongoing and what could be done to reverse these.

WAD is based on the scientific findings that suggest that the manifold reported causes of land degradation can be clustered into well-defined groups or main desertification issues[38,39] and that these interplay differently at various scales. Using the most up-to-date, and, at global scale, available information on these issues, e.g., on drought, human population changes, and inappropriate land use, it analyses the cause–effect relations with observed land system productivity dynamics as derived from satellite time series and regarding these as coupled processes. Consequently, areas where a single or multitude of land stress processes, such as an apparent reduced land system productivity, drought events, and agriculture intensification or expansion, are simultaneously ongoing are identified as areas probably prone to land degradation. In this way, trade-offs and solution pathways for land use and land use strategies can be better identified.

Addressing one of the major problems in mapping land degradation at various scales, this WAD concept is scale independent. WAD, starting at global level, illustrates how

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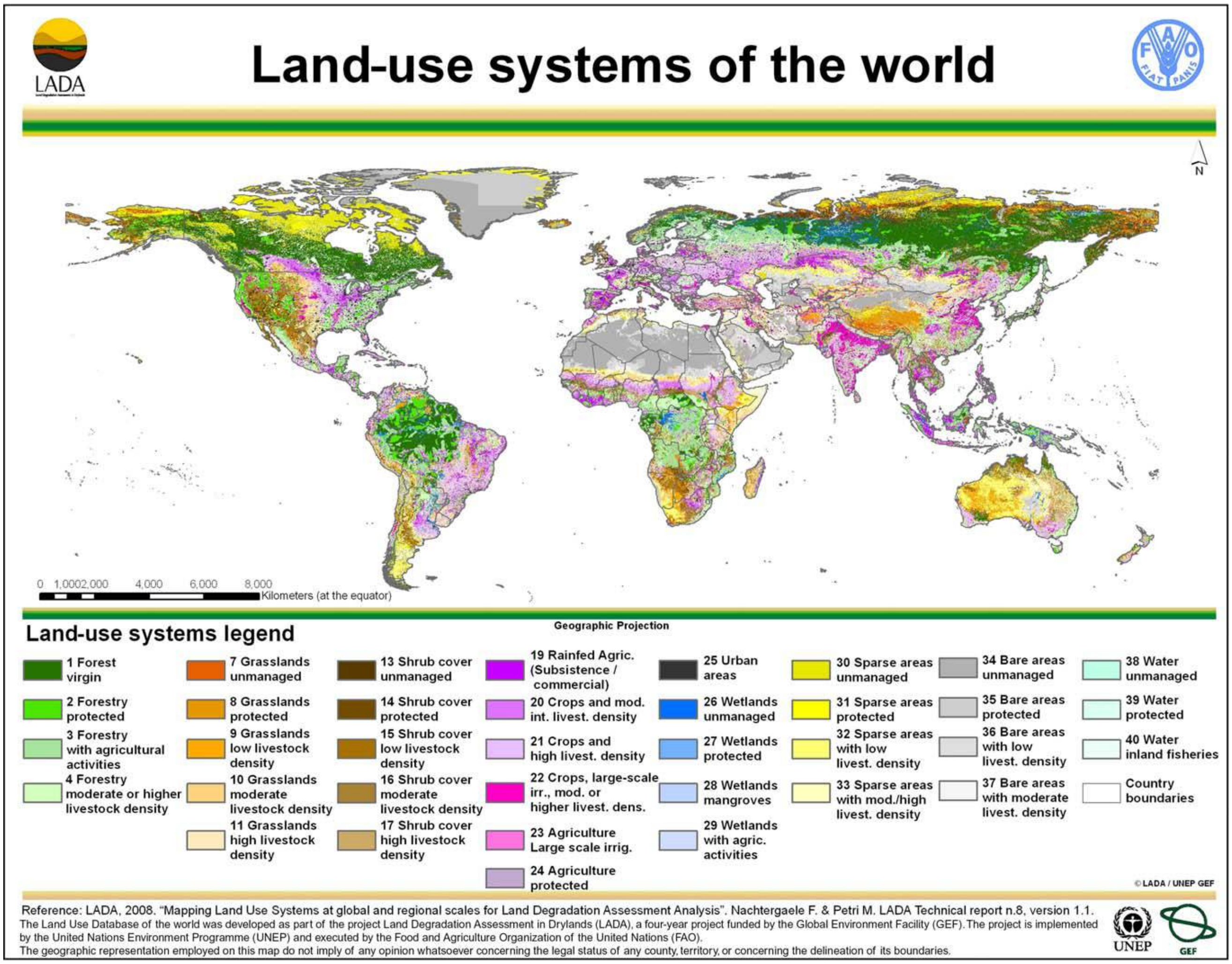


**Fig. 2** Land use systems of the world.

an assessment can be taken down to the local conditions by adding more detailed contextual information while keeping thematic compatibility at all scales. Spatially inventorying such knowledge offers a basis for designing and economically evaluating options to mitigate desertification, in particular through implementation of SLM practices. WAD therefore wants to promote a change from a negative focus on land degradation, e.g., mapping merely problems, to a more useful positive consideration in that areas are marked to a degree that improvements in land management are needed jointly with identification of the causes on which mitigation strategies need to concentrate.

The Joint Research Centre of the EC has developed the land system productivity dynamics data layer and a tool to compile this from RS time series. Figs. 5 and 6 represent an analysis of 15 years of SPOT VGT-based phenology and productive variables, for the period of 1999–2013 at 1-km resolution. It combines long-term undercurrents with performance of productive seasonal biomass developments of the land system. This is not a land degradation map in itself but an important layer for its evaluation.

## CONSTRAINTS AND CHALLENGES

If a comparison was to be made between Figs. 1 and 4, very few areas are in common and this, caused by differences in methods and time periods considered, is the crucial handicap in global desertification mapping that often creates confusion for the end users, mostly decision-makers. Fig. 1, for instance, puts almost the whole of China into humid and not vulnerable areas, while the LADA map provides better details on land degradation classes. Same holds true for much of the Western Europe and eastern parts of the United States and Canada.

Other problems related to desertification assessment and mapping are linked to spatial and temporal scales. Such global maps provide only approximate assessments on the distribution of degradation but are insufficiently detailed to be useful at local level. Conversely, the temporal aspect is often a contradictory constraint because if a comparison has to be made between the present status of degradation with an earlier stage, the comparison period has somehow to be established arbitrarily. GLASOD, e.g., used a period of

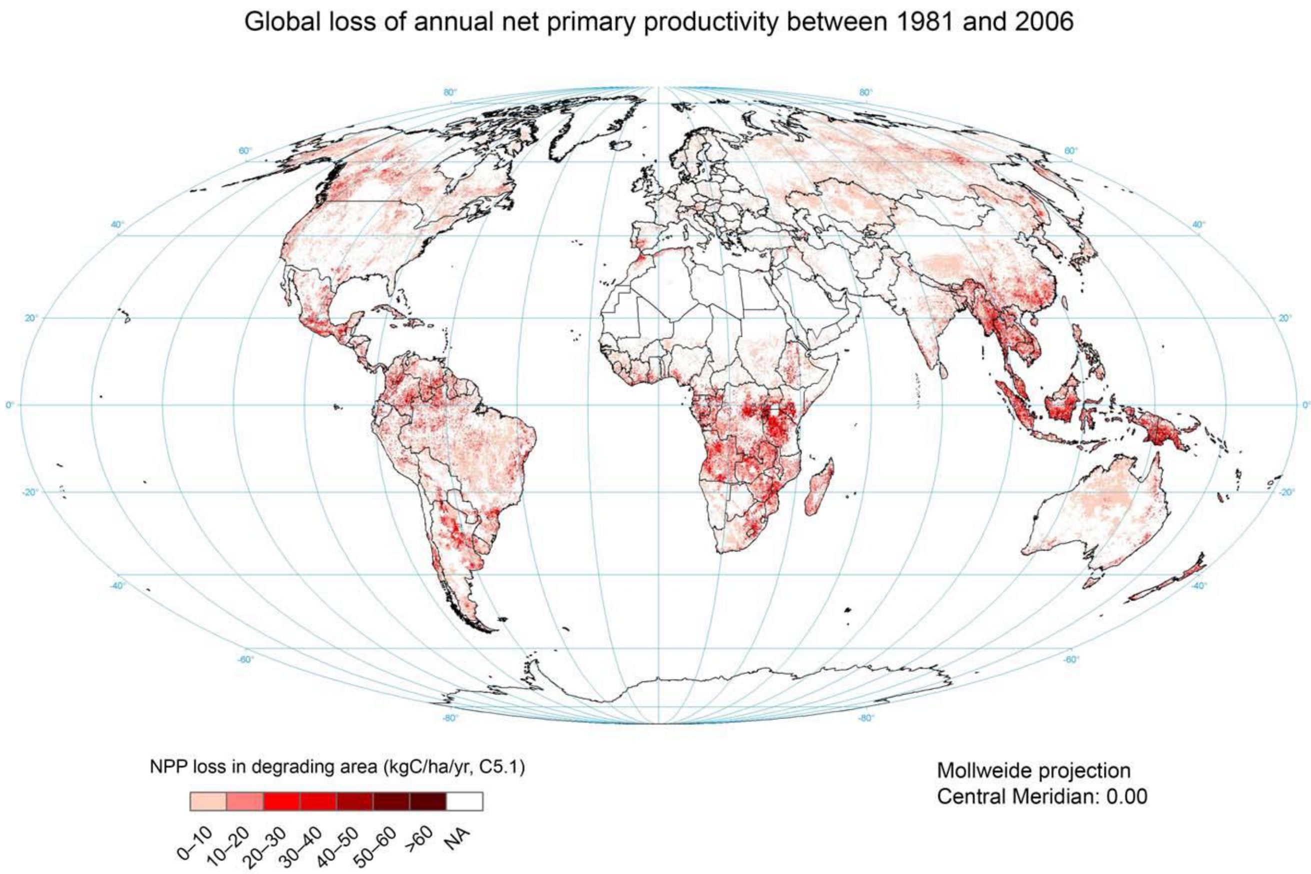


**Fig. 3** Global loss of net primary productivity between 1981 and 2006.

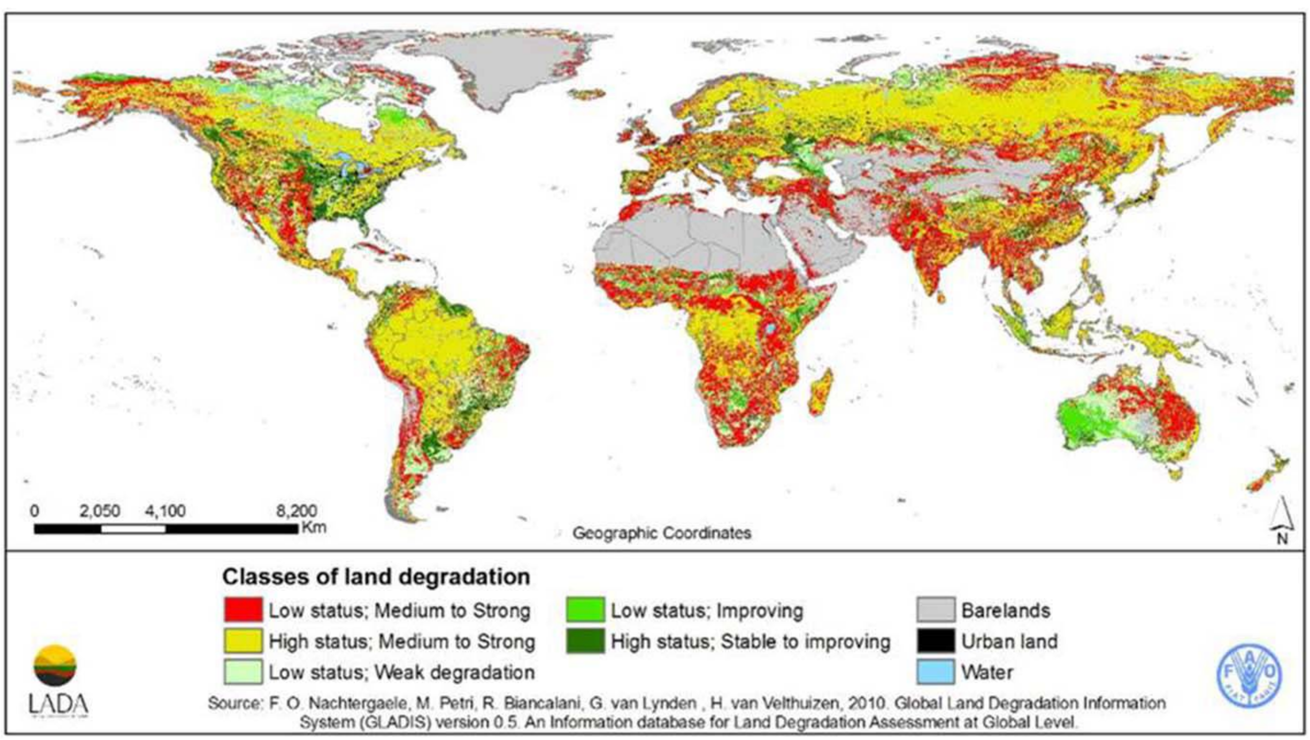


**Fig. 4** Classes of land degradation.

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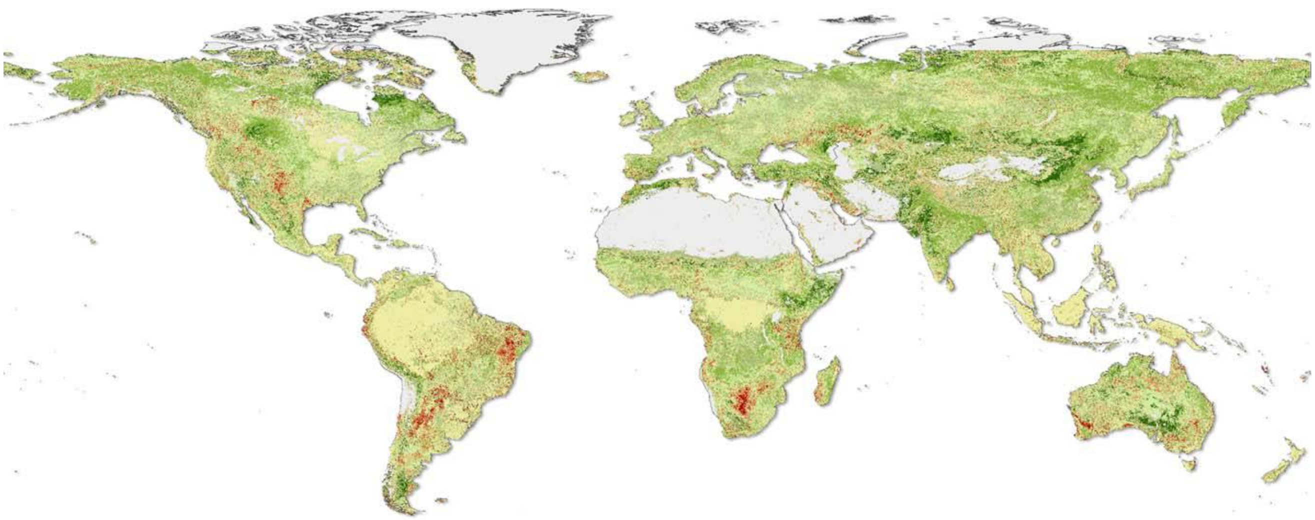

Fig. 5 Consistent decline in ecosystem productivity.

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25 years, but it is often difficult to obtain evidence that conditions were better (or worse) in the past than at present and that the presumed degradation was due to present land use changes.[15]

Mapping desertification is complicated also by the diversity of methodologies used, the selection of indicators included in the assessments, and the intrinsic complexity of the process itself.[40] A major constraint though is the perceptive aspect of deciding what land degradation really is. This can only be defined in view of the needed or planned optimal land use combination. For example, a land use change (i.e., infrastructure development, housing, and increased economic activity) might provide better income sources for the local population in the short term, but in the long term, ecosystem's stability could be disturbed and perhaps will never return to its original status. Is this degradation and how to map it? LADA indicated indeed that there are trade-offs between socioeconomic gains and environmental losses and vice versa, and this cannot be captured simply in a single index. Related to this is that these gains and losses are subjective and depend on the interests of different stakeholders which are often completely different. This is true at all levels, be it local or global. The UNCCD is struggling for years to establish a minimum set of indicators to be used in land degradation and desertification assessments even though yet final agreement is far away.[41]

However, a global assessment can be undertaken, bringing together the best of the available databases supplemented with proxies, and probably the best option could be to develop a map of pressures of land degradation based on conditions of ecosystems and land use systems.[42]

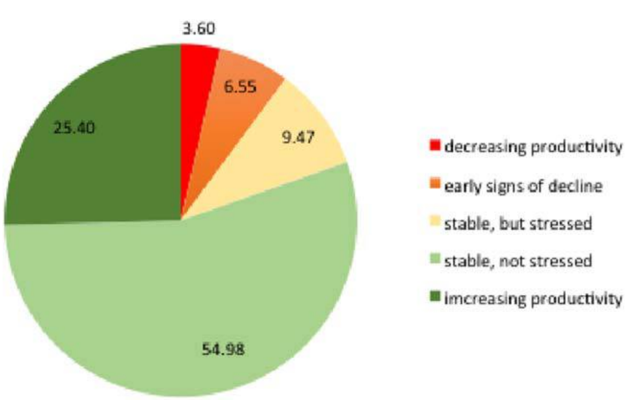


Fig. 6 Global distribution of productivity dynamics.

## Mitigating Desertification and Its Consequences

Until 2013, the UNCCD has held 11 conference of parties (COP) as the highest governing body. At COP8 held in Madrid, Spain, in 2008, the UNCCD adopted the 10-year strategy (2008–2018) that aims *to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability.* These goals are under scrutiny of the COP and of the civil society organizations that strongly endorse the bottom-up approach.

Despite criticism on the achievements of the UNCCD, data show that there are many positive results worldwide, demonstrating that when local stakeholders are both managers of natural resources and implementers of the right policies, it is possible to make a change.[43–46] Surely these results are not attributed solely to UNCCD activities; however, implementing SLM practices could make a difference. The most common SLM techniques include soil and water management (i.e., terracing, contour planting, living barriers, low or no tillage, mulches, cover crops including biological nitrogen-fixing legumes, grazing corridors, and water harvesting) and soil fertility management (i.e., manure, compost, biochar, biomass transfer, agroforestry including nitrogen–fixing trees like *Faidherbia albida*, and overall integrated good soil management).

## CONCLUSION

The outcomes of assessments of desertification are often debated as they use different methods, measure different variables, and operate at different scales (both temporal and spatial), with some of them focusing on particular bounded systems such as the drylands. This means that the results from different assessments cannot be usefully compared. Despite these issues, in the context of other sustainable development, challenges such as population growth, food security, climate change, and biodiversity loss, nevertheless desertification assessments demonstrate that this is a key issue and that it is likely to worsen unless timely action is taken and appropriate mitigation practices are implemented.

Land degradation is also a natural process. Without soil erosion, neither the fertile Nile floodplain in Egypt, the floodplains of many other valleys around the world, nor most of the Netherlands would exist. The most visible human land degradation impact is probably soil sealing, a "modern" form of desertification present in Europe, in North America, and in the fast-growing economies of China, India, Brazil, South Africa, and Russia and threatening fertile valleys around the world.

Therefore, efforts to map desertification should be accompanied by more emphasis on mapping also sustainable land use practices and by identifying areas that must be protected from unsustainable human activities as the WAD is proposing. The concept of *endangered soil species* should be fostered, especially for the highly productive Mollisols of U.S. soil taxonomy[47] or the Phaeozems, Kastanozems and Chernozems of the World Reference Base (WRB) for soil resources.[48] These soils cover only 3% of the global land surface but produce 40% of the global food and 90% of the world's cereals. The United Nations proclaimed 2015 as the International Year of Soils. This is an excellent opportunity to raise awareness on land protection, how to assess it, and to engage in concrete actions to combat desertification and conserve our natural land resources for the future generations.

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