





# PART I

## INTRODUCTION

Twenty years have passed since the last atlas of desertification was published. Within that short period, the environment has undergone enormous global changes due largely to human activities. Fortunately, because of the massive increase and growth in the availability of global and regional datasets – and the tools necessary to analyse them – significant progress has been made in understanding human-environment interactions.

WAD3 thus begins at a very different place than WAD2 in terms of scientific information and understanding. That said, we are also confronted by the rapidly growing appreciation of the complexity of the land degradation phenomenon and all the human factors that both drive it and are derived from it. As a consequence, WAD3 offers an approach that accommodates and embraces these complexities and provides an information framework from which to pursue solutions that fit specific local situations.



Copernicus Sentinel-2 image over SE Afghanistan and part of the Indus river in Pakistan. Fertile riparian areas in desert and dry mountain ranges have sustained ancient civilisations. The Pakistani city of Quetta is visible at the centre of the image.



While the first pictures of Earth from deep space invoked awe and wonder, they also graphically revealed the startling reality of the finite and stark boundaries in which humanity exists. Within these boundaries, the Earth has entered the age of the *Anthropocene*, where humans are the dominant force altering the Earth system.



⋯ First deep space image of the Earth, 'Earthrise' by Apollo 8 on Christmas Eve, 1968.  
Source: NASA



# Introduction

## Historical Perspective

Although ‘desertification’ remains in the title, this atlas represents a significant departure from the first two editions of the World Atlas of Desertification because deterministic maps on global land degradation are not presented. Rather, land degradation is considered to be a global problem of human dominance involving complex interactions between social, economic and environmental systems, which is not amenable to mapping at a global scale.

To many, the term desertification invokes alarmist images of “deserts moving across the landscape, engulfing fertile lands and leaving starving people in their wake”<sup>1</sup>. The term was first popularised by Aubréville in 1948, who used it to describe how tropical forest regions in Africa were being transformed into “desert-like regions”. Over time, ‘desertification’ became enshrined as a permanent and dominant part of the lexicon of land degradation, even being institutionalised through the establishment of the United Nations Conference on Desertification (UNCOD) in 1977 and the United Nations Convention to Combat Desertification (UNCCD) in 1994.

The focus on the term ‘desertification’ to indicate land degradation in drylands is unfortunate because as a global phenomenon it is “a nebulous, all-encompassing concept” that defies simple description and measurement<sup>2</sup>. In part this is due to a lingering imprecision about the nature of the problem, including disagreements about its root causes and consequences, whether or not it is reversible, how to measure it and the role of climate (e.g. drought) versus human activities (e.g. overgrazing by livestock)<sup>1</sup>. Scale is also at play because key processes that can drive land degradation occur at multiple scales: for example, soil erosion due to severe overgrazing could be the result of local drivers, e.g. famers trying to pay back bank loans, or regional-global drivers, e.g. increased international demand for meat. Furthermore, degradation can manifest in a multitude of ways, including the conspicuous erosion of soil or loss of net primary production, but also in less obvious ways such as through changes in plant species composition. The temporal scale over which various types of degradation take place influence results when using different monitoring periods or baselines. This has led to ambiguity as to how to define and quantify desertification, making it difficult to reach consensus, adopt effective action plans and agree on replicable measurement criteria, the latter of which is needed to identify the extent of the impacts of land degradation on human livelihoods<sup>3</sup>. Given this, it is not surprising that while the UNCCD has served an important role in highlighting issues of land degradation, poverty and sustainability (especially in Africa), it has been criticised as being ineffective<sup>4,5</sup>. The UNCCD

### Definitions of desertification and land degradation

The UNCCD defines desertification as **land degradation in dryland areas due to various factors, including climatic variations and/or human activities** (Article 1 of the UNCCD).

Land degradation refers to reduction or loss, in arid, semi-arid and dry subhumid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including those arising from human activities and habitation patterns, such as:

- i soil erosion caused by wind and/or water;
- ii deterioration of the physical, chemical and biological or economic properties of soil; and
- iii long-term loss of natural vegetation.

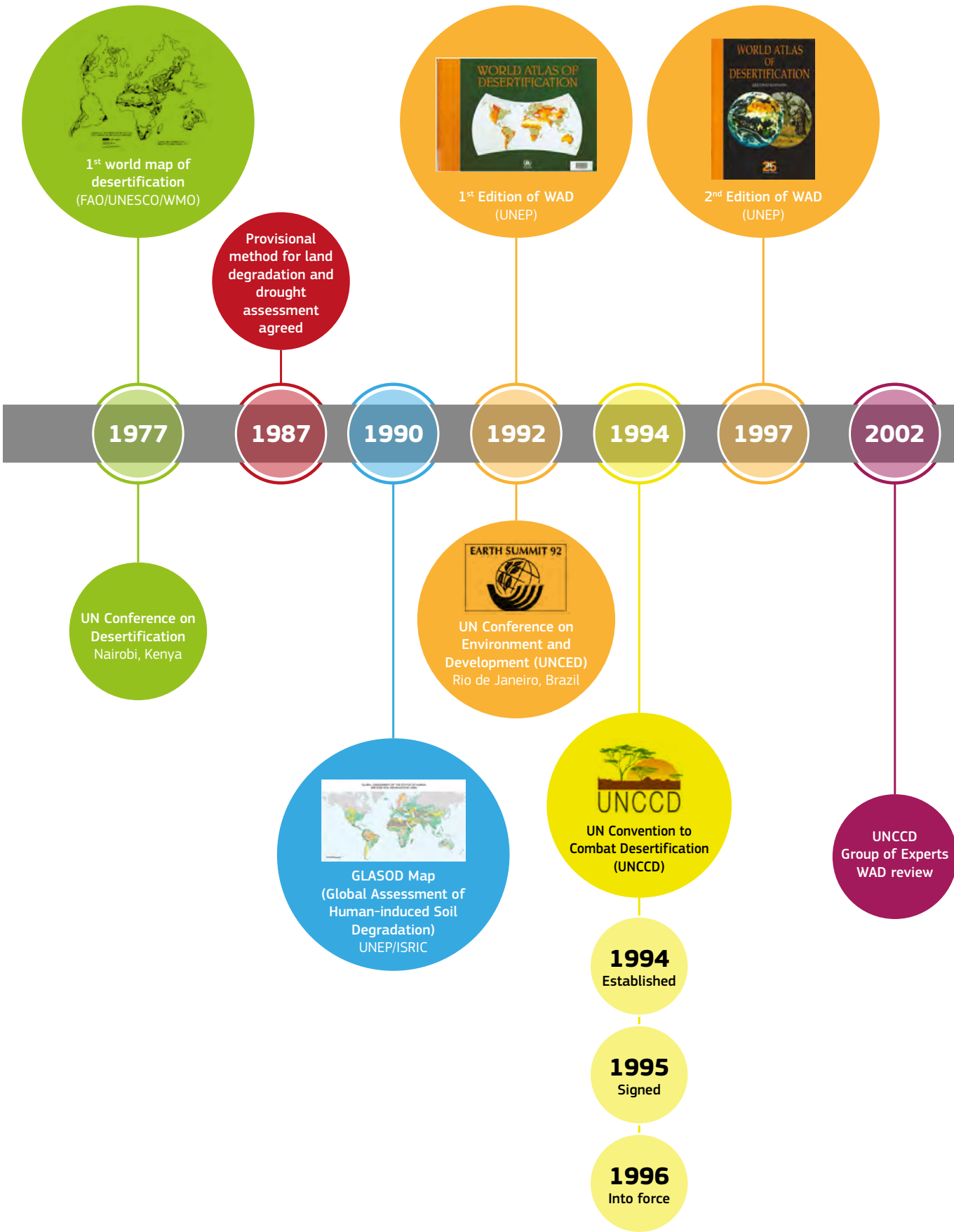
In this atlas, the more expansive definition of land degradation as given by the Millennium Ecosystem Assessment is used: **land degradation leads to a long-term failure to balance demand for and supply of ecosystem goods and services**<sup>13</sup>. Essential goods and services include food, forage, fuel, building materials, fresh water (for humans and livestock, for irrigation, sanitation), control of agricultural pests, nutrient cycling, purification of air and water, the moderation of extreme weather, biodiversity and cultural and recreational benefits. Lastly, since land degradation is a global problem WAD3 considers all regions of the world and not just drylands – although emphasis is placed on the latter – and therefore the term ‘land degradation’ is used in this WAD.

was instrumental in establishing strategies for monitoring land degradation, which paved the way for the adoption of the Land Degradation Neutrality concept within the framework of the UN Sustainable Development Goals<sup>6</sup>.

Acknowledging recent scientific progress and the upsurge in the collection of global data, in 2007 the UNCCD COP8 invited institutions and stakeholders to produce a new World Atlas of Desertification. This atlas is the 3<sup>rd</sup> edition of the World Atlas of Desertification (WAD3), which appears 20 years after the 2<sup>nd</sup> edition<sup>7</sup>. The major premise of WAD3 is that ‘desertification’ or

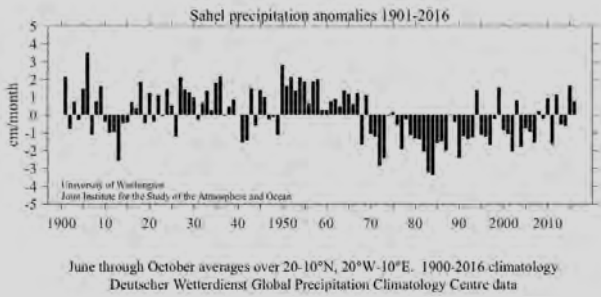
land degradation cannot currently be captured comprehensively in global maps, despite the fact that local manifestations can often be clearly identifiable. This atlas therefore calls for a ‘rethinking of land degradation and sustainable land management’ and although ‘desertification’ remains in the title, it represents a significant departure from the first two editions (WAD1, WAD2).

The maps of WAD1 and WAD2 were based on the Global Assessment of Soil Degradation (GLASOD) database<sup>8-10</sup>. Building on the 1987 FAO/UNEP/UNESCO ‘provisional methodology for assessing and mapping desertification’, GLASOD was compiled from the expert opinions of soil scientists who mapped the ‘status of soil degradation’ following structured questionnaires. Such attempts to delineate globally relevant instances of desertification have been criticised as being overly simplistic, inaccurate and unhelpful. In addition to the issues raised above pertaining to the nebulous meaning of the word ‘desertification’, maps cannot capture the vast differences reported in specific case studies of land degradation<sup>3,11,12</sup>. For example, based on GLASOD the entire Sahel region in Africa was classified as severely degraded, which led to the establishment of an ‘irreversible degradation’ dogma for this region.



Sahel: The Desert Encroachment that wasn't

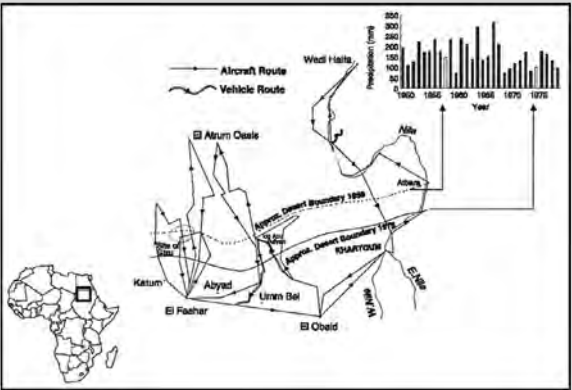
The West African Sahel experienced numerous droughts from the mid-1960s onward (see chart). Because of the scope of human suffering, it received much political and popular attention. During the drought of 1968-1974, Aubréville's term 'desertification' came into broad use to describe those processes that appeared to be transforming large parts of Africa. It was argued that due to mismanagement of the land by pastoralists and farmers – albeit exacerbated by drought – the Sahel region was being transformed into a desert. There was a general acceptance that desertification was widespread and irreversible and that deserts were “expanding”, particularly across the Sahel and east Africa<sup>14</sup>. In 1977, the United Nations Environment Programme (UNEP) convened the United Nations Conference on Desertification (UNCOD) to bring international attention to bear on assessing and addressing these issues<sup>15</sup>.



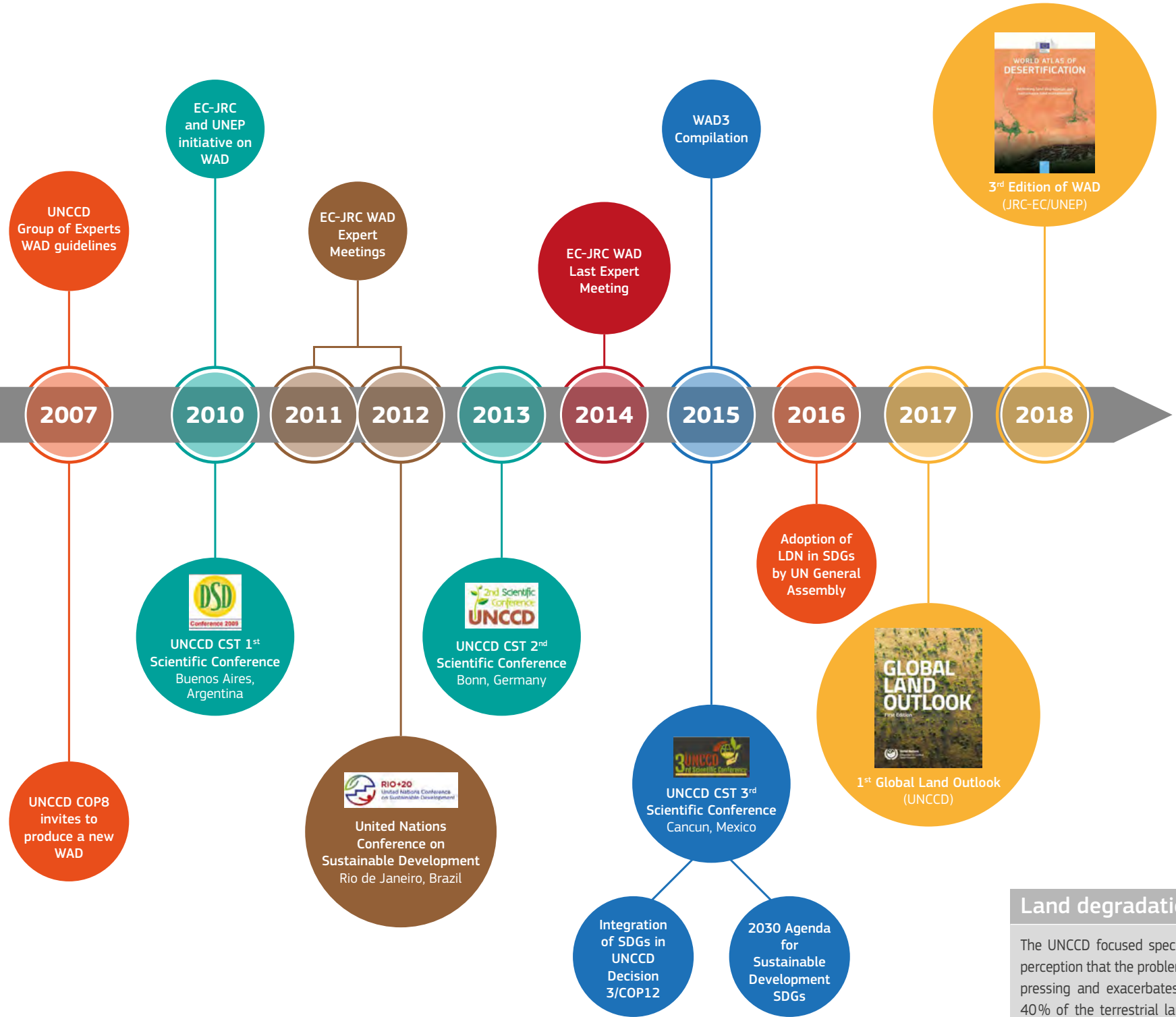
How were assessments of desertification conducted during this time? This was problematic due to a general paucity of data for the region as a whole, but also the challenge of newly established governments to provide consistent data on agricultural conditions. In the absence of rigorous quantitative data, assessments were gleaned from anecdotal narratives of environmental degradation that had been constructed from the 1940s onward, along with vague and poorly corroborated observations of an “expanding” Sahara during the mid-1970s.

It was not until the advent of continuous global satellite observations that it was possible to document the general response of Sahelian vegetation over the decade of the 1980s. However, the results were equivocal: while these data did indeed show that the apparent boundary between the Sahara and the Sahel may have initially moved south, it then moved north again. Rather than transformative change, it showed the variability that is characteristic of drylands on a decadal time scale<sup>17</sup>.

Sahel precipitation 1901–2016.  
Source: [http://research.jisao.washington.edu/data\\_sets/sahel/](http://research.jisao.washington.edu/data_sets/sahel/)  
doi:10.6069/H5MW2F2Q



A reconnaissance study in Sudan was performed in 1975 by H. Lamprey<sup>14</sup>. The boundaries of a vegetation map compiled in 1958 were compared with field observations (from a vehicle) and from light aircraft. The study concluded that, between 1958 and 1975, the boundary between the Sahara and the Sahel had advanced southward 100 km at a rate of about 5.5 km/year. Lamprey's conclusion was widely reported and accepted by the general public, but it also received substantial scientific criticism contending that it ignored the dramatic seasonal differences in vegetation and the fundamental role of climate variability. In fact, a detailed rainfall analysis showed that Lamprey's assessment was, actually, a comparison between a wet year (1958) preceded by a series of wet years, and a dry year (1975) preceded by a series of dry years (see inset and climograph above)<sup>14, 16</sup>. This is a vivid example of the perils of inductive reasoning – taking a few local measures of dubious quality and extending them across a region.



15. In 1977, the United Nations Conference on Desertification (UNCOD) adopted an action plan to Combat Desertification informed by a map of desertification made by the FAO, UNEP and UNESCO. In 1991, UNEP concluded that the problem of land degradation in arid, semi-arid and dry subhumid areas had intensified. This was based on the GLASOD map compiled in 1990, which was used in WAD1 preparing for the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. Based on the recommendation of UNCED, the United Nations General Assembly established the UN Convention to Combat Desertification (UNCCD). The Convention was adopted in 1994 and entered into force in 1996. As decided in 2007, the Committee for Science and Technology convened three scientific conferences, in 2010, 2013 and 2015. At the 2007 UNCCD COP8, a ten-year strategic plan was adopted, inviting stakeholders to compile a new atlas and, in response, the JRC accepted the task of coordinating the compilation of WAD3. Source: WAD3-JRC, 2018.

Land degradation is a Global Issue

The UNCCD focused specifically on drylands because of the prevailing perception that the problem of land degradation in dryland areas is most pressing and exacerbates the risk of poverty. Drylands occupy about 40% of the terrestrial land mass of the Earth, presently contain over 40% of the world's population and were at the time considered to be the areas where degradation was most severely impacting livelihoods. Drylands are climatic zones where the ratio of long-term mean annual precipitation to potential evapotranspiration is less than 0.65. However, land degradation is a problem of global dimensions, affecting all regions of the world, not only drylands.



Current perspective

This third edition of the *World Atlas of Desertification* focuses on land degradation and global environmental change under five major subject headings:

**Global Patterns of Human Domination.** Highlighting the role of *Homo sapiens* as the major driving force of global environmental change;

**Feeding a Growing Global Population.** The ability to feed 10–12 billion humans by the end of the century is one of the great challenges facing humanity, creating enormous burdens on the land;

**Limits to Sustainability.** The Brundtland Commission defined sustainable development as “development which meets the needs of the present, without compromising the ability of future generations to meet their own needs”. There are numerous obstacles that must be overcome to achieve this goal;

**Convergence of Evidence.** Many of the anthropogenic-induced environmental changes can be measured and their combined effects are indicative of the multiple stresses humans exert on the land. WAD3 draws on this complexity by adopting the concept that evidence or signals from multiple sources may “converge”, thus leading to the development of testable hypotheses and/or conclusions that are supported by data. Convergence of evidence maps replace the ‘maps of desertification’ of WAD1–WAD2; and

**Solutions.** Potential solutions to land degradation need to be identified and implemented within the context of local social,

Commensurate with the theme of human domination of the Earth, WAD3 stresses that the modern paradigm of ‘desertification’ and land degradation is based on interactions and feedbacks between social and ecological systems<sup>23</sup>. The basic building blocks are coupled social-ecological systems (SESSs), which permit structured, interdisciplinary inquiry to assess the social (economics, culture, politics, etc.) and ecological (biotic, abiotic) dimensions of sustainable resource use, development and management. While the role of human activities in modifying the Earth’s vegetation and land has long been recognised<sup>16</sup>, what has become increasingly apparent over the past several decades is that the linkages of climate and human activities within the SES framework are complex and interactive, and operate at a wide range of scales<sup>23</sup>. For example, rather than mapping traditional global biomes, WAD3 emphasises anthromes or “human biomes,” which depict global patterns of sustained human interactions with ecosystems<sup>24</sup>. Anthromes (page 114) portray the geographical extent and functional depth of human impact on the world’s ecosystems. In addition to developing an understanding of the types of SES interactions (e.g. impacts of land tenure, historical colonial authority, export policies, drought, soil fertility), we are now confronted with a vast increase in the scale of those interactions, which are more and more interconnected in a global environment (page 40).

A critical consideration that often dictates the adoption and implementation of technological innovation is farm size. More than 80% of farms in the world are comprised of less than 2 ha and are managed by individual households, largely in Asia and Africa (page 64). These rural, smallholder producers use mainly family labour, and their farms provide their principal source of food and income; therefore, their ability to acquire new technologies is severely limited. Importantly, the absolute number of farmers in these regions is so large that even simple and inexpensive interventions can have regional impacts (e.g. stone contour lines to prevent runoff, increase infiltration, reduce erosion and increase yields; or planting trees along field boundaries to reduce the effects of wind and provide households with poles, fuel and fodder) (see Solutions PART IV, page 226). Smallholders are now seen as part of the solution of land degradation rather than a main problem, which was a prevailing view of the past. Hence, government programmes that subsidise smallholders, such as in China and India where fertilisers are provided, can have significant impacts that increase production but also may pose environmental threats.

Limits to Sustainability

WAD3 focuses on some key phenomena that will ultimately dictate limitations on resource consumption and sustainable development. The term ‘sustainable development’ was coined by the Brundtland Commission<sup>29</sup> as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Realising the goal of sustainable development – while feeding a growing global population – is one of the greatest and enduring challenges facing humanity. There is evidence that the capacity of the planet has already been reached, or even surpassed, with regard to various ‘planetary boundaries’<sup>30</sup>. Current rates of resource consumption and waste production, coupled with climate change, human population growth and widespread environmental degradation suggests that there are indeed limits: This is the critical issue for sustainability science<sup>31</sup>.

Productive soils are fundamental to achieving sustainable development. Soils sustain the diverse agricultural production systems of the Earth, filter and regulate freshwater dynamics (both surface and groundwater) and sequester vast amounts of carbon (pages 86–94). As with other natural resources, maintaining productive soils is a challenge under current conditions of climate change, human population growth and poor agricultural management. If lost to degradation, previously productive soils cannot be reclaimed in human timescales. Therefore, prevention of degradation is almost always far more cost effective than restoration of degraded land.

It is estimated that humans appropriate 20% to 25% of the Earth’s terrestrial primary production (pages 38, 112); if large amounts of bioenergy are consumed in the future, this could increase to over 40%<sup>32</sup>. Human appropriation of net primary production is a prominent measure of the human domination of the biosphere since it affects the energy flow of ecosystems, impacts biodiversity (page 132) and has many environmental impacts. Understanding and managing human appropriation is a key factor in developing strategies for sustainable use of the land system<sup>33</sup>.

Perhaps the most fundamental limit to sustainability is the availability of water. The current situation is sobering. Although there is more surface water now than at any other time over the past 30 years (page 86), this does not necessarily mean increased water availability. Many new dams have been constructed to store large volumes of water for irrigation and power generation. While this may benefit one organisation or country, it often negatively impacts downstream populations and economies and leads to political disputes. For example, proposed dam construction on the Mekong River will impact 60 million people who rely on the river system for fish as their main source of dietary protein. Paradoxically, it is estimated that dam-building on the Mekong will result in a 4% to 17% increase in water use due to the establishment of livestock production systems to replace the river fisheries<sup>34</sup>.

Other “new” surface water is the result of warming in the Tibetan plateau. While this has led to greater water discharge, the volume and timing of these flows are uncertain and potentially disrupting. Moreover, some of this water has flowed into old lake beds, becoming saline and unusable.

Sustainable Intensification in Agriculture

Sustainable intensification in agriculture entails numerous components, including increasing production through higher yields, technological innovation, moderating demand for resource-intensive foods such as meat and dairy, reducing waste, improving the efficiency and resilience of the food system and making food more accessible and affordable<sup>28</sup>.

economic and political conditions.

Global Patterns of Human Domination

Underlying the central theme of this atlas is an acknowledgement that humans are at the core of global environmental change. Human activities are responsible for global warming, land degradation, air and water pollution, rising sea levels, eroding the ozone layer, extensive deforestation and acidification of the oceans, and are driving Earth’s sixth “mass extinction”<sup>18</sup>.

One of the more iconic illustrations of human domination of the Earth is the detection from space of lights on the planet’s surface (PART II, page 20). Just as the Apollo 8 photo of Earthrise captures the finite nature of Earth, night lights dramatically depict the footprint of human activities, from the spread of cities to industrial activity to fires due to land-clearing.

The population of the Earth, now over 7 billion, is projected to increase to between 10–12 billion by the end of this century (pages 26–32). This does not bode well for the future since the planet has a finite capacity to support humanity, especially in the face of continued resource depletion and environmental change. WAD3 presents examples of the extent of human presence on Earth. Currently, humans appropriate 20 to 25% of the Earth’s annual net primary production (NPP) from land, while representing less than 1% of the total global mass of organisms<sup>19, 20</sup> (page 108). Through mining industries, humans move more sediment into the ocean than all the world’s rivers combined<sup>18</sup> (page 134). About 45% of Earth’s land surface is dedicated to livestock and livestock-feed production<sup>21</sup> (page 58). Increasingly, the Earth is transforming into the “urban planet”: by 2050, over two-thirds of the world’s population will reside in cities (page 30). The current rate of human consumption creates enormous pressures on the natural resources of the globe and, within the context of Earth’s finite boundaries, the current footprint of humankind is not sustainable<sup>22</sup>.

Feeding a Growing Global Population

As the world population continues to grow, nearly 3 billion people will be added to the global middle class by 2030<sup>25</sup>. These middle-class consumers tend to have dietary preferences that favour meat, dairy and other resource-intensive foods. Can this demand be met? This basic question – whether a growing human population will outstrip the ability of agriculture to meet its food demands – has been pondered for centuries<sup>26</sup>.

In the past 200 years, vast areas of land have been brought into agricultural production, especially in North and South America, Africa, Asia and Australia (PART III, page 46). In fact, most of the productive lands in the globe have already been converted to agriculture (page 48). In the future, it is likely that some marginal lands will be brought into production, particularly in developing countries where pressures are highest, but this option is limited. Most of these lands are forests, wetlands and grasslands, and converting them to agriculture would have serious environmental costs in terms of increasing greenhouse gas (GHG) emissions, losses of biodiversity and negative impacts on essential ecosystem goods and services (e.g. food, forage, fuel, water, control of agricultural pests, nutrient cycling, purification of air and water)<sup>27</sup>. Alternatively, it is possible to increase food production on existing farmland via the practice of “sustainable intensification”<sup>27</sup> (see Limits to Sustainability, below).

With regard to technological innovation, dramatic advances in increasing crop yields (page 52), have been achieved through various means, including plant breeding, genetic manipulation, fertilisers and irrigation (pages 54–56). The rate at which farmers adopt new technologies, however, depends on a number of risk factors such as economics, environmental consequences, characteristics of each farm (and the farmer) and the ease and convenience of adopting new technology<sup>28</sup>. Yield gaps, i.e. the difference between current yields and what might be possible under optimum conditions (for example, good pest control and sufficient water and nitrogen), are lowest in the world in areas/regions where the aforementioned risk factors are easily manageable, which are principally in developed countries. Where large yield gaps exist there are the greatest opportunities for meaningful gains (e.g. developing economies). Opportunities might however lead to over- or misuse of technologies (such as irrigation, fertiliser use, etc.), destroying vital land resources and thereby compromising ecosystem services.



Much of the rapid increase in agricultural production during the past century is due to the use of groundwater (page 92). Until quite recently, groundwater was immeasurable but new satellite technologies have enabled the relative magnitude of changes in groundwater to be monitored. Not surprisingly, areas that have shown the largest decline in groundwater are in the major irrigated regions (page 56). Groundwater depletion threatens sustained agriculture production systems in both developed (e.g. California) and emerging (e.g. India) economies.

As noted in Feeding a Growing Global Population above, the pathway toward increasing agricultural production is through increasing the efficiency of existing croplands. Most gains in production are projected to come from fertiliser and water. However, sourcing additional water for irrigation is likely to be problematic, as is the case in vast areas of low-yielding croplands in Russia and Kazakhstan. If large inputs of fertilisers were used to increase the production of these croplands, local surface and groundwater reserves would be threatened, as would adjacent ecosystems upon which they depend.

Climate change is one of the greatest threats to achieving food security and agricultural sustainability. Although climate is unequivocally changing, there is a large degree of uncertainty as to how much change can be expected and its local or regional manifestations. What is certain is that as the planet warms, global average rainfall is expected to increase; however, so will evaporation, which complicates predictions of the overall net impact on average aridity (pages 72-84). Further, many arid areas are most likely to experience reduced rainfall as a consequence of global warming. The global hydrological cycle is tightly coupled to climate, land use and direct consumption and, hence, future water availability for human consumption, agriculture and industrial usage is problematic (page 84).

In addition to agriculture, changing patterns of global aridity have the potential to impact the majority of the human population. By 2050, over 66% of the world's population will reside in cities<sup>35</sup>. How increasing aridity could potentially impact the local climate of cities is considered in pages 80-82. Meeting the demand of urban populations for food, energy and water under increasingly restrictive climate conditions and limited land resources will be a challenge.

Global assessments must focus on big issues: e.g. land use and land-use change patterns, climate change and the effects of land management on biogeochemical cycles (e.g. water, nitrogen). Economic considerations are an important component of these assessments because building sustainable economies and social institutions require united action to overcome the many obstacles before us, including land degradation. However, smallholders are also an important component of these assessments. First, as major land managers, smallholders already play a large role in determining the uses of land and resources. Second, while it is a moral imperative to improve the overall well-being of smallholders, it is also a practical one: if they are in a better economic position they will better enabled to adopt new technologies and to become contributing agents of the global economy (pages 64-68).

### Convergence of Evidence

The causes of land degradation, the processes involved and the impact they have on ecosystems services changes over space and time as well as in regard to changing social perceptions of the value of ecosystem services. As such, land degradation cannot be globally mapped by a single indicator or through any arithmetic or modelled combination of variables<sup>2</sup>. A single global map of land degradation cannot satisfy all views or needs.

When it comes to land degradation in different parts of the world, the problem of conveying a sense of local context is perhaps the most fundamental challenge in making global data useful. Attempting to interpret global data at the local level tends to undermine confidence in virtually any global assessment. The challenge is to convey a sense of what any finding means “on-the-ground” with respect to its importance to livelihoods, economies, regional biodiversity or any other selected measure of importance at that location. Why and how conditions – such as size of the human population, abandonment of cropland, fertiliser deficiency, soil erosion and so forth – are more or less problematic or impacting in one area rather than another is of local importance. Local users typically want guidance on how they can deal with their particular problem.

To address these concerns, WAD3 attempts to move beyond a prescribed, fixed representation of land degradation. In lieu of producing static ‘maps of desertification’, WAD3 applies the

principle of “convergence of evidence”, which entails dynamic, abductive logic to ascertain what a given finding means “on-the-ground” (see text box on “forms of inference” below). Convergence of evidence is a measure based on accumulated evidence that certain core issues related to land degradation currently co-exist at a given location. From this a ‘most likely explanation’ may evolve, which can be in the form of a hypothesis, inference, explanation, conclusion or best guess about that status of land degradation at a given location. The ‘most likely explanation’ is not necessarily considered final – it can be improved or updated in a recursive, highly flexible manner as additional information – that has local context – becomes available.

As the format of a printed atlas constrains what can be presented on a single page, various maps presenting convergence of a number of key issues that relate to land degradation represent some of the key stakeholders’ interests at global scale. Some of the conclusions that emerge from convergence of evidence (PART V, page 142) may be judged to be more significant than others, for example: (i) large numbers of people or critical resources may be impacted; or (ii) strategically important concerns are identified that impact certain segments of the local economy or ecological sustainability. The convergence of evidence approach is intended to be flexible in order to address such concerns.

## A Web-Based Platform



<http://wad.jrc.ec.europa.eu/>

Accompanying this atlas is a web-based platform that enables independent interrogation and analysis. WAD3 seeks to advance a dynamic, interactive set of global data and analytical tools that can be continuously expanded and updated, to produce custom-configured products to meet the divergent needs of users. The webpage will be gradually upgraded and improved.

Establishing a more meaningful context can be pursued in at least two ways that draw on the data that have already been assembled: The ability to query global data sets (i) individually or (ii) in combination within a local setting. The convergence of evidence approach is a deliberate and structured guide that can lead to a more valid and reliable understanding that was not possible when working with a single printed map.

This scale-independent framework can be used to explore land degradation in a collaborative, online environment. It is intended to foster the development and testing of hypotheses concerning degradation phenomena that can lead to broader understanding of land degradation and, hence, successful interventions and solutions.

The appropriation of net primary production is a prominent measure of the degree of human domination of the biosphere.

### Solutions

Understanding land degradation is contextual<sup>36</sup>, hence, Potential solutions to land degradation can only be identified and implemented within the context of localised social, economic and political conditions. Therefore, it is necessary to frame ‘solutions’ within the context of what local characteristics of land degradation actually matter to local stakeholders, especially the socio-economic consequences. The concept of sustainable land management (SLM) evolved in response to the need for solutions to the myriad problems associated with land degradation. SLM is based on the principles of enhancing the productivity and protection of natural resources while maintaining an economically viable use of the land<sup>37</sup>. SLM practices are constrained by local conditions (the environment, technological limitations, local knowledge, climate, policy, etc.) (see Limits to Sustainability). When successful solutions are found, the challenge is to define similar contexts to which those solutions might be applicable (PART VI, page 226).

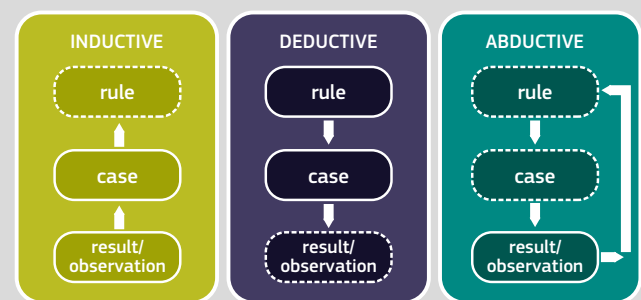
WAD3 offers a number of findings that emerge from multiple issues related to land degradation and its geographic and temporal coincidence. WAD3 illustrates an approach to interactively deal with such information at all scales and, thus, is solution-oriented and focuses on ongoing pressures that can lead to land degradation (rather than a diagnostic mapping of it). Global users and institutions can learn from global convergence patterns for a variety of thematic interests, while local stakeholders can add local information and knowledge for broader understanding and planning of successful interventions and solutions.

## Forms of Inference

**Inductive reasoning** is a model that begins with specific observations and proceeds to generalised conclusions. This approach is supported by the multitude of documented case studies of observed land degradation.

**Deductive reasoning** is a model that moves from generalised principles to specific conclusions, which are rigid and prescriptive. This approach is tempting and has been the basis for previous and ongoing attempts to make global assessments of land degradation. However, given the complexity of factors underlying land degradation within the SES context, it is usually not possible to take one set of observations and directly extrapolate them to another area of the globe.

**Abductive reasoning** is at the core of WAD3. It's a perfect fit because abductive logic, which typically moves from an incomplete set of observations to the most likely explanation for these observations, entails incomplete information. The ‘most likely explanation’ may be in the form of assumptions, hypotheses, inferences, explanations, conclusions or best guesses, which are not necessarily considered final but can be improved in a recursive, highly flexible manner as additional information becomes available. The abductive approach may consist of elements of both induction and deduction. Given the nonlinear, complex nature of land degradation, this is an ideal fit.



Forms of inference.  
Source: adapted from: Fisher, H.R., 2001<sup>39</sup>.



Challenges

Global Data – a further challenge

The problem of conveying a sense of local context is perhaps the most fundamental challenge in making global data useful. It is the one issue that serves to undermine confidence in virtually any global assessment. In short, the challenge is to convey a sense of what this finding means on-the-ground with respect to its importance to livelihoods, economies, regional biodiversity or any other selected measure of importance at that location. The used case studies – or the telling of local “stories” – proven to be the most powerful and useful approach to conveying how complex the phenomenon is and thus the difficulty in developing and presenting useful generalisations. WAD3 employs case studies to show that contextual information down to the local level is required to properly explain and interpret patterns derived from global data.

WAD3 has a large number of data sets potentially available that can be readily located and acquired by anyone with access to the internet. While this creates a challenge in dealing with numerous data layers and huge data volumes, the fundamental mapping challenge remains similar: how to provide an adequate context to interpret global patterns under local conditions. The format of a printed atlas constrains by what can be presented on a single page and compels the compiler to compress the content into one, or a few variables – with overlays – that can be mapped and displayed in a single image. This has been achieved in many ways. In the case of GLASOD, in WAD1 and WAD2, the maps were based on experts’ best judgment. In more formal, automated approaches, it has been achieved by arithmetically combining mapped variables, often with weights applied to variables to reflect their relative importance, that can yield a surface single value<sup>38</sup>. This might yield satisfactory results at fairly local levels but, as noted, the complexity of land degradation, when considered globally, has rendered it virtually impossible to define satisfactorily. Without a satisfactory definition, land degradation cannot be mapped through any combination of variables.

Convergence of evidence - challenges

WAD3 builds on the availability of multiple, reliable global data sets and 20 years of scientific study since WAD2, especially relating to socio-economic factors.

Fundamental challenges remain. First, what is the most judicious way to select and analyse the wide array of existing and future global data sets in order to convey the location and severity of a land degradation problem? Second, what is the appropriate context? What is the relative severity of a problem, how does it compare to other places, and what might be learned from multiple experiences?

Land use expresses the human-ecosystem interactions, hence reflects the level of human exploitation of the ecosystem. WAD3 provides a framework of context at the global scale and begins with broad classes of land use and land cover (e.g. agriculture, rangeland, forest). It is understood that, while mapped as discrete units, these are sometimes “pure,” but often grade into each other or are mosaics of many classes. The purpose of looking to convergence patterns through such stratifications is to allow for comparison of “apples with apples” (e.g. agriculture vs agriculture) at a global scale.

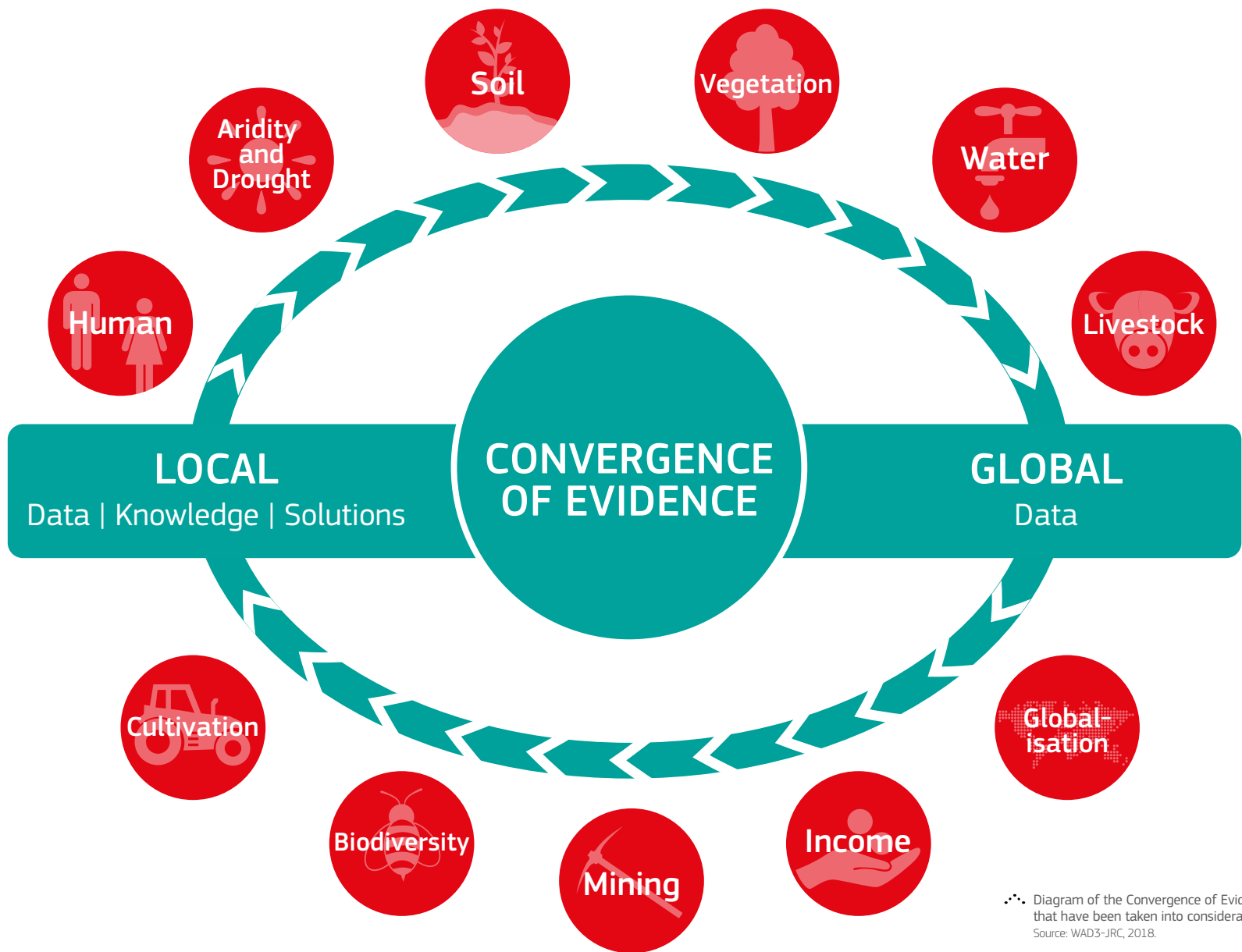
Within this framework, rather than attempting to combine multiple data sets into a single index or model outcome, WAD3 considers 14 variables often associated with land degradation. Global maps of these variables were processed by considered land cover/use stratification class by applying simple thresholds, typically median values, to identify those areas where median values were exceeded (positively or negatively). These maps may then be combined or overlaid. The coincidence (or convergence) of these “lines of evidence” may signal a potential stress or disturbance on the land resources, which may warrant more intense investigation.

The examples presented in ‘Section V Convergence of Evidence’, show a number of variables that have been flagged because they occur at every point within the rainfed agriculture class or smallholder areas, etc. It may be that the occurrence of a number of variables, or the larger the number that co-occur (converge) at any one point suggests that there is a problem worthy of examination with regard to land degradation.

In section V, convergences are presented and examined from various interests and viewpoints, such as areas with high and low density cultivation, high and low input cultivation, smallholders, irrigation, rangeland, forest, as well as protected areas. This provides an initial framework to help interpret the convergence patterns for which global and continental statistics are given on key issues and the number of issues coinciding at any place, as well as the distribution of issues according to land productivity dynamics. This approach can be applied across scales from global to local using additional datasets.

The web-enabled WAD3 platform:

- a. provides opportunities to examine global data sets with user-defined models to identify areas where degradation might be expected within a region of interest (as above)
- b. and aims at providing tools to validate or discard those findings by comparing them with more geographically specific local data provided or obtained by the user,
- c. compare results with similar sites and situations in other parts of the world to establish under the conditions under which they might be extended, and
- d. consider solutions that have been applied in other places to determine when and where they might be extended.





## Key messages

Although desertification remains in the title, the 3<sup>rd</sup> edition of the World Atlas of Desertification represents a significant departure from the first two editions: it is asserted that ‘desertification’ or ‘land degradation’ cannot be captured in global maps in a way that satisfies all stakeholders. Instead, WAD3 illustrates the geographic distribution of coincident patterns of issues that may indicate potential land degradation.

In lieu of a “global assessment”, WAD3 uses a convergence of evidence approach.

Global change issues involve complex socio-ecosystem interactions that drive land transformations. Where on-going issues converge (e.g. population decline, high yield gaps, loss of land cover), this may indicate land degradation is occurring and suggest potential underlying drivers.

The significance of land degradation as global problem is determined by the local social, economic and ecological context in which it occurs.

### Key messages that emerge include:

1. underlying and familiar factors - some old, some new - are driving environmental change/land degradation at a global scale;
2. some recurring global issues (such as surface and ground water) have an alarming urgency that could not be known 20 years ago;
3. there is a growing confirmation of suspected global trends (such as a decline in productivity) that may impact sustainability;
4. global issues that were only suspected previously will shape how we look at both processes and solutions (such as telecouplings; smallholders vs. largeholders);
5. some regional patterns of potential degradation are reconfirmed (south Asia; China) and some underlying causes are revealed (heavy fertiliser use and irrigation);
6. new regional patterns of potential land degradation are revealed (especially in central Asia); and
7. concerns emerge at the regional level that brings into question our ability to meet the demands of future populations, e.g. maintaining and increasing yields on high-density croplands and increasing crop yields (by closing yield gaps) on low-density and low-input croplands.

#### Underlying global trends

By 2050, the world’s population will exceed 9 billion. To meet the increased demand for food, fibre and energy, pressure on the planet’s finite natural resources will be exacerbated.

Significant trends include:

**Urbanisation.** The proportion of the population residing in urban areas will continue to rise, particularly in drylands (PART IV, pages 80-84). Urban areas and their supporting infrastructure will continue to consume agricultural land (page 50).

**Climate change.** Over the remainder of this century, the climate of the globe is expected to become both warmer and drier. In concert with the growth in urban areas, much of the pressure of climate change will be felt in urban areas, particularly in drylands (PART IV, pages 74-82).

**Dietary changes.** Over the past 50 years, increases in population income has brought about a shift in human diet preferences away from foods largely derived directly from plants, to one increasingly focused on animal products (milk, meat, eggs). This trend significantly exacerbates the pressure on finite land resources (PART III, page 46).

#### Global issues: Recurring

**Old issue, new urgency.** New global data on the Earth’s water resources highlight this critical issue. While surface water area is greater than any time in the past 30 years, much of this is due to the construction of dams. Dams may benefit local interests but threaten livelihoods and environments downstream, often across international borders. The dynamics of global groundwater, which were unknowable 20 years ago, show alarming declines; this is especially the case in areas of high demand (e.g. irrigated agriculture). Global patterns of surface- and groundwater indicate the need to manage risk and strategically plan for water shortages, especially since the human population is growing, demand for water is increasing and the threat of climate change adds increasing uncertainty (PART IV, pages 86-94).

#### Global trends: Potential

**Declining land productivity.** There is a concern that the productivity of the land resources of the Earth is declining (PART IV, page 114).

#### Global issues: New

**Telecoupling.** The globalisation of the world’s economy has environmental consequences, which were little considered 20 years ago. Now, changes in land use may be geographically displaced. For example, increased demand for agricultural products in developed countries (e.g. Japan) may lead to deforestation in developing countries (e.g. Brazil) to meet that demand (PART II, page 40). Moreover, the export of products (e.g. maize) from one country to another involves not only the grain itself, but the water required to produce it. Also, a further effect of telecoupling provoked by increased consumption is a mental decoupling of the cause-effect relation of possible land degradation, resulting in public apathy. As our understanding of environmental lifecycle accounting and international value chains grow, so too must our appreciation of the true costs of perceived benefits.

**Smallholders.** The role of smallholders as agents of land management and environmental change has been underappreciated (PART III, page 64). More than 80% of all farms on the planet are less than 2 ha in size and are managed by poor households. The types of technology that must be adopted globally to increase agricultural production, while minimising or reversing environmental impacts, is dependent on how well potential interventions match existing management strategies and the ability of smallholders to adapt.

#### Regional patterns: Old and New

Although WAD3 does not offer a comprehensive assessment of global land degradation, a number of findings emerge when examining multiple global data sets within an analytic framework (i.e. convergence of evidence, see PART V):

##### *Familiar patterns, old concerns*

A number of key issues ‘converge’ throughout the Sahel and eastern Africa. These include yield gaps, decreased productivity and chronic low income.

Transformation of forest to irrigated farmlands threatens vast areas of the Chaco in Argentina, Paraguay and Bolivia.

In densely populated areas of Europe and North America, urban expansion is consuming land resources, and high-intensive agriculture requires large, continuous inputs of nutrients.

##### *Familiar patterns, new concerns*

The coincidence of many issues in the northern part of southern Asia, largely within the Indo-Gangetic plains of India and Pakistan and the North China plain, suggest the role of land degradation. Most notable are the high population densities, dependence on high inputs of fertilisers and the persistence of low incomes. Some new issues have emerged in WAD3 that underscore these concerns. In particular, the dominance of smallholders in both southern Asia and China suggest challenges and vulnerabilities that may have been underappreciated in the past. Moreover, alarming declines in groundwater in both areas may foreshadow significant problems in the future, particularly in the face of climate change.

##### *New patterns, potential concerns*

The vast wheat-producing region developed by the former Soviet Union emerges as an area of concern. Large-scale, low-input agricultural operations, mainly in sparsely populated parts of Russia and Kazakhstan, are seen as a potential opportunity to increase global agricultural production but also as a potential environmental threat. Increased production could be achieved by increasing fertiliser inputs. Projected changes in climate may also make these areas more favourable for agricultural intensification. However, much of the land currently in production is marginally productive and may have higher value as habitat areas. Moreover, increased fertiliser inputs could have negative impacts on water resources and adjacent habitats.