European Commission

WORLD ATLAS OF DESERTIFICATION

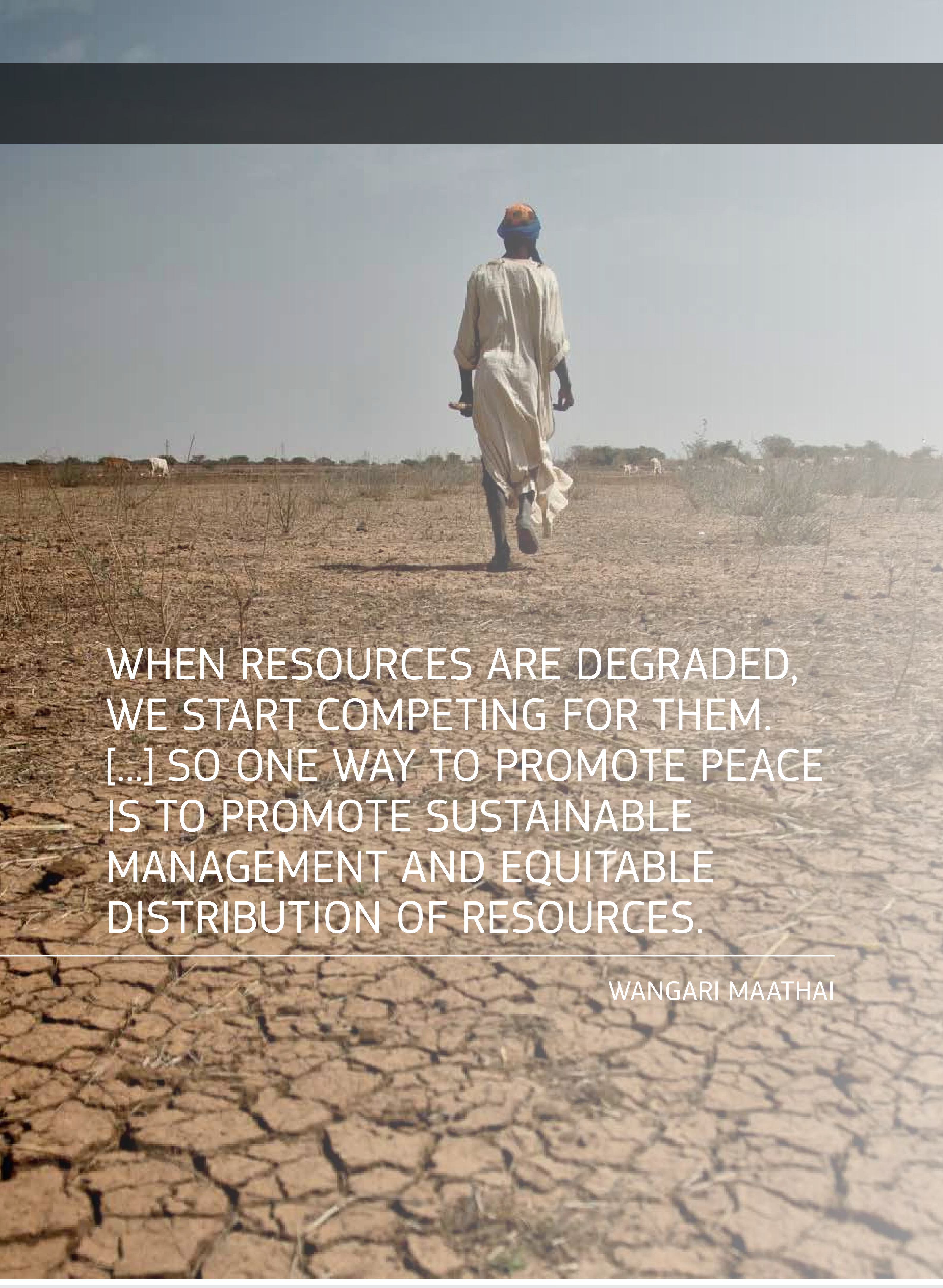
Third Edition

Mapping Land Degradation and Sustainable Land Management Opportunities

Introductory brochure

Joint Research Centre

JRC97776



WHEN RESOURCES ARE DEGRADED, WE START COMPETING FOR THEM. [...] SO ONE WAY TO PROMOTE PEACE IS TO PROMOTE SUSTAINABLE MANAGEMENT AND EQUITABLE DISTRIBUTION OF RESOURCES.

WANGARI MAATHAI

Introduction

Exponential increase in human population and changes in consumption patterns have created unprecedented pressure on the Earth's natural resources. These natural resources (land, water, air, etc.), and the ecosystem goods and services derived from them, support the livelihoods of all humans. It is the responsibility of all to manage these resources so that the present generation can fulfil their needs without compromising the ability of future generations to meet theirs.

In a rapidly changing world this is an enormous challenge because a multitude of global drivers - including demographic pressures, globalised economies, intensified agriculture, overharvesting of natural products, and climate change - are interacting simultaneously. When this leads to land degradation it poses serious threats to nutrition and food security, water resources, clean air, cultural values, and economic development.

To properly address the complicated challenge of land degradation, decision makers, environmental managers and all interested stakeholders need reliable and understandable information.

The third edition of the World Atlas of Desertification (WAD) builds on state-of-the-art scientific concepts on land degradation. Given the complexity underlying land degradation, it is not amenable to single global maps that can satisfy all views or needs. Rather, this WAD presents a number of global datasets to identify important, on-going biophysical and socio-economic processes that, on their own or combined, can lead to unsustainable land use and land degradation. This brochure provides a short overview of these issues. It also provides some examples that reflect global patterns of land degradation to highlight and extract practical principles and methods for developing solutions.

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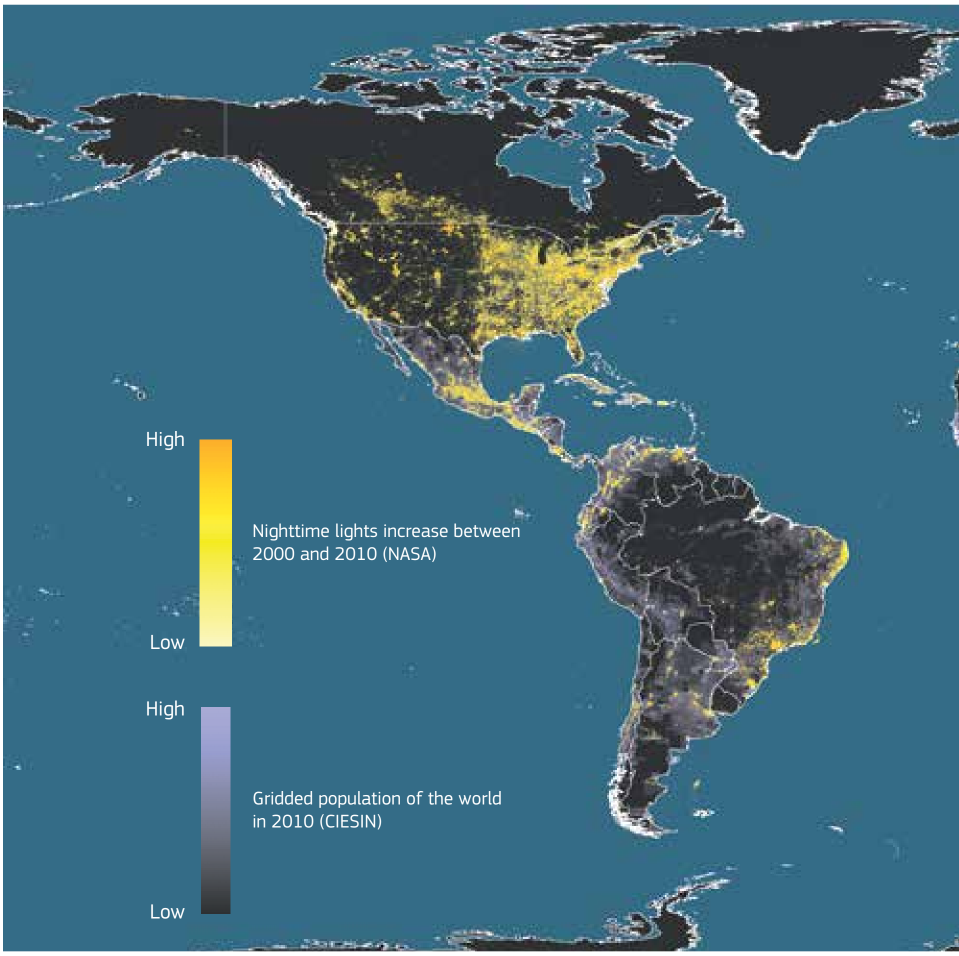
Human Dominance

HUMANS DRIVE GLOBAL ENVIRONMENTAL CHANGE.



Humans dominate the planet and their influence extends to every part of the world. Global population has reached seven billion people and is projected to reach 8.3 billion by 2030 [1]. This is expected to create unprecedented pressure on the Earth''s natural resources [2]. The term *anthropocene* has been introduced to describe the current era in which human actions have become the main driver of global environmental change [3]. Acknowledging this, new approaches such as "anthropogenic biome" mapping depict global patterns of land use based on sustained, direct human interactions with ecosystems [4].

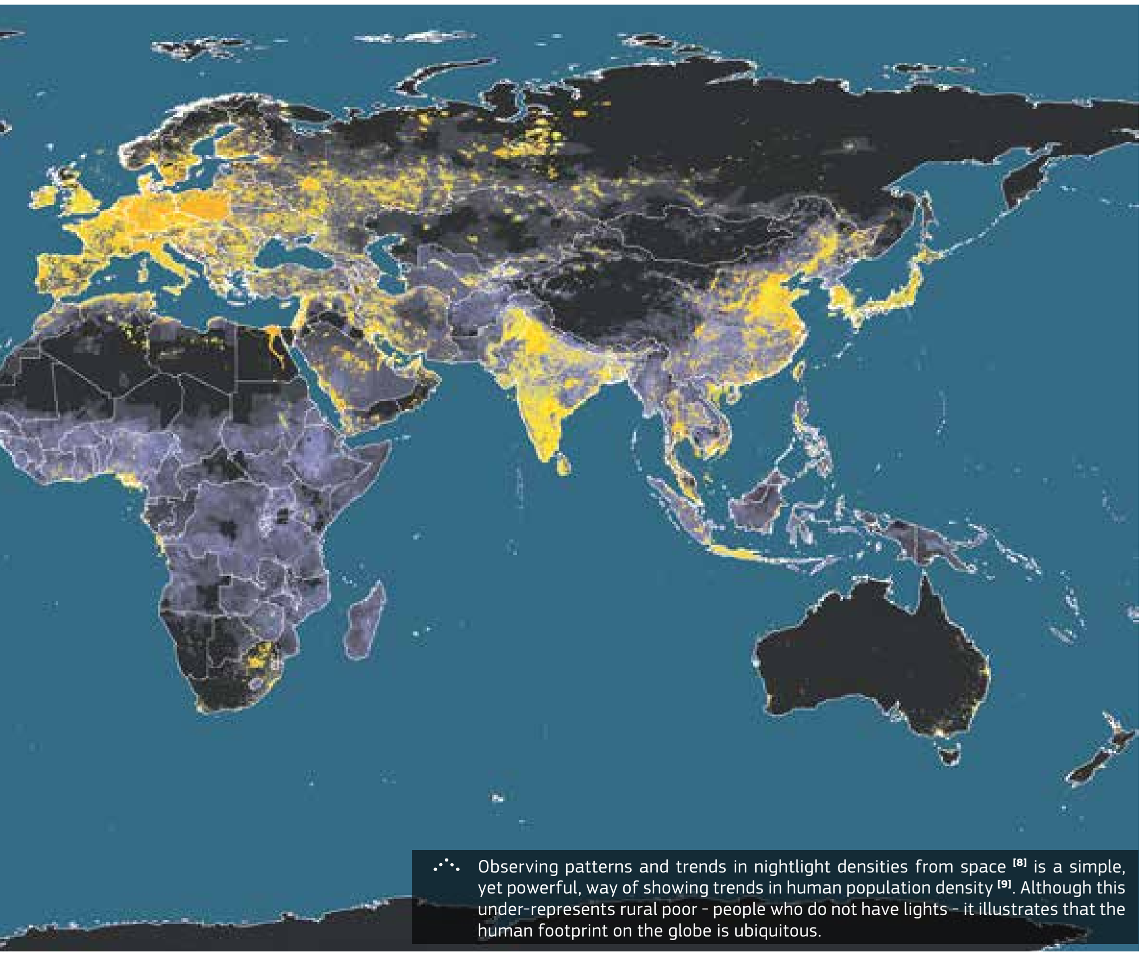
There is enormous pressure on global land resources due to rising food demand, a global shift in dietary habits, biofuel production and urbanisation [2,5]. Landfills, mining and other extraction activities also contribute to the pressure on land resources. Hence, productive land is becoming scarce.

The rural poor often are forced to overexploit available land via low-input and low yield agriculture, deforestation, and overgrazing, all of which contribute to land degradation [6]. The consequences of degraded land are disproportionately borne by the poor, are a principal factor contributing to poverty, and remain a barrier to be tackled for achieving the Sustainable Development Goals set by the United Nations [7].

This WAD examines and illustrates examples of:

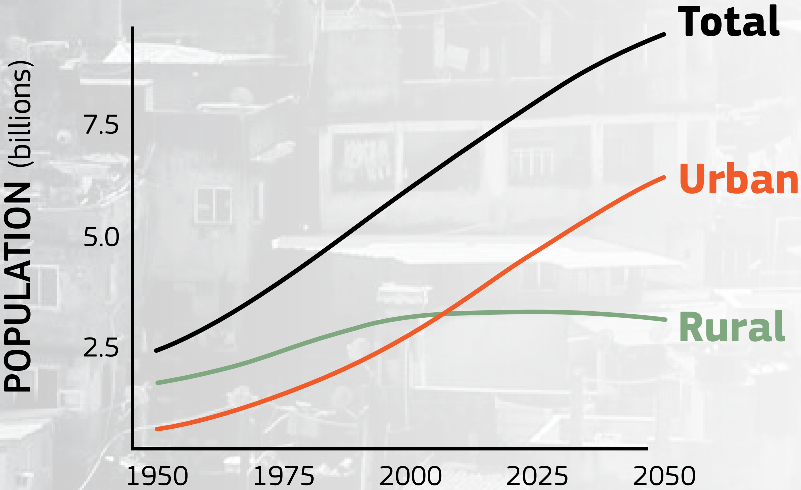
1. human-environment interactions globally, but with a focus on drylands;
2. underlying causes and consequences of land degradation; and
3. potentials and limitations of efforts to combat desertification.

More than 75% of the land is used by humans (excluding Greenland and Antarctica) [10].



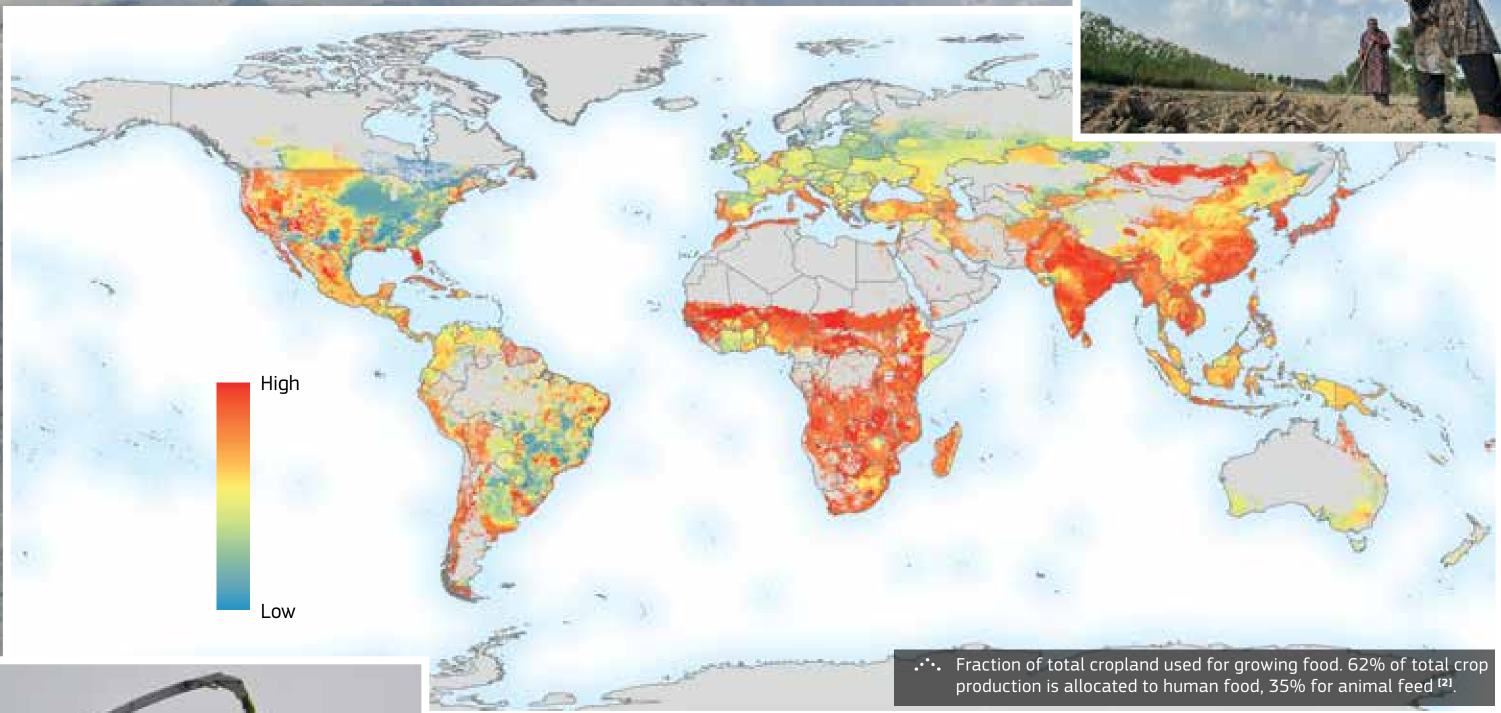
Observing patterns and trends in nightlight densities from space [8] is a simple, yet powerful, way of showing trends in human population density [9]. Although this under-represents rural poor - people who do not have lights - it illustrates that the human footprint on the globe is ubiquitous.

2007 was the first year in human history when most people on Earth live in cities.[11, 12]

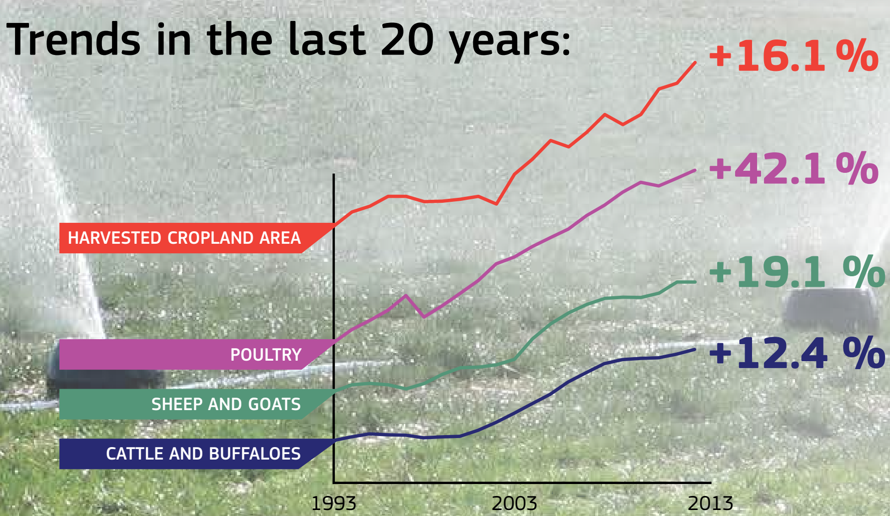


Feeding a growing global population

EXPANSION AND INTENSIFICATION OF AGRICULTURE INCREASE PRESSURES ON LAND.



Fraction of total cropland used for growing food. 62% of total crop production is allocated to human food, 35% for animal feed [2].



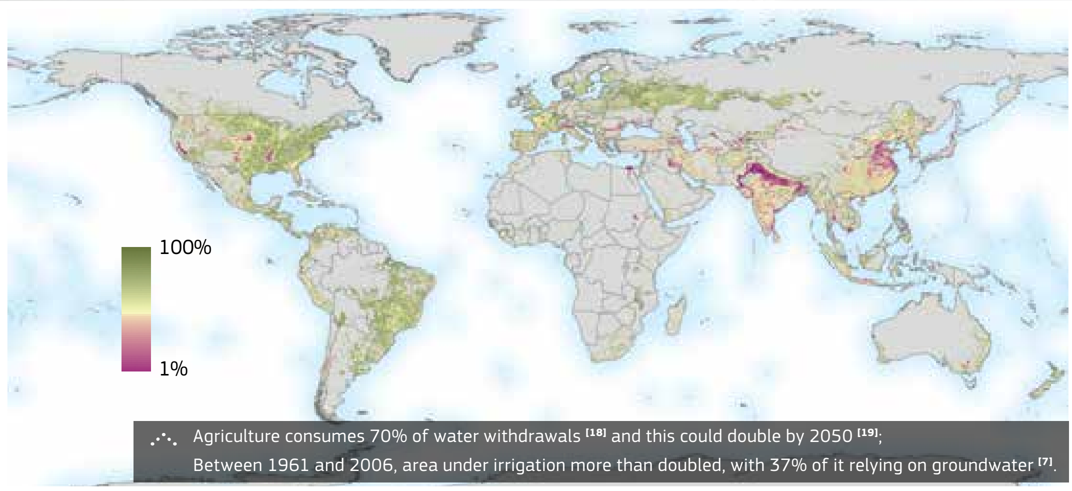
As the income of the global population rises, meat consumption increases. The demand for fodder drives expansion or intensification of agriculture [17].

4 times more land and 10 times more water is needed to produce 1 kg of protein from beef than from pulses [21,22]

Over the last 20 years the extent of land area harvested has increased by 16%, the area under irrigation has doubled, and agricultural production has grown nearly three-fold [7]. Yet, close to one billion people remain undernourished [13].

In large parts of Africa, South America and Asia, agricultural yields are well below their maximum potential. The difference between actual agricultural productivity and its potential productivity is called the "yield gap." Yield gaps can be mapped at global scales [14] and highlight those areas where agriculture production has reached its maximum (intensive agriculture in industrialised countries) and where it is low (rural areas on marginal lands where there is limited access to seed, fertiliser and technology). Over large parts of Africa, fields are expanded into rangeland to compensate for low productivity and poor management practices.

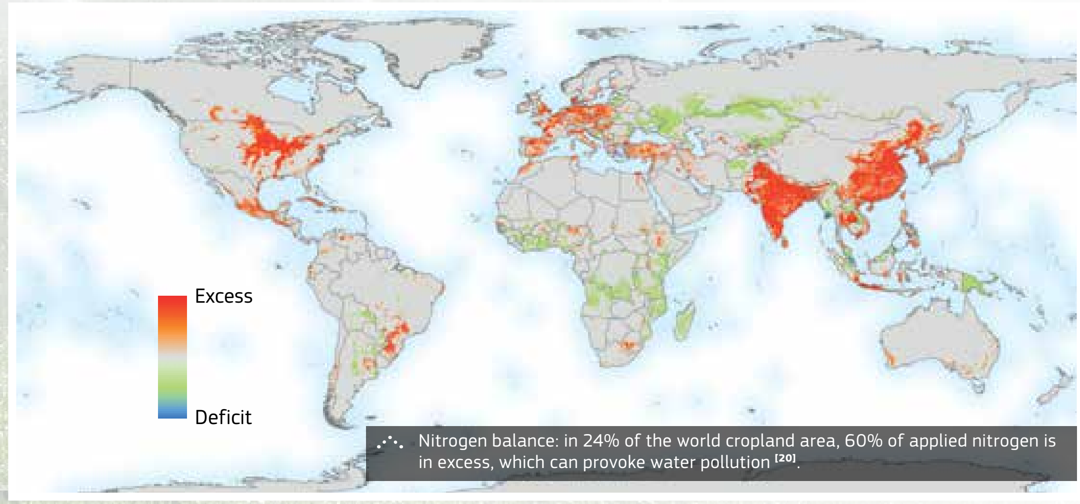
Closing yield gaps usually entails inputs of nutrients and water, both of which have serious environmental consequences. Introducing improved management practices including contouring, terracing and techniques for soil management can improve yields without the negative impacts.



Agriculture consumes 70% of water withdrawals [18] and this could double by 2050 [19]; Between 1961 and 2006, area under irrigation more than doubled, with 37% of it relying on groundwater [7].

As the world's economy grows – however unevenly – there is a corresponding increase in the demand for animal protein, especially in developing countries. Expansion of livestock production is a key factor in deforestation. In recent years, global livestock production is shifting, mainly from rural to urban areas, to get closer to consumers, sources of feedstuff and transport and trade hubs [15]. Although this intensification of the livestock sector to feedlots is predicted to meet the demand for meat and dairy products for developing countries by 2030 [16], more agriculture land is used intensively to indirectly produce food.

The WAD documents these global trends in agricultural land use and maps where some of them occur and coincide with other drivers to potentially increase land degradation.



Nitrogen balance: in 24% of the world cropland area, 60% of applied nitrogen is in excess, which can provoke water pollution [20].

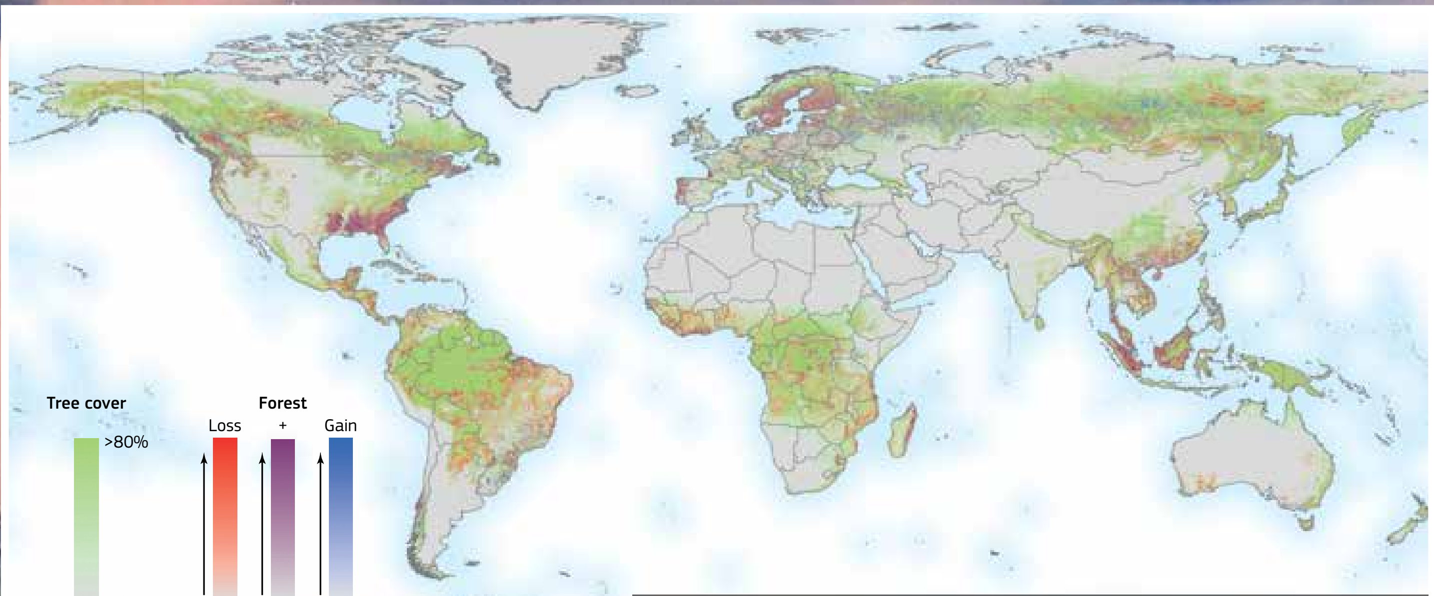
QUANTIFYING GLOBAL LAND RESOURCE EXPLOITATION.

Unsustainable human activities put land at risk. In Europe alone, inappropriate land management practices account for an estimated 970 million tons of soil loss due to erosion each year [23]. Worldwide, the annual loss of soil is estimated at 24 billion tonnes [24].

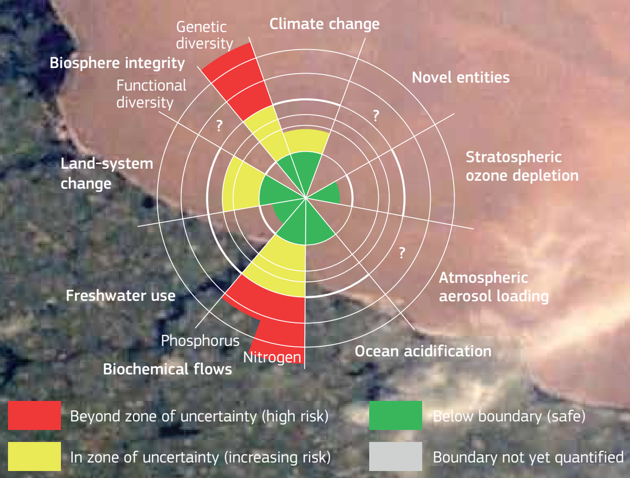
Satellite observations suggest that globally between 2000 and 2012, 2.3 million square kilometres of forest were lost, while only 0.8 million kilometres were reforested [25]. Loss of forest affects biodiversity, nutrient, carbon and water cycles and climate. Whilst some forest is converted into sustainable cropland, much of the cleared forest remains in a degraded state.

If we wish to arrest or reverse the decline of our natural resource base, we must first understand and monitor the land status as well as understand the various processes of land degradation so as to know the extent of the problem and prospects for remediation.

This will allow us to establish "planetary boundaries" – the limits of the biophysical envelope that sustains life on Earth [26]. By understanding the thresholds within which human actions can be maintained we can avoid severe or catastrophic disruption in the future.



New possibilities for detailed systematic mapping at global scale of forest cover depict a globally consistent and locally relevant record of forest change. A clear trend can be observed in the tropics with forest loss increasing by 2101 square kilometres per year [25].



Planetary boundaries quantify the risk that human perturbations will destabilise the Earth System at planetary scale [26].

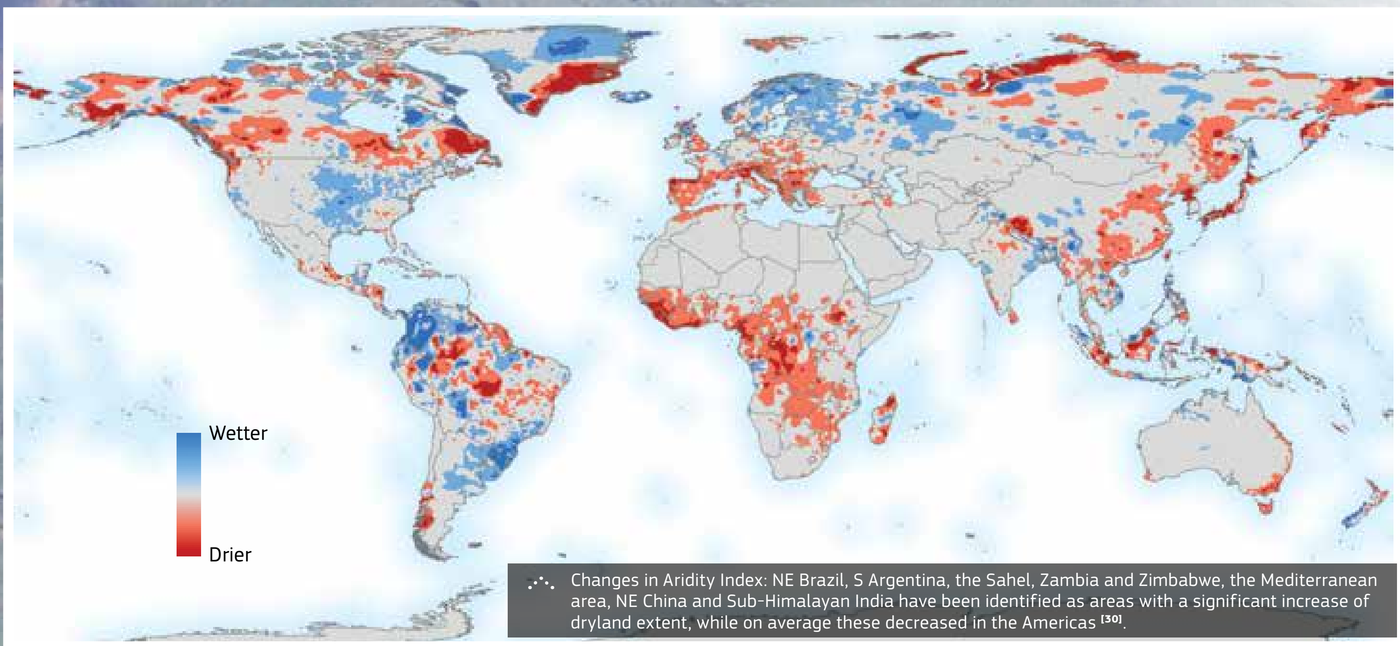
Aridity and drought patterns cause increasing pressure on land and water resources.

ARIDITY AND DROUGHT.

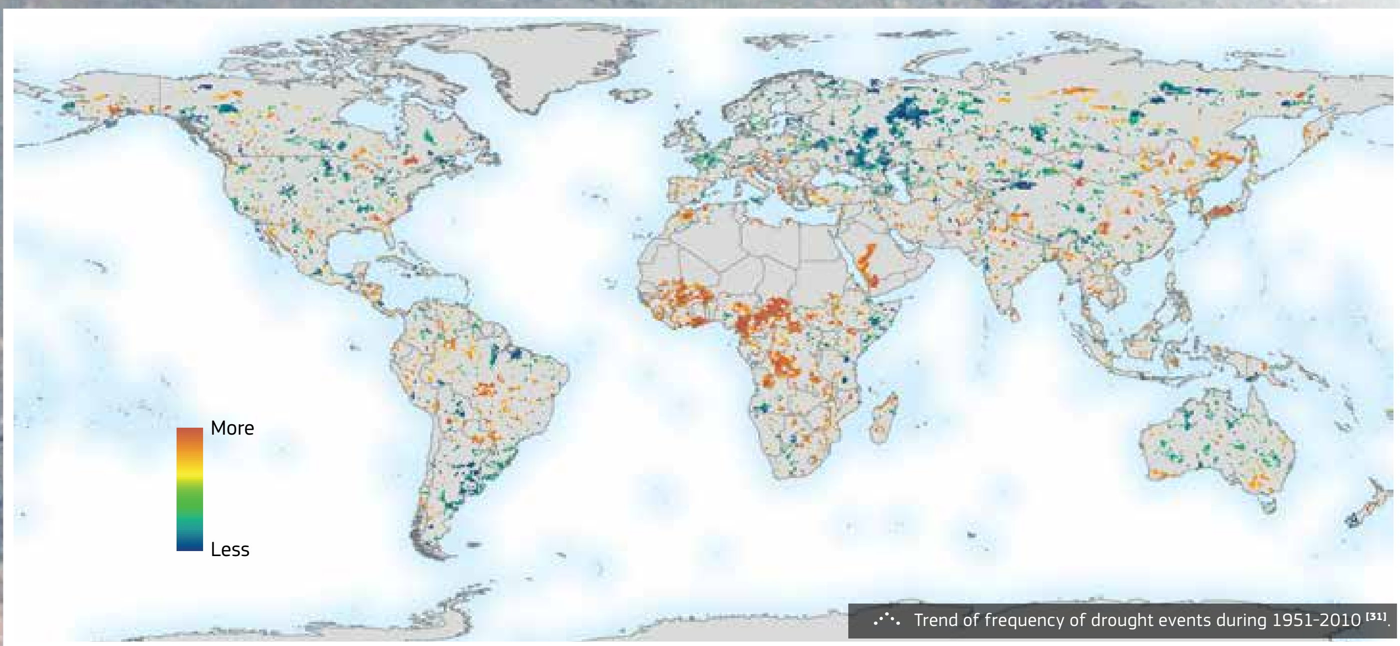
By 2025, 1.8 billion people will be living in regions with absolute water scarcity [27]. More than half the world's people already live in countries where aquifers are being depleted [28,29].

Globally, arid areas increased between 1951–1980 and 1981–2010, many of them coinciding with land degradation problems [30].

Drought is one of the most relevant natural disasters and can aggravate the land degradation processes. Between 1951 and 2010 a small increase in global drought frequency, duration, and severity has been observed, especially over Africa, but drought frequency decreased in the Northern Hemisphere [31].



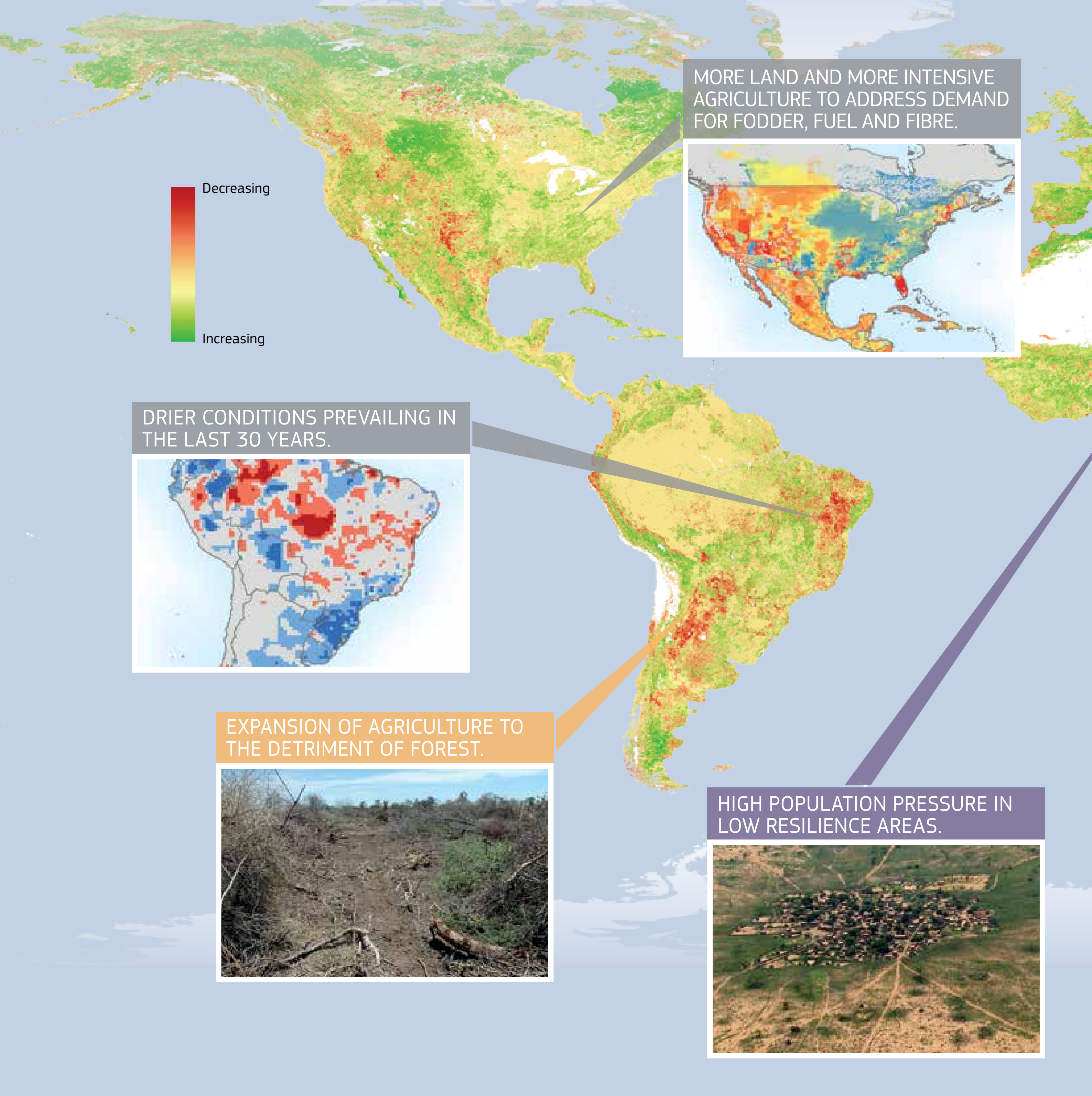
Changes in Aridity Index: NE Brazil, S Argentina, the Sahel, Zambia and Zimbabwe, the Mediterranean area, NE China and Sub-Himalayan India have been identified as areas with a significant increase of dryland extent, while on average these decreased in the Americas [30].



Trend of frequency of drought events during 1951-2010 [31].

Converging evidence

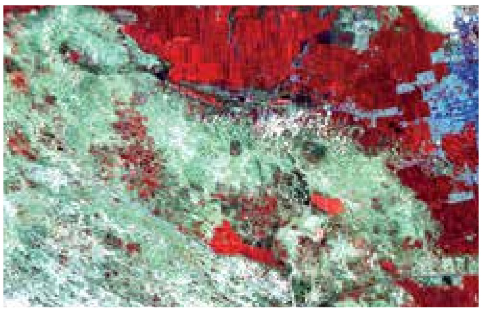
A growing global population has led to an increase in the demand for food, fibre and fuel. This has a significant impact on limited land resources, which often leads to land degradation. However, at any given place on Earth, complex human-environment interactions are at play, which include differing rates and magnitudes of drivers (e.g., overgrazing, climate change, agricultural practices) and consequences (e.g., soil erosion, changes in productivity, loss of biodiversity) [32,33]; hence, land degradation is not a phenomenon that can be modelled at a global scale. To acknowledge and accommodate these complex local interactions and dynamics, the new World Atlas of Desertification relies on a "convergence of evidence" in global datasets.



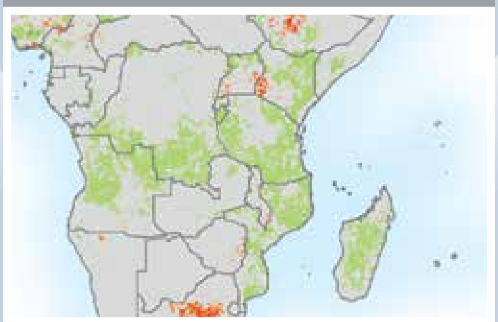
HIGH POPULATION DENSITY AND INFRASTRUCTURE DEVELOPMENT CHALLENGES LIMITS TO SUSTAINABILITY.

LAND AND WATER CONSERVATION FOR SUSTAINABLE AGRICULTURE EXPANSION.

UNSUSTAINABLE WATER USE FOR AGRICULTURE EXPANSION AND INTENSIFICATION.

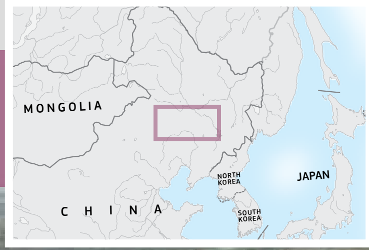


YIELD GAPS AND RESOURCE EXHAUSTION DUE TO NUTRIENT DEFICIT.



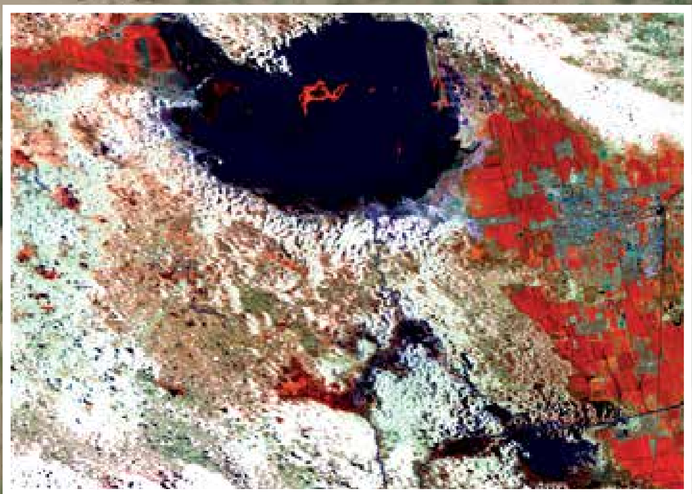
Land productivity is an essential concept for monitoring land degradation. Various approaches to map land productivity provide consistent and repeatable views regarding what areas of concern or improvement to highlight. The map shown here is based on 15 years of satellite observations at ten-day intervals [34,35]. While not an absolute measure of land productivity, it depicts long-term seasonal dynamics and departures that may relate to productivity change. The "convergence of evidence" in regional productivity trends illustrated here - as well as in other global data sets - provides insights for further examination of more local data to understand the underlying causes and consequences of observed trends [36].

UNSUSTAINABLE WATER USE FOR AGRICULTURE EXPANSION AND INTENSIFICATION.

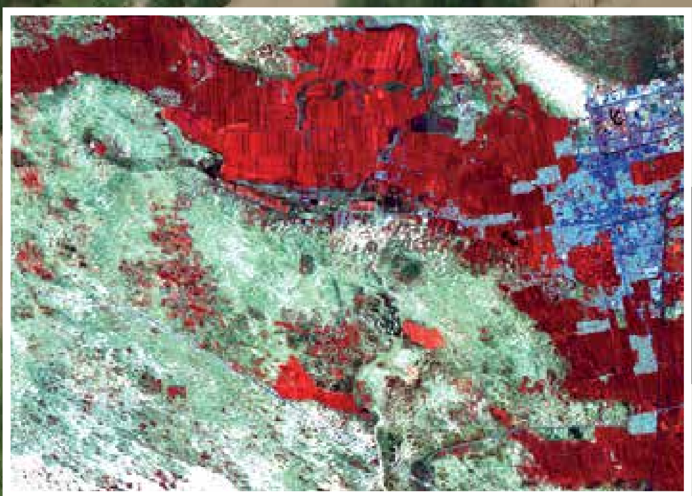


Land use change in Northern China.

1987



2013

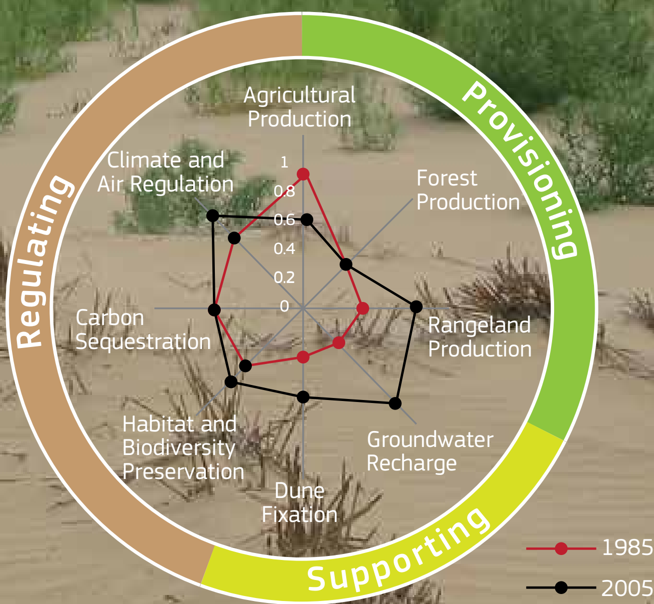


Introducing agriculture in marginal lands that have traditionally been used for grazing sheep and cattle has caused erodable soil surfaces that easily become mobilised by wind, a process known as "Sandification" in large areas of Northern China [37].

From 1980 onward, the privatisation of farmland coupled with the introduction of state incentives has increased productivity, largely driven by groundwater irrigation and fertiliser use. Together with the legal implementation of access regulations and restrictions, the expansion of cropland into environmentally sensitive rangelands was slowed, and moving dunes and sand sheets were partially stabilised. These positive actions, however, were accompanied by a rapid depletion of groundwater resources and today most of the lakes and wetlands have disappeared.

Governmental decisions have thus triggered trade-offs between essential ecosystem services, primarily by optimising crop production at the cost of groundwater recharge capacities. Using high resolution satellite imagery the dynamics in trade-offs can be quantified [38,39] and this information used for better decision making.

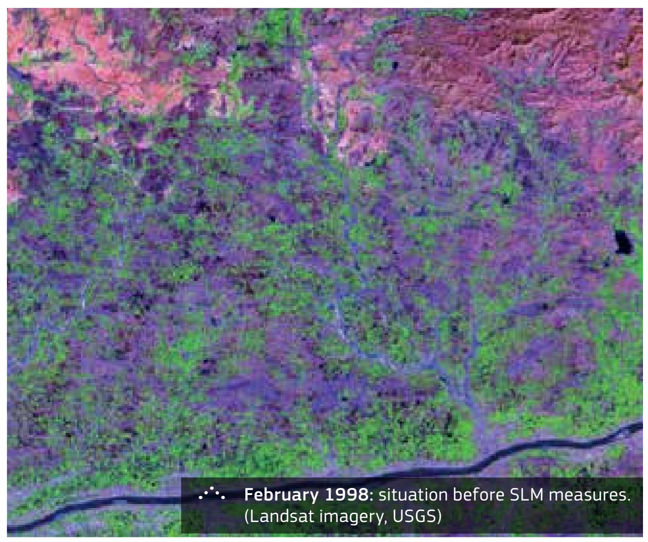
Land use change between 1987 and 2013. Water bodies in dark blue give way to agriculture in red (Landsat imagery (USGS) processed by Hill J. *et al.*). Smallholder irrigation systems are increasingly replaced by large-scale pivot irrigation schemes for producing fodder. This tends to lower the water table and to reduce the area accessible for grazing. The sustainability of the current land use concepts should therefore be questioned.



LAND AND WATER CONSERVATION FOR SUSTAINABLE AGRICULTURE EXPANSION.

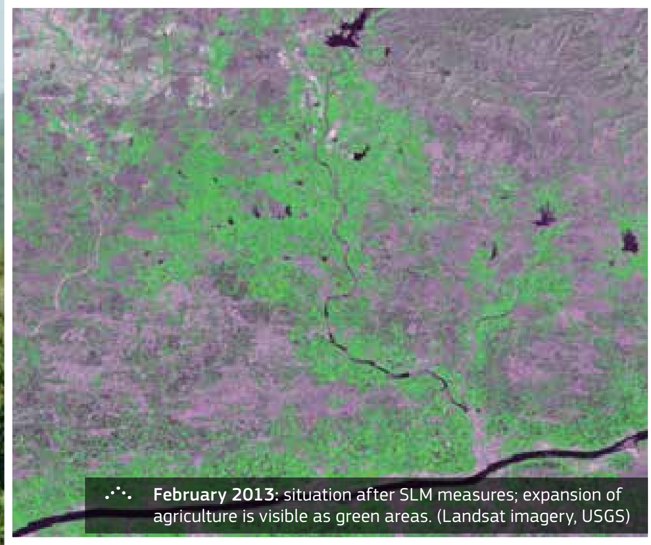
Rainwater harvesting in Central India.

1998



February 1998: situation before SLM measures. (Landsat imagery, USGS)

2013



February 2013: situation after SLM measures; expansion of agriculture is visible as green areas. (Landsat imagery, USGS)

Evidence of new surface water bodies, many by small dam construction, in support of agriculture expansion. Black: water bodies; green: new water bodies (water occurrence, JRC/GEE).

In many parts of India, sustainable land management practices have been implemented as part of watershed development programs to combat land degradation, desertification and drought. Such practices aim to conserve and improve land and water resources for agriculture expansion. About 60% of the land area of India is used for agriculture, of which 35% is under irrigation [40]. Responding to the need of water and increased food production, soil and water conservation measures have been successfully implemented in the Jhabua and Dhar districts of Madhya Pradesh (central India) during the last two decades. From 1998 to 2013, cropped area has increased by 15%. Such agriculture expansion has been made maintainable by construction of rainwater harvesting structures, such as check dams and small stop dams (nala bunds), in addition to soil conservation practices. The number of surface water bodies increased by 23%, from 210 in 1998 to 270 in 2013. These water bodies support the increased use of water for irrigation and domestic purposes as well as recharging of groundwater.

Combination of high-resolution imagery, spanning a 30-year period, with high computing capability now allows for detailed and regular surface water monitoring at global scale.

AGRICULTURE EXPANDS, FORESTS RETREAT.

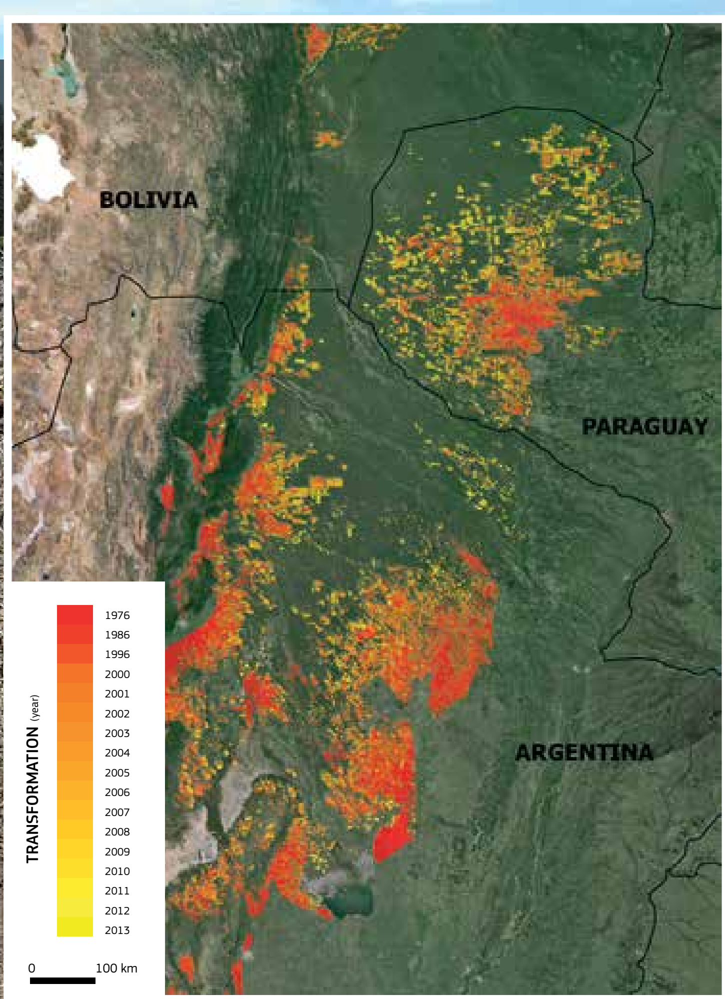
Example of the Dry Chaco: change in land use and land cover driven by globalisation [41].

The South American Dry Chaco is a vast semiarid plain spreading over Argentina, Paraguay and Bolivia. However, the native vegetation, particularly dry forests, is undergoing one of the highest deforestation rates in the world. This transformation is due to rapid agricultural expansion and intensification, especially crop production (soy, maize) and cattle ranching. Opportunities created by socioeconomic globalisation, including increase in global demands for feedstuff and attractive economical returns are driving and accelerating these changes. These land transformations have resulted in significant losses of biodiversity, fragmentation of the landscape, and a reduction of essential ecosystem services [42].

Large-scale conversion of Dry Chaco forests to annual crops and pasture affects climate changes, alters regional ecosystem functioning, and may lead to unanticipated social problems and increased degradation of the land resource [43].

Monitoring is essential to identify biophysical, social, political and economic drivers of changes and to develop land use planning and management policies to mitigate or reverse them.

Between 1976 and 2012, 20% of the whole ecoregion has been transformed, with exponentially growing annual transformation rate in Paraguay. Areas coloured from red (transformed in 1976) to yellow (transformed in 2013) show the extent and rapid pace of transformation of Dry Chaco into crops or pastures.



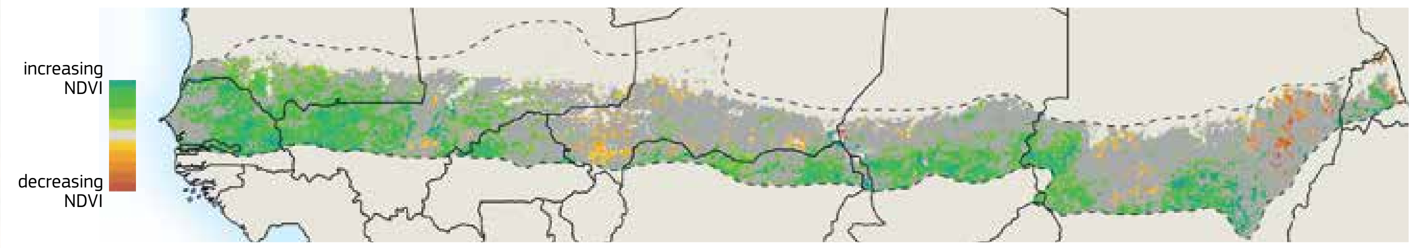
HIGH POPULATION PRESSURE IN LOW RESILIENCE AREAS.

The Sahel: a transition zone between the Sahara desert and the tropics.

In the past 50 years, an increase of sedentary human presence and activities, together with climatic variability, has caused major environmental changes in the semi-arid Sahelian zone. As a result the degradation of arable lands has been a major concern for livelihoods and food security. Despite decades of intensive research on human-environmental systems in the Sahel, there is no overall consensus about the severity of land degradation [44].

Earth observation data suggest an overall increase in vegetation greenness that can be confirmed by ground observations. However, it remains unclear if the observed positive trends provide an environmental improvement with positive effects on people's livelihood [36]. Long-term assessments of biodiversity at finer scales highlight in some cases a negative trend in species diversity [45].

The WAD illustrates and underlines the need to monitor land dynamics by combining long-term information from Earth observation with *in situ* observations to improve understanding of the site specific impact of changes in land use and observed land cover trends.



Recent Earth Observation studies show a positive trend in rainfall and vegetation index over the last decades for the majority of the Sahel - known as the re-greening of the Sahel [46]. This has been interpreted as an increase in biomass and contradicts prevailing narratives of widespread degradation caused by human overuse and climate change. Yet, observable areas of decreasing productivity, e.g. in Niger and Sudan, indicate that the re-greening process is not uniform across the entire Sahel.

Solutions

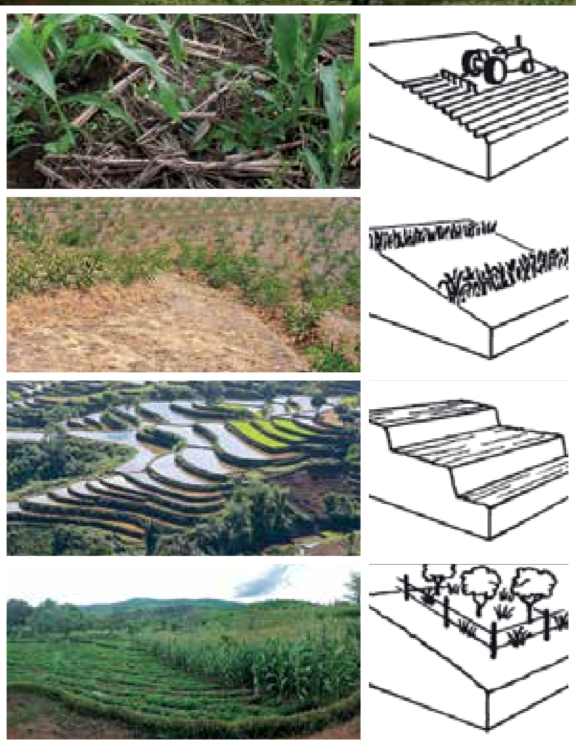
TOWARDS LAND DEGRADATION NEUTRALITY.

Maintaining or improving the productive capacity of land requires a move towards land degradation neutrality [47]. This is a matter of preserving or enhancing the ability of land resources to support ecosystem functions and services. Sustainable management of soil, water and biodiversity can help close yield gaps, increase the resilience of land, and thus support the people who depend on it for their livelihoods.

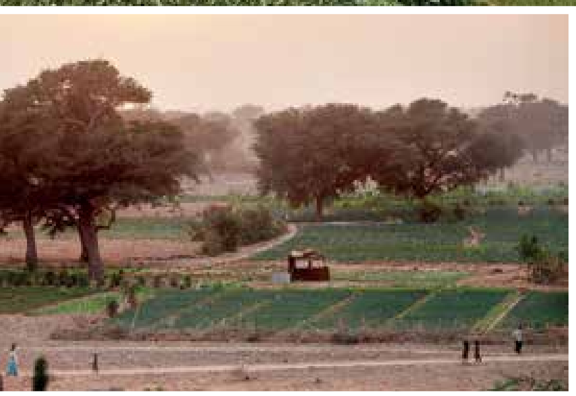
The World Overview of Conservation Approaches and Technologies (WOCAT) is an example of an initiative that promotes sustainable land management (SLM) and knowledge sharing. This network of specialists facilitates the reporting, dissemination and the implementation of locally adapted SLM practices. WOCAT defines four categories of measures to prevent, mitigate and rehabilitate land degradation and restore ecosystem services which can be combined on a same site to achieve a comprehensive management.

National, regional and international initiatives to recover degraded land are numerous and diverse. The **Great Green Wall of the Sahara** and the **Sahel Initiative** is an example of an international project. Its objective is to increase the resilience of human and natural systems in Sahel and Saharan areas faced with climate change. It encourages innovative solutions to manage ecosystems and to sustain natural resources. Emphasis is placed on the protection of tangible and intangible rural heritage, the development of rural production systems, and the improvement of the living conditions and livelihoods of people living in these areas.

The new World Atlas of Desertification highlights options and possibilities for sustainable solutions to halt and prevent land degradation.



WOCAT SLM measures: (1) agronomic measures to improve the soil (mulching, manuring, conservation tillage); (2) vegetative measures such as planting trees, shrubs or grasses; (3) structural measures that change the land (terraces, dams, ditches); and (4) management measures, including change of land use, intensity or timing.



Implementing the Great Green Wall of the Sahara and the Sahel.

The WAD Core Features

The WAD considers land degradation and desertification to be a persistent reduction or loss of biological and economic productivity of land caused by human activities, often accelerated by natural factors like increasing aridity and climate change. Focus is on land used by people whose livelihoods depend on this productivity, yet the reduction or loss of this productivity is driven by their use.

While the previous editions of the WAD started by considering primarily the bio-physical boundary conditions for land and soil degradation, the new WAD puts the Human-Environment (H-E) interaction in the centre of its analytical review of state and trends of global land degradation and desertification.

The new WAD thus acknowledges that human societies and their use of land are on one hand drivers of land degradation and desertification, but also the key to sustainable solutions of this global problem.

The WAD mapping does not strive for a single land degradation index but builds on a systematic framework of providing a convergence of evidence of human-environment interactions for identifying pathways of land degradation and restoration. This approach of providing spatial information on land degradation and restoration trends is consistent with the United Nations Convention to Combat Desertification (UNCCD) progress indicator framework and with the on-going debate for applying an integrated landscape approach to implementing land degradation neutrality.

Considering a reference period of approximately 15 to 20 years since the last Atlas and the Millennium Ecosystem Assessment, the WAD global mapping approach is designed to identify areas affected by persistent land degradation factors as well as land areas that are showing signs of recuperating their productive capacity. This is put in relation to mapped information on the most commonly known and documented underlying and proximate causes of land degradation [48] but also to sustainable land use practices such as agro-forestry and conservation agriculture.

The basis for implementing the WAD mapping framework has been facilitated by the increased availability of current global and regional data sets of bio-physical and socio-economic information. These layers are frequently (but not exclusively) compiled from spatial information provided by Earth Observation satellites in combination with statistical and field data. Despite this progress in developing global monitoring data sets there are still substantial gaps in the thematic coverage and continuity of data collection systems. This calls for further, more coordinated efforts for establishing systematic monitoring under a specific land degradation topic of existing political framework such as GEO-GEOSS.

References

1. UN DESA PD. *World Population Prospects : The 2015 Revision, Key Findings and Advances* (ESA/P/WP.241). (2015).
2. Foley, J. a. *et al.* Solutions for a cultivated planet. *Nature* 478, 337–342 (2011). doi: 10.1038/nature10452
3. Crutzen, P. J. Geology of mankind. *Nature* 415, 23 (2002). doi: 10.1038/415023a
4. Ellis, E. C. & Ramankutty, N. Putting people in the map: Anthropogenic biomes of the world. *Front. Ecol. Environ.* 6, 439–447 (2008). doi: 10.1890/070062
5. Rulli, M. C., Saviori, A. & D'Odorico, P. Global land and water grabbing. *Proc. Natl. Acad. Sci.* 110, 892–897 (2013). doi: 10.1073/pnas.1213163110
6. Sustainable development - Knowledge platform. at <https://sustainabledevelopment.un.org/index.html>
7. FAO. *The State of the World's land and water resources for Food and Agriculture, Managing systems at risk.* (2011). doi: 978-1-84971-326-9
8. NOAA. Version 4 DMSP-OLS Nighttime Lights Time Series. at <http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html>
9. Columbia University - Center for International Earth Science Information Network (CIESIN). Gridded Population of the World, Version 4 (GPWv4), Preliminary Release 2 (2010). (2014). at <http://www.ciesin.columbia.edu/data/gpw-v4>
10. *SERI. LAND FOOTPRINT SCENARIOS A discussion paper including a literature review and scenario analysis on the land use related to changes in Europe's consumption patterns Report for Friends of the Earth Europe.* (eds. Giljum, S. & Kennerley, P. R.) (2013).
11. UNEP. *Global Environment Outlook GEO4.* (UNEP, 2007). at <http://www.unep.org/geo/GEO4/report/GEO-4_Report_Full_en.pdf>
12. UN DESA PD. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). (2014).
13. FAO, IFAD & WFP. *The State of Food Insecurity in the World 2015. Meeting the 2015 International hunger targets: taking stock of uneven progress.* (FAO, 2015).
14. Mueller, N. D. *et al.* Closing yield gaps through nutrient and water management. *Nature* 490, 254–257 (2012). doi: 10.1038/nature11420
15. Steinfeld, H. *et al. Livestock's Long Shadow: Environmental Issues and Options.* (FAO, 2006).
16. Naylor, R. AGRICULTURE: Losing the Links Between Livestock and Land. *Science (80-.).* 310, 1621–1622 (2005). doi: 10.1126/science.1117856
17. Lambin, E. F. & Meyfroidt, P. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl. Acad. Sci.* 108, 3465–3472 (2011). doi: 10.1073/pnas.1100480108
18. UN Water. Water for food factsheet. (2013).
19. Earthscan & IWMI. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* (ed. Molden, D.) (London: Earthscan, and Colombo: IWMI, 2007).
20. West, P. C. *et al.* Leverage points for improving global food security and the environment. *Science (80-.).* 345, 325–328 (2014). doi: 10.1126/science.1246067
21. Mekonnen, M. M. & Hoekstra, A. Y. A Global Assessment of the Water Footprint of Farm Animal Products. *Ecosystems* 15, 401–415 (2012). doi: 10.1007/s10021-011-9517-8
22. Nijdam, D., Rood, T. & Westhoek, H. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy* 37, 760–770 (2012). doi: 10.1016/j.foodpol.2012.08.002
23. Panagos, P. *et al.* The new assessment of soil loss by water erosion in Europe. *Environ. Sci. Policy* 54, 438–447 (2015). doi: 10.1016/j.envsci.2015.08.012
24. UNCCD. Towards a land degradation neutral world: Land and soil in the context of a green economy for sustainable development, food security and poverty eradication. (2011).
25. Hansen, M. C. *et al.* High-resolution global maps of 21st-century forest cover change. *Science (80-.).* 342, 850–3 (2013). doi: 10.1126/science.1244693
26. Steffen, W. *et al.* Planetary boundaries: Guiding human development on a changing planet. *Science (80-.).* 347, 1259855– (2015). doi: 10.1126/science.1259855
27. UN Water. Water scarcity factsheet. (2013).
28. Brown, L. R. *Full planet empty plates: The new geopolitics of food scarcity.* (Norton & Company, Inc., 2012).
29. Famiglietti, J. S. The global groundwater crisis. *Nat. Clim. Chang.* 4, 945–948 (2014). doi: 10.1038/nclimate2425
30. Spinoni, J., Vogt, J., Naumann, G., Carrao, H. & Barbosa, P. Towards identifying areas at climatological risk of desertification using the Köppen-Geiger classification and FAO aridity index. *Int. J. Climatol.* 35, 2210–2222 (2015). doi: 10.1002/joc.4124
31. Spinoni, J., Naumann, G., Carrao, H., Barbosa, P. & Vogt, J. World drought frequency, duration, and severity for 1951-2010. *Int. J. Climatol.* 34, 2792–2804 (2014). doi: 10.1002/joc.3875
32. Geist, H. *The causes and progression of desertification.* (Ashgate Publishing, Ltd., 2005).
33. *Global Desertification: Do Humans cause Deserts? Dahlem Workshop Report 88* (eds. Reynolds, J. F. & Stafford Smith, D. M.) (Dahlem Univ. Press, 2002).
34. Ivits, E., Cherlet, M., Mehl, W. & Sommer, S. Ecosystem functional units characterized by satellite observed phenology and productivity gradients: A case study for Europe. *Ecol. Indic.* 27, 17–28 (2013). doi: 10.1016/j.ecolind.2012.11.010
35. Ivits, E., Cherlet, M., Sommer, S. & Mehl, W. Addressing the complexity in non-linear evolution of vegetation phenological change with time-series of remote sensing images. *Ecol. Indic.* 26, 49–60 (2013). doi: 10.1016/j.ecolind.2012.10.012
36. Herrmann, S. M., Sall, I. & Sy, O. People and pixels in the Sahel: a study linking coarse-resolution remote sensing observations to land users' perceptions of their changing environment in Senegal. *Ecol. Soc.* 19, art29 (2014). doi: 10.5751/ES-06710-190329
37. State Forestry Administration. *Atlas of Desertified and Sandified Land in China.* (2008).
38. Hill, J. *et al.* Integrating MODIS-EVI and gridded rainfall/temperature fields for assessing land degradation dynamics in Horqin sandy lands, Inner Mongolia (China). in *30th EARSeL Symposium: Remote Sensing for Science, Education and Culture, 31 May--3 June 2010, UNESCO, Paris, France* 247–254 (2010).
39. Hill, J., Stellmes, M. & Wang, C. Land Use and Land Cover Mapping in Europe. *Land Use and Land Cover Mapping in Europe* (eds. Manakos, I. & Braun, M.) 18, (2014). doi: 10.1007/978-94-007-7969-3
40. World Bank. Agricultural irrigated land. at <http://data.worldbank.org/indicator/AG.LND.IRIG.AG.ZS/countries>
41. Vallejos, M. *et al.* Dynamics of the natural cover transformation in the Dry Chaco ecoregion: A plot level geo- database from 1976 to 2012. J. Arid Environ. 1–9 (2014). doi: 10.1016/j.jaridenv.2014.11.009
42. REDAF. *Monitoreo de deforestación en los bosques nativos de la Región Chaqueña Argentina. Informe No1 Bosque Nativo en Salta: Ley de Bosques, análisis de deforestación y situación del Bosque chaqueño en la provincia.* (2013).
43. Grau, H., Gasparri, I. & Gasparri, M. in *Valoración de Servicios Ecosistémicos. Conceptos, herramientas y aplicaciones para el ordenamiento territorial* (eds. Laterra, P., Jobbagy, E. & Paruelo, J.) (2011).
44. Rasmussen, K. *et al.* Environmental change in the Sahel: reconciling contrasting evidence and interpretations. *Reg. Environ. Chang.* (2015). doi: 10.1007/s10113-015-0778-1
45. Brandt, M. *et al.* Ground- and satellite-based evidence of the biophysical mechanisms behind the greening Sahel. *Glob. Chang. Biol.* 21, 1610–1620 (2015). doi: 10.1111/gcb.12807
46. Fensholt, R. et al. Assessing Land Degradation/Recovery in the African Sahel from Long-Term Earth Observation Based Primary Productivity and Precipitation Relationships. *Remote Sens.* 5, 664–686 (2013). doi: 10.3390/rs5020664
47. UNCCD. at <www.unccd.int>
48. Geist, H. J. & Lambin, E. F. Dynamic Causal Patterns of Desertification. *Bioscience* 54, 817 (2004). doi: 10.1641/0006-3568(2004)054[0817:DCPOD]2.0.CO;2

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Published by the Publications Office of the European Union, L-2995 Luxembourg, Luxembourg.

Printed version:
ISBN: 978-92-79-52207-9
doi: 10.2788/928958
Catalogue number: LB-01-15-766-EN-C

Online version:
ISBN: 978-92-79-52206-2
doi:10.2788/21872
Catalogue number: LB-01-15-766-EN-N

JRC registration number: JRC97776
2015 – 16 pp. – 21,0 x 29,7 cm

Printed in Italy.

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