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CHAPTER 4. THE EXTENT AND COST OF LAND DEGRADATION

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4.1. Assessing global land degradation

In any effort to curtail or remedy LD it is of importance that the location and extent of the problem can be assessed and monitored. Indicators for LD assessment have generally included soil-based and vegetation-based parameters. The earlier global LD assessments used the soil-based approach (Dregne, 1977; Oldeman et al., 1990; Eswaran et al., 2001). The Global Assessment of Soil Degradation (GLASOD) in 1987-1990 (Oldeman, 1990) evaluated the LD stage using 4 severity classes based on expert opinions on degradation intensity and extent. Land Degradation Assessment in Dryland (LADA) also evaluated degradation stages based on indicators such as sightings of soil erosion, which can be observed on the field but are hard to capture at regional scale (Caspari et al., 2015). Measuring temporal changes in soil properties is difficult at regional and global scales and the magnitudes of errors of the resulting global soil degradation maps remain unknown.

Due to these uncertainties and because LD encompasses more than soil degradation alone, the vegetation-based approach has been increasingly used in recent global LD studies using globally available remotely sensed data. These vegetation-based LD assessments look at historic loss of net primary production (NPP) through a proxy parameter (e.g. Normalized Difference Vegetation Index – NDVI) such as demonstrated by Bai et al. (2008), Vlek et al. (2010), Le et al. (2016) and Fensholt et al. (2012). Alternatively, NPP is estimated based on ecosystem production models using global datasets of remote-sensed vegetation, climate and biomes (Nemani et al., 2005). A more elaborate method relies on this modelling approach but focuses on the shift from modelled potential to actual NPP or the NPP gap and the degree of human appropriation of the natural NPP as LD indicators (Sutton et al., 2016; ELD Initiative, 2015). Both methods have their limitations and drawbacks that can be mitigated but not eliminated (Pettorelli et al., 2005; Tucker et al., 2005; Le et al., 2016). These limitations need to be communicated with the assessment results to avoid their over-interpretation (Le et al., 2016).

Land degradation assessment provides information to guide management and policy of land which may vary in nature dependent on geographic scales. A degradation phenomenon at a certain scale may be explained by processes operating at the scale immediately below it and constrained by processes operating at the higher scale. Different data and methodological

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approaches are therefore needed to satisfy management goals at specific scales (Vogt et al., 2011). Trade-offs often occur in dealing with LD at multiple scales with a variety of stakeholders. Scale dependency thus will play a role in the selection of assessment instruments.

4.2 Mapping hotspots of land degradation

In a recent comparative review, global LD assessments estimates of total degraded area vary from less than 1 billion ha to over 6 billion ha, with equally wide disagreement in their spatial distribution (Gibbs and Salmon, 2015). This large divergence can be related to a wide spectrum of methodologies in terms of data sources and data versions, types of indicators, temporal and spatial aggregation of data, calculation metrics and ways of treating confounding factors (Le, 2012). This results in a high degree of uncertainty in the LD maps making it difficult to target remedial action of degraded areas. The hotspot mapping approach is a way to cope with the current poor convergence in global LD assessments. The aim of hotspot mapping is different from efforts that aim to map all degraded areas accurately. The approach aims to delineate only the degraded areas where there is high confidence in the results using the current methods and data and focuses on areas where LD is affecting large numbers of people. This will help in better geographical targeting and resource prioritization in preventing, mitigating and reversing LD.

Procedures used in hotspot mapping can include:

- Factors confounding the relationship between indicators and LD are corrected as much as possible, i.e. the ‘specific’ criterion in SMAR (Specific-Measurable-Achievable-Relevant) standard,
- Degraded areas must emerge from different indicators and methods, i.e. convergent validity,
- Degraded areas are those with persistent signals of LD indicators that are stronger than background noises,
- Hotspot areas are those that affect the livelihoods of sizable human populations, i.e. ‘relevance’ criterion.

Land degradation may indeed be largely driven by a diminishing soil resource base. However, when other factors are playing a major role in vegetative decline, such as variation in inter-annual rainfall (Herrmann et al., 2005) or regular irrigation and intensive use of chemical fertilizers (Potter et al., 2010) or atmospheric fertilization (Boisvenue and Running, 2006; Reay et al., 2008; Lewis et al., 2009; Buitenwerf et al., 2012; Le et al., 2012), the reliability of NPP-based indicators are reduced. Maps can be corrected for the effects of these factors (Vlek et al., 2010; Le et al., 2012, Le et al., 2016).

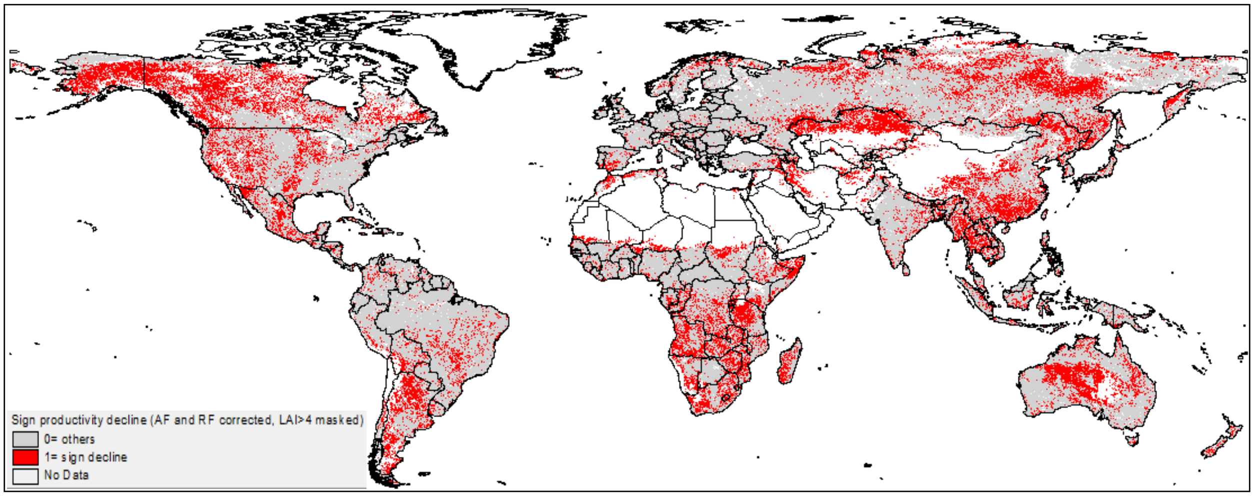

Figure 4.1 Areas of human-induced biomass productivity decline over 1982-2006 (red area) with significant trend ($p < 0.1$, trend magnitude > 10% of base line year / 25 years), rainfall and atmospheric effects corrected. Source: Le et al. (2016).

The most recent global LD mapping based on remote sensing was done using the long-term trend of biomass productivity as a proxy of land degradation (Le et al., 2016). In this study, factors confounding the relationship between mean annual NDVI and land-based biomass productivity - such as inter-annual rainfall variation, atmospheric fertilization and intensive use of chemical fertilizers – were taken into account. Moreover, biomass productivity decline was considered to indicate LD only if the trend was statistically significant and exceeded 10% compared to NDVI of the baseline year over the 25 years (i.e. 0.4% annually). The results are presented in Figure 4.1. Over this period, about 29% of global land area (or 3.6 billion ha) has been degraded, covering all agro-ecologies and land cover types. About 3.2 billion people reside in these degrading areas. Follow-up analysis shows that > 90% of the total LD area had the annual reduction rate of NDVI < 1% / year, falling within the noisy zone for NDVI signals. Thus, the actual hotspots would be a subset of the total degraded area delineated by this method.

Identification of actual hotspot areas is better done on a more local scale where knowledge on degradation processes and their drivers can help interpret the findings from global analyses. The contextual geographic setting can be helpful in pinpointing the relevant hotspots such as the combination of climate zone, general soil and terrain constraints, population density and land use type (Vlek et al., 2010; Sommer et al., 2011; Vu et al., 2014a, b). In a LD assessment across Vietnam, Vu et al. (2014a) found that such combined contextual settings help understand the degradation process involved as the drivers of these processes. The authors found, for instance, that the growth of rural population promotes degradation of forest land with unclear tenure rights which, in turn, mitigates degradation of agricultural land where long-term land-use rights of smallholder farmers are clear and secured. In the condition of better tenure security and links to urban markets and extension services, the high land pressure stimulated lowland Vietnamese farmers to intensify their farms and adopt relevant technologies leading to increase crop production. This situation agrees with Boserup's hypothesis on the population - technology-resources degradation nexus, or the relationship 'more people, less soil erosion' documented in particular areas in East Africa (Tiffen et al., 1994).

To the extent that LD is man-made, there are likely remedial interventions in the management of the land that can mitigate or reverse the process. Deforested land can be afforested but the better option would be to avoid deforestation by adopting sustainable selective tree- harvesting techniques. Similarly, salinized irrigated land can be retro-actively equipped with pipe drainage but it might be better to install these during construction of the perimeter. Mine tailing can be reclaimed but avoiding their development is environmentally preferable. As long as a land ecosystem is disturbed or degraded but has not yet crossed the *threshold of the system buffering capacity* (tipping point), mitigation is a relevant management strategy. In that situation, current land use regimes may be retained with improved land management practices including temporary resting of the land. However, when the land resources are degraded beyond the tipping point, combatting LD needs a restoration strategy that brings the productivity of the land back to the earlier stage. Reversing LD (i.e. restoration or reclamation) is usually much costlier in terms of resources and time needed, than preventing or mitigating LD (Fig. 4.2).

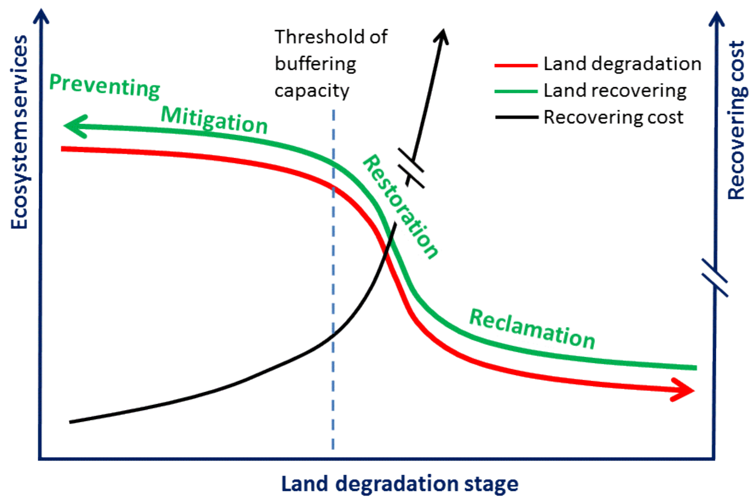

Figure 4.2 Stages of land degradation (red line) and the relevant management strategies at the various stages of this process and the associated cost. The reversal (green line) often takes much longer than the degradation process. Source: modified from Le (2012).

4.3 The costs of land degradation

Quite often, human activities result in a trade-off between the provisioning and non-provisioning land ESSs, where maximization of a provisioning service, such as food production, could lead to the reduction in non-provisioning ESSs of land (Figure 2.1). Unfortunately, most non-provisioning ESSs do not have market values, and thus, are significantly undervalued (von Braun et al., 2013; ELD Initiative, 2015). Land degradation will reduce the production of both food and other ecosystem services of land (*a1* shifting to *b1* in Figure 4.3), while also putting pressure on prices of both food and other ecosystem services (shifting *a* to *b*).

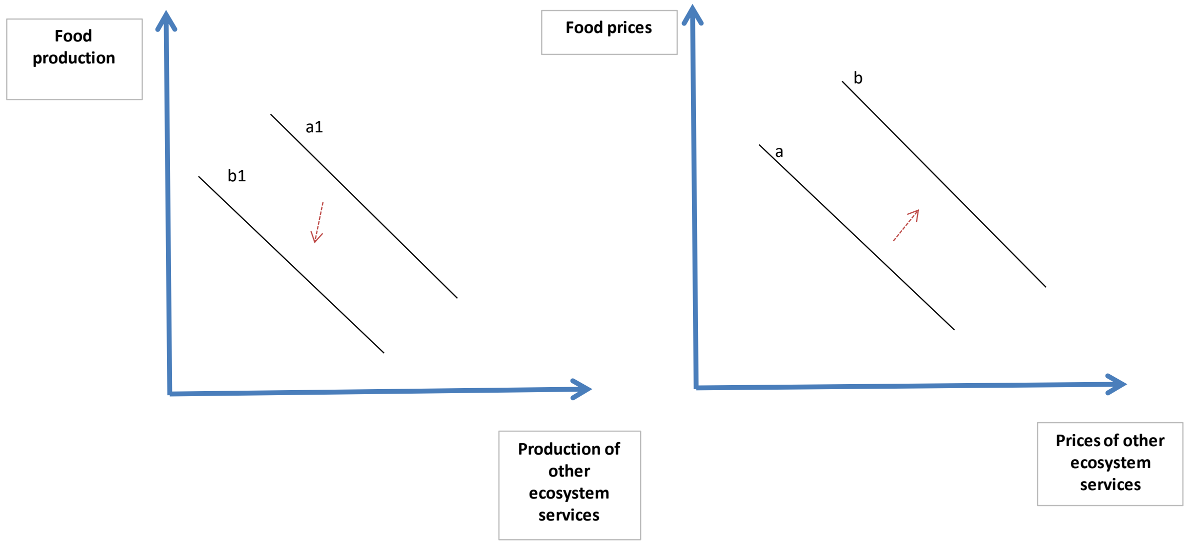

Figure 4.3 The impact of land degradation on the prices of food and other ecosystem services.

The higher prices of food and other ecosystem services are likely to set back the poorest households the most as food expenses constitute a larger share of their household budgets. The increase in food prices, reducing people's disposable income, would have the effect of lowering their willingness-to-pay for non-provisioning ESSs, which are primarily global public goods, thus limiting the funds available to protect the land.

Estimations of the costs of LD thus need to be comprehensive and should include, a) losses in both provisioning and non-provisioning ecosystem services across various time scales, and b) direct as well as indirect costs of LD (Nkonya et al., 2016; ELD Initiative, 2015). Direct costs of LD relate to the diminished provision of ecosystem services by degraded biomes whereas indirect costs are subsequent economy-wide costs of LD in terms of their impacts on various sectors of the economy. These would include effects on poverty and other domains of social wellbeing as well as their feedback loops on sustainable land management. Such complex interactions between food production, provision of non-food ESSs and social wellbeing need to be studied through an interdisciplinary systems research.

There have been a number of efforts to estimate the costs of LD at the global level using different approaches (Mirzabaev et al., 2016). These studies showed that the costs of LD are substantial and could reach up to US$ 10.6 trillion annually. Dregne and Chou (1992) estimated that the global cost of degradation in croplands and rangelands was about US$ 43 billion. A UNCCD (2013) review showed that the global cost of LD could be US$ 450 billion annually. Trivedi et al. (2008) projected that cutting down of tropical rainforests alone resulted in about US$ 43-65 billion of losses in ESSs a year. Myers (2000) estimated that annual investments of up to US$ 300 billion are needed to prevent loss of biodiversity. Basson (2010) estimated that soil erosion is leading to about US$ 18.5 billion in losses each year due to siltation of water reservoirs. Costanza et al. (2014) using the total economic value (TEV) approach, including the value of all terrestrial ecosystem services, estimated the cost of degradation of terrestrial ESSs to be about US$ 9.4 trillion annually, with the costs of wetland degradation making up an important part of these costs. These estimates, high as they are, might still be conservative. The current TEV methodology is likely to undervalue non-provisional ESSs and annual losses might indeed exceed 10.6 trillion globally, representing 17% of the world's GDP. Even then, there are a range of non-anthropocentric values – defined as biocentric values – that are not necessarily captured through the TEV analysis (Sagoff, 2008; ELD Initiative, 2015).

Nkonya et al. (2016) found that the annual costs of LD, excluding wetlands, are equal to about US$ 295 billion. They also found that the global community bears 54% of the LD costs (corresponding to supporting, regulatory and cultural ecosystem services), whereas the land users where degrading biomes are located bear the remaining 46% of the costs in the form of losses in provisioning ecosystem services. This finding emphasizes that land degradation is not just a local problem, but affect all of us. Moreover, Nkonya et al. (2016) found that globally each dollar invested into land restoration and SLM will return 5 dollars over 30 years. Several national studies also find high returns to actions for addressing LD. For instance, the costs of restoring degraded lands were found to be less than the costs of allowing LD to continue by a factor of about 4.3 and 3.8 over a 30-year period in Malawi and Tanzania, respectively (Kirui, 2016). Similarly, each dollar invested in land restoration was found to generate 5 dollars of returns during a similar period in Central Asia (Mirzabaev et al., 2016). An economic assessment of Turkmenistan's desert pastures shows that (i) maintaining pastoral plant communities all year round (ii) establishing seasonal pastures with planting in gypsum deserts and (iii) improving forage productivity of the halophytic pastures in clay deserts has increased the economic benefit to US$ 64 ha^{-1} compared to US$ 29 ha^{-1} of the baseline (Nepesov and Mamedov, 2016; Quillérou et al., 2016). Analyses of global scenarios based on different development pathways indicate that the adoption of SLM-enabling environments can provide an additional US$ 75.6 trillion annually (ELD Initiative, 2015).

Far fewer studies have included the indirect costs of LD. For example, Kirui (2016) estimated that LD in Tanzania and Malawi amounts to the equivalent of 15% and 10% of their respective Gross Domestic Products (GDP). Similarly, Mirzabaev et al. (2016) found that Kyrgyzstan and Tajikistan are losing the equivalence of about 10% of their GDP annually to LD. Diao and Sarpong (2011) showed that LD over the last decade increased the national poverty rate by 5.4% in Ghana.

Because they are based on differing approaches and methodologies, the estimates of costs of LD vary substantially but are invariably high. What is not disputed is that investing in land restoration is economically more sensible than inaction (Nkonya et al., 2016; ELD Initiative, 2015). Nevertheless, the levels of investments into restoration and rehabilitation of degraded lands remain low. To stimulate investments, there is a need to internalize the benefits from SLM by enabling frameworks that allow for valuation of ecosystem services. Only then will it be possible to reward SLM through subsidies and payments for ESSs. It would also make it easier to remove existing barriers to SLM and promote access to markets, agricultural advisory services, agricultural inputs, and credit.

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4.4 Bright spots of land restoration and rehabilitation

Efforts have been underway around the world to mitigate or reverse LD and some of these efforts have met with remarkable success. In a review on the extent and cost of LD an assessment of efforts to combat and prevent degradation should not be missing. In the context of LD "bright spots", can be considered as the opposite of LD hot spots, i.e. areas where the land is actually improving in quality (Bai et al., 2010). Such improvements may occur due to natural rehabilitation of the land due to abandonment of degrading practices or the land itself, or as a result of SLM practices (WOCAT, 2016).

The *World Overview of Conservation Approaches and Technologies* (WOCAT) initiative, in a reaction to the GLASOD map in 1991, made a first attempt to consider land improvement in a comprehensive way (WOCAT, 2007). WOCAT developed a method for documentation and evaluation of SLM "technologies" (what is actually implemented in the field) and "approaches" (the enabling conditions that allow successful implementation of a technology), as well as a mapping method quite similar to the one used in GLASOD. Although WOCAT has established an impressive database with many case studies of SLM from all over the world, it has not yet succeeded in making a new global map of LD and SLM, which was its original goal.

The WOCAT sites where SLM technologies are documented to have improved the status of the land are displayed in Figure 4.4, without specification of what these practices entailed or the extent of their adoption. It is encouraging to see the widespread successful adoption of SLM practices, but the map does not give any insight into the failure rate of introducing SLM as those tend to be underreported. Also, very few reports have been provided to WOCAT from North America or Australia or large parts of Russia. The regional success stories reported may serve as useful experiences for other areas with similar conditions.

Figure 4.4 Location of documented sustainable land management (SLM) technologies with claimed land conservation outcomes in the WOCAT database.

Based on the many years' experience in documenting a range of SLM case studies worldwide (see Figure 4.4), WOCAT identified a number of key elements which, if missing or not properly addressed, will limit the effectiveness of efforts to achieve SLM (Liniger et al., 2004). These include pre-conceptions, biases and wishful thinking, poor understanding of LD processes, lack of impact assessment of conservation, lack of a holistic assessment and failure to understand the context, insufficient use of land users' own experiences, corruption and greed and the inflexibility of interventions. Knowledge gaps and fragmented information also proved to be an obstacle towards successful implementation of SLM. Reij and Steeds (2003) and McDonagh and Lu (2007) discussed a number of criteria to assess success in an SLM project. However, the indicators of "success" remain somewhat arbitrary and depend on the envisaged goals.

From an evaluation of many WOCAT case studies, the success stories cannot be considered to represent blue prints for success elsewhere. It should be recognized that many of the SLM technologies are site-specific and not amenable to out-scaling. Moreover, many "success stories" are often partial failures when one considers the original objectives given the overall outcomes rather than the immediate outputs. After all, it depends on the intended goal of the action undertaken to determine whether it was a success. If the goal was "only" to reduce erosion by say 50% in terms of soil loss, the intervention may be considered a success if just that goal was achieved. But in a broader context it may have been less successful if, for instance, it did not also lead to better livelihoods of the stakeholders involved or improve food security and enhance carbon sequestration. The SLM concept aims for more holistic outcomes. A comprehensive analysis of the factors determining the success rate of SLM was described in "where the land is greener" (WOCAT, 2016).

Noble et al. (2008) summarized the basic characteristics of LD bright spots. They considered that the more efficient resource utilization derived from appropriate technologies must lead to increased income and employment opportunities making better use of local skills and resources, improve the health of the community and/or environmental quality and build the capacity of individuals within the community for effective technology transfer. Finally, mechanisms should be developed that ensure long-term benefits to the community as a whole by ensuring the community's involvement. The challenge is to find ways and means to create such bright spots and scale them up.

Halting or reversing LD is an essential pillar in the quest to reach the SDGs. Various United Nations agencies have captured this task as attaining land degradation neutrality (LDN). The arguments presented in this chapter regarding the cost of inaction on LD are convincing support for this goal. However, it is clear from what was presented above that society is poorly equipped with the tools to target this issue globally as we have a poor understanding of the location, extent and rate of LD. Locally, enough knowledge is often available to act on the problem, but due to contention among stakeholders on the issues proper action may be prevented or sabotaged. Political support and an enabling institutional environment are keys to accomplishing LDN without which a host of SDGs will be difficult to reach.

References

Bai, Z.G., de Jong, R., and van Lynden, G.W.J. (2010). An update of GLADA - Global assessment of land degradation and improvement. ISRIC report 2010/08. ISRIC – World Soil Information, Wageningen.

Bai, Z.G., Dent, D.L., Olsson, L., and Schaepman, M.E. (2008). Proxy global assessment of land degradation. *Soil Use and Management* **24**, 223-234.

Basson, G. (2010). Sedimentation and Sustainable use of reservoirs and river systems. International Commission on Large Dams (ICOLD) Bulletin.

Boisvenue, C., and Running, S.W. (2006). Impacts of climate change on natural forest productivity - Evidence since the middle of the 20th century. *Global Change Biology* 12, 862-882.

Buitenwerf, R., Bond, W.J., Stevens, N., and Trollope, W.S.W. (2012). Increased tree densities in South African savannas: >50 years of data suggests CO_2 as a driver. *Global Change Biology* **18**, 675-684.

Caspari, T.M., van Lynden, G.W.J., and Bai, Z.G. (2015). Land Degradation Neutrality: an evaluation of methods. Report commissioned by German Federal Environment Agency (UBA).

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, Anderson, S.J., Kubiszewski, I., Farber, S., and Turner, R.K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change* **26**, 152-158.

Diao, X., and Sarpong, D.B. (2011). Poverty Implications of Agricultural Land Degradation in Ghana: An Economy-wide, Multimarket Model Assessment. *African Development Review* **23**, 263-275.

Dregne, H.E. (1977). Generalized Map of the Status of Desertification of Arid Lands. *In* "1977 United Nations Conference on Desertification". FAO, UNESCO and WMO.

Dregne, H.E., and Chou, N.T. (1992). Global desertification dimensions and costs. *In* "Degradation and restoration of arid lands" (H. E. Dregne, ed.). Texas Tech. University, Lubbock.

ELD Initiative (2015). The value of land: Prosperous lands and positive rewards through sustainable land management.

Eswaran, H., Lal, R., and Reich, P. (2001). Land Degradation: An Overview. *In* "Responses to Land Degradation. Proc. 2nd International Conference on Land Degradation and Desertification in Khon Kaen, Thailand" (E. Bridges, I. Hannam, L. Oldeman, F. Penning de Vries, S. Scherr and S. Sompatpanit, eds.). Oxford Press, New Delhi.

Fensholt, R., Langanke, T., Rasmussen, K., Reenberg, A., Prince, S.D., Tucker, C., Scholes, R.J., Le, Q.B., Bondeau, A., Eastman, R., Epstein, H., Gaughan, A.E., Hellden, U., Mbow, C., Olsson, L., Paruelo, J., Schweitzer, C., Seaquist, J., and Wessels, K. (2012). Greenness in semi-arid areas across the globe 1981–2007 — an Earth Observing Satellite based analysis of trends and drivers. *Remote Sensing of Environment* **121**, 144-158.

Gibbs, H.K., and Salmon, J.M. (2015). Mapping the world's degraded lands. *Applied Geography* **57**, 12-21.

Herrmann, S., Assaf, A., and Compton, J.T. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change* **15**, 394-404.

Kirui, O.K. (2016). Economics of land degradation and improvement in Tanzania and Malawi. . *In* "Economics of Land Degradation and Improvement–A Global Assessment for Sustainable Development" (E. Nkonya, A. Mirzabaev and J. von Braun, eds.), pp. 609-649. Springer International Publishing.

Le, Q.B. (2012). Indicators of Global Land and Soil Degradation - Slides of oral presentation at the 1st Global Soil Week, 18-22 November 2012. IASS, Berlin.

Le, Q.B., Nkonya, E., and Mirzabaev, A. (2016). Biomass Productivity-Based Mapping of Global Land Degradation Hotspots. *In* "Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development" (E. Nkonya, A. Mirzabaev and J. von Braun, eds.), pp. 55-84. Springer International Publishing.

Le, Q.B., Tamene, L., and Vlek, P.L.G. (2012). Multi-pronged assessment of land degradation in West Africa to assess the importance of atmospheric fertilization in masking the processes involved. *Global and Planetary Change* **92-93**, 71-81.

Lewis, S.L., Lopez-Gonzalez, G., Sonké, B., Affum-Baffoe, K., and Baker, T.R. (2009). Increasing carbon storage in intact African tropical forests. *Nature* **457**, 1003-1006.

Liniger, H. P., Douglas, M., and Schwilch, G. (2004). Towards Sustainable Land Management – 'Common Sense' and some other key missing elements (The Wocat Experience). *In* "ISCO 2004 - 13th International Soil Conservation Organisation Conference – Brisbane, July 2004".

Mcdonagh, J., and Lu, Y. (2007). Success stories in reversing land degradation and the role of UNCCD. *In* "Working Paper". UK Department for International Development (DFID).

Mirzabaev, A., Goedecke, J., Dubovyk, O., Djanibekov, U., Nishanov, N., and Aw-Hassan, A. (2016). Economics of Land Degradation in Central Asia. In: Nkonya E., Mirzabaev A., von Braun J., ed. The Economics of Land Degradation and Improvement. Springer, Dordrecht, Netherlands.

Myers, S., Gaffikin, L., Golden, C., Ostfeld, R., Redford, K., Ricketts, T., Turner, W., and Osofsky, S. (2013). Human health impacts of ecosystem alteration. *Proceedings of the National Academy of Science* **110**, 18753-18760.

Nemani, R.R., Keeling, C.D., Hashimoto, H., Jolly, W.M., Piper, S.C., Tucker, C.J., Myneni, R.B., Running, S.W. (2003). Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science* **300**, 1560-1563.

Nepesov, M., and Mamedov, E. (2016). Economics of Land Degradation (ELD) Initiative: Turkmenistan Case Study. An economic valuation of current and future use of desert pastures in Turkmenistan. Report for the ELD Initiative from the Consultative Group for International Agricultural Research (CGIAR). Amman, Jordan.

Nkonya, E., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J., and Meyer, S. (2016b). Global cost of land degradation. *In* "Economics lf Land Degradation and Improvement – A Global Assessment for Sustainable Development" (E. Nkonya, J. von Braun and M. A., eds.), pp. 117-165. Springer International Publishing, Switzerland.

Noble, A.D., Bossio, D., Pretty, J., and Penning de Vries, F. (2008). Bright spots: pathways to ensuring food security and environmental integrity. *In* "Conserving Land, Protecting Water" (D. Bossio and K. Geheb, eds.). CAB International.

Oldeman, L.R., Hakkeling, R.T.A., and Sombroek, W.G. (1991). World Map of the Status of the Human-Induced Soil Degradation: An Explanatory Note. International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands.

Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.-M., Tucker, C.J., and Stenseth, N.C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution* **20**, 503-510.

Potter, P., Ramankutty, N., Bennett, E. M., and Donner, S. D. (2010). Characterizing the Spatial Patterns of Global Fertilizer Application and Manure Production. *Earth Interactions* **14**, Paper No. 2.

Quillérou, E., Thomas, R.J., Guchgeldiyev, O., Ettling, S., Etter, H., and Stewart, N. (2016). Economics of Land Degradation (ELD) Initiative: Broadening options for improved economic sustainability in Central Asia. ELD Initiative from the Dryland Systems Program of CGIAR c/o ICARDA, Amman, Jordan.

Reay, D.S., Dentener, F., Smith, P., Grace, J., and Feely, R. (2008). Global nitrogen deposition and carbon sinks. *Nature Geoscience* **1**, 430-437.

Reij, C., and Steeds, D. (2003). "Success Stories in Africa's Drylands: Supporting Advocates and Answering Skeptics. A Paper Commissioned by the Global Mechanism of the Convention to Combat Desertification," CIS / Centre for International Cooperation, Vrije Universiteit, Amsterdam, The Netherlands.

Sagoff, M. (2008). On the economic value of ecosystem services. *Environmental Values* **17**, 239-257.

Sommer, S., Zucca, C., Grainger, A., Cherlet, M., Zougmore, R., Sokona, Y., Hill, J., Della Peruta, R., Roehrig, J., and Wang, G. (2011). Application of indicator systems for monitoring and assessment of desertification from national to global scales. *Land Degradation & Development*, **22(2)**, 184-197.

Sutton, P. C., Anderson, S.J., Costanza, R., and Kubiszewski, I. (2016). The ecological economics of land degradation: Impacts on ecosystem service values. *Ecological Economics* **129**, 182-192.

Tiffen, M., Mortimore, M., and Gichuki, F. (1994). "More people, less erosion: environmental recovery in Kenya," John Wiley & Sons Ltd.

Trivedi, M., Papageorgiou, S., and Moran, D. (2008). "What Are Rainforests Worth? And Why It Makes Economic Sense to Keep Them Standing.," Global Canopy Programme, Oxford, UK.

Tucker, C.J., Pinzon, J.E., Brown, M.E., Slayback, D.A., Pak, E.W., Mahoney, R., Vremote, E.F., and El Saleous, N. (2005). An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT Vegetation NDVI data. *International Journal of Remote Sensing* **26**, 4485 - 4498.

UNCCD (2013). "Desertification, land degradation & drought (DLDD) – Some global facts and figures.."

Vlek, P.L.G., Le, Q.B., and Tamene, L. (2010). Assessment of land degradation, its possible causes and threat to food security in Sub-Saharan Africa. *In* "Food Security and Soil Quality" (R. Lal and B. A. Stewart, eds.), pp. 57-86. CRC/Taylor and Francis, Boca Raton, Florida.

FOR CITATION: Le, Q.B., Mirzabaev, A., Nkonya, E., Lynden, G.W.J. (2017). The extent and cost of land degradation (Chapter 4). pp. 40-47. In: Vlek, P.L.G. et al. (Eds.). The Threat of Land Degradation to Realizing the SDGs and Its Remedies. Book Manuscript. CGIAR Research Program on Dryland Systems and Center for Tropical Agricultural Research (CIAT). 72 pp.

Vogt, J. V., Safriel, U., Von Maltitz, G., Sokona, Y., Zougmore, R., Bastin, G., and Hill, J. (2011). Monitoring and assessment of land degradation and desertification: Towards new conceptual and integrated approaches. *Land Degradation & Development* **22**, 150-165.

von Braun, J., Gerber, N., Mirzabaev, A., and Nkonya, E. (2013). The economics of land degradation. *In* "(ZEF Working Papers 109)", Bonn, Germany.

Vu, Q.M., Le, Q.B., Frossard, E., and Vlek, P.L.G. (2014a). Socio-economic and biophysical determinants of land degradation in Vietnam: An integrated causal analysis at the national level. *Land Use Policy* **36**, 605-617.

Vu, Q.M., Le, Q.B., and Vlek, P.L.G. (2014b). Hotspots of human-induced biomass productivity decline and their social–ecological types toward supporting national policy and local studies on combating land degradation. *Global and Planetary Change* **121**, 64-77.

WOCAT (2016). The Global Database on Sustainable Land Management.