REMOTE SENSING OF GLOBAL AND REGIONAL LAND DEGRADATION PROCESSES FOR IMPROVED LAND GOVERNANCE

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KEY WORDS: desertification, land degradation, assessment, monitoring, remote sensing

ABSTRACT:

Understanding the environmental and socio-economic significance of land degradation and desertification is constrained by many uncertainties, ranging from agreed definitions on the phenomenon to grasping causes, associated processes and their relevance for information gathering, and for developing measurable criteria to implement relevant actions and policy. While the world's drylands continue to be the most vulnerable, land degradation is a global phenomenon extending beyond desert lands, which despite decades of research is yet to have agreed standards to measure its progression, that is, global mapping and monitoring system(s), to reverse the uncertainty on current estimations due to data gaps.

Remote sensing-based assessments of land degradation at regional and global scales have been advocated because in combination with ground-level observations, they can provide a wealth of data relating to land condition and its changes. Satellite imagery provides continuity of observations since the early 1970s (e.g. Global Inventory Modelling and Mapping Studies –GIMMS-, MODIS, Landsat-like), essential for global and regional monitoring tasks, including determining trends in biomass and vegetation health, and baselines on the state of landscapes.

This paper recalls the significance of land degradation assessment and monitoring in the context of improved land governance; it provides a review of global and sub-global land degradation studies that have used remote sensing-based approaches in land characterisation and landscape assessment and monitoring , and discusses global research initiatives where geospatial technologies can play a role in data and information supply for better management and decisions.

1. THE SIGNIFICANCE OF LAND AND SOIL DEGRADATION

Land and soil degradation are accelerating, and drought is escalating worldwide. At the Rio+20 Conference, world leaders acknowledged that desertification, land degradation and drought (DLDD) are challenges of a global dimension affecting the sustainable development of all countries, in particular developing countries (UNCCD, 2013). Land degradation, including desertification processes have accelerated rapidly in the last century, with an estimated 24 billion tons of fertile soil lost to erosion in the world's croplands (FAO, 2011). In Asia alone, it estimated that more than two million hectares of grasslands are being degraded every year, and roughly 400 million hectares of degraded forestlands in the region are badly in need of restoration (FAO, 2014).

While the world's drylands continue to be the most vulnerable, land degradation is a global phenomenon extending beyond desert lands, which despite decades of research is yet to have agreed standards to measure its progression, that is, global mapping and monitoring system(s), to reverse the uncertainty on current estimations due to data and knowledge gaps.

1.1 Current developments related to assessment and monitoring of degraded lands

Following the UN-Conference on Sustainable Development (Rio+20), the international community seeks to develop universal Sustainable Development Goals (SDGs); this provides a timely opportunity to respond to the threat of soil and land degradation, ensuring that at least one of the SDG goals addresses land and soil degradation. The set of SDGs proposed in the latest documents of the Open Working Group (2014) has one goal (ie. Goal 15) acknowledging the need to " *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*" to achieve sustainable development.

The inclusion of soil and land resources in the aforementioned SDGs and the post-2015 Development Agenda presents a unique opportunity for reinforcing the need for up-to-date, reliable information at global (and local) scales. More because the need to learn how best to track land degradation using satellite data, to provide a baseline from which to measure if and how land is degraded still remains, despite over 30 years of applied research in this area (Gilbert, 2011). Accordingly, in this paper I recall current definitions of land degradation adopted by the international community, and their implications for the design of assessment and monitoring studies, followed by a review of global and sub-global land degradation studies that have used remote sensing-based approaches in land characterisation and landscape assessment and monitoring , and discuss global research initiatives focused on actions and strategies to address land degradation, where geospatial technologies can have a vital role in data and information supply.

1.2 Understanding drivers, pressure, state and impacts for remote sensing-based assessment and monitoring of land degradation

The Ten-year strategy of the United Nations Convention to Combat Desertification (UNCCD) adopts a broad interpretation of land degradation and desertification, defining both desertification and land degradation by a state (reduction or loss) of a supporting ecosystem service (biological productivity) and also incorporating the definition of the cause, or driver of change of that service (e.g. due to human activities), and the spatial (ie., climatological) boundary of these phenomena. Thus, it is important that methodologies and tools for monitoring and assessing land degradation and desertification cater for dynamics associated to variations in state and space, to offer data and information for efficient valuation of the status and trends of land degradation and desertification from local to global scales (Vogt et al., 2011).

Recognising that land is a complex medium, with abundant biodiversity, performing a wide range of socio-economic and ecological functions, the European Environment Agency developed a conceptual framework in the 2000s for the assessment of the conditions of soils and its multiple effects on the environment (Figure 1). This framework, based on the drivers-pressure-state-impact-response (DPSIR) framework proposed by the OECD in the 1990s and subsequently adopted and modified by UNEP and the MEA for their global assessments enables identifying causes of land degradation, rather than only its ‘symptoms’, and this is essential for assessment and monitoring tasks.

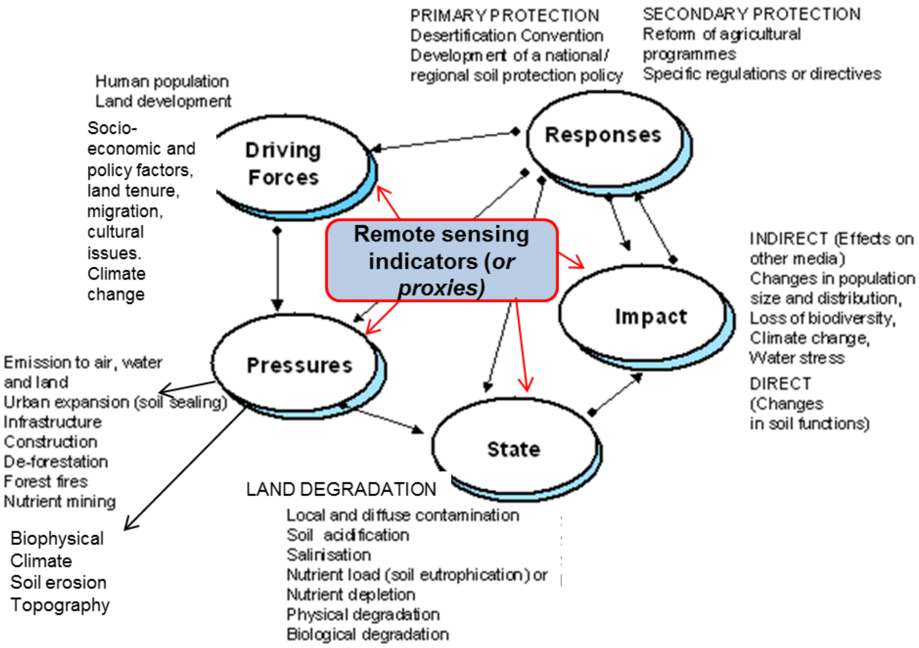

Figure 1: Example of the DPSIR framework applied to the assessment of land degradation process, with an indication of the role remote sensing-derived indicators can play in the different components of the framework. Remote sensing can assist in mapping Drivers (e.g. Land use change, urban growth); Pressures (e.g. deforestation, topographic position, irrigation mismanagement); State (presence of saline efflorescence, vegetation decline); Impacts (eg. Persistent reduction of NPP); Response (e.g. monitoring systems for programmes/actions). Modified from EEA.

The DPSIR framework identifies drivers (underlying causes) and pressures (proximate causes), which interact with each other to result in different levels of land degradation. Proximate causes, having a direct effect on terrestrial ecosystems can be further divided into biophysical factors (e.g. climate, soil erosion, salinization, waterlogging and topography) and human (unsustainable land management practices, deforestation, infrastructure development). Drivers of land degradation are socio-economic and policy factors, land tenure, migration, population and demographic change, and cultural issues (Nkonya et al., 2013, Stringer, 2012, Metternicht, 1996). Land degradation manifests through natural (e.g. wind and water erosion, soil salinization) or human-induced (overgrazing, overcultivation, irrigation mismanagement) processes. These processes can be detected and measured through indicators, that is, measurable characteristics which provide information about the condition being investigated, ie.,land and soil degradation processes. Indicators can be physical, biological, socio-economic or a combination thereof. Common examples of indicators are changes in soil status, surface crusting, presence of saline efflorescence, vegetation degradation, density of human settlements, landuse/land cover change, loss of ecosystems functions and productivity. Some of these indicators can be directly identified in remotely sensed imagery; others require the use of proxies (e.g. loss of ecosystem functions and productivity).

Remote sensing-based assessments of land degradation at regional and global scales have been advocated because in combination with ground-level observations, earth observation by satellites can provide a wealth of data relating to land condition and its changes. Satellite imagery provides continuity of observations since the early 1970s (e.g. Global Inventory Modelling and Mapping Studies –GIMMS-, MODIS, SPOT VGT, Landsat-like), essential for assessment and monitoring tasks, including determining trends in biomass and vegetation health, and baselines; the environmental information generated offers greater detail over large areas as compared to ground-level observation alone, and a unique opportunity to evaluate changes using consistent time-series across geographical boundaries (SCU, 2012). Research from the 1990s and 2000s (Metternicht, 1996; Le et al., 2012; Shoshanya et al., 2013) reports the benefits of a synergistic use of satellite- and/or air-borne remote sensing with ground-based observations to provide consistent, repeatable, cost-effective information for land degradation studies at regional and global scales.

2. MONITORING, ASSESSMENT AND LAND CHARACTERISATION: THE ROLE OF REMOTE SENSING APPROACHES

Understanding the causes of land degradation, their interactions, and associated processes is essential for identifying suitable indicators for remote-sensing based monitoring, baseline development and assessment of this phenomenon. This information helps reducing uncertainties regarding the relationships amongst land degradation, ecosystem services, biodiversity and human well-being (MA, 2005). Past and current earth observation based monitoring and assessments have focused mainly on the symptoms of land degradation (ie., consequences of pressures on soil and land), such as loss of top soil and biodiversity, and decreased biomass production. Moreover, much research conducted over the last decade has been on remotely-sensed based biophysical indicators of land degradation processes (e.g. soil salinization, soil erosion, waterlogging, flooding), (Metternicht and Zinck, 2003, 2009; Allbed and Kumar, 2013), without integration of socio-economic indicators. Studies from the 1970s onwards have related soil erosion severity to variations in spectral response, or backscattering in the case of microwave imagery. Others indirectly assessed land degradation from landuse/land cover patterns, and changes in vegetation greenness (i.e. NDVI and its relation to biophysical variables that control vegetation productivity and biospheric fluxes). Landscape features such as topography, drainage and vegetation health have also been used to infer processes and phenomena not directly detectable on images by spectrally-based processing. Good reviews of potential and limitations of spectrally based mapping of land degradation are provided by Metternicht and Zinck (2003); Bai et al. (2008); Marini and Talbi (2009), de Jong et al. (2011) and Shoshanya et al. (2013). Table 1 and the section hereafter present frequent applications of remote sensing in the context of *global or sub-global* assessments and/or monitoring of land degradation.

Table 1: Common time series of vegetation imagery for broadscale land degradation studies. From: de Jong et al., (2011)

Data set/product	Sensor	Platform	Time range	Spatial resolution	Indicator	Temporal resolution
Pathfinder Land (PAL)	AVHRR	NOAA satellites	1981–2006	8 km (GVI 16 km)	NDVI	10-day MVC
Global vegetation index (GVI)						Weekly MVC
GIMMS						15-day MVC
FASIR						15-day MVC
MOD13/MYD13	MODIS	Terra/Aqua	2000–present	250 m–1 km	NDVI/EVI	8- or 16-day MVC
MOD17A2/MYD17A2				1 km	GPP	8-day composite
VGT-S10	VGT	SPOT-4	1998–present	1 km	NDVI	10-day synthesis
L3-SMI NDVI	SeaWiFS	OrbView-2	1997–present	4.63 km	NDVI	Weekly MVC

2.1 Biomass and vegetation health modelling: Net Primary Productivity (NPP) and NDVI

The NDVI has been used to estimate vegetation change either as an index (Julien et al., 2011), or as input to dynamic vegetation models (Fensholt et al., 2006). Consistency of long-term NDVI time series derived from AVHRR, SPOT-Vegetation, SeaWiFS, MODIS, and Landsat ETM+ sensors at spatial resolutions ranging from 30 m (Landsat-like) to 8 km (NOAA-AVHRR) has enabled integrating historic 25-year AVHRR NDVI data series with these other sensors' NDVIs, providing a critical historical perspective on vegetation activities necessary for global change research (Brown et al., 2006). NDVI is related to variables such as leaf-area index (Myeni et al, 1997), the fraction of photo-synthetically-active radiation absorbed by vegetation (APAR) (Baret and Guyot, 2003) and NPP (Xu et al., 2012). In their framing of land degradation as long term loss of ecosystem function and productivity, Bai et al (2008) used the normalised difference vegetation index (NDVI) as a proxy indicator of changes in net primary productivity (NPP). They assumed that a deviation from the NPP norm was indicative of land degradation (or improvement) if factors such as climatic variability and land use change were considered.

Global estimations of NPP for land degradation studies have relied on GIMMS-AVHRR data conversion to NDVI using fortnightly maximum value composite imagery at 8km spatial resolution, corrected for calibration, view geometry, volcanic aerosols (Tucker et al., 2004), with the annual sum of NDVI representing accumulated greenness; on MODIS NPP (MOD17) that provides the fraction APAR at 1 km resolution, or a combination thereof, as done in the Land Degradation Assessment in Drylands (LADA) project (see next section). This project used GIMMS-AVHRR NDVI data, and 'translated' it to NPP using MODIS NPP data (MOD 17) for the overlapping period 2000-2003(Running et al., 2004; Tuner et al., 2006; Bai et al., 2008; Zhu and Southworth, 2013).

The ration of NPP to rainfall (ie., rain use efficiency) was used to distinguish between the relatively low NPP of drylands (associated to its inherent moisture deficit), and the additional decline in primary production due to land degradation (Le Houerou et al. 1988; Pickup 1996). In the context of the Land Degradation Assessment (LADA) project, Bai et al (2008) estimated RUE from the ratio of the annual sum of NDVI to annual rainfall, and used it to identify and mask out areas where declining productivity was a function of drought. This recalibration process was though to yield a proxy index for land degradation, assuming that a decline in vegetation for any other reason than rainfall (and temperature) differences is an expression of some form of degradation (Nachtergaele et al., 2010).

2.2 Ground validations and local NPP scaling

Global and regional assessments of land degradation by Bai et al. (2008) and Le et al. (2012) show that NPP results derived from NDVI trend patterns need ground validation. In the global LADA project (see Table 2), Bai et al. (2008) used the NDVI-NPP product to identify, delineate and rank 'hot' (degraded) or 'bright' (improvement) spots of land, for subsequent assessment of the actual field situation. The sole use of NPP as a proxy indicator of land degradation in natural ecosystems can be misleading, as for instance biomass productivity can increase due to an invasion of exotic plant species, which may reduce biodiversity (one of the consequences of land degradation) and misguide trends on land improvement or degradation. Furthermore, the rising level of atmospheric CO_2 and NO_x can cause divergence between NPP trend and soil fertility change (Reay et al., 2008), requiring corrections of this effect as suggested by Vlek et al. (2010) and Le et al (2012).

The local net primary productivity scaling (LNS) of Prince (2002) is another earth observation-based product used for land degradation assessment at regional and national scales. In this approach the seasonal sum of NDVI of a single pixel in homogeneous biophysical land units (e.g., similar soils, climate, landforms, etc.) is used as proxy for annual aboveground net primary productivity (ANPP), and expressed relative to the highest pixel value observed in the unit itself. The highest $\sum$NDVI value is assumed as a proxy for the potential ANPP for each unit, and the other $\sum$NDVI values are rescaled accordingly; the protocol requires identifying large regions with non-degrading and degrading land uses. This method has been applied at national scale in South Africa and Zimbabwe for discriminating degraded and non-degraded rangelands using the NDVI time series acquired by coarse resolution satellite sensors (e.g. MODIS, NOAA AVHRR) (Wessels et al., 2007; 2008; Prince et al., 2009), and more recently for assessing pasture conditions in the Mediterranean (Fava et al., 2012). Severe land degradation processes in these studies were associated with a strong plant fractional cover reduction.

3. GLOBAL ASSESSMENT OF LAND DEGRADATION: THE EVOLUTION OF REMOTE SENSING USE

Table 2 shows the evolution in the use of remote sensing technology from the first global assessment of land degradation, expert-driven (GLASOD), with no use of remote sensing imagery, to the latest LADA-GLADIS, heavily reliant on remote-sensing derived data coupled with an ecosystem-approach. The table summaries the objectives, methods and main outputs derived from these programmes, including the use of remote sensing technologies in their implementation.

The GLASOD, an expert-opinion based study (see Table 2 and Oldeman, 1991) had two follow up assessments, namely: the Regional assessments of soil degradation status - South and Southeast Asia (ASSOD), Central and Eastern Europe (SOVEUR); and the global LADA project, under UNEP/FAO.

Table 2: Some Global programmes of land and soil degradation assessment (status and trends)

Programme	Objective	Methodology – remote sensing usage	Comments (including limitations)
GLASOD-Global Assessment of Human Induced Soil Degradation (UNEP) (1987- 1990)	Produce a world map of human-induced *soil degradation*, on the basis of incomplete knowledge, in the shortest possible time. The focus was on type (e.g. causes) and degree (at 1990) of degradation process.	• No remote sensing; expert-based approach; distinguishes 'types' of soil degradation, based on perceptions; it is not a measure of land degradation. • The status of soil degradation was mapped within loosely defined physiographic units (polygons), based on expert judgement. • The type, extent, degree, rate and main causes of degradation presented in a 1:10M scale global map. • GLASOD recognised interventions	• Qualitative judgments have proven inconsistent and hardly reproducible; • Small scale: not appropriate for national breakdowns; • Limited number of attributes due to cartographic restrictions; • Extent expressed in qualitative classes (5) rather than percentages; • Complex legend: combined extent and degree (severity) for four major degradation types (water and wind erosion, physical and chemical

		(pressures) that caused current degradation.	deterioration); • It shows only 'degradation' (not areas of improvement).
LADA-GLADA Land Degradation Assessment *in Drylands* (LADA) - Global project, under UNEP/FAO. (2006 – 2009)	Assess (quantitative, qualitative and georeferenced) land degradation at global, national and sub-national levels to identify status, driving forces and impacts, and trends of land degradation in drylands; identify *hot* and *bright* spots.	The Global LADA was based on 22 years (1981-2003) of fortnightly NDVI data, derived from GIMMS and MODIS-related NPP (MOD 17). Method: 1. Identify degrading areas (negative trend in sum of NDVI) 2. Eliminate false alarms of productivity decline by: masking out urban areas; areas with a positive correlation between rainfall and NDVI, and a positive NDVI-RUE 3. Produce RUE-adjusted NDVI map 4. Calculate NDVI trends for remaining areas. The methodological framework adopted the DPSIR model.	• No data available to account for the effect of land use change on biomass trends over the period 1983-2005*; • No real direct verification possible of vegetation or greenness trend at such a large scale; 6 countries implemented LADA at national level (to check results of hot and bright spots). • Rainfall-corrected NDVI trends shows a systematic relation with climatic conditions • NDVI/NPP trends highlight places where biologically significant change is happening. • Degraded areas of less than 8 km may fail to be identified (coarse data resolution).
LADA-GLADIS Global Land Degradation Information System FAO-UNEP-GEF (2006-2010)	Focus on land degradation as a process resulting from pressures on a given status of the ecosystem resources. Definition of land degradation implies change in the capacity to deliver ecosystem services. Six parameters (Biomass, Soil Health, Water Quantity, Biodiversity, Economic services and Socio-Cultural services) can describe the **status** of any ecosystem service in a semi-quantitative way.	An ecosystem-Land Use system approach; it informs on the status of land resources: degradation or improvement processes. Outputs are a series of global maps on the **status and trends** of the main ecosystem services considered, and radar graphs. Remote sensing is used for biomass status and trends, based on a correction factor to the GLADA- RUE-adjusted NDVI, to present trends in NDVI (1981-2006) translated in greenness losses and gains distinguished by climatic and human-induced (e.g. deforestation from FAO-FRA dataset) causes. Organic Carbon above-ground biomass is estimated as function of land cover -from the Global Land Cover (GLC-2000) data set	Limited availability of global data with sufficient detail and resolution is the greatest limitation. Datasets have been harmonised to a 5 arc minute (9x9 km at the Equator); Aggregated indexes can be calculated: Environmental Services Status Index (ESSI); Biophysical Status Index Land Degradation Index Biophysical Degradation Index. Land Degradation Impact Index (LDII) weighs land degradation according to poverty levels and population density.

*extended from 2003-2005. Prepared by the author with resources from Oldeman (1996); Bai et al., (2008); Nachtergaele et al., (2010).

The LADA aimed at developing and testing an effective methodological framework for land degradation assessment in dry lands, at global, national and sub-national scales, identifying the status, driving forces and impacts, as well as trends of land degradation in all its components including physical resources (such as soils, water, vegetation, biodiversity) and human resources (livelihood systems, cultural societies). The global component of LADA (ie. GLADA) provided a baseline assessment of global trends in land degradation using a range of indicators collected through satellite data processing and existing global databases (net primary productivity, rainfall use efficiency, aridity index, rainfall variability and erosion risk) as described in Bai et al., (2008). Not all changes measured by the RUE-adjusted NDVI/NPP index of the GLADA are land degradation (e.g. conversion of forest or grassland to arable usually results in an immediate reduction in NPP and NDVI, which may (or not) be accompanied by land degradation. The GLADA was implemented between 2006-2009, based on 22 years (1981-2003) of fortnightly NDVI data collection and processing (see Table 2). The project developed and validated a harmonized set of methodologies for the assessment of land use, land degradation and land management practices (eg. sustainable land management) at global, national, sub-national and local levels (Ponce-Hernandez and Koohafkan, 2004).

The Global Land Degradation Information System (GLADIS) was developed by FAO, UNEP and the GEF using pre-existing (ie. LADA-GLADA data) and newly developed global databases to inform decision makers on all aspects of land degradation. The GLADIS developed a global Land Use System (LUS) classification and mapping using a set of pressures and threats indicators at global level, allowing access to information at country, land use system (LUS) and pixel (5 arc-minute resolution) levels. This assessment incorporates the idea of a time zero status (baseline), and it requires specifying the period over which the decline or improvement is measured (eg GLADIS 1990-2005). The GLADIS identifies six ecosystem good and services status, pressures and consequent land degradation processes. It accounts for socio-economic factors of land degradation, using a variety of ancillary data to this end, as described in Nachtergaele et al. (2010).

More recently, Zika and Erb (2009) produced a global estimate of net primary production (NPP) losses caused by human-induced dryland degradation using existing data sets from GLASOD and other regional, sub-regional and national studies on land degradation; they modelled global potential productivity using the Lund- Potsdam-Jena dynamic global vegetation model, and information on the extent and NPP of croplands and grazing lands.

4. ACCESSING RELIABLE ESTIMATIONS ON THE EXTENT OF LAND DEGRADATION: IMPLICATIONS FOR LAND GOVERNANCE

The GLASOD estimated that 20% of drylands (*excluding* hyper-arid areas) was affected by soil degradation. A study commissioned by the Millennium Assessment based on regional data sets (*including* hyper-arid drylands) derived from literature reviews, erosion models, field assessments and remote sensing found lower levels of land degradation in drylands, to be around 10% (although coverage was not complete) (Lepers et al., 2005). The LADA project reported that over the period 1981-2005, 23.5% of the global land area was being degraded. On the other hand, Zika and Erb (2009) report approximately 2% of the global terrestrial NPP is lost each year due to dryland degradation, or between 4% and 10% of the potential NPP in drylands.

This paper does not expand on finding the reasons for the divergence; however it is worth noting that:

- GLASOD was a process to produce a map of human induced soil degradation based experts' opinion, it was not a measure of land degradation; it compounded land degradation at the time of the assessment (1990) with the legacy from past centuries (ie., a *one point in time assessment* incorporating accumulated effects of land degradation); unlike LADA/GLADA that assessed and 'monitored' degradation trends over 25 years;
- GLASOD's qualitative judgments have proven inconsistent. However, it provided for the first time, cartography of the extent, type and degree of land degradation (Sonneveld and Dent, 2007).
- LADA-GLADA identified areas of interest in which the vegetation greenness has declined or increased, but direct relationships with other aspects of land degradation (e.g. soil degradation) could not be made (Nachtergaele et al., 2010); and ground truthing of results in South Africa revealed that only half of the sites classified as hotspots could be labelled as land degraded (Pretorius, 2008).

The aforementioned sections confirm that Earth Observation can play a significant role in providing salient information and knowledge for designing actions to address land degradation and desertification in the international arena (e.g. implementation of the UNCCD Convention, the Sustainable Development Goal 15 of '*…. combat desertification, and halt and reverse land degradation and halt biodiversity loss*'), and at national and regional levels (e.g. implementation of National Action Plans). However, the design of effective early warning, assessment and monitoring systems –combining remote sensing with field surveys of key indicators as proposed by UNEP (2007) remains a contentious field. Some important steps towards the provision of more reliable information from Earth Observation datasets, that could be incorporated in much need scientifically sound and practical methodologies for monitoring and assessing the *state and trend* of land degradation, as well as for monitoring the performance of management actions and programmes are listed below.

- Radar satellite-based aboveground biomass estimations at national level as researched by Carreiras et al. (2012), or regional vegetation cover (Dong et al., 2014) could be investigated further for their applicability to global studies of land degradation assessment; as this satellite data could overcome the cloud issues faced by LADA-GLADA and GLADIS, discussed in Nachtergaele et al. (2010).
- Alternatives to land use mapping units used in GLADIS, more suitable to remote sensing-based cartography could be trialed; in this regard Blanco et al. (2014) propose ecological site classification of semi-arid rangelands. An ecological site is a distinctive kind of land with specific soil and physical characteristics that differs from other kinds of land in its ability to produce distinctive types and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances (Bestelmeyer and Brown, 2010).
- Engaging citizens in knowledge-production (including field verification of remotely sensed-derived information), as fostered by current global (UNEP-Live, Future Earth, GEO-BON) and sub-global initiatives (Eionet of the European Environmental Agency) could address the significant lack of ground thruthing of previous global land degradation studies.
- The synergy of remote sensing and crowdsourcing has been reported as successful for mapping croplands at national level (See et al., 2014); with data collected over a very short period of time using an existing network of volunteers and supported by Google Earth imagery via tools in Geo-Wiki; such approach could provide a novel and inexpensive way to map state and trends of land degradation.

Data collected, and information and knowledge derived, from remote sensing continues to be critical input for advancing understanding of land degradation at global and sub-global scales. New technology and fundamentally approaches to data collection and integration for information production are the way forward to deliver accurate, complete and timely information about the state of our planet that environmental policy makers need for addressing global environmental change through effective management programmes and strategies. This in turn contributes to improved governance of soils and land, a finite natural capital on which humanity depends for a sustainable development.

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