A REVIEW OF LAND DEGRADATION ASSESSMENT METHODS

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ABSTRACT

Land degradation is an increasing problem in many parts of the world. Success in fighting land degradation requires an improved understanding of its causes, impact, degree and acquaintance with climate, soil, water, land cover and socio-economic factors. Therefore, land degradation assessment is a primary goal in a decision support system for reversing degradation. Fortunately, scientists around the world started long ago to look at the problem and have developed assessment and monitoring methods. This study, aimed at exploring and reviewing existing assessment methods, used a global, regional, local and field/farm levels in an attempt to assess land degradation issues. This paper discusses and describes various methods for assessing land degradation and its processes. The study concludes that there are plenty of different approaches for assessing land degradation worldwide. Expert opinions, field measurements, field observations, land user's opinions, productivity changes, remote sensing and modelling methods act as a backbone for many approaches to assess land degradation at different levels. Moreover, the first distinction that has to be made is land use and land types and scale. Significantly, methods or techniques need to be critically selected, taking into account their suitability, applicability and adaptability to local conditions. This helps in comparing areas and involving stakeholders as much as possible as aids in land use and restoration planning and prioritizing projects. It is also important to integrate local knowledge with scientific knowledge, but care should be taken in interpreting local knowledge and interests, which can be complex. Furthermore, use of statistical methods, ordination, and modelling approaches are costly, complicated, and time consuming. The lack of experienced people and availability of resources are some of the main barriers to successful assessment. This review revealed very few failures in using different assessment methods, which is somewhat surprising. Does this mean that everything works?

1. INTRODUCTION

Land degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation (Bai *et al.*, 2008). Millions of hectares of land per year are being degraded in all climatic regions. It is estimated that 2.6 billion people are affected by land degradation and desertification in more than a hundred countries, influencing over 33% of the earth´s land surface (Adams and Eswaran, 2000). This is a global development and environmental issue highlighted at the United Nations Convention to Combat Desertification, the Convention on Biodiversity, the Kyoto protocol on global climate change and the millenium development goal (UNCED, 1992; UNEP, 2008).

The decline in land quality caused by human activities has been a major global issue since the 20th century and will remain high on the international agenda in the 21st century (Eswaran *et al.*, 2001). The immediate causes of land degradation are inappropriate land use that lead to degradation of soil, water and vegetative cover and loss of both soil and vegetative biological diversity, affecting ecosystem structure and functions (Snel and Bot, 2003). Degraded lands are more susceptible to the adverse effects of climatic change such as increased temperature and more severe droughts.

Land degradation encompasses the whole environment but includes individual factors concerning soils, water resources (surface, ground), forests (woodlands), grasslands (rangelands), croplands (rainfed, irrigated) and biodiversity (animals, vegetative cover, soil) (FAO, 2005). On the other hand the NRC (1994) stressed that land degradation is complex and involves the interaction of changes in the physical, chemical and biological properties of the soil and vegetation. The complexity of land degradation means its definition differs from area to area, depending on the subject to be emphasized.

The phenomenon is most pronounced in the drylands, which cover more than 40% of the earth's surface (Dobie, 2001). Around 73% of rangelands in dryland areas are currently degraded, together with 47% of marginal rain-fed croplands and a significant percentage of irrigated croplands (UNCCD Agenda 21, 1992; UNCCD, 1994). Overgrazing has damaged about 20% of the world's pastures and rangelands (FAO, 1996).

In Africa, land degradation and desertification processes result from both human activities and climatic variability (UNEP, 2008). An estimated 65% of Africa's agricultural land is degraded due to erosion and/or chemical and physical damage. Thirty-one per cent of the continent's pasture lands and 19% of its forests and woodlands also are classified as degraded (UNEP, 2008; FAO, 2005). Overgrazing has long been considered the primary cause of degradation in Africa but it is now thought that rainfall variability and long-term drought are more important determinants (UNEP, 1997 cited in GEO, 2000).

Land degradation is especially widespread in Sub-Saharan Africa, affecting 20-50% of the land and some 200 million people (Snel and Bot, 2003). Furthermore, Snel and Bot (2003) stated that land degradation is also widespread and severe in Asia and Latin America as well as in other regions of the globe. In Latin America and the Caribbean, land degradation affects 16% of the land area. The impact is more severe in Meso-America (reaching 26% of the total, or 63 million hectares) than in South America (where it affects 14% of the total or almost 250 million hectares) (UNEP-ISRIC 1991 cited in GEO – Latin America and the Caribbean, 2000).

The extent of desertification in China is approximately 2.67 million sq. km, about 28% of the country, based on the monitoring results by the end of 1999 (FAO, 2005). Climate is one of the causes of desertification in China, but human factors are dominant (FAO, 2005). These include overgrazing, the main cause of rangeland degradation; intensive collection of fuel wood and Chinese medicinal herbs; and over-exploitation of mineral resources. Graham *et al.* (1989) regards land degradation as Australia´s most critical environmental issue, with significant implications for agricultural, pastoral and forest production.

In Europe, soil erosion is regarded as one of the major and most widespread forms of land degradation, and as such poses severe limitations to sustainable agricultural land use (Gobin *et al.*, 2004). In general, deterioration of resources in Europe comes as a result of climate change, land use and human activities. Soil erosion in Europe is mainly caused by water and to a lesser extent by wind (Gobin, 2004).

According to the expert-based *Global Assessment of Human-induced Soil Degradation* (GLASOD) survey about 15% of land is degraded (Oldeman *et al.*, 1991). The highest proportions were reported for Europe (25%), Asia (18%) and Africa (16%); the least in North America (5%). As a proportion of the degraded area, soil erosion is the most extensive, causing more than 83% of the area degraded worldwide (ranging from 99% in North America to 61% in Europe); nutrient depletion causes a little over 4%, but 28% in South America; salinity less than 4% worldwide but 7% in Asia; contamination about 1% globally but 8% in Europe; soil physical problems 4% worldwide but 16% in Europe (Oldeman *et al.*, 1991).

Fortunately, scientists around the world started long ago to look at the problem of land degradation and have developed assessment and monitoring methods. Therefore assessment methods has been developed to determine the status of the land, extent and impact of land degradation and to help designing possible conservation activities. Accurate and relevant assessment methods of land degradation in drylands with a flexible scale combining socio-economic, institutional, and biophysical aspects and driving forces are needed to plan actions and investments to reverse land degradation, improve socio-economic livelihoods, and conserve dryland ecosystems and its unique biological diversity (Snel and Bot, 2003).

The aims of this study were to explore and review existing assessment methods used at global, regional, local and field/farm levels in an attempt to assess land degradation. This knowledge will be used to help recommend assessment methods that are suitable for Namibia's environment in particular.

2. ASSESSMENT METHODS

The most common methods used to assess land degradation are: expert opinions, land users' opinions, field monitoring, observations and measurement, modelling, estmates of productivity changes and remote sensing. The methods have been applied to different approaches which use either qualitative or quantitative measures or both. Table 1 (a – d) summarizes the systems assessed; assessment methods used; factors/processes/ and parameters of the land that is being assessed; and the units or values in which measurements were given for the different assessments of land degradation at different levels. Details are identified at the global, national, regional, local and field/farm level. Below is a summary of the different assessment methods used in assessing land degradation processes in different systems at different levels.

Table 1. *Summary of system of land; assessment method used; what was assessed and units/values at different levels*

(a)*: Global level*

Units/Systems assessed	**Methods used**	**What was assessed**	**Units / values**
Full Cover Analysis Partial cover (soils/ rangelands/ agricultural lands/ drylands, etc.)	**Experts opinion** (e.g. indicators, questionnaires, etc.) **Remote sensing and GIS** (e.g. mapping)	Land/soil degradation: (severity, degree, extent) Soil (erosion, fertility, productivity, etc.) Vegetation change Biodiversity loss	%, Classes (1,2,3,4,5 -light – very severe / excellent – very poor, etc.), t/ha/yr

(b)*: Regional level*

Systems assessed	**Methods used**	**What was assessed**	**Units / values**
Drylands, rangelands, grasslands, forests, deserts, etc., Soils, Rivers systems, etc.	**Expert opinion** (e.g. indicators, questionnaires, interviews, focus groups, etc..) **Remote Sensing and GIS** (e.g. NDVI, MODIS, etc.) **Modelling** (e.g CORINE, PESERA erosion models, etc.) (mainly for croplands) **Field monitoring and measurements** (measurements to verify models) -pilot areas **Grid System Monitoring (EU)**	Land/soil degradation: - severity, degree, extent, impact, causes, & risks - Soils (erosion, fertility, productivity, etc.) Vegetation change Land cover Land uses Slopes Climate (rainfall, temperature) for modelling Biodiversity loss Landscapes/ Ecosystem function	%, Classes (1,2,3,4,5 for light – very severe / excellent – very poor, etc..), t/ha/yr

***(c)**: National level*

Systems assessed	Methods used	What was assessed	Units / values
Lands (agricultural lands, grasslands, forests, conserved area, deserts, etc.), Soils, Rivers, Rangelands systems	**Expert opinion** (e.g. indicators, questionnaires, interviews, focus groups ect.) **Land users opinion** (e.g. indicators, etc.) **Remote Sensing and GIS** (e.g. NDVI, MODIS, MSDI ect.) **Modelling** (e.g CORINE, PESERA models, etc.) **Field monitoring and measurements** (measurements to verify models) - pilot areas	Land/soil degradation: - severity, degree, extent, impact, causes, & risky - Soil (erosion, fertility, productivity, etc.)	%, Classes (1,2,3,4,5 for light – very severe; extremely health – extremely unhealthy, etc.), t/ha/yr Frequency of indicators
		Vegetation change Land cover Biodiversity loss Land uses	
		Rangeland health/conditions, Climate (rainfall, temperature), etc.	

***(d)**: Local and Field/Farm levels*

Systems assessed	Methods used	What was assessed	Units / values
Lands (cropland lands, grasslands, forests, conserved area, deserts etc.), Soils, Rivers, Rangelands, etc.	**Expert opinion** (e.g. indicators, questionnaires, interviews, focus groups, etc.) **Land users opinion** (e.g. indicators etc.) **Remote Sensing and GIS** (e.g. NDVI, MODIS, MSDI ect.) **Modelling** (e.g USLE/ RUSLE, CORINE, PESERA models, etc.) **Field monitoring and measurements** (verify models) - farm plots **Estimates of productivity changes**	Land/soil degradation: - severity, degree, extent, impact, causes, & risks;, Soil erosion (Sediment yields)	%, Classes (1,2,3,4,5 for light – very severe; extremely health – extremely unhealthy, etc.), t/ha/yr Frequency of indicators
		Rangelands Health/ condition Soil condition (quality, salinity, stability, fertility, etc.), Crop yield & suitability, Soil condition, Landscape/ ecosystem function, Land cover, Biodiversity loss, Land uses, Climate (rainfall, temperature), etc.	

2.1 Soil Degradation and Erosion

Assessment of soil degradation is important to determine the possible consequences and potential management measures by first finding out the causes, degree, status and extent of the type of erosion in the region. Methodologies for predicting soil erosion have been developed since the early 1930s (Ballayan, 2000).

2.1.1 Global Assessment of Human-induced Soil Degradation (GLASOD) method

The purpose of GLASOD was to provide factual information, to replace sweeping statements about soil and land degradation, and to raise awareness of policy makers and governments for the continuing need for soil conservation (Bridges and Oldeman, 1999). GLASOD is the only approach that has been applied on a worldwide scale. It is based on responses to a questionnaire which was sent to recognized experts in countries around the world.

The GLASOD survey provides basic data on the world distribution and intensity of erosional, chemical, and physical types of degradation (Bridges and Oldeman, 1999). Its maps identify areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce such erosion (Oldeman *et al.*, 1990). Oldeman *et al.* (1991) developed a classification based on types of soil degradation, degree of degradation and causative factors in soil degradation, as well as the definition of the classifications.

The GLASOD survey results enable comparisons to be drawn between degraded soils of different continents, and the methodology used can be a basis upon which plans for restoration of degraded lands can be based. However, the study did not include any remote sensing or field measurements; it was just based on experts' opinions (Jones *et al.*, 2003). The questionnaires were sent to experts around the world but some didn't reply at all and some replied only partly. Results from such kinds of studies are difficult to use to compare regions (Jones *et al.*, 2003).

2.1.2 Assessment of the Status of Human-Induced Soil Degradation (ASSOD)

The ASSOD is a follow-up activity of GLASOD in South and South-East Asia (ISRIC, undated). The same methodology, slightly refined, was used on a more detailed scale (1:5M). The study provides data for 17 countries and includes data on several degradation types including water and wind erosion and their subtypes (e.g. loss of topsoil and terrain deformation, in millions of hectares) and the dominant subtypes of chemical deterioration (including salinization).

In the ASSOD study, the degree of soil degradation is expressed by degradation subtypes using qualitative terms such as *impact on productivity* (negligible, light, moderate, strong, or extreme impact). Classification is based on estimation of the changes in productivity and also takes the level of management into consideration. Changes in productivity are expressed in relative terms, i.e. the current average productivity compared to the average productivity in the non-degraded situation (or non-improved, where applicable) and in relation to inputs (ISRIC, undated). Compared to GLASOD, the ASSOD study is more detailed and thus also more accurate. A comparison of the studies was presented by van Lynden and Oldeman (1997).

2.1.3 A Standardised Method for Assessment of Soil Degradation and Soil Conservation: World Overview of Conservation Approaches and Technologies (WOCAT) Methodology

The WOCAT programme has developed a set of standardized tools to document, monitor and evaluate soil and water conservation (SWC) know-how worldwide, and to disseminate this knowledge around the globe in order to facilitate exchange of experience and better decision making and planning (van Lynden *et al*., undated). Van Lynden *et al*. (undated) discussed the methodology for mapping soil degradation and conservation, and its use for better decision making. The paper provides good guidance about activities and parameters used for assessment.

Van Lynden *et al*. (undated) explained that a set of three comprehensive questionnaires and corresponding databases were developed to document all relevant aspects of SWC technologies and approaches, and the mapping of their area coverage. The collection of information on SWC technologies and approaches focuses on case studies that describe the technology and its human and natural environment, where it is used, and which approach was used for its implementation. The questionnaire and database on the SWC map aims at providing a spatial overview of soil degradation and conservation.

Furthermore, van Lynden *et al*. (undated) described that the mapping methodology covers assessment of land use, soil degradation, SWC technologies and soil productivity aspects. Data are collected through a "Participatory Expert Assessment" method which includes both expert knowledge and existing documents and which reflects the current state of knowledge. Ideally several experts who know the status of the land sit together and fill in the data in a process of negotiation and consultation of existing documents. By using the base map in the country or region, information on land use, soil degradation, soil and water conservation, and productivity issues need to be entered into the matrix table.

The mapping methodology comprises of an interactive mapping tool for data entry and map viewing. The resulting maps help planners, co-ordinators and decision makers to make appropriate plans and set priorities for future investments. They also help in identifying knowledge gaps and research priorities (van Lynden *et al*. undated). The vital part is that it can be applied at different scales, from local, national, and regional levels to a global level.

2.1.4 Classification Approach

Arnalds *et al*. (2001) described the project and methods developed for mapping soil erosion in Iceland. The project provides a comprehensive survey of soil erosion in Iceland. The methods for mapping soil erosion were developed by the Agricultural Research Institute (RALA) and Soil Conservation Service (LR) and are partly based on the methods used to determine the condition of soils in New Zealand and New South Wales in Australia (Arnalds *et al*., 2001).

The method is called RALA/LR classification methods for mapping soil erosion. The methods developed have four primary characteristics: 1) classifying erosion according to erosion forms; 2) applying standard scales to assess the severity of soil erosion; 3) using satellite images as the basic map and as an aid for field mapping; and 4) use of a geographical information system (GIS). The erosion scale developed reflects the recognition of soil both as a living resource that is part of the ecosystem and as a factor in the sustainable utilization of the ecosystem (Arnalds *et al*., 2001). The scale rates erosion using 6 degrees (0 for no erosion to 5 for extremely severe erosion). As a result of the project, a soil erosion map for the whole of Iceland was developed, at the scale of 1:100,000.

The New Zealand Land Resource Inventory (NZLRI) classification system is based on mapping erosion forms and determines severity. Before, the New Zealand system was built on mapping how much soil had been lost, as in some erosion categories. The NZLRI system has five physical factors on which Land Use Capability assessments were made: rock, soil, slope, erosion and vegetation (Graham *et al.*, 1989; Landcare Research, 1996-2008). The assessments make use of classification and scale to measure the factors. For example, there are seven different classes of slope A–G, G being all land >35°, and the erosion was mapped using 14 erosion types together with an assessment severity on a scale of 0–5.

Scientists at Landcare Research in New Zealand are upgrading the vegetation component of the NZLRI using satellite images to identify where changes have occurred during the past 20 years or so (Landcare Research, 1996-2008). In addition to the inventory code, the method also looks at the assessment of Land Use Capability (LUC) for each map unit (Graham *et al.*, 1989). The aim being to assess the capacity for sustained productive use taking into account physical limitations, soil conservation needs and management requirements.

In the study done by Berry *et al.* (2003) in Chile, to assess the extent, cost and impact of land degradation, soil erosion was assessed in the field by means of expert protocols, using 5 degrees (states of erosion). Table 2 shows the classification concept and the description of the concept, as well as the class values for each concept used by Berry *et al.* (2003).

Table 2. *Classification of the state of erosion in Chile (Berry et al., 2003).*

CONCEPT	DESCRIPTION	VALUE
Very light	*Very light erosion signs, the process is incipient and not very evident, some sedimentation is observed in small places where rainwater accumulates.*	**1**
Light	*Light erosion, signs begin to be visible. Removal of fine material is visible leaving the thicker material exposed (gravel, small stones), runoff water is not totally clear.*	**2**
Mean/ medium	*Moderate erosion, clear signs of particle removal from the surface of the ground. Erosion is evident, with the hardpan material clearly exposed on the surface. Some rill erosion is noticeable.*	**3**
Strong or severe	*Erosion strong, strong mantle erosion leaves gravel spread on the surface, rill erosion is abundant and increasing, some gullies appear in their initial state of formation. There are very few materials left from the original surface soil, the soil has begun to change in colour.*	**4**
Very strong/ severe	*Very strong erosion, all original surface materials have been removed generating a change in colour of the soil, a widespread change in soil texture due to the dominance of horizon C on the surface. Active gullies are observed.*	**5**

Adapted from Berry, Olson, and Campbell (2003) except for the medium and severe concepts which were added as used by other authors.

2.1.5 Indicators Approach

In Kenya, de Bie (2005) used indicators for a maize-based agro-ecosystem to assess soil erosion in the Taita Taveta district. The study makes use of easily assessable soil erosion indicators to monitor the cumulative effects of erosion between tillage and harvesting. The indicators were: eroded clods, flow surfaces, pre-rills and rills. Indicators were expressed in terms of percentage incidence of bare area; the thickness of soil accumulation over solid subsoil was also assessed (de Bei, 2005). The study collected data on soil/terrain, land cover, infrastructure, land management, and incidence of soil erosion.

Seventy maize plots in 11 map units, having considerable variation in altitude, land cover, rainfall, and geomorphology, were surveyed. De Bei (2004) reported that soil loss was considered variable between plots due to differences in surface soil, land cover, infrastructure, crop management, slope, and map unit. According to de Bei (2004) the model was not map unit specific and had an adjusted R2 of 67%. A log linear relationship indicated that combined positive conditions exponentially reduce the occurrence of erosion features (pre-rills indicators).

The pre-rill indicator related best to management-affected site conditions and seemed to reflect best the cumulative effects of soil loss over time (de Bei, 2004). Furthermore, rills were found at 18 sites located in drier areas on sandy–clay soils. For this study, the model suggested more rills if the topsoil contain no silt; silt makes the soil susceptible to compaction and rill formation (de Bei, 2004).

Reed and Dougill (2002) provide a report on the experience of implementing the first stages of the proposed Land Degradation Assessment in Drylands (LADA) methodological framework (discussed under 2.2) in the Kalahari, Botswana. In this study, Reed and Dougill focus on participatory degradation appraisal. The approach borrows from the field of Participatory Monitoring and Evaluation (PM&E) (see Estrella and Gaventa, 2000, for a recent review cited by Reed and Dougill, 2002). They stated that the approach integrates three of the five degradation assessment methods identified by van Lynden and Kuhlmann (2003 - LADA draft): land user opinion/ farm-level field criteria, field monitoring and productivity changes.

In southern Africa, Reed and Stringer (2006) investigated the potential for the integration of scientific experience with local knowledge with the aim of enhancing accuracy, coverage and relevance of land degradation assessment. Reed and Stringer (2006) followed the participatory approach, using methods from a variety of disciplines, to elicit potential land degradation indicators from communities in Botswana and Swaziland. In both countries, the main land degradation problems and the affected agro-ecosystems were indentified through a combination of key informant interviews, focus groups and questionnaires. Identified potential indicators were obtained both from the scientific literature and local stakeholders. These were evaluated and integrated in follow-up semi-structured interviews and focus groups (Reed and Stringer, 2006).

Communities used degradation indicators focused on agriculture, vegetation, soils, wild animals and insect indicators. Communities in Swaziland used many indicators that focused on the soil system (Reed and Stringer, 2006). The indicators were empirically verified and evaluated using sampling and either ecological or remotely sensed data (Reed and Stringer, 2006). Participatory mapping, vegetation and soil sampling, and land use mapping from time-series aerial photographs were some of the activities carried out during empirical testing of indicators and integration of knowledge.

The developed indicators were deemed both accurate and easy to use by local people (Reed and Stringer, 2006) . It may be possible to obtain monitoring data that are highly relevant to the local area, while providing comparable data at regional and/or national scales; by running local degradation assessment programmes using the full range indicators alongside regional and/or national initiatives using indicators shared by all regions (Reed and Stringer, 2006).

The authors (Reed and Stringer, 2006) noted a significant overlap between scientific and local knowledge about land degradation in most instances. They stated that where discrepancies occurred, the integrated participatory approach used allowed an appropriate explanation to be reached, and that this interactive process can lead to both accurate and relevant monitoring of land degradation. Reed and Stringer (2006) concluded that both scientific and local knowledge has its limitations.

2.1.6 Modelling of Soil Erosion and Land Cover

Assessment of soil erosion both by water and wind has been carried out using models designed for the purpose. The mathematical models are continually being improved and scientists from many countries have adopted them to meet the requirements of their local conditions (Arnalds *et al.*, 2001). Many more models have now been developed and used by different countries in different regions. Below is a summary of several models for measuring soil erosion and land cover used in different environments.

a) USLE model

The Universal Soil Loss Equation (USLE) and Wind Erosion Equation (WEE) have been used worldwide to assess soil loss by water and wind erosion. They were first developed by the United States Soil Conservation Service (USSCS) in 1935. The equations have proved to be successful in assessing agricultural lands but not as suitable for rangeland assessment (Arnalds *et al.*, 2001). One reason among others is that rangelands are said to be not uniform like agricultural fields. The society for Range Management, a USA-based association of rangeland specialists, rejected the use of the USLE equation (see box 1) for assessing erosion on rangelands (SRM, 1992 cited in Arnalds *et al.*, 2001).

The USLE has been used widely in assessing long-term annual soil loss. An example cited here for the USLE comes from Italy, where,in an attempt to identify erosion-prone areas in the Mediterranean, a project was initiated to assess erosion risk at national level (EUSOILS, 2008). An approach based

Box 1: USLE/RUSLE models equations
USLE *simple empirical model that is widely used for assessing long-term annual soil loss. The equation:* **A = R * K * L * S * C*P (P – factor only for RUSLE, an empirical models).** *where: A - Mean (annual) soil loss [t/(ha.y)], R - Rainfall erosivity factor [(MJ.mm)/(ha.h.y)], K - Soil erodibility factor [(t.ha.h)/(ha.MJ.mm)], L - Slope factor (dimensionless), S- Slope length factor (dimensionless), and C - Cover management factor (dimensionless), P - factors for Human Practices aimed at erosion control.*

on the Universal Soil Loss Equation (USLE) was adopted. The method only accounts for rill- and inter-rill erosion by water, but gully erosion, which is a major problem in large parts of Tuscany, cannot be predicted by the method. Furthermore, mass movements such as landslides are not taken into account at all.

The USLE model has been adapted to other conditions through modified versions such as MUSLE (Williams and Berndt, 1977 cited in FAO, 2005) and RUSLE (SWCS, 1993 cited in FAO, 2005) for sediment yield estimation.

b) RUSLE model

The Revised Universal Soil Loss Equation (RUSLE) was applied to the whole alpine space of the Alps, with a specific setting on mountain areas for slope and rain erosivity parameters (EUSOILS, 2008). The alpine territory includes Italy, Switzerland, France, Austria, Germany, and Slovenia. The study produced maps that show the rate of soil erosion by water in the alpine territory. The map was basically derived from the RUSLE model, which calculates the actual sediment loss by soil erosion using Arnoldus's formula to determine the rainfall erosivity factor. The index values indicate the intensity of the soil erosion rate (EUSOILS, 2008). The equation for RUSLE uses all factors of USLE, but P-factors for Human Practices aimed at erosion control were added.

In Italy, Marker *et al*. (2007) did a study in the Albegna river basin in southern Tuscany, in which they utilized the RUSLE approach to evaluate the different scenarios of land uses (the scenarios referred to are: convectional, transitional and biologic) for current and future climatic change on a monthly basis. During the study, they kept the K-factor, LS-factor and P-factor value constant and only rainfall erosivities (R-factor) and C-factor values were changed according to the scenario settings. The analysis demonstrates the potential of this approach to assess landscape soil erosion susceptibility with scenario analysis (Marker *et al*., 2007). The authors state that the analyses might help to develop adaptation strategies for future climate change scenarios such as modification in land management techniques.

Castro Filho *et al*. (2001) discussed the use of tool and techniques for the measurement of sediment load in regions of great agricultural potential, such as the Paraná River Basin in Brazil. In this paper they presented the utilization of models such as the RUSLE and the Water Erosion Prediction Project Model (WEPP) to assess the risk of land degradation on large scale agricultural lands as well as the techniques used for continuous monitoring.

The study addressed issues and problems with the adaptation of small scale erosion models to function as large scale risk assessment tools. The essential part of this methodology is the integration of these models with tools such as GIS and the use of various thematic maps derived from satellite imagery and land surveys to feed the models. Castro Filho *et al.* (2001) mentioned that the identification of areas with high degradation risks will allow for better soil conservation plans to reduce the sediment load to the rivers and lakes in the region of interest.

Because they were concerned with soils for agricultural purposes, land degradation was defined as the action on land that decreases sustainable crop production over time. They emphasize that the definition is applicable to any area in which basic soil conservation principles were not obeyed when establishing agricultural lands after deforestation or other land-use change. Furthermore, Castro Filho *et al.* (2001) discussed the use of biotic and abiotic early warning indicators of land degradation which can be easily seen along the road in southern Brazil. It is important to have enough data of the area of interest when assessing large-scale land degradation. The Paraná River basin was used as an example to illustrate tools and techniques that can be utilised to assess sediment load in large watershed. The use of modelling tools and techniques was beneficial as it gave information on areas that were at great risk of land degradation at the time of the study.

RUSLE is still intended primarily to meet the needs of the USLE user, concentrating on predicting long-term annual average erosion by water on disturbed slopes (Yoder *et al.*, 2004). They said that the RUSLE effort followed the lead of the USLE in realizing that the users are not specifically erosion science experts, and emphasized making both the model use and the logic behind the calculations accessible to users. The results from a study in the western US rangelands shows that RUSLE provides routines specifically to model erosion on rangeland sites, including descriptions of rangeland vegetative communities and of range improvement field operations (Yoder *et al.*, 2004). The changes in RUSLE make it useful for estimating erosion and sediment yield, not only for agronomic settings but also for situations involving construction, mine spoils, and land reclamation (Yoder *et al.*, 2004). The RUSLE is a powerful programme that is capable of predicting soil loss from fields or hill slopes that have been subjected to a full spectrum of land manipulation and reclamation activities (Warner and Foster, 1998).

c) CORINE model

CORINE methodology is a standard method used by the countries of the European Community to determine the erosion risk and qualities of the land being studied (Doğan *et al.*, undated). Countries of the European Community sharing the Mediterranean region have completed their erosion maps and classification of their lands using CORINE methodology (Doğan *et al.*, undated).

The CORINE method of erosion mapping analyses several factors for the determination of actual erosion risk (Doğan and Küçükçakar, 1994 cited in Doğan *et al.*, undated). These factors are: vegetative cover, land slope, meteorological conditon and soil properties. Doğan *et al.* (undated) conducted an erosion mapping study in the Dalaman River Basin in Turkey based on CORINE methodology. The study utilized remote sensing (RS) and geographic information system (GIS) methods. They concluded that the existence of plant cover had highly reduced the potential erosion risk in the basin.

Dengiz and Akgul (2004) did a study to determine the soil erosion risk in the Gölbaşl Environmental Protection Area and its vicinity in Turkey using the CORINE model. The model consists of 6 steps, each of which uses different overlaying combinations of soil texture, depth, stoniness, climatic data, land use and land cover information. Dengiz and Akgul (2005) described how, in the first step, soil texture, depth and stoniness layers were extracted from a 1:25,000 scaled digital soil map and overlaid to form a soil erodibility map. Secondly, Fournier and Bagnouls-Gaussen aridity indexes calculated from the climatic data were used to form the erosivity layer of the study area. The third step consisted of obtaining slope angle classes from a digital elevation model of the study area. As the fourth step the land cover layer was prepared from the land use map considering the density of the plant cover. Then the potential soil erosion risk layer was produced by overlapping soil erodibility, erosivity and slope layers. For the final step, the land cover and potential soil erosion risk layers were combined to form the actual soil erosion risk map. The results from the Dengiz and Akgul study showed that 72.9% of the study area had low, 23.8% of the area had moderate and a small part of the study area (1.0%) had a high soil erosion risk. In addition, the study showed that the geographic information system (GIS) technique has an important role in the prediction of soil erosion risk studies (Dengiz and Akgul, 2005).

Cebecauer and Hofierka (2007) studied the consequences of land cover changes on soil erosion distribution in Slovakia. The assessment was based on principles in the USLE modified for application at the regional scale and the use of CORINE land cover (CLC) databases for 1990-2000. The C factor for arable land has been refined using statistical data on the mean crop rotation and the average and land area for particular agricultural crops in the district of Slovakia, while the L factor has been calculated using sample areas with parcels identified by LANDSAT TM data.

Cebecauer and Hofierka (2007) emphasize that the USLE model was developed for a local scale assessment of soil erosion by sheet and rill erosion, thus its application to regional assessment needs some modifications. The RUSLE conservation practice factor, P, is not considered in this model (Cebecauer and Hofierka, 2007). The C factor was determined from the CLC database and crop rotation statistical data for 72 Slovak districts. From this study, the result shows that the land cover and crop rotation changes had a significant influence on the soil erosion pattern predominately in the hilly and mountainous parts of Slovakia. The analysis of regional differences in land cover and the crop rotation system showed the main causes of changes and helped explain the ongoing changes in soil erosion patterns.

Kiunsi and Meadows (2006) conducted a study in northeast Tanzania in an area typifying the drylands of Africa. In their study, three sets of land cover maps synchronized againist long-term rainfall data (1960s, 1991 and 1999) were used to assess land degradation in the area. The method took into account both vegetation and soil degradation (Kiunsi and Meadows, 2006). They explained that the utilization of three sets of land cover maps as a basis for the detection of change makes it possible to distinguish areas that experienced changes in vegetation due to rainfall variability from those that are caused by land use. They concluded that all areas that displayed overall depletion of natural and semi-natural vegetation due to human factors were deemed to have undergone land degradation, whereas areas that experienced inter-annual land cover changes due to rainfall variability were classfied as experiencing cover change due to ecosystem dynamics. The use of historical land cover maps gave a good indication of how the ecosytem changes over time. For this study the method provided complete and appropriate assessment of land degradation and can be used to improved degradation assessment in other semi-arid areas (Kiunsi and Meadows, 2006).

d) PESERA model

The Pan-European Soil Erosion Risk Assessment (PESERA) is a run-off based model used to predict run-off with a daily time step, estimating changes in soil water storage capacity and vegetation interception and links this estimated run-off to soil loss by an equation developed by Kirkby *et al.* (2004). PESERA uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe.

EUSOILS (2008) reported that the conceptual basis of the PESERA model can also be extended to include estimates of tillage and wind erosion. The model is intended as a regional diagnostic tool, replacing comparable existing methods, such as the Universal Soil Loss Equation (USLE), which are less suitable for European conditions and lack compatibility with higher resolution models. Preliminary results suggest that, although the model can be applied at regional, national and European levels, low resolution and poor quality input data cause errors and uncertainties. However quantification of the erosion problem enables evaluation of the possible effects of future changes in climate and land use, through scenario analysis and impact assessment, taking into account cost-effectiveness, technical feasibility, social acceptability and possibilities for implementation (EUSOILS, 2008). Therefore it is viewed as most conceptually correct because of the parameters it measures (Kirkby *et al.*, 2004). The PESERA model produces results that depend crucially on land cover data as identified by CORINE and the accuracy of the interpolated meteorologicl data.

In addition to the USLE, RUSLE, CORINE, and PESERA soil erosion models discussed above, examples of models that have been used are: the SPADS model for sediment yield measurement; Sediment Delivery Ratio (SDR), which is assumed to be more accurate for measurements of soil erosion by water at the catchment level than the USLE; RIVM, a factor model like CORINE but in many ways a more simplified approximation of the USLE model; the Institute National Recherche Agronomique (INRA) model, which takes into account crust formation, land use and soil erodibility. Many other models have been developed and used for soil erosion measurement (see box 2).

Box 2: Other Soil Erosion models

- *SLEMSA - the Soil Loss Estimation Equation for Southern Africa (Stocking, 1981) was developed in Zimbabwe on the basis of the USLE model*
- *MMF - the Morgan-Morgan Finney model (Morgan et al., 1984) is comparatively simple, flexible, has a strong physical basis, and can be applied in mountainous areas (Shrestha, 1997). MMF was reported to provide useful information on the source areas of sediment, sediment delivery to streams and annual sediment yield (Morgan 2001)*
- *WEPP - the Water Erosion Prediction Project (Nearing et al., 1989) is a process-based erosion model, designed to replace the Universal Soil Loss Equation*
- *Models such as ANSWERS, Areal Non-point Source Watershed Environment Response Simulation (Beasley et al., 1980), and AGNPS - Agricultural Non-Point Source Pollution Model (Young et al., 1987) are available for computer soil erosion within a watershed; and the use of IF–THEN–ELSE logic provides an alternative for land degradation assessment (Shrestha et al., 2004).*

These models with their explanations were adapted from FAO, 2005. Agro-Ecological Zoning and GIS application in Asia, with special emphasis on land degradation assessment in drylands (LADA).

2.2 Land Degradation Assessment

2.2.1 Land Degradation Assessment in Drylands (LADA) methodology

LADA follows a participatory, decentralized, country-driven and integrated approach and makes ample use of participatory rural appraisals, expert assessment, field measurements, remote sensing, GIS, modelling and other moden means of generation of data, networking and communication technologies for sharing information at national and international levels (Koohafkan *et al*., 2003; LADA project document, 2005). LADA[1] considers both biophysical factors and socio-economic driving forces. The project is intended to make an innovative generic contribution to methodologies and monitoring systems for land degradation, supplemented by empirically derived lessons from the six main partner countries involved in the project. These countries are: Argentina – for the Latin America region, China – for the East Asia region, Cuba – for the Caribbean region, Senegal – for the Francophone area of West Africa, South Africa – for the southern, central and eastern Africa region, and Tunisia – for the Near East, north Africa and Mediterranean region (LADA project document, 2005).

The guidelines for a methodological approach for assessing land degradation for the LADA project were developed by Koohafkan *et al.* (2003). They proposed that the causes, status and impact of land degradation and possible responses can be determined and assessed at the same time. The proposed LADA methodology was based on the DPSIR framework where D indicates the driving forces, P the pressures, S the condition of land and its resilience, I the impacts of the increased or reduced pressures, and R the responses by the land users to release or reduce the pressures on the land.

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[1] *LADA defines land degradation as a reduction in the capacity of land to perform ecosystem functions and services that support society and development.*

The approach is said to allow for flexibility for each country to adopt indicators pertinent to their situation and specific problem (LADA project document, 2005). Ponce-Hernandez (2002) said that the proposed LADA approach was to develop a methodological framework rather than a method. The framework was hoped to bring enough flexibility, in term of the procedures, techniques and state of the databases, to accommodate the particular circumstances of the country or region where it is applied (Ponce-Hernandez, 2002). The procedures for the assessment under the approaches are based fundamentally on indicator variables and "proxies". However, the framework would use any "hard" data provided by detailed measurement wherever they are available (Ponce-Hernandez, 2002).

In the context of the LADA project, Snel and Bot (2003) suggested indicators that might be used for assessing land degradation in drylands. In the paper by Snel and Bot (2003) indicators on the biophysical condition of land, on how land is being managed, and the policy and social environment for instituting improvement in land management are discussed. The proposed set of indicators documented in the Snel and Bot paper are based on a review of existing land degradation indicators, data sources and methods, and expert consultation. The list of potential indicators for uses at global, national, and regional, watershed or village and farm levels are listed by FAO (2003) in the summary for the e-mail conference in 2003. However the list of potential indicators is too long; therefore the LADA project uses the indicators as a stating point aiming to have a short list. Indicators for the LADA project will be determined by the SMART measure stick (specific, measurable, achievable, relevant, and time-bound) and checked agaiinst the DESERTLINK indicators (LADA document) (box 3).

Box 3: The DESERTLINKS project

In Mediterranean Europe, desertification indicators havebeen summarized by the DESERTLINKS project. Around 150 indicators relevant to Mediterranean desertification have been designed to provide a tool to help users from a wide range of backgrounds including scientists, policy makers and farmers to: identify where desertification is a problem, assess how critical the problem is, and better understand the processes of desertification (DESERTLINKS).

Besides, Burning and Lane (2003) proposed a framework for indicators of biodiversity, land and socio-economic conditions as part of a stocktaking of biodiversity issues for the LADA project. They state that the causes of declining biodiversity and land degradation are often multiple, complex and usually involve a combination of human and natural factors. Furthermore, the impact of land degradation are also multiple and affect a range of natural and socio-economic considerations. The assessment and monitoring of biodiversity and the associated ecosystem processes, therefore, requires an integrated suite of biophysical and socio-economic indicators (Burning and Lane, 2003).

Finally, Burning and Lane (2003) summarised the key biodiversity, land condition, socio-economic and natural resource management indicators that can be used for local (plot and farm-household), ecosystem and national level assessments (example, see table 3). These selected variables are indicators

Table 3. *Key biodiversity, land condition and socio-economic indicators and levels of assessment (local, ecosystem or national).*

State of biodiversity and natural resources	**Local (plot, F-H)**	**Ecosystem/ AEZ/ catchments**	**National**
I. Ecosystem			
I.1 Diversity of ecosystem/habitats			
Change in vegetative cover		X	X
Land use change		X	X*
I.2 Loss of species			
Loss of key species (economic, cultural, eco-services)	X	X	X*
Flora and fauna species diversity	X	X	X*
Rate of harvesting of certain wild target species		X	X
I.3 Demographics			
Human population growth, Poverty,	X	X	X*
Urban/rural areas		X	X
II. Soil			
II.1 soil biodiversity			
Soil organic biomass	X		
II.2 Soil Physical degradation			
Soil surface condition	X		
Erosion	X	X	
Vegetative cover; composition; structure; health	X	X	
II.3 Soil Chemical degradation			
Area of salinity, sodicity, acidity	X	X	X*
Vegetative cover, productivity, composition, health	X	X*	
III. Vegetation (non-agricultural)			
III.1 Diversity and composition			
Distance from stock watering points	X	X	
IV. Water			
IV.1 Water quality – contamination			
Flora and fauna bio-indicators, nutrient load, and sedimentation	X	X	
V. Agro-biodiversity			
V.1 Crop diversity			
No. of species cultivated by local smallholders	X	X	X*
V1. Food and livelihood security			
Farm size, Area under cultivation, Land tenure, Crop and livestock productivity, Education (highest level in HH and schooling of children, quality and quantity), etc.	F-H	X	X*
V11 Land and water management practices			
Water management	F-H	X	
Grazing regime	P	X	
Fire management	P	X*	X

Note: This is just an example showing some of the indicators proposed for indicating biodiversity, land and socio-economic factors as part of stocktaking of biodiversity issues for the LADA project by Burning and Lane (2003) - not a complete list. National level assessments often collate information collected at local and ecosystem levels. These national indicators are indicated as X.*

of the changing state of biodiversity, land condition and human dimensions as a result of pressure (Burning and Lane, 2003). In addition they also discussed some management responses to indicators and provide a more detailed table that lists the socio-economic driving forces, pressures and potential impacts on biodiversity, indicators of state, indicator methods and potential limitations, and levels of assessment. The authors (Burning and Lane, 2003) suggested that the indicators should be applied at the local level and supply information for broader assessments at the catchment, agro-ecological zone and national levels. They note that the specific attributes of biophysical and socio-economic indicators that are monitored will vary between human-managed systems and the questions being asked. In addition, Burning and Lane gave examples of indicators: in irrigated cropping systems, soil salinity determination and mapping may be seen as a priority, while in rainfed cropping, monitoring of nutrient balance may be important. In contrast, in designated conservation areas, monitoring the population status of threatened species and the condition and distribution of their habitat will be important, and in rangelands the focus may be on the cover and composition of desirable perennial grasses as a functional group. Burning and Lane (2003) also commented that remote sensing techniques can be used to monitor indicators such as land use change, vegetation clearing and habitat fragmentation at zonal and national levels.

Moreover, in the context of the LADA project, Van Lynden *et al*. (2004) discussed the guiding principles for quantifying soil degradation. They considered soil degradation as a process that describes human-induced phenomena which lower the current or future capacity of the soil to support human life. In contrast, they also considered land degradation as the reduction in the capacity of land to produce benefits from a particular land use under a specified form of land management. Van Lynden *et al*. (2004) developed indicators, focusing only on indicators for salinization, nutrient cycling and soil pollution. They used information from the work done by GLASOD, ASSOD and SOVEUR were indicators are well defined and documented.

Van Lynden *et al*. (2004) suggested that soil quality is the most restrictive land change concept, followed by land quality and then sustainable land management. Soil quality will likely be based on soil organic matter turnover. Soil quality is effectively a condition of the site and can be studied using soil data alone, while land quality requires integration of soil data with other biophysical information such as climate, geology and land use. Sustainable land management requires the integration of land quality with economics and social demands. In particular, the dynamic carbon pool is most affected by environmental conditions and land use change (van Lynden *et al*., 2004).

2.2.2 Agro-ecological (AEZ) methodology

The FAO agro-ecological (AEZ) methodology was developed in 1975 and is a major system aimed to assess land resources. The methodology has since been used to address various questions related to soil inventory, land evaluation, land use planning and management, land degradation assessment and land use mapping at global, regional, national and sub-national levels (FAO, 2005). The AEZ concept involves the representation of the components of land as layers of spatial information or map layers and the integration of the layers using GIS. In the AEZ database, various kinds of geo-referenced data sets are integrated, which can include the following: topography, administrative boundaries, road/ communications, towns and settlements, rivers and water bodies, geology, soil, physiography, landforms, erosion, rainfall, temperature and moisture regimes, watersheds, land use or land cover and forest reserves, and population (FAO, 2005).

The AEZ methodology is based on the following principles, which are fundamental to any sound evaluation of land resources: application of an inter-disciplinary approach, based on inputs from a number of disciplines, including crop ecologists, pedologists, agronomists, climatologists, livestock specialists, nutritionists and economists. Land evaluation is related to specific land uses and land suitability refers to use on a sustained basis, i.e., the envisaged use of land must consider degradation, e.g. through wind erosion, water erosion, salinization or other degradation processes (FAO, 2005).

Furthermore, FAO (2005) states that soil regeneration is assumed to be achieved by means of fallowing land, appropriate crop rotations and soil conservation measures: 1) evaluation of production potential with respect to specified levels of inputs, e.g., whether fertilizers are applied, if pest control is effected, if machinery or hand tools are used (agricultural inputs and farming technology); 2) different kinds of land use must be considered in the context of meeting national or regional demands for food and agricultural products, including livestock and forestry; and 3) land-use patterns must be constructed so as to optimize land productivity in relation to political and social objectives taking into account physical, socio-economic and technological constraints and environmental considerations.

2.3 Rangeland Health and Condition Assessment

Rangeland health, as defined, is very important as it reflects changes in land condition and resilience because it is an ecological potential that is used as a reference. Furthermore, it can be used to plan and prioritize restoration projects (Pyke *et al.*, 2002). Indicators have a long historical use in rangeland assessment and monitoring and resource inventories.

2.3.1 Use of attributes and indicators

Pyke *et al.* (2002) developed a rapid, qualitative method for assessing a moment-in-time status of rangelands in the US. The evaluators rate 17 indicators to assess 3 ecosystem attributes[2] (soil and site stability, hydrological function, and biotic integrity) for a given location. The seventeen indicators refered to are: rills, water flows pattern, pedestals, bare ground, gullies, wind-scoured and depositional areas, litter movement, soil surface resistance to erosion, soil surface loss or degradation, plant community composition and distribution relative to infiltration and runoff, compaction layer, functional/structural groups, plant mortality/decadence, litter amount, annual production, invasive plants, and reproductive capability of perennial plants (Pyke *et al.*, 2002).

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[2] *An ecosystem component that cannot be directly measured, but can be approximated by a set of observable indicators of the component (Pellant et al., 2002).*

The techniques used to evaluate each attribute are outlined relative to the potential of a particular site. Pyke *et al.* (2002) used concepts and materials from the NRC book. The National Research Council described range condition as the present state of vegetation on a range site in relation to the climax plant community for that site; and ecological status described as the degree of similarity between existing vegetation and soil condition compared to the potential natural community and the desired soil condition on a site. To determine whether the land is degraded or not, assessment needs to be done based on different criteria including soil stability, vegetation, nutrient cycling and many others aspects (NRC, 1994). In addition, Pyke *et al.* (2002) reviewed the intended applications for this technique and clarified the differences between assessment and monitoring that led them to recommend this technique for moment-in-time assessments and not to be used for temporal monitoring of rangeland status. Lastly, Pyke *et al.* (2002) proposed a mechanism for adapting and modifying this technique to reflect improvements in the understanding of ecosystem processes. Adequate knowledge of the ecological site and soils is necessary to interpret many of the indicators and apply them on the ground.

The qualitative assessment is not a stand-alone tool as it does not quantitify any measure (Pyke *et al.*, 2002). The addition of quantitative information to supplement this preliminary evaluation is recommended if the goal is a better certainty of the results of the assessment. In the document they also provided some quantitative measurements and indicators that relate to the 17 indicators previously mentioned.

In 2005, Pellant *et al.* discussed the interpretation of the rangeland health indicators described in Pyke *et al.* (2002), but with the addition fo some improvements. Three ecosystem attributes are assessed in this protocol by rating 17 indicators tied to the attributes as they are listed in Pellant *et al.* (2002). The ecological processes and site integrity[3] are well evaluated using biological and physical components as indicators (Pallent *et al.*, 2005). However, according to Pellant *et al.* (2005) ecological process indicators are difficult to observe in the field due to the complexity of most rangeland ecosystem. Therefore Pellant *et al.* (2005) describe a protocol to educate the public and agency personnel on using observable indicators in order to interpret and assess rangeland health. The assessment protocol is said not intended to be used to identify the causes of resource problems and determine trend but for selecting monitoring sites in the development of monitoring programmes and providing early warning of potential problems and opportunities by helping land managers identify areas that are potentially at risk of degradation (Pellant *et al.*, 2005). According to Pellant *et al.* (2005) these developed indicators are used nationally (USA) as well as internationally in Mexico for regional planning and management plans of ranches, and in Mongolia for rangeland assessment. It is important for land managers and technical assistance specialists to be able to assess the health of rangelands in order to know where to focus management efforts (Pyke *et al.*, 2002).

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[3] *"maintenance of the functional attributes characteristic of a locale, including normal variability"* (USDA 1997, cited in Pallent *et al.*, 2005).

2.3.2 Classification approach

Manske (2002) discusses the use of four condition categories used in most rangeland health status assessment methods to define the levels of ecosystem health in a grassland. The categories range from an extremely healthy to an extremely unhealthy conditon. The most commonly used categories are: excellent, good, fair and poor condition (Manske, 2002).

Manske (2002) illustrated the four rangeland health condition categories by comparision with human health conditions. Here are two examples of four given categories: A grassland ecosystem in *excellent* condition is like a highly trained athlete and in *poor* condition would be like a chronically ill person, with all processes functioning ineffectively and inefficiently, unable to endure stress, and only capable of recovering from stress over a considerable period of time and with special treatment. The use of such illustrations simplifies the method and makes it easy for the grassland manager to understand the categories faster and also to adopt the assessment methods quickly. However, knowledge of the ecological processes is always needed for evaluation of rangelands and good management.

During the health status assessment the ecosystem components being considered are the aboveground and belowground vegetation, soil development processes, levels and types of erosion, ecological processes, and infiltration of precipitation (Manske, 2002). In this document he further points out the evaluation criteria and characteristics for each rangeland health condition category as well as a set of questions to help the evaluator to interpret the health status criteria and characteristics. This is a self-explanatory assessment method which can be adopted in the field, with all its concepts and materials. In the same vein NRC (1994) and Napcod (2003) also proposed the use of similar condition categories for the assessment of rangeland health status at the local level.

2.3.4 Landscape Function Analysis (LFA) approach , Australia

Landscape Function Analysis (LFA) is a monitoring procedure, using simple indicators, that assesses how well an ecosystem works as a biogeochemical system (Tongway, 2008). Tongway recommends the LFA as a key component of Ecosystem Function Analysis[4] (EFA),which is intended for repeated measurements to obtain data as a time series. The approach is quick and simple in the field and has been applied to a wide variety of landscape types and land uses and is amenable for use by a range of end-users (Tongway, 2005, 2008).

The LFA approach is comprised of three components: a conceptual framework[5], a field methodology[6]

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[4] *A tool for monitoring mine site rehabilitation success.*

[5] *Conceptual framework treats the landscapes as systems: defining how landscapes work in terms of sequences of processess regulating the availability of scare resources.*

[6] *The field methodology uses indicators at the scale of landscape and patches to provide structural information to satisfy the needs of the conceptual framework.*

and an interpretive framework[7] (Tongway, 2005, 2008). The conceptual framework is based on the "trigger-transfer-reserve-pulse" (TTRP) system for the way in which rangelands function, based on how landscapes function to conserve and utilise scarce resources. The framework represents the sequences of ecosystem processes and feedback loops (Tongway, 2005; Ludwig *et al.*, 1997). The LFA indicators have been developed from many published materials from a variety of sources and are based mainly on processes involved in surface hydrology, i.e. rainfall, infiltration, runoff, erosion, plant growth and nutrient cycling (Tongway and Hindley, 2004).

LFA has been implemented in climatic ranges from 50 mm to 10,000 mm a.a.p and in a number of other land-use scenarios (nature reserve design and rehabilitation, rangelands) (Tongway, 2008). The approach is good to help land managers know the trends and current status and what is being lost from the ecosystem (Tongway, 1994). If the rangelands become poor and do not retain resources, there will be leakage from the system leading to unproductivity. Apart from soils, the LFA system can also be used to assess the functional properties of vegetation (Tongway and Hindley, 2004).

2.3.3 Soil Surface Condition Assessment

Tongway (1994) developed the soil condition assessment (a component of LFA) for tropical grasslands in Australia. He describes the method for asssessing soil condition in three principal steps: describing the geographical setting of the site, characterising fertile-patch/inter-patch associations and recognising the erosion model, and assessing the soil surface condition (SSC).

It is best to assess both vegetation and soil status when monitoring the condition of rangeland sites in order to have an accurate description of the current status and some information about future trends (Tongway, 1994). Furthermore, he states that methods for assessment of the vegetation are now well-developed in Australia and informative, but methods for assessing soil condition have not been very successful. Vegetation monitoring is important in rangelands in order to know if changes in composition are due to interaction between grazing and vegetation alone or whether the soil as a habitat for pasture plants has been degraded. The soil surface indicators used here are similar to those described in the LFA manual and the field procedures are well explained in the manual.

2.3.6 Visual Soil – Field Assessment Tool (VS-Fast)

McGarry (2004) worked on the development of a methodology of a Visual Soil–Field Assessment Tool (VS-Fast) to support and enhance the LADA program of the FAO. The VS-Fast methodology has been developed to address a principal requirement of the newly developed methodological framework for the LADA programme (McGarry, 2004). He explained that the VS-Fast methodology is an upgraded and integrated approach for the field-based, farmer-usable visual assessment of soil condition and health, with particular emphasis on simple, repeatable methods using everyday, low

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[7] *The interpretation framework provides processes to identify critical thresholds in landscape function and thus provide a function-based state and transition landscape assessment. (Ludwig et al., 1997; Tongway and Hindley, 2004; Tongway, 2005, 2008)*

cost apparatus. Techniques for this methodology include both visual observation of soil excavated by spade, and simple yet robust measures of soil slaking and dispersion, pH, water infiltration and organic matter (labile carbon) (McGarry, 2004).

The VS-Fast methodology was tested in China, one of the pilot study areas of the LADA project (Fengning Manchu County, Hebei Province) and in a large scale, intensive nursery enterprise south of Beijing. During field work, farmers were asked to identify "hot spots" and "blight spots" representing "not so good", "moderate" and their "best" land (McGarry, 2004). A field score card that gathers information on land use (current and past), site location, recent weather conditons, soil type, soil structure and visual indicators of soil quality and field measurement form that records pH, infiltrations and other aspects was used to collect information.

The farmer himself decided the rank based on his perception of current growth and past harvest of his crops (McGarry, 2004). McGarry (2004) mentioned that the methods proved to be simple yet robust, ensuring immediate data availability, farmer acceptance and rapid update of the descriptive and measurement tools, leading to rapid assessment of the current condition with a potential for longer-term monitoring.

Positive reponses ranged from the policy level, with requirements for regional level understanding of land condition – particularly direction of land condition/health in terms of current state with traditional practices and the potential for improvements with innovative practices, to the farmers' level where there was genuine enthusiasm that so much could be learned about soil conditon and health in a 20 – 30 minute field visit (McGarry, 2004). The method is simple, as described by the author, so it can be easily adopted and applied to any other condition as it doesn´t require much investment (money, personnel and time).

2.3.4 Grazing Gradient Method (GGM)

Land degradation in rangelands involves accelerated soil erosion, soil degradation and adverse changes in vegetative composition (Pickup *et al.*, 1998; Bastin, 2002). Land degradation is difficult to assess in arid rangelands because of short-term variations in rainfall, landscape diversity and the problems of sampling large areas (Pickup and Chewings, 1994). In arid and semi-arid Australia, most of the spatial variability due to grazing occurs because animals are confined by fences and must rely on wells or dams for drinking water (Pickup *et al.*, 1998). Therefore,- the animal impact decreases with distance from these watering points and produces radial patterns of grazing impact in uniform country.

Two different grazing gradient techniques have been developed, the resilience method and the wet period average cover method (Bastin, 2002). The methods have been used in arid and semi-arid Australia to assess rangeland degradation[8]. The Grazing Gradient Method as described by Pickup

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[8] Bastin *et al.* (1993) defined rangeland degradation as a grazing-induced long-term reduction in the ability of landscape to respond to rainfall.

et al. (1998), uses the spatial pattern produced by grazing animals as a spatial filtre to separate the impact of grazing on vegetative cover or cover change over time from that of other factors. Following are two study examples.

Bastin *et al.* (1993) conducted a land degradation[9] assessment in central Australia. They aimed at finding accurate and repeatable techniques capable of separating grazing impact from both seasonal variability and natural landscape heterogeneity because rangeland monitoring using ground-based methods has been fraught with difficulty. The study analysed the entire grazed landscape using remotely-sensed data and grazing gradient[10] methods which separate grazing effect from natural variation. Vegetation increases across the whole landscape following rain and the extent of the recovery of the vegetation in the vicinity of watering points (Bastin *et al.*, 1993). The amount of rainfall that was significant was determined for each mapped land system. Furthermore, the study uses a percentage cover production loss index, allowing grazing management effects across land systems (and paddocks) to be compared. The land systems that contained a high proportion of palatable forage had high index values and are most adversely affected by grazing (Bastin *et al.*, 1993). Animals always target the area with palatable forage.

In a different study the same method (Grazing Gradient Method) was used to identify trends in the state of arid and semi-arid rangelands over one or two decades (Pickup *et al.*,1998). The first step of this study was a brief description of the spatial filtering techniques used in the Grazing Gradient Method. Subsequently, changes with time in vegetative cover were examined and how vegetation response to rainfall may be used as a variable for the filtering procedure to identify trends in the level of degradation or recovery over time (Pickup *et al.*,1998).

The method was then applied to a number of large paddocks or grazing units in central Australia where a particular type of change can be inferred from historical information because of changes in the management regimes. Apart from this, Pickup *et al.* (1998) also showed how the method may be varied when paddocks are not sufficiently large to define a benchmark area far from a watering point. However, in most cases, the study concentrated on landscape types that are mostly favoured for grazing since it is here that degradation and recovery are likely to be most pronounced. The study concluded that GGM is efficient when compared to conventional ground-based vegetation sampling that has also been used in Australia. This trend detection method has wide applicability in Australian rangelands but is not expected it to work in the higher rainfall regions of northern Australia where grazing is much less dependent on a small number of artificial watering points. They further stated that other variants of this method have been used successfully in regions with median annual rainfall varrying bettween 150 and 450mm/yr (Pickup *et al.,*1998).

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[9] A reduction in the capacity of landscapes to produce vegetative cover from rainfall (Bastin *et al.*, 1993).

[10] A decrease in vegetation cover as water is approached, producing a spatial pattern (Bastin *et al.*, 1993).

Livestock grazing has been an important factor in shaping rangelands in the Mediterranean. Despite their long history of utilization, recent changes in socio-economic frameworks and the intensification of grazing systems have frequently caused rangeland ecosystems to depart from equilibrium states and initiated degradation processes. Roder *et al.* (2007) state that remote sensing allows quantifying temporal and spatial trends of vegetative cover as an indirect indicator of land degradation. Moreover, vegetative cover can reveal gradients of attenuating grazing pressure away from places where animals are concentrated. Roder *et al.* (2007) explain that adapting such grazing gradient approaches to Mediterranean rangelands, however, is difficult due to the heterogeneity of these ecosystems. The study area was selected in the county of Lagadas in northern Greece to evaluate how grazing gradient approaches may be adapted to small-structured rangelands, where grazing areas are interwoven with agriculture and other land use types. A cost surface model was parameterized to represent driving factors of grazing pressure. Furthermore, woody vegetation cover as an indicator of grazing pressure was derived from Landsat-TM imagery. Results from this study showed decreasing grazing pressure away from points of livestock concentration, which is characterized by distinct zones (Roder *et al.*, 2007). The study suggests the method can be used as a management tool to detect areas of over- and undergrazing and to test different grazing regime scenarios.

2.4 Remote Sensing

Satellite remote sensing data have been available since the early 1970s (Lantieri, 2003) The quantity and quality of information, in terms of spectral and spatial accuracy, is increasing as a result of the rapid development of spatial and information technology (Lantieri, 2003). It should be borne in mind that most of the satellite data is provided as digital images characterized by arrays of pixels registered in different spectral bands from the visible, near infrared, infrared and microwave range of the electromagnetic spectrum depending on the "mission" (Lantieri, 2003). Furthermore, Lantieri (2003) explained that these data are taken by sensors mounted onboard the satellite whose lifetime is typically several years (3-5); satellite data are therefore more comparable as "spectral measurements" of the earth and remain complex to process and analyse . The usual three characteristics of these data are: *spatial resolution* (area on the ground covered by one pixel), *spectral resolution* (spectral wavelengths recorded by the sensors), and *temporal resolution* (time lapse between two passages of the satellite over the same area) (Lantieri, 2003).

Ostir *et al.* (2003) pointed out that remote sensing has developed as an important tool for assessment and monitoring of vegetation, erosion, and desertification. It can provide calibrated, quantitative, repeatable and cost effective information for large areas and can be related to the field data (Graetz, 1987; Pickup, 1989; Tueller, 1987 cited in Jafari *et al.*, 2008). Remote sensing has been used successfully utilised in land degradation assessment and monitoring over a range of spacial and temporal scales (Bastin *et al.*, 1993a; Greerken and Ilaiwi, 2004; Pickup and Nelson, 1984; Symeonakis and Drake, 2004; Wessel *et al.*, 2004, 2007 cited in Jafari *et al.*, 2008).

Lantieri (2003) reviewed the potential of spatial remote sensing application to the LADA project. This report reviews information sources on the nature, extent, severity and impact of land degradation on ecosystems and livelihoods in drylands as potentially assessed through satellite remote sensing. Lantieri grouped the remote sensing data into four categories: low- and medium- resolution civilian optical satelites, high-resolution civilian optical data, very high-resolution civilian optical data, and space-borne radar data. He grouped them because of the large number of sensors available today and the wide range of characteristics. Lantieri concluded that there are six broad applications of remote sensing: land cover which includes vegetation types and their changes over time; land form and landscape; vegetation activity and growth; rainfall and related drought; soil types and state; and indicators based on climate and ecological modelling. For the LADA programme, remote sensing probably offers the greatest opportunities for looking at rangelands because it does a good job of sensing vegetation differences (Lantieri, 2003).

In addition, remote sensing can also provide useful information regarding erosion. The use of satellite image interpretation to identify changes in the extent of land cover provides a prediction of erosion potential rather than a measure of actual erosion (Þorarinsdottir, 2008). Lantieri (2003) concludes that in future remote sensing will increase dramatically in cost effectiveness and efficiency, but it will never 'see' or understand the socio-economic and cultural factors.

Jafari *et al.* (2008) investigated the use of the moving standard deviation index (MSDI) applied to Landsat TM band 3 data for detection and assessment of these zones in the arid grazing lands of south Australia. The study compared the normalised difference vegetation index (NDVI) (see box 4 for description) and the perpendicular distance vegetation index (PD54), used reference indices, and showed that the PD54 was more appropriate than the NDVI in this perennially dominated arid environment.

The piospheres (a zone of extreme degradation around the water points in grazed landscapes) were found to be more heterogenous in vegetative cover, with higher MSDI values, compared with non-degraded areas, and spatial heterogeneity in cover decreased with increasing distance from water points. The study indicates that MSDI can be used as an appropriate method for land degradation assessment in the naturally heterogeneous arid lands of south Australia.

Tanser and Palmer (1999) used the spatial diversity index, MSDI, to assess land degradation in South Africa. They found that degraded areas were more heterogeneous in reflectance than non-degraded areas. The study applied MSDI to Landsat TM band 3 data. Degraded/unstable landscapes exhibit higher MSDI values than their undisturbed/stable counterparts. Significant differences in MSDI were detected across four fence-lines which separated rangeland of contrasting condition. The relationship of the index to the normalized difference vegetation index (NDVI) was tested in five different ecosystems and significant correlations were obtained in all cases. Tanser and Palmer (1999) proposed that the MSDI was a powerful addition to vegetation indices. These two studies (Jafari *et al.*, 2008; Tanser and Palmer, 1999) applied the MSDI to Landsat TM data and came to a similar conclusion: recommendation of use of MSDI to assist in characterizing vegetation indices.

Box 4. Description of CCA, SAVI and NDVI

Canonical Correspondence Analysis (CCA):
"… a multivariate technique to relate composition of a species when species have a bell-shaped response curve with respect to environmental gradients and is widely used in ecology (Ter Braak, 1986; 1987). As the name suggests, this method is derived from correspondence analysis, but has been modified to allow environmental data to be incorporated into the analysis". It is calculated using reciprocal averaging form of correspondence analysis (Ter Braak, 1986; 1987). Ter Braak (1986) has shown a complete derivation and applications of CCA techniques. Also, Ter Braak (1988) has developed a computer program CANOCO to perform CCA and several other multivariate statistical techniques to analyse species-environmental relations.

Soil Adjusted Vegetation Index (SAVI):
A vegetation index that accounts for, and minimises, the effect of soil background conditions.
Equation: $SAVI = (NIR-R)\,(1+L) / (NIR+R+L)$
The **SAVI** *equation introduces a soil-brightness-dependent correction factor,* **L**, *which compensates for the difference in soil background conditions. As in the* **NDVI**, **NIR** *is the reflectance from the near-infrared band, and* **R** *is the reflectance from the red visible band. Applying the correction for the soil provides more accurate information on the condition of the vegetation itself. When* **L**=*0*, **SAVI** = **NDVI**.

Normalized Difference Vegetation Index (NDVI):
An index calculated from reflectance measured in the visible and near infrared channels. It is related to the fraction of photosynthetically active radiation. **Equation:** $NDVI = (NIR-R) / (NIR+R)$
where: **NIR** *is the reflectance in the near-infrared band, and* **R** *is the reflectance in the red visible band. The chlorophyll (green pigment) absorbs incoming radiation in the visible band, while the leaf structure and water content are responsible for a very high reflectance in the near-infrared region of the spectrum. NDVI has been correlated to a variety of vegetation parameters, including quantity, productivity, biomass, etc.*
SAVI and NDVI information are from: http://www.ccrs.nrcan.gc.ca/glossary

In the same vein, Bai and Dent (2006) reported on a pilot study done in Kenya during the global assessment of land degradation in drylands. The study applied the Global Assessment of Land Degradation (GLADA) approach that involves a sequence of analyses to indentify *hot spots* of land degradation (reffered to by LADA program of FAO) using remote sensing and existing data sets. Bai and Dent (2006) describe how the study was carried out using simple NDVI indicators such as mean annual sum NDVI and the trend of biomass productivity; integration of biomass and climatic data (rain-use efficiency); linking NDVI to net primary productivity and calculating the changes of biomass production for dominant land use types; and then, stratification of the landscape using land cover and soil and terrain data to enable a more localised analysis of the NDVI data.

The *hot spots* were characterised manually, using 30m-resolution Landsat data, to identify the probable kinds of land degradation (Bai and Dent, 2006). At the same time, the continuous field of the index of land degradation derived from the NDVI and climatic data enable a statistical examination of other data for which continuous spatial coverage is not available. Finally field inspection was to be undertaken by national teams within the wider LADA programme. Bai and Dent (2006) explained that the study anaysed the spatial temporal trends of green biomass across Kenya using 23 years of fortnightly NOAA-AVHR-R time series NDVI data and monthly precipitation records (CRU TS 2.1 station). They found that over the period of 1981-2003, green biomass and net primary productivity increased over 80 per cent of the land area and decreased over 20 per cent. Furthermore, ArcGIS Spatial Analyst and ERDAS IMAGINE were used to calculate various biomass indicators of climatic variables, and their trends were determined by linear regression at annual intervals and mapped to depict spatial changes (Bai and Dent, 2006). Green biomass and net primary productivity were estimated from NDVI data using MODIS 8-day values for 4 years.

Overall, net primary productivity was said to incease for all dominant land cover types but hardly at all in croplands. *Hot spot*s are also identified in the semi-arid grassland around Lake Turkana in Kenya. The study also concluded that remote sensing indicators may indicate *hot spots* but that a combination of the biomass and rain-use efficiency trends is a more robust indicators of land degradation. Bai and Dent (2006) stressed that it is important to address present-day land degradation.

Þorarinsdottir (2008), assessed land cover in a desert rangeland (reclaimed and unreclaimed areas) of Iceland for sand drifting in the area. She looked at the land cover in the area, identified as rocks, sand on surface, vegetation, and lava as well as dominant grass species and tephra soils. The study used SPOT imaging delivered from satelite remote sensing imagery. Scores were set and given as percentage of the total area examined by means of visual observation and interpreted using expert estimation skills. In addition, areas were categorized based on the uniformity and similarities of cover, with the result that polygons were draw to show boundaries. The study is still in progress, with the hope of getting good results from this approach (Þorarinsdottir, 2008).

As with any other method, the use of remote sensing tools requires good undestanding of the environment, decisions on what to do and how to do it and why?

3. NAMIBIA AND ASSESSMENT OF LAND DEGRADATION

Land degradation is an increasing problem in Namibia. The key environmental issues in Namibia are: degradation of ecosystems, desertification; loss of productivity, decline of water availability; depletion of natural resources; loss of biodiversity, decline of water quality, pollution, including toxic chemicals; waste generation, littering; the greenhouse effect; ozone layer depletion; and acidification (DEA, undated). Assessment and monitoring have been carried out to ascertain the causes and impact of land degradation at national, local and farm levels, even though there is still much more to gain an understanding of environmental threats in Namibia.

3.1 Development of a national monitoring system

Klintenberg and Seely (2004) discussed the process of developing land degradation indicators for a national monitoring system and also the results of an assessment generated by developed indicators which they applied to two communal areas in Namibia. Furthermore, a monitoring system was developed to provide information about the extent and rate of land degradation in the country (Klintenberg and Seely, 2004).

Indicators for this monitoring system were developed through consultation of representatives ranging from local communities to experts working at the national level. The actual development of indicators was done using three different GIS tools: Map-Info (MapInfo, 1997), ArcView (ESRI, 2001) and Idrisi (IDRISI, 1999). As a result of the process of developing a monitoring system, four key indicators were defined as: population pressure, livestock pressure, rainfall variability and the hazard of soil erosion (Klintenberg and Seely, 2004). The four indicators were combined into an annual land degradation risk index for which maps were generated for the period 1971 - 1997. Fig. 1 shows a national land degradation risk map based on the four indicators discussed by Klintenberg and Seely (2004).

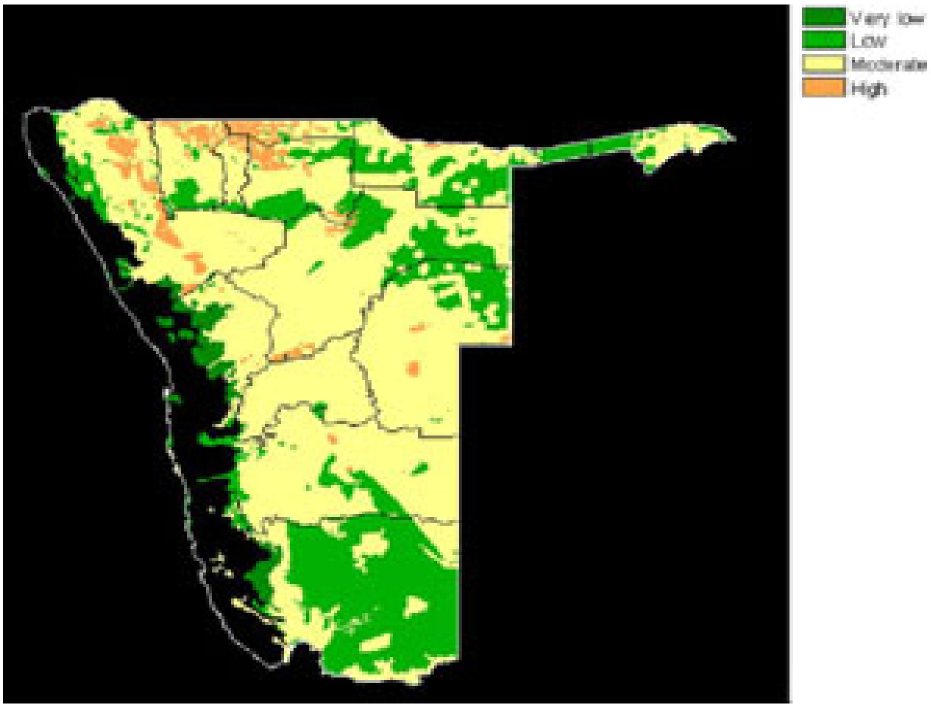

Fig. 1. *National land degradation risk map, 1997 (Bethune and Pallent, 2002).*

3.1.1. Application of developed national monitoring system indicators

According to Klintenberg and Seely (2004) the developed national monitoring system indicators were applied for evaluation in two rural communities, Onkani in central northern Namibia, and

Gibeon in southern Namibia. Interestingly, indicators suggested that Onkani in central northern Namibia has been experiencing increased livestock numbers and decreasing rainfall since the early 1990s. On the other hand, at Gibeon in southern Namibia, factors causing increasing degradation risk in the area are increasing rural population pressure and decreasing rainfall (Klintenberg and Seely, 2004).

The rainfall gradient in Namibia decreases as you move from the north down to the southern regions. On average, the southern parts receive low rainfall whereas the northern part receives more. However, Namibia's rainfall is erratic, causing periodic droughts and poverty over the whole country. Figure 2 shows the mean average rainfall and rainfall variability for Namibia. Population pressure on land is the major contributing factor to deterioration of resources in Namibia. As the population increases, livestock numbers and over-cultivation also increase because a large proportion of Namibia's population is heavily dependent on subsistence farming and livestock husbandry. Fig. 3 shows the livestock density in different part of Namibia.

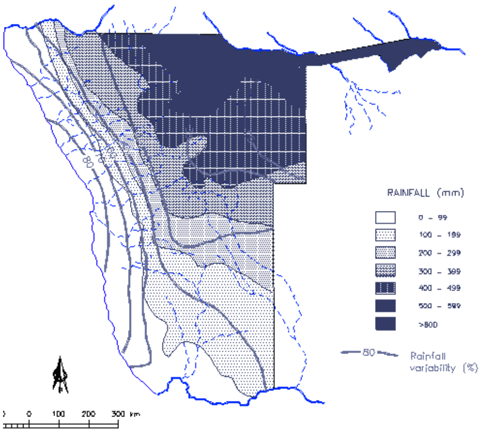

Fig. 2. *Mean Annual Rainfall and Rainfall Variability in Namibia, (Wardell-Johnson, 2000).*

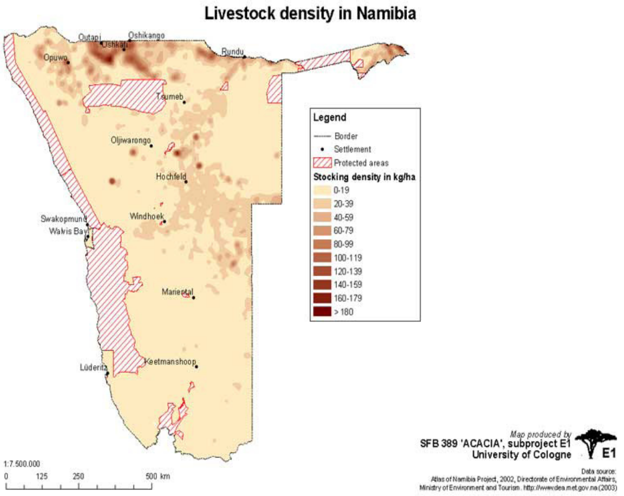

Fig. 3. *Livestock density in Namibia. (Atlas of Namibia, 2002 from: IIASA website)*

Klintenberg and Seely (2004) concluded that land degradation is a multi-faceted phenomenon with many causes and effects. They state that the indicators developed for a Namibian monitoring system are not sufficient to provide a complete picture of land degradation in the country. Therefore, this should rather be seen as a first national monitoring system developed in a fully participatory manner, involving stakeholders from all levels (Klintenberg and Seely, 2004). They suggested that to improve the monitoring system the four indicators have to be tested and evaluated in the field and additional indicators developed.

3.1.2 Integrating local people perceptions

The results from the above paper were compared to those obtained from interviews of local farmers about their perceptions of the past and present states of the environment in and around Ombuga grassland in central northern Namibia (Klintenberg *et al.*, 2007). In the interview they asked 50 representatives from the study area key questions such as: Have you noticed any changes in the environment since you came here, and if so, can you describe them? Where have you observed changes? What are the causes of these changes? Results from this study suggest that availability of palatable grasses, open access to areas, and permanent access to water would make it possible for more farmers to settle in the area. Therefore the increase in the number of livestock in an uncontrolled area is a major factor causing the environmental changes identified by the interviewees (Klintenberg *et al.*, 2007).

Klintenberg *et al.* (2007) commented that the factors identified in the interviews as those causing environmental changes reflected the conditions in the study area and are most likely also applicable for other semi-arid areas where inhabitants rely on natural resources. Furthermore, the results suggest that assessment of local knowledge in a relatively small area can provide a valuable contribution to development and assessment of national monitoring initiatives.

3.2 Modelling

In another study, Klintenberg and Verinden (2008) investigated the impact of grazing on grass composition around permanent water points along the pipeline and a traditional hand-dug well in the same area (Ombuga grassland in central northern Namibia). The objective was to verify the results obtained from interviews with the local farmers about their perceptions of the past and present states of the environment in and around the study area. Klintenberg and Verinden (2008) described how vegetation sampling was done using a point step method to collect data along 7 – 10 km long transects radiating out from permanent water points and hand-dug wells. Grass species abundance and selected environmental variables sampled along transects radiating out from these water points were analysed using Canonical Correspondence Analysis (CCA) (see box 4). The results of this study suggest that there is fairly high grazing pressure throughout the area with a high frequency of grazing tolerant species, mainly annual grasses compared to more palatable, perennial grasses (Klintenberg and Verinden, 2008). Grazing around the water points has resulted in significant changes in the grass species composition in comparison to the results obtained around the traditional hand-dug well. In addition, Klintenberg and Verinden (2008) state that the impact could be seen as far as 6 - 8 km from these water points. This is the issue in communal areas as the water point belongs to the whole community, and individuals feel powerless to do anything about it if there is no control by others. The situation differs between the two water sources for several reasons. Private ownership of the hand-dug well contributed to better management of the adjacent area is one of the factors discussed by Klintenberg and Verinden (2008).

3.3 Remote sensing

Klintenberg *et al.* (in prep.) investigated the usefulness of satellite remote sensing in detecting environmental changes around permanent water points in the Ombuga grassland. They used a supervised classification of Landsat TM imagery and calculated vegetation indices. Landsat TM data recorded after the rainfall season (March – April) 1989 - 2005 were used for the analysis.

In addition, land cover classification was done based on supervised classification applying maximum likelihood classification and the nearest neighbour algorithm, using bands 1-5 and 7. The following land cover classes were identified: *woodland, shrubland, grassland, water, saltpan and bare ground*. Furthermore, the soil-adjusted vegetation index was used to assess grazing impacts along transects radiating out from permanent water points. Changes over time series were analysed by re-classifying images.

The authors (Klintenberg *et al.*, in prep.) concluded that the results of the land cover classification showed a fairly consistent distribution of grassland, shrubland and woodland in the study area throughout the time series. However, the occurrence of bare ground shifted notably over time (Klintenberg *et al.*, in prep.). Similar changes were revealed after analysing how SAVI varied during the time series. Results showed that the areas with the lowest SAVI over the time series were in the northern part of the study area, corresponding to the land cover classifications (Klintenberg *et al.*, in prep.). In addition, Klintenberg *et al.* (in prep) concluded from the results that remote sensing could be used for monitoring environmental changes in semi-arid grasslands. However, results also showed that there are difficulties in separating different classes of woody vegetation from each other and also from grassland, in some instances. Additionally, the results suggested that the use of a soil-adjusted vegetation index provides valuable information about the fluctuation of green biomass in semi-arid environments over time (Klintenberg *et al.*, in prep.).

However, due to the strong influence of the underlying soil and the fact that ground cover is generally sparse in these environments it is suggested that any investigation based on satellite remote sensing should be supported by an in-depth ground-based assessment, taking into account the high spatial and temporal variability of these environments.

3.4 Local Level Monitoring (LLM) approach

The Local Level Monitoring[11] approach has been initiated through the Namibia Programme to Combat Desesrtification (NAPCOD). Since initiation, it has been used to assess rangeland condition in several communities in Namibia. With recognition of the situation over the country, recogonisable and usable sets of indicators for assessing rangeland condition have been identified and developed to help farmers be aware of the beginning of land degradation processes. The indicators are identified

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[11] *LLM is a tool that can be used directly by farmers to collect information on important indicators so that they can make timely management decisions and thus better manage their natural resources (Napcod, 2003).*

by farmers themselves and the responsibility for monitoring rangelands and promoting sustainable development rests with the communities involved.

In north-east Namibia farmers have developed and defined indicators for the area and implemented the approach. Due to differences in culture, climate and ecology of the different regions, each community has to identify their own indicators. Participation of all community members is very important in developing indicators which they then, together, use to monitor and apply, adapt and maintain rangeland health (Napcod, 2003). The approach focused on regular and continued observation and assessment of conditions of a variety of relevant factors covering livestock, rangeland condition (including bush density), carrying capacity and rainfall over time by the resource users. However, the list of indicators may expand as skills, needs and faith in the programme grows (Napcod, 2003).

A field guide was developed with colour photos, graphics, colour coded information sheets and charts and guidelines for use by the farmers. The general assumption is that the condition of livestock reflects the condition of rangeland and is independent of breed, sex, age and body mass (Napcod, 2003). A resource user can select up to 25 animals randomly from his/her herd and 5 nominal sites of varying fodder availability, using forms in the guide to assign values (1-5 for very thin – fattest) to the condition of the animal and carrying capacity values (1-10 for poor – excellent) to fodder availability based on similar features in the photos in the guide.

Thereafter, the average herd condition is calculated and the number of individual animals in each class is recorded on a monthly basis. Therefore information generated monthly, seasonally and annually enables the farmer to track and monitor the status and changes in animal condition (Napcod, 2003). For fodder availability, the farmer matches any piece of land to the most appropriate picture and determines the carrying capacity of the rangeland on a seasonal and yearly basis (Napcod, 2003). This is an easy, effective and more immediate method for farmers to determine carrying capacity and to adjust stock numbers accordingly.

In addition, daily rainfall is recorded and information is used to calculate the total monthly and annual rainfall. On rangeland condition, a specific site is selected on which benchmark photographs are taken from a specific angle and from the same position each time. Then the site is visited every year at the end of the rainy season to compare the benchmark photographs. Napcod emphasises that the process needs long-term commitment by all resource users to be truly useful in monitoring and assessment of rangeland conditions over an extended time period. The approach has been implemented and used in some communities in Namibia (Napcod, 2003).

3.5 Degradation Gradient Method (DGM)

The Degradation Gradient Method uses multivariate ordination techniques to reduce multidimensional data sets (sample plots with relative species frequency data) to two dimensions, where the first one explains the greatest variability in the data (Getzin, 2005). As mentioned in in the Klintenberg and Verinden (2008) study and by many other authors, grazing pressure on land is one of the major causes of rangeland degradation in Namibia.

Getzin (2005) did a study to test the suitability of the DGM in the central Highland Savanna of Namibia and compared the results against a univariate analysis of herbaceous data in a simple but robust Range-Unit Model. A grazing gradient was established in April 1999 by sampling five RUs with partly known grazing history at different distances from a watering place (Getzin, 2005). He stated that the DGM is a sophisticated technique for the assessment of range condition. It applies multivariate analyses of herbaceous species data to detect subtle degrees of overgrazing. Despite aridity and topographical heterogeneity, the DGM performed unexpectedly well under these conditions. The relative instability of this dry savanna system favoured the applicability of the DGM by promoting a clear grazing gradient (Getzin, 2005). Getzin (2005) points out that using species density data only resulted in an incorrect outcome of the multivariate analysis. Getzin suggested that the sensitivity of the DGM could be improved by combining density and cover data.

In contrast, Zimmermann *et al.* (2001) conducted a quantified range condition assessment of open Camelthorn savanna along a degradation gradient. The degradation gradient method as described by Bosch and Gauch (1991), as cited in Zimmermann *et al.* (2001), relies on the ordination of data, obtained objectively, to produce a gradient with a score for each site. Zimmemann *et al.* (2001) aimed at constructing a degradation model based upon grass species composition. Ideally, such model should be able to determine a single range condition score through data obtained from any survey within the same relatively homogeneous area (RHA). However, since such a model may be too cumbersome for use by many land managers, the objectives of the study were extended to seek simpler indicators through testing the relationship between other measurements and the range condition score obtained from the degradation model (Zimmermann *et al.*, 2001).

They described how the study measurements were taken at 20 different sites in relatively homogeneous areas of open Camelthorn savanna in eastern Namibia. In most surveys 200 points were sampled along transects by roughly uniform pacing combined with a randomly thrown dart. Detrended Correspondence Analysis (DCA) was used to determine whether the sites all fell within the same RHA, and whether the sites were ordered roughly according to their state of degradation (Zimmermann *et al.*, 2001). If the latter held true, a Centred Principal Component analysis (PCA) ordination was then performed to determine the range condition scores. Through analysis of results, Zimmermann *et al.* (2001) concluded that it seems that a single score of range condition can be obtained objectively for the open Camelthorn savanna by combining measurements of perennial grass species composition and density. Furthermore, ordination of grass species composition did not provide a good degradation gradient due to the domination by different species of annual grasses at many of the sites but a centred PCA ordination of perennial grass species indicated a degradation gradient (Zimmermann *et al.*, 2001). This may therefore be an appropriate indicator to include in the range condition score for such types of savanna, according to Zimmermann *et al.* (2001).

3.6 Landscape Function Analysis in Namibia

Landscape Function Analysis has been introduced in Namibia recently by David Tongway, Australia. Early in 2008, Tongway gave a presentation and practical training to a group of environmental specialists and managers from mining companies and research institutions. Application of LFA to restoration of damaged landscapes is a special objective (Tongway, 2008). According to participants in this training, the tool is easily understandable and useful in assessing land degradation.

The soil surface condition assessment part of the LFA approach was reported used to measure features in a trial restoration project on Farm Lichtenstein-sud in the Highland Savanna of Namibia, with a mean annual rainfall of roughly 300mm (Shamathe *et al.*, 2008). According to Shamathe *et al.* (2008) the features were sampled with transects running across rills or gullies. (For more information on the LFA approach, see section 2.3.4 in this paper).

3.7 Comments on the Namibia approaches to the land degradation issue

The monitoring system indicators that have been developed (Klintenberg and Seely, 2001) offer a good approach to defining land degradation in Namibia. However, as mentioned in Klintenberg and Seely (2004), the four indicators (named above) need to be tested in the field and additional indicators should be developed. So far the indicators were applied in two communities - Onkani in central northern, and Gibeon in southern Namibia (Klintenberg and Verinden, 2008). Therefore there is a need for applying these indicators to other communities as well. The development needs to be a continual process until approximation and relevant national monitoring indicators are developed. Many studies done in Namibia are on a small scale only, though they do provide good information about the specific areas surveyed.

There have been many programmes addressing different possible environmental issues and suggesting possible solutions in Namibia (e.g. Napcod, CCP, Biodiversity project, OLDeP). There is an impressive forum FIRM (Forum for Integrated Resource Management) which aims at putting the community at the centre of its own development, encouraging community members to be the drivers of resource planning and management. The approach has been introduced into communities where representative groups were formed to act as leaders and communication channels with stakeholders such as the government, NGOs, etc.

Namibian farmers are willing to tackle the problem, but from a personal point of view their knowledge of a managerial approach is still limited; therefore they need technical support from government departments as well as other organisations for them to start. For example, OLDeP (a development program) and the LLM approach have changed the farmers in the pilot area in north central Namibia. During and after the implementation of this programme farmers' understanding of, to mention a few critical concerns, livestock management, conservation of available resources, and community organization was enhanced.

Furthermore, the issue of land degradation and other environmental problems have been addressed in many policies such as in the National Action Plan (NAP), Namibia´s Vision 2030, education syllabus and ministries programmes as well as NGO projects. It is hoped that integration of all parties in assessment, monitoring and planning for management action will improve in the near future. However the main problem is that development of programmes and projects has tended to adopt a sectoral approach when addressing a problem and this in most cases results in failure. Therefore there is a need to establish the principle of an integrated approach, combining the economic sectors and involving public, private and civil societal institutions. At this time, capacity constraints at the systematic, institutional and individual levels are hampering the ability of people to realise the need for integration. Some of the constraints are: lack of sectoral planning, implementation and management of land use; lack of skilled personnel; neglect of root causes (local communities) by some projects or programmes; lack of understanding and ignorance; and inadequate resources (money and people).

4. GENERAL DISCUSSION

The different approaches described in the preceding sections provide extensive information about methods used to assess land condition. The selection of a method depends on the goals and conditions under which it is applied. Each approach has its limitations from an economical, experience, and/or environmental point of view. In this discussion the main approaches are examined in relation to their applicability at different levels.

4.1 Use of Classification

Classification of different aspects of the degradation processes helps to rate the degree and extent of the problem (such as soil erosion) and also assists with mapping of the area affected. The GLASOD survey maps help planners, co-ordinators and decision makers to make appropriate plans and set priorities for future investments. They also help in identifying knowledge gaps and research priorities (van Lynden *et al.*, undated). The vital part is that it can be applied at different scales, from local to national to regional and global levels. However, comparing GLASOD to the ASSOD study, ASSOD is more detailed and thus also more accurate. A comparison of the studies is presented in van Lynden and Oldeman (1997). Some authors have objected to the fact that the GLASOD survey methodology relies heavily on expert opinion. On the other hand, both studies provide useful data which are being used in different studies on different scales.

The RALA/LR classification methods are objectively sound and easily applicable in the field. Although Icelandic conditions are different from those in many other countries, the method can be improved to suit conditions found elsewhere. Land degradation in Iceland has much in common with desertification in the arid countries (UNEP cited in Arnalds *et al.*, 2001).

The Rangeland health/condition assessment rating of soil and soil surface, vegetation, and livestock health condition gives a good indication and acts as a guide for applying or improving ecosystem management practices. Livestock condition is a good indicator of rangeland health. When rangelands become poor, livestock condition and production decrease and vice versa. The use of classes, for example those used by Manske (2002), relates to human health and helps farmers to understand and adopt the method quickly.

4.2 Use of Indicators

Generally, indicators are selected and used because people think that they reveal an underlying pattern that ties a cause with a problem or a problem with an effect. However, local circumstances may be so different in one respect or another that the same indicator is a reflection of very different underlying relationships than the one it is thought to reveal. Global indicators (e.g. of soil erosion) are not directly applicable to regional, national nor local and farm levels, nor can regional indicators be applied to national or local and farm levels.

Thus indicators need to be developed for different levels. However, a set of criteria on which the indicators have to be based are required to ensure the relevance and usefulness of developed indicators and also consistence. Klintenberg and Seely (2004) suggested that a globally accepted set of a small number of criteria be developed on an international level to ensure that indicators meet set demands of quality, e.g. relevance and accuracy. The group of indicators that has been developed by experts for use at global, regional, national, local and farm levels mentioned in FAO (2003 is too long and it is difficult to apply them directly. This was why the LADA project recommended using this list only as a starting point (Snel and Bot, 2003). A long list of recommendations is difficult for land users to apply and this may lead to missing important information which then may lead to biased conclusions. On the other hand, a small number of indicators may not be realistic across ecological boundaries.

Indicators need to be usable, measurable and have recognizable applicable data constraints. Snel and Bot (2003) and many other scientists propose that indicators should be SMART: specific, measurable, achievable, relevant, and time-bound. Notably, indicators for land degradation assessment need to include evaluation of both *on-site* and *off-site* effects of the problem. Burning and Lane (2003) stressed careful evaluation of the relationships between biophysical condition in the context of changes in demographics, policy, land use, technology and management practices and natural events. Therefore, evaluation of on- and off-site effects will provide a basis for informed management decisions by a range of stakeholders from resource users and managers to technical advisers, planners and policy makers. This means that indicators for such specific purposes should be developed by people with a good understanding of the problem and its root causes and impact on the land.

In developing indicators or thinking of any assessment or monitoring to do, it is necessary for the group involved to define objectives. Van Lynden *et al*. (2004) stated that it is essential to ask: What is happening? Does it matter? Are we improving? Are we on the whole better off? This is a good example of the types of questions to ask so that methods developed will provide useful information. The good side of indicators is the high adaptability and applicability level, even by non-experts. As indicated above, indicators need to be developed by people with a good understanding of the problem and its root causes and impact; both scientific and local knowledge are required in this process. Local knowledge needs to be integrated with and validated by scientific knowledge to provide greater depth of explanation, and to help quantify the extent and magnitude of change (Reed and Stringer, 2006). This is true in order to assure that local people will understand and so that it will be easy for them to apply the methods.

However, it is equally important to critically assess local perceptions against scientifically accepted principles and knowledge to allow room for improvement and avoid getting stuck in old ideas and practices. Science can provide measurements which are useful in informing management strategies; however local knowledges of the ecosystem and land degradation are deeply, socially embedded and constructed within specific land management contexts, and this is not always reflected in scientific degradation assessments (Reed and Stringer, 2006).

A qualitative assessment is not a stand-alone tool as it does not quantify any measure (Pyke *et al.*, 2002). Both qualitative and quantitative measures are needed to obtain quality data. Quantitative measures require some knowledge in collecting samples and analysing the data obtained. Rangeland assessment approaches have been developed by several scientists such as Pyke *et al.*, 2002; Pellant *et al.*, 2005; Tongway, 2005; Tongway and Hindley, 2004; Herrick and Herrick *et al.*, 2005; Napcod, 2003; NRC, 1994 and tested in different ecosystems. Many of these approaches are applicable to most arid and semi-arid conditions. This approach to rangeland health assessment using indicators is good and provides a wealth of information that can help in management decisions.

Even though the protocol discussed by Pellant *et al.*, (2005) does not provide information on what is causing the problems with the three rangeland health attributes it can assist in determining if there are problems relative to soil/site stability, watershed function, and biotic integrity. Thus additional quantitative assessment is required which will provide enough information that can be used at regional or national levels.

Promising approaches developed included landscape function analysis (LFA) and soil condition assessments by Tongway of Australia. The LFA approach has been implemented in climatic ranges from 50 to 10000mm a.a.p. and in a number of other land-use scenarios (Tongway, 2008). The approach can be applied to arid Namibia without difficulty as it has already been introduced to some stakeholders by Tongway earlier in 2008. Shamathe *et al.* (2008) have used the soil surface condition assessment which is part of the LFA approach in a restoration project.

The training forms a platform that a stakeholder can then use to train others to make the best use of the method. LFA results also help in deciding what action should be taken to maintain the functioning of the ecosystem and prevent further degradation of resources. The LFA approach and VS-Fast methodology are both approaches that use simple indicators and have been found to be easily applicable on a large scale.

The Grazing Gradient Method (GGM) has been of use in Australia for rangeland assessment. As described by Australian scientists, the method involves visual field observations, measurements and modelling with remote sensing tools for quantifying temporal and spatial trends of vegetative cover as an indirect indicator of land degradation. The implementation of GGM is relatively simple and uses the standard grazing gradient software described by Bastin, Chewing and Pearce (1996) cited in Pickup et al. (1998). The method has potential for use in arid and semi-arid rangelands in North and South America, Asia, and Africa as they are managed on a large enough scale to allow development of the spatial patterns of grazing impact that the method exploits (Pickup et al., 1998). On the other hand, Pickup et al. (1998) stated that the method also has potential as an early warning technique, if applied routinely. In addition Roder et al. (2007) stated that the GGM can be used as a management tool to detect areas of over- and undergrazing and to test different grazing regime scenarios. The Grazing Gradient approach has been applied in Namibian rangelands where it has shown good results (Getzin, 2005; Klintenberg et al., in prep).

4.3 Use of Models (soil erosion and land cover)

The empirical (e.g. USLE/RUSLE) and mechanistic (e.g. WEPP) erosion models are primarily designed for cropland systems and are difficult to adapt for use on rangelands (Pierson, 2000). The models involve mathematical equations that are used to estimate or calculate sediment yield and erosion risk by water and wind. Pierson (2000) stressed that this is due to critical lack of erosion data representing rangeland ecosystems. Arnalds *et al.* (2001) commented that in Iceland there are other factors that detract from the reliability of the known models for soil erosion This is simply because Icelandic soils (andosols) have very specific characteristics that correspond poorly with the parameters of the model.

The USLE model was developed for a local scale assessment of soil erosion by sheet and rill erosion; thus its application to regional assessment needs some modification. The change to RUSLE makes it useful for estimation of erosion and sediment load, not only for an agronomic setting but also for situations involving construction, mine spoils, and land reclamation (Yoder *et al.*, 2004). The model's equation is also discussed by many other authors such as SWCS, 1993 cited in FAO, 2005; Marker and Foster, 1998; Ballayan, 2000; Arnalds *et al.*, 2001; Lal, 1994a; Yoder *et al.*, 2004; Marker *et al.*, 2007; Lal *et al.*, 1997 and others. RUSLE demonstrates the potential to assess landscape soil erosion susceptibility with scenario analysis as reported by Marker *et al.* (2007).

The guidelines, which include some information on the history of research and RUSLE approach, software, database, description of each factor, examples of each factor values for specific sites, and application of RUSLE, were developed by Toy and Foster (1998) for mined lands, construction sites and reclaimed lands. These make good paths to follow when applying the model and help you to understand each step. On the other hand, Warner and Foster (1998) discussed the advantages of the model, pointing out that RUSLE and other erosion-control measures can be estimated and alternative reclamation plans can be readily compared.

Apart from the USLE and RUSLE erosion models, other models have been developed and used in some countries. Within the European community sharing the Mediterranean region, the CORINE model is used to determine erosion risk and land quality. The method was integrated with GIS and remote sensing tools to map erosion. Another model is PESERA, which is used to quantify soil erosion by water and its risk across Europe and it can also be extended to include estimates of tillage and wind erosion. Other regions can also try to develop standard methods for erosion that suit their own environmental conditions. There are many other models (see box 2) which have been used to assess soil erosion and land cover.

The literature suggests that all these models yield good results where they were used, even though conditions may differ. However, all these models are expert-based methods and can be extremely difficult to adopt by non-specialists, especially at local and farm levels. For example, the USLE/RUSLE requires calibration and adequate input data. In this regard, soil erosion indicators are used even though they will not provide enough information; one approach is to bypass the massive data requirement of soil models (de Bei, 2005). Many scientists claim that soil erosion is not easy to measure, thus erosion-based methods are more complicated than general assessment of land health or condition. Furthermore, Pierson (2000) suggests that, to address global desertification issues, erosion modelling must move beyond general or simplistic long-term erosion estimates.

4.4 Use of remote sensing

The use of remote sensing in assessing and monitoring of vegetation, erosion and land degradation under different environmental conditions is reported by many researchers. As can be seen from the above studies that use remote sensing, the methods can be quite beneficial. These examples show that integration of remote sensing with land degradation assessment gives useful results. A remote sensing tool has been available for more than 30 years (Lantieri, 2003). Remote sensing is recommended by many users because of its broad areal coverage, repeatability, and cost and time effectiveness. It has the greatest comparative advantage when the scale is small because it can provide data for a large area at one time (Van Lynden and Kuhlmann, 2003). Therefore it is, in principle, an ideal methodology for regional or global degradation assessments.

The main problem with the method is that the data should not be used as such alone but should be accompanied by adequate ground data in order to obtain reliable estimates. This is one of the reasons why remote sensing is most often used for degradation assessments of relatively small areas. Experienced and knowledgeable people are required to interpret the data and run the software.

Van Lynden and Kuhlmann (2003) and Oldeman (undated) reviewed the six methodologies for land degradation assessment in the context of the LADA project: expert opinion, remote sensing, field monitoring, productivity changes, land users' opinion, and farm-level field criteria and modelling. They evaluated each of these methodologies according to a set of criteria. Appendix 2 provides a table which summarises these methods based on Oldeman (undated).

5. RECOMMENDATIONS FOR NAMIBIA

- Local studies by Klintenberg and others (previously cited) provide useful results; therefore it is recommended that similar approaches should be applied in other areas of the country. This will help to improve the four national monitoring system indicators.
- Namibia could try to come up with a soil erosion map, for example. Different approaches used by other countries such as Iceland and Australia are referenced earlier in this paper.
- Co-ordination of different activities by different parties should be improved (e.g. ministries, NGOs, etc) while healthy competition can also be useful.
- The LFA approach should be applied. It could well be a simple and useful way to assess land degradation.
- The VS-Fast methodological approach may be worth trying at the local level.
- Namibian junior, senior and professional scientists, researchers, and other practitioners should equip themselves with assessment and monitoring skills and encourage involvement and leadership of local people when conducting studies on land issues.
- Introduction of FIRM and LLM approaches to all communities will be helpful so that all farmers take part in managing their own resources.
- Remote sensing tools should be used instead of just using current methods. New methods could be tried on the more sensitive satellites that are being developed, in the hope of finding a better interpretation.

6. CONCLUSION

In conclusion, there are a wealth of different approaches for assessing land degradation worldwide. There is no single best method for assessing land degradation. Studies done at the global level are mainly based on expert opinion. However, field measurements, field observations, land user's opinions, productivity changes, remote sensing and modelling act as a backbone for many approaches used to assess land degradation.

Many researchers and scientists amphasize that assessing land degradation can be complex since more than one type of degradation may occur in any one place. Therefore, complexity makes it impossible to use the same tools, techniques and methods for assessing different types of degradation. Many methods have been improved and justified to gather as much useful data as possible. However, development of any method requires people with good understanding of ecosystems and socio-economic drivers of land degradation.

The first distinction that has to be made defines land uses and land types (croplands, rangeland, mining area, etc.) and scale (global/ regional/ national/ local/farm). Significantly, methods or techniques need to be critically selected, taking into account their suitability, applicability and adaptability to local conditions. Developing and using simple but yet robust methods (e.g. classes of 0-5, very good to bad; simple indicators) are good as they can be easily adapted and used even by non-experts. This helps in comparing areas; involving stakeholders as much as possible aids in land use and restoration planning and prioritizing projects.

Under rangeland conditions, information about soils alone (erosion or other indicators) or vegetation alone (% palatable, climax, etc.) is not sufficient, a system approach is needed. Involvement of local people when working at the local level is also very important – this encourages them (e.g. local people or farmers) to take responsibility and reinforces their ownership when it comes to the implementation of management practices. It is also important to integrate local knowledge with scientific knowledge, though care must still be exercised in interpreting such information.

Furthermore, the use of statistical methods, ordination, and modelling approaches are important research tools to understand the systems and processes involved. For example, a remote sensing-based approach can provide a comprehensive, objective and repeatable analysis of the problem after future events. However, most such approaches are costly, complicated, and require much time. Lack of experienced people and availability of resources (e.g. money) are some of the main barriers to successful assessment. This review revealed that there are very few accounts of failures in using the different assessment methods, which is somewhat surprising. Does that mean everything works?

Last but not least, massive information on methods and their application in different environments was found during this study. Unfortunately, time did not allow the summation of each and every methodology. This paper provides a summary and discussion of the methods that were deemed most important to consider, with, as applicable, comments on their potential use in Namibia. For interest's sake, references provided in this document can lead to more references of assessment and details of monitoring methods for those wishing to explore further this important field of science.

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APPENDIX 1: Summary of land degradation assessment approaches reviewed

Approaches	Levels	References
GLASOD survey	Global	Bridges and Oldeman, 1999; Oldeman *et al.*,1990; Jones *et al.*, 2003; & Lynden and Oldeman, 1997;
ASSOD survey	Regional	ISRIC & Lynden and Oldeman,1997
WOCAT mapping methodology	Global, Regional, National, & Local	van Lynden *et al.*, undated; http://www.wocat.net/methods.asp
LADA methodology	Global, National & Local	Koohafkan *et al.*, 2003; LADA project document, 2005; Ponce-Hernandez, 2002; Lynden and Kuhlmann; 2003; Snel and Bot, 2003; Burning and Lane, 2003; Van Lynden *et al.*, 2004;
GLADA approach	Global, National & Local	Bai and Dent, 2006.
Other Land degradation assessments	National, Local, and Farm	de Bie, 2005; Reed and Dougill, 2002; Lynden and Kuhlmann; 2002; Reed and Stringer, 2006; Klintenberg and Seely, 2004; Klintenberg *et al.*, 2007; FAO, 2003;
RALA Classification methods	National / Local	Arnalds *et al.*, 2001;
NZLRI erosion classification	National, Local	Landcare Research (http://www.landcareresearch.co.nz/databases/nzlri.asp)
More on erosion classification	local/farm	Berry *et al.*, 2003
MODELLING USLE/RUSLE	Local/Farm	USSCS; EUSOILS; SWCS, 1993; Marker *et al.*, 2007; Castro Filho *et al.*, 2001; Lal, 1994a; Yoder *et al.*, 2004; Arnalds *et al.*, 2001; Warner and Foster, 1998; Lal *et al.*, 1997; FAO, 2005;
CORINE	Regional, National, local	Doğan *et al.*, undated; Dengiz and Akgul, 2005; EUSOILS; Cebecauer and Hofierka, 2007; Kiunsi and Meadows, 2006;
PESERA	Regional, National, local	EUSOILS; Kirkby *et al.*, 2004;
CCA	Local	Klintenberg and Verinden, 2008;
REMOTE SENSING (MSDI, MODIS, SPOT images, NDVI, PD54, SAVI, etc.)	All levels	Lantieri, 2003; Ostir *et al.*, 2003; Jafari *et al.*, 2008; Thorarinsdottir, 2008; Tanser and Palmer, 1999; Bai and Dent, 2006; Klintenberg *et al.*, in prep; http://www.ccrs.nrcan.gc.ca/glossary;
AEZ methodology	Local/Farm	FAO, 2005
VS-FAST methodology	Local/Farm	McGarry, 2004
Grazing Gradient Method (GGM); Degradation Gradient Method (DGM); species composition methods	Local/Farm	Pickup *et al.*,1998; Bastin, 2002; Pickup and Chewings, 1994; Bastin *et al.*, 1993; Roder *et al.*, 2007; Klintenberg and Verinden, 2008; Getzin, 2005; Zimmermann *et al.*, 2001;
Rangeland Health/Condition Assessment (Attributes, indicators & Classification (LLM; LFA; SSC approach);	National, local & Farm	Pyke *et al.*, 2002; NRC, 1994; Pellant *et al.*, 2005; Herrick *et al.*, 2005; Manske, 2002; NRC, 1994; Napcod, 2003; Tongway, 1994; Tongway, 2008; Tongway, 2005; Tongway and Hindley, 2004; Ludwig *et al.*, 1997; Shamathe *et al.*, 2008)

Some approaches might be applicable to other scales (large or small). To draw conclusions, further research on specific approaches is required.

APPENDIX 2: Land degradation assessment (criteria and methods)

	Methods					
Criteria	Expert opinon	Remote sensing	Field Monitoring	Productivity change	Farm level studies	Modelling
Subjectivity	moderate to high	low	low	moderate	high	low
Scientific credibility	moderate	high	high	moderate	moderate	high
Replicability	moderate	high	high	moderate	low	high
Scale applicability						
*Global	yes	yes	no	no	no	possible
*Regional	yes	yes	no	no	no	possible
*National	yes	yes	no	yes	no	yes
*Local	yes	yes	yes	yes	yes	yes
Data requirements	low	low	high	moderate	low	high
Degradation status	yes	yes	yes	yes	yes	no
Degradation risk	no	possible	no	no	possible	yes
Degradation type	generic	specific	specific	no	generic/ specific	specific
Vegetation degradation	yes	yes	possible	possible	yes	yes?
Rehabilitation	yes	possible	possible	possible	yes	possible
Costs / unit area	low	moderate	high	moderate	high	low, but....
Time to produce result	short	short	long	short	short	short
Constraints	validation	*ground observations *equipment *skills	high lab. quality	confounded	elaborate	data sets validation
Stakeholder involvement	low to moderate	low	low	high/ moderate	high	low

The table above shows that each methodology scores high for some criteria and low for others (Oldeman, undated). Consideration should also be given to a combination of methodologies (e.g. to increase objectivity and credibility). Furthermore, Oldeman (undated) states that the ultimate choice of the methodology depends on the user of the degradation assessment.