Evaluating Environmental Sensitivity through the use of Geographical Information Systems in Oshana Region (northern Namibia): Towards land degradation mitigation

Emma N. Noongo
E-mail: ennoongo@hotmail.com

May 2001

Abstract

Environmental Sensitivity may be conceptualized in terms of the response of landscape systems to perturbation on different time and spatial scales. Unstable systems behave chaotically but may show high levels of resilience at critical stages, while stable systems may recover once threshold values of systems parameters are exceeded. The aim of this study is to develop a methodological reference framework, for use at a regional scale, from which environmental sensitivity can be evaluated. This is to integrate the myriad of factors, disciplines, environmental components, types of data and scale of measurements with a single tool. More specifically the paper aims to develop a simple and efficient computational structure for evaluating the response of selected layers to degradation phenomena at regional scale. All data are managed with in a GIS, which not only facilitates access to information but also has a potential in displaying, manipulating and analyzing large amount of spatial data with different backgrounds. GIS also enables cross procedures and various classifications to be performed. As a result, the current landscape generic can be identified, and appropriate intervention simulated rapidly.

Key words: Environmental sensitivity; Desertification; Land degradation; Geographic information systems; Oshana Region

1. Introduction

The concept of desertification has been continuously redefined over the past 20 years (UNEP, 1977, 1992) possibly attesting to the lack of general consensus on what it entails. In the late 1970's, UNEP defined this concept as a reduction or destruction of soil biological potential leading to desert-like conditions (UNEP, 1977). In the early 1990's the definition was refashioned to land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNEP, 1992). From an agronomic point of view Basso (1995) argues that there is a substantial difference between degradation and desertification: The former is not necessarily an irreversible process and can be controlled and stabilised with appropriate technical intervention, while the latter is a permanent, practically irretrievable, situation with a virtual total loss of biological potential. The study of desertification includes the causes and impacts of degradation on land resources, to the extent where these can be identified and be measured. The types of environments prone to land degradation are fragile, generally characterised by small amounts of green biomass, low content of organic matter in soils, low and erratic rainfall patterns while supporting high number of agronomic human populations.

The concept of Environmental Sensitivity (ES) can be defined, as the rapidity and magnitude of adverse response by the environment, or part of it, to changes in one or more internal or external factors (Usher, 2000; Thomas and Allison, 1993). The relationships between the cause of changes and the effects is often complex and intertwined because separate environmental components respond with differing sensitivities, whilst, because of the interrelationships amongst the components, an effect on one component may become a cause on another. Land degradation occurs when the response is considered deleterious to the 'health' of the environment. What the health of an environment exactly should be, and how a deleterious change is physically defined, are questions open to considerable debate. Environmental Sensitive Area (ESA) can be considered, in general, as a specific and delimited entity in which environmental and socio-economic factors are not balanced or are not sustainable for that particular environment (Stocking, 1995 and Stewart, 1968). The importance of ES remains central to many arguments about conservation and sustainable land use (Quine and Walling, 1993). It is a term that expresses some concepts about non-linear dynamic systems and their capacity to respond to or resist changes. It is a concept that can be applied to most aspects of the landscape complex, because it also focuses on the interactions between landscape components and between neighbouring landscape elements in a spatial land system (figure 1). Understanding time series and spatial variability is essential in environmental studies; however, their contribution to understanding mechanisms of systems may be limited by such properties as multi-complexity of processes and inheritance. The temptation is to model the present, but it can be argued that land management is fundamentally about conserving the past although its aim may be to secure the future. This is true within a range of timescale.

Land degradation is often evaluated in several different ways by various groups of people often leading to a lack of consensus regarding the rates and severity of land deterioration. Degradation also depends on the perspective of the observer. There are many environmental components, which can be measured, and changes in each one can be deemed beneficial or harmful. As degradation can arise from many different factors, the importance and relevance of changes in each component, for an individual observer, depends, partly, on the interests of that observer and to an extent, on the availability of data. These measurements can be precise and quantitative, or very broad, nebulous, and qualitative; spatially coherent over scales of millimetres, or cover hundreds of kilometres; instantaneous, or continuously updated; of real physical nature, or of abstract socio-economical character. How can these data be integrated? What are the relationships amongst the factors? These are major issues that are not easily resolved. However, through an integrated, multi-level approach, both the different degradation stages and the existing interactions amongst the individual components of the landscape can be evaluated.

This paper presents an application of GIS technology in identifying and measuring environmental sensitivity. In particular the paper aims at developing a methodological reference framework for use at regional scale from which environmental sensitivity can be evaluated.

2. Study area

The Oshana Region is located in the north-central Namibia (figure 2), covering an area of 5 180. Km^2. It is the second most densely populated region with 134 884 total population size. Oshana region has particular climatic, ecological and land use characteristics, which play a major role in determining the key questions that have to be answered when evaluating environmental sensitivity to land degradation. The region is classified as arid to semi-arid with mean annual rainfall ranging from approximately 550mm in the east to less than 300mm in the west. High evaporation rates around 3 500mm per annum coupled with extreme rainfall variability places severe constrains on farming activities. Particularly in the west, agricultural activities are marginal. Temperature variability in the Region is similarly high, ranging from zero to 42 ^{0}C. Oshana region is topographically relatively flat with relief ranging between 1050 to 1200 mamsl. South-east flowing ephemeral watercourses draining towards the Etosha Pan dominate the drainage pattern in the region. Limited runoff is normally absorbed into the sandy substrate or collects in the numerous pans (oshanas) that are a result of the flat topography.

Most of the area is overlain by infertile unconsolidated to semi-consolidated aeolian Kalahari deposits being largely sands, clays and calcretes. Underlying geology represents a succession of sedimentary deposition of Damara, Karoo to Kalahari Sequence sediments within the Ovambo Basin, which is part of the "Kalahari Basin". Occurrence of shallow groundwater in the Kalahari Sequence is widespread within the region but is often highly saline. Different aquifer types, including perched aquifers, in Oshana are exploited by boreholes of which a great percentage yields 1-5 m^3. The land tenure in Oshana Region involves communal subsistence farming areas and protected (state owned) land.

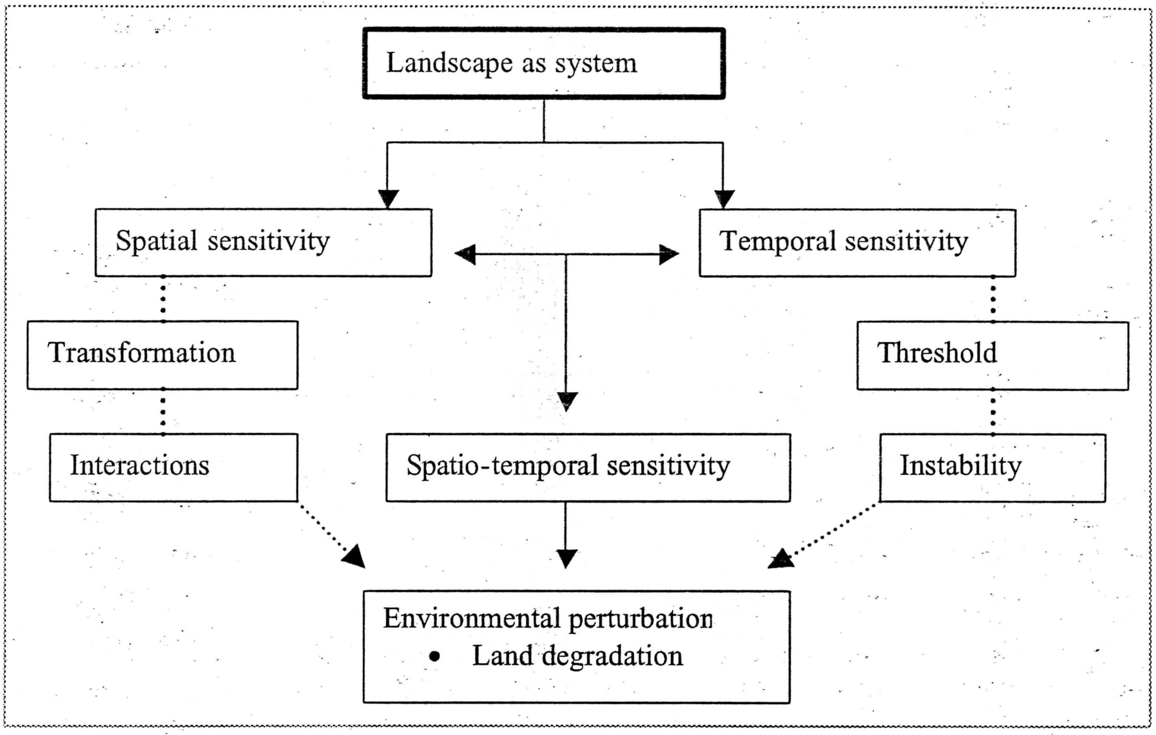
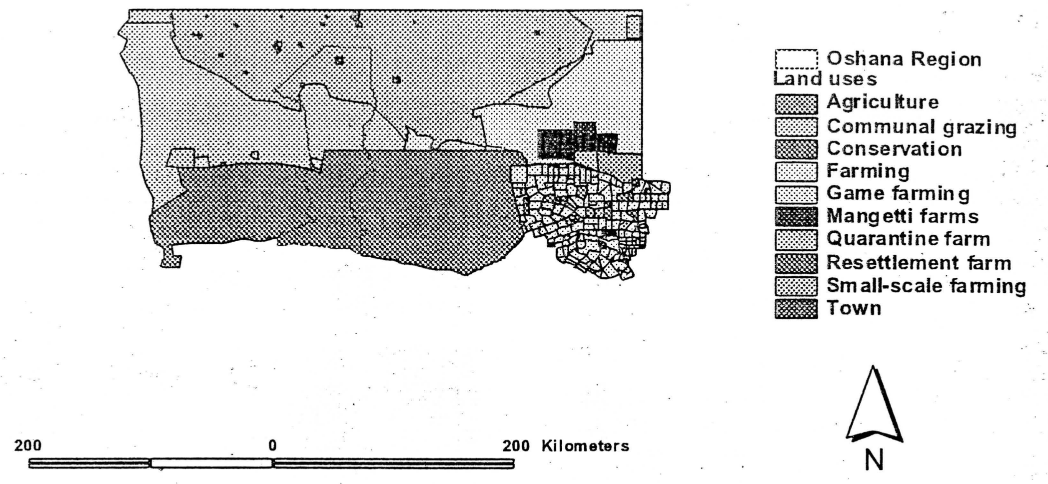


Figure 1. Aspects of sensitivity in landscape
After: Gerrard, 1993 and Brunsden, 2000
Note: The diagram is designed to show how environmental factors interact to bring about land transformation and cause instability as thresholds are exceeded.

Figure 2. The location of the study area



3 Methodology and Results

3.1.The layers used

The most important sets of parameters that affect an environment's sensitivity to degradation are of ecological and socio-economical nature (Brusden, 1980 and Brusden, 1993) ES is closely related to many environmental factors such as climate, soil, vegetation cover, and morphology where their characteristics; and their intensity, contribute to the evolution and characterisation of different degradation levels or stages. Sensitivity is also strongly linked to socio-economic factors since human's behaviour, social and economic actions can greatly influence the evolution of numerous environmental characteristics. Four main criteria were considered when selecting the information layers for the study:

- The relationship with the degradation phenomena or environmentally critical situations;
- The extent of the data coverage;
- The ease of updating the data timely and economically;
- The fact that the structure of the system will allow the information layers to be refined, developed, and/or removed as appropriately with gained experience.

The working set of thematic layers, used in the GIS to assess ES to land degradation in Oshana Region, is given in figure 3. The sources of the data used to construct the categories are given in table 1. In this scheme, scores were assigned to the elements of a particular parameter with valid scores ranging from 1, the best conditions, to 2, the worst conditions. A value of 0 (zero) was assigned to areas where a measure was not appropriate (unclassified).

This scheme means that the layer results are independent of the structure (number of classes, etc.) of the layers. This, in turn, means that the layers can be compared on an equal basis, irrespective of the original data format, and higher level processing is decoupled from the details of the data, and layers can be revised or developed without affecting the remaining structures. The classes and scores assigned were based on the influence and strength of the association that the different layers have with the soil degradation processes and their relationships to the onset of irreversible degradation or desertification phenomena (FAO, 1976). A more comprehensive description on how the environmental layers are linked to the degradation or desertification phenomena is given in the works of Kosmas (1998) and Kosmas et al. (1999).

Incorporation of socio-economic data is more problematic. These data are very important in order to evaluate the interactions of humankind with the environment, but their intangibility make them difficult to define. Many indicators have been evaluated to find out their link, through their spatial distribution, to landscape degradation (Brusden and Thornes, 1979). The temporal dynamics of these indicators is also important: the current situation arises from the current distribution (possibly with some lag involved) whereas the pressure on the environment to change is related, in part, to the rate of change of these indicators. Population density for example, can have two critical thresholds: at one extreme a sparse population which does not ensure the maintenance of a productive landscape jeopardising its stability and, at the other extreme, high anthropic pressure with respect to the available resources resulting in the exploitation On the other hand, some socio-economic indicators are easily interpreted because they give only one critical threshold. Unemployment indexes are indicators directly related to degradation from a demographic perspective. In Oshana Region, Census statistics having a ration of 10 employed /100 unemployed (1991 index) and 5 employed / 30 unemployed (1998 index) can be found (NPC, 1994), demonstrating a serious demographic and economic imbalance. In additional, illiteracy indexes that report on the general economical vitality of the entire Region indicate a high level of illiterates. If the level of education is low and most people live on pensions and agricultural productions, the relationship with the land, and, therefore with its 'well-being' is very insecure increasing emigration pressures.

One of the particular aspects of the proposed approach is that the ES classes are not directly linked to an absolute value of sensitivity but are related indirectly, and relatively, through scores that define different levels of sensitivity, for different parameters, for a particular area. As a result, sensitivity calculated at the top layer imposes a common framework on the components of an area. The elements, which are grouped into broad categories, can be investigated and characterised in a different phase by other analyses.

The selection of the layers is an open process, though only meaningful layers will produce meaningful results, the choice of the layers, and their metric, is not critical: many other layers can be used and they can be subsequently refined in light of greater acquired knowledge.

3.2 Computational methodology

The quantification of different ES levels at the regional scale is carried out by evaluating the overall influence that single information layers have on the phenomena under study. The first task was to establish a data bank and develop suitable techniques to manage the information layers while accommodating their different types and levels of detail. Intermediate and final maps were produced after various elementary layers were rasterised and registered. The next task was to develop a system, which would function irrespective of the number and type of information layers at its most primitive level. This is achieved by adopting a two-stage approach as illustrated in figure 4. In the first stage, the four single quality layers are first determined from the basic data layers and in the second phase the final sensitivity of an area is evaluated from the quality layers. Each elementary unit in each Quality Layer is estimated as the geometric mean of its own layers:

$$Quality\_x_{ij}=(layer\_1_{ij})(layer\_2_{ij})(layer\_3_{ij})...(layer\_n_{ij})(^{1/n}) \text{-----------------------} (1)$$

Where i,j represent rows and columns of a single elementary pixel of each layer and n the number of layers used. The first level (basic data layers) isolates the rest of the system from the details of data. The quality layer (level 2) acts as a buffer between the level data layers and the derived ESA layers, (level 3). The weight of each quality layer is equivalent, so as with level 1 components, the results are comparable amongst the layers and the constituents of a particular layer are hidden from the rest of the system. This approach allows the overall 'quality' themes to be developed independently and without changing the structure of the overall methodology. With the four qualities obtained from the above, the ES is estimated by:

$$ES_{ij}=(Quality\_1_{ij})(Quality\_2_{ij})(Quality\_3_{ij})(Quality\_4_{ij})(^{1/4}) \text{-----------------------} (2)$$

Where i,j represent rows and columns of a single elementary pixel (of each quality) and $Quality\_n_{ij}$ = computed values.

Table 1. Characteristics of the used layers

LAYERS	SOURCE
Population density	Published data (Census, 1991 & NNEP, 1998)
Land use	Published data (MAWRD), Data on Land use and Pressure on land (NNEP, 1998)
Employment index	National census data, 1991
Illiteracy index	National census data, 1991
Plant cover	Published vegetation index data (1993-1998)
Fire risk	Published vegetation index data (1993-1998) Published fire event/scars data, 1993-1998 Land use data, 1998
Aridity index	Published data (MAWRD)
Rainfall	Published rainfall data (MAWRD, Inter-Consult)
Slope angle	DEM (5 m contour lines), Inter-Consult, 1999
Aspect	DEM (5 m contour lines), Inter-Consult, 1999
Drainage	Published data (Inter-Consult)
Soil properties	Published data (AEZ, NNEP)

CLIMATIC QUALITY

Aspect	
Score	Classes
1	North
2	South

Aridity Index	
Score	Classes
1	Sub-humid
1.5	Semi-arid
2	Arid

Rainfall	
Score	Classes
1	> 550mm/yr
1.5	280-550mm/yr
2	< 280 mm/yr

SOIL QUALITY

Drainage	
Score	Classes
1	Well drained
1.5	Imperfectly
2	Poor drained

Slope	
Score	Classes
1	< 6%
1.33	6-18%
1.66	18-35%
2	>30%

VEGETATION QUALITY

Plant Cover	
Score	Classes
1	> 40%
1.5	40-10%
2	<10%

MANAGEMENT QUALITY

Illiteracy index	
Scores	Classes
1	< 6
1.33	6-7
1.66	7-10
2	> 10

Employed index	
Scores	Classes
1	>40
1.33	30-40
1.66	20-30
2	<20

Land uses	
1	Protected areas
1.5	Communal crop farming
1.8	Game farming
2	Livestock farming

Population density	
Scores	Classes
1	<15 pr/sq km
1.8	15-80 pr/sq km
2	> 80 pr/ sq km

Fire Risk	
Scores	Classes
-	Urban
1	Barren soils/areas
1.3	Grassland
2	Commercial

Figure 3. Layers and classes with adopted scores

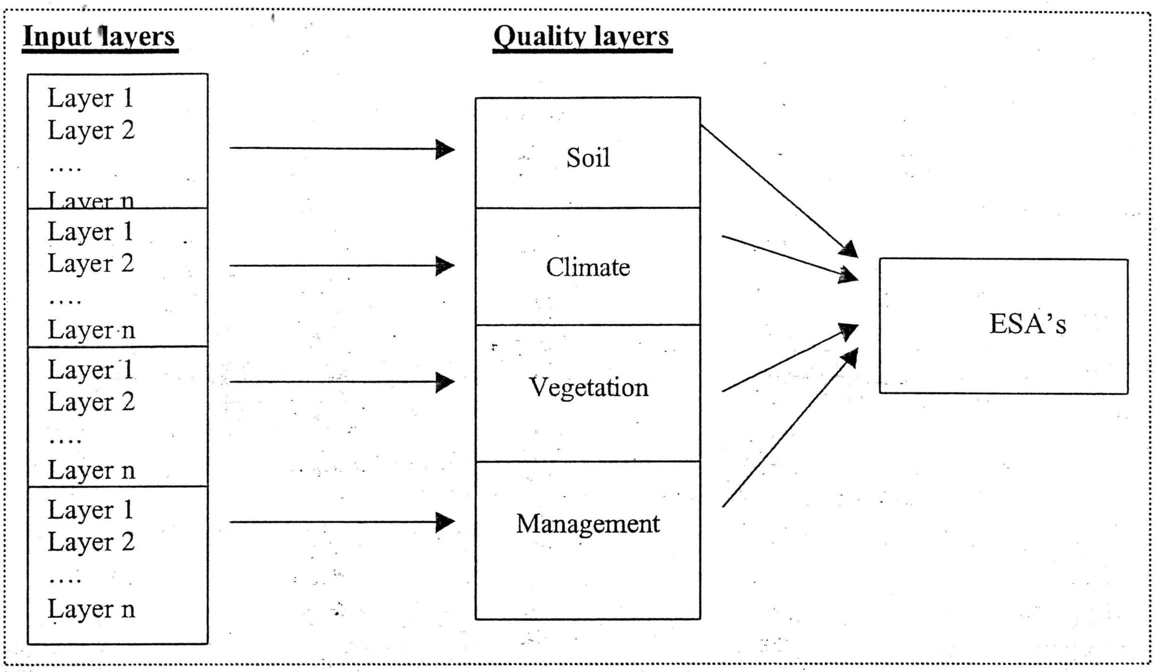


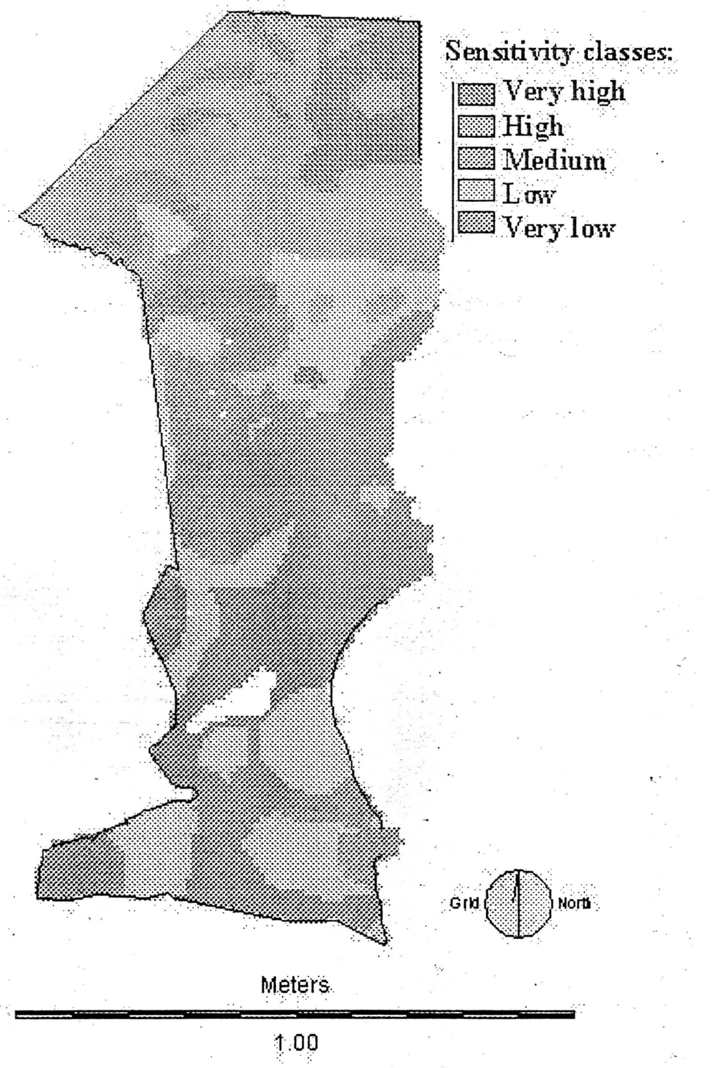
Figure 4. Scheme of the ESAs estimate

The ES for land degradation in the study area, using the method as outlined in proceeding section, is shown in figure 5. Similar maps can be produced for each of the quality layer components. Areas with high sensitivities are clearly pointed out. Areas with poor socio-economic conditions (high population densities, low employment and high levels of illiteracy) are seen to be at a high risk of land degradation. The biophysical factors on the other hand, seem to have a relatively less pressure on the environment as long as the socio economic conditions are kept in check.

4. Evaluating model performance

Through the analysing of the relationships between the derived sensitivity classes and other parameters, which are commonly used at the field level to evaluate land degradation and local sensitivity, the model behaviour and its interpretative capacity can be assessed. To appraise the model, the importance of field evaluation is emphasised. Representative areas of vegetation cover and land use, for instance, can be identified within the area of interest taking into account the different prevalent ecological situations. The area should be defined according to its environmental condition and geographical position. The ability of the proposed model to estimate different levels of ES at the regional scale can be assessed by analysing the relations that exist amongst the different field indicators, taken alone and in combination, and the estimated sensitivity.

Figure 5. environmental Sensitivity in Oshana Region



5. Summary and Perspectives

In this study, GIS procedures were used to evaluate ES in Oshana Region as a means of identifying the environmental components effecting and being affected by land degradation. There is a need for systems that allow identification of and understand the factors that combine and accelerate land degradation in order to adequately manage the land and its resources. The system being developed, as outlined here, can be used to isolate current factors, effects and components of degradation phenomena. To do this, cross-analysis techniques are applied to the data in the information layers. The model has its relevant aspects in the use of information derived from different disciplines and various sources – some based on pre-existing themes, some based on combinations of these themes and some created *ex novo* from other analyses; allowing the maximisation of available information. The method used in this paper enables not only the degradation phenomena to be identified but also the information layers and causal paths to be preserved allowing the origin of the degradation to be identified and examined. Linking a real scale information (an important point which however, is not feasible during this study), with detailed studies of land degradation at the plot scale would increase the understanding of dynamics of degradation and the interrelationships amongst the causal factors. Moreover, using updated information and modelling, conclusions and considerations derived from regional scale studies can be interpolated to a detailed field scale be used to evaluate and control degradation at the local level.

The method also has a specific per se descriptive value: it can be used as a common framework whereby further, and different, analyses can be used to investigate, define and qualify the contents of the classes. In this context, ES evaluation can contribute a preliminary tool towards better land management to mitigate land degradation.

The emphasis of this presentation has been on a static system, however, degradation, sensitivity, and management are all dynamic entities. Considerable attention is currently being paid to developing the system as a continuous monitoring system in which data can be updated and compared over a range of time scales. To this extent, some layers can be considered static, whose environmental parameters change slowly, or rarely, if at all, and by their nature are infrequently measured or mapped (e.g., soil properties), whilst others are more dynamic. In any given event the aim of such a monitoring system is to define and predict trends and changes in the ES of a defined environment so as to promote efficient and optimal management.

References:

Basso, F., 1995. Difesa del Suolo e Tutela dell'Ambiente, Pitagora (Ed.), Bologna, pp. 486.

Brunsden, D., 1980. Applicable models of long term landform evolution. In: Hagedorn, H. and Thomas, M.F., Editors, 1980. Perspectives in Geomorphology Z. Geomorphol., Suppl. vol. 36, pp. 16‾26.

Brunsden, D., 1993. Barriers to geomorphological change. In: Thomas, D.S.G. and Allison, R.J., Editors, 1993. Landscape Sensitivity, Wiley, Chichester, pp. 7‾12.

Brunsden, D., 2000. A critical assessment of the sensitivity concept in geomorphology. Catena 42, pp. 101‾125.

Brunsden, D. and Thornes, J.B., 1979. Landscape sensitivity and change. Inst. Br. Geogr. Trans. NS 4, pp. 463‾484.

Burrough, P.A., 1983. Multiscale sources of spatial variation in soils. J. *Soil Sci.* 34, pp. 577‾620.

Central Statistics Office (1994) 1991 Population and Housing Census. National Planning Commission, Windhoek, Namibia.

Dietrich, W.E., Reiss, R., Hsu, M. and Montgomery, D.R., 1995. A process-based model for colluvial soil depth and shallow landsliding using digital elevation data. Hydrol. Processes 9, pp. 383‾400.

FAO, 1976. A framework for land evaluation. FAO Soils Bull. (Roma) 32.

Gerrard, A.W.J., 1993. Landscape sensitivity and change on Dartmoor. In: Thomas, D.S.G. and Allison, R.J., Editors, 1993. Landscape Sensitivity, Wiley, Chichester, pp. 49‾63.

Kosmas, C., 1998. Qualitative indicators of desertification. Proceedings International Seminar on Indicators for assessing desertification 18‾20 September 1998. In press (information at: nrd@ssmain.uniss.it).

Kosmas, C., Poesen, J., Briasouli, H., 1999. Key indicators of desertification at the ESAa scale. In 'Manual on Key Indicators of desertification and Mapping Environmentally Sensitive Areas to Desertification'. MEDALUS III Project, King's College, London. In press (information at: medalus@medalus.demon.co.uk).

Quine, T.A. and Walling, D.E., 1993. Use of 137Cs measurements to investigate relationships between erosion rates and topography. In: Thomas, D.S.G. and Allison, R.J., Editors, 1993. Landscape Sensitivity, Wiley, Chichester, pp. 31–48.

Stewart, G.A., Editor, , 1968. Land Evaluation, Macmillan, Melbourne.

Stocking, M.A., 1995. Soil erosion in developing countries: where geomorphology fears to tread. *Catena* 25, pp. 253–267

Thomas, D.S.G. and Allison, R.J., 1993. Landscape Sensitivity, Wiley, Chichester.

UNEP (United Nations Environmental Programme), 1977. Draft plan of actions to combat Desertification. UN Conference on Desertification, Nairobi.

UNEP (United Nations Environmental Programme), 1992. World Atlas of Desertification, Edward Arnold, Seven Oaks.

Usher, M.B., 2000. Landscape sensitivity: from theory to practice. Catena 42, pp. 377–385.