

# **MORE WATER, LESS GRASS?**

**AN ASSESSMENT OF RESOURCE DEGRADATION AND  
STAKEHOLDERS' PERCEPTIONS OF ENVIRONMENTAL  
CHANGE IN OMBUGA GRASSLAND, NORTHERN NAMIBIA**

**Patrik Klintenberg**



## ABSTRACT

The three overall objectives of this thesis are to assess 1) to what degree have soil and vegetation resources deteriorated, if at all, 2) how do perceptions of environmental change held by local stakeholders correspond to scientific assessments of present and past environmental conditions in the Ombuga grassland and surrounding mopane savanna, an important grazing area in central northern Namibia, and 3) how do these relate to national level assessments? Analysis of the process of developing national level indicators for monitoring of land degradation in Namibia concluded that specific indicators should be developed on national level, and in some instances even on regional and local level, instead of the often proposed development of a global set of indicators to be used everywhere. Reasons for this are: 1) there are no universal causes and effects of land degradation. 2) the participatory approach, involving stakeholders on both local and national levels gave them ownership of the process and the resulting indicators, and led to an increased understanding of the concepts of environmental monitoring. 3) the participatory process of developing national indicators taken in Namibia created a common platform for representatives from various sectors, leading to increased interaction among sectors, an important aspect in most developing countries, where sectoral approaches predominate. Assessment of local perceptions of environmental change in and around Ombuga grassland showed that farmers there claimed that overgrazing and low rainfall since the beginning of the 1990s cause negative environmental changes in the area, confirming findings from national monitoring. However, results from interviews give a more complex picture of causes and effects of environmental change, suggesting that 1) decreasing availability of grazing outside the study area, 2) improved access to the area, 3) provision of permanent water supply, and 4) fencing of large areas of the commons, are major factors contributing to environmental changes in the area. The results suggest that introduction of permanent water supply was the single most important factor, allowing more people and livestock into the area. Results suggest that assessments of local knowledge in a relatively small area can provide valuable contributions to development and assessment of national monitoring initiatives. Investigation of the influence of permanent water points on grazing resources in Ombuga grassland and surrounding mopane savanna showed that significant grazing induced changes, manifested by palatable perennial grasses being replaced by less palatable annual grasses, were identified around water points along a water pipeline as far as 6 km from water points. However, no significant grazing induced changes in grass composition were observed around privately owned hand dug wells. Private ownership leading to stronger control of access to traditional wells compared to open access water points along the pipeline seems to be a key factor preventing over-utilization of grazing resources around the former. Assessment of the usefulness of satellite remote sensing in detecting observed environmental changes in and around Ombuga grassland shows that the Landsat TM sensor is capable of identifying bare ground, salt pans and grassland with a fair accuracy. However, there are apparent difficulties in separating woodland from shrubland, and also shrubland from grassland, using supervised classification. The results suggest that the use of the soil adjusted vegetation index (SAVI) provides valuable information about variations of green biomass over time in semi-arid environments. However, because of the strong influence of underlying soil related to the relatively sparse ground cover in semi-arid environments, it is suggested that any investigation based on satellite remote sensing in dry environments be supported by a thorough ground based assessment, taking into account the high spatial and temporal variability of rainfall in these environments.

*Key words: Environmental monitoring, semi-arid, pastoralism, rural water supply, indicators, local knowledge, vegetation survey, satellite remote sensing*

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Front cover illustration: Livestock on their way to find grazing after drinking at water point along the pipeline in Ombuga grassland, central northern Namibia (Photo: Patrik Klintonberg)



# More Water, Less Grass?

## An assessment of resource degradation and stakeholders' perceptions of environmental change in Ombuga Grassland, Northern Namibia

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This doctoral thesis is composed of a summary of the research project and the following four papers:

**Paper I:**

Klintenberg, P. and Seely, M.K., 2004. Land Degradation Monitoring in Namibia: A First Approximation. *Environmental Monitoring and Assessment*, 99: 5-21.

**Paper II:**

Klintenberg, P., Seely, M.K. and Christiansson, C., 2007. Local and national perceptions of environmental change in central northern Namibia: Do they correspond? *Journal of Arid Environments* 69(3): 506-525.

**Paper III:**

Klintenberg, P. and Verlinden, A., 2007. Water points and their influence on grazing resources in central northern Namibia. *Land Degradation and Development* (in press).

**Paper IV:**

Klintenberg, P. Niipele, N. and Kleman, J. in prep. Can remote sensing detect environmental changes in a grazing area in northern Namibia? Manuscript

In this summary references to the above papers are made by their Roman numbers. The author of the thesis was responsible for the design and realisation of the whole project, including the development of methods, field surveying, data analyses and writing. Paper I is presented in this thesis with permission from the journal *Environmental Monitoring and Assessment*. Paper II is presented with permission from *Journal of Arid Environments*, and Paper III by permission of the journal *Land Degradation and Development*. The co-author of paper I, Dr. Seely contributed to the discussion of findings and the over-all structure of the paper. Co-authors of paper II, Dr. Seely and Professor Christiansson contributed to the interpretation and discussion of results. The co-author of paper III, Dr. Verlinden introduced the author to the CANOCO software package, helped with sampling and identification of species in the field, and contributed towards the interpretation and discussion of results. In paper IV ms. Niipele assisted with the rectification and classification of Landsat TM scenes and professor Kleman contributed to the analysis and discussion of the findings.



## INTRODUCTION

The debate about the threat of negative environmental change in Africa, often referred to as land degradation and desertification by various authors, caused by both natural and human factors has been high on the agenda of the United Nations, the international donor community, the scientific community, and national and local politicians since the early 1970s (Rapp, 1974; Rapp *et al.*, 1976; UNCED, 1977; Hellden, 1991; Mainguet, 1994; Leach and Mearns, 1996b; Koning and Smaling, 2005). The driving force behind much environmental policy and project implementation in Africa is a set of powerful, widely perceived images of environmental change, e.g. overgrazing, desertification of drylands and mining of soil and vegetation resources caused by rapidly growing populations (Leach and Mearns, 1996a). The occurrence, causes and effects of these phenomena are generally regarded as common knowledge among development professionals in African governments, international donor agencies, and non-governmental organizations. The power of these commonly accepted truths about environmental change is exemplified by the formulation of international conventions such as the United Nations' Convention to Combat Desertification and the Convention on Biological Diversity. The body of knowledge forming the basis for these widely accepted phenomena is here referred to as received wisdom. The origins and persistence of received wisdom about environmental change in Africa lie in the substance of science, many times making science the primary definer of what constitutes an environmental problem (Corell, 1999; Stott and Sullivan, 2000). Various authors have questioned the validity of that science forming the basis on which policy frameworks and international conventions are built (Ellis and Swift, 1988; Scoones, 1995; Leach and Mearns, 1996b; Stott and Sullivan, 2000; Sullivan and Rohde, 2002). Significant in much of the research of environmental change in Africa is that knowledge about the function of the environment held by local land users is often not acknowledged. Instead, the users of the land are frequently seen as the cause of negative environmental change and are the focus of interventions and often restricting remedies believed to halt or reverse negative trends of change (Leach and Mearns, 1996b; Sullivan, 2000).

### Monitoring of the environment

Monitoring of states and changes in environmental conditions is central to this thesis. Here the natural environment is defined as the complex of physical, chemical, and biotic factors (as climate, soil, and organisms) that act upon an individual, population or community and ultimately determine its form and survival (Merriam-Webster, 2003). The social environment is here defined to be the human society and

its organization, e.g. the quality of people's lives. The state of the environment is then a measure of both the present state of physical, chemical and biotic factors and the human society and its organization. Ideally both natural and social environments should be integrated when monitoring the state of the environment. However, on national level, monitoring of natural environments tends to dominate the reporting (Klintonberg, 2001; Enne and Yeroyanni, 2006; Klintonberg, 2006).

In 1992 the United Nation's Conference on Environment and Development (UNCED) approved Agenda 21 as an international action plan for sustainable development (Corell, 1999; CIESIN, 2001). Chapter 40 of Agenda 21 calls for improved environmental information as a prerequisite for reporting on progress toward sustainability. Further, it was recommended that each nation develop environmental indicators and environmental monitoring systems to strengthen decision-making. GRID-Arendal in Norway, being part of UNEP, has taken the lead in developing a common framework for national and regional state of the environment reports (Denisov *et al.*, 1998). In response to the lack of information about extent and rate of desertification on national, regional and continental levels, UN recommends that countries that are signatories to the UNCCD develop indicator based monitoring systems to support development and evaluation of policy and National Action Plans (NAPs) (UN, 1994).

There are several methods to evaluate the state of the environment, e.g. direct observations and measurements, mathematical models and parametric equations, remote sensing techniques, and application of indicators. The use of indicators has the advantage of providing simplified, synthetic information on the state and tendency of complex processes. Further, indicators can generally be easily communicated to the public and policy-makers (Rubio and Bochet, 1998). In response to decision-makers' increasing needs for information about environmental conditions on global, regional, national and local levels, the development and use of indicators for environmental monitoring has become a common approach (Bockstaller and Girardin, 2003). Indicators, as a measure of environmental health, should ideally determine the present state of the environment and be able to timely identify changes in measured environmental conditions (Rubio and Bochet, 1998). Indicators should be developed to represent quantifiable properties, symptoms or parameters of a phenomenon relating to a feature of the environment as precise and unambiguous as possible (Mendizabal, 1998).

The need for a more rigorous definition of indicators became apparent already at the World Summit in Rio 1992, when the UN Conference on Environment and Development (UNCED) adopted Agenda 21, which led to a large number of countries initiating preparation of national, indicator-based state of

environment reports. An assessment of the state of the art of development of indicators for national state of the environment reporting in Namibia (Klintonberg, 2001) and benchmarks and indicators in the countries in southern Africa (Klintonberg and Seely, 2005; Klintonberg, 2006) revealed that there are still many uncertainties and contradictions regarding the general concept of indicators. Some clarity and consensus are required about the definition of what an indicator is, as well as in the definition of related concepts such as threshold, index, target and standard (Gallopín, 1997; Enne and Yeroyanni, 2006). There is currently a variety of different definitions of indicators e.g. "An indicator is a measure that summarizes information relevant to a particular phenomenon, or a reasonable proxy for such a measure" (McQueen and Noak, 1988) and "...a parameter, or a value derived from parameters, which provides information about the state of an environment with a significance extending beyond that directly associated with a parameter value" (OECD, 1993). This means that the indicator not only provides us with a value, but also explains the significance of that value in relation to what is being monitored, e.g. the value means that the state of the environment is good or that the risk of land degradation is high. A review done by Gallopín (1997) concluded that due to the diverse meanings assigned to the concept of indicators there is a need to develop a unified, generic and rigorous definition of indicators. Indicators should, according to Gallopín: assess conditions and trends; be comparable across places and situations; assess conditions and trends in relation to goals and targets (threshold values), provide early warning information and anticipate future conditions and trends.

In Namibia, desertification has been addressed under the umbrella of the United Nations Convention to Combat Desertification (UNCCD) since 1994 (Napcod, 1997; Napcod 1999). As part of the National Action Programme (NAP) national and local monitoring systems were developed attempting to quantify extent and rate of environmental change in Namibia, aimed at providing decision makers on both national and local levels with relevant information to enhance their decision making (Napcod, 1999). The process of developing this monitoring system is discussed in paper I below. In general national level monitoring systems are intended to support decision-making on national and regional levels and it is therefore essential to verify to what extent results agree with actual environmental conditions and perceptions held by local land users.

### **Local perceptions of environmental change**

Several authors have drawn attention to the importance of local knowledge and perceptions to improve understanding of often complex systems in arid en-

vironments, e.g. (Tiffen *et al.*, 1994; Kinlund, 1996; Leach and Mearns, 1996b; Seely, 1998; Ward *et al.*, 1998; Dahlberg, 2000; Sullivan, 2000; Verlinden and Dayot, 2000; Verlinden and Dayot, 2005). In the Kalahari of southern Africa Thomas and Twyman (2004) investigated the relationship between perceptions about land degradation and change in savanna ecosystems held by scientists and land users. They concluded that a combination of local and scientific knowledge can lead to a more useful assessment of environmental change and its implications for local land users. In Botswana Kinlund (1996) and Dahlberg (2000) compared scientific thinking with local stakeholders' perceptions regarding environmental change and land degradation. Findings from these two studies suggest that local perceptions held by local land users can provide valuable insights into the extent and impact of environmental change, many times contradicting the common views of causes and effects of environmental change held by other stakeholders, e.g. the scientific community and policy makers. Verlinden and Dayot (2005) and Hillyer *et al.* (in press) showed the existence of an elaborate environmental knowledge system used by local farmers in central northern Namibia for resource management. Ward *et al.* (2000) investigated perceptions of land degradation held by local farmers in Otjimbingwe, a communal ranging area in Namibia, concluding that some causes of environmental degradation perceived by local farmers were inconsistent with scientific assessments of the state of environment in the area. This discrepancy between local perception and scientific analysis illustrated the importance of understanding local views of how environments have changed, because they often include broader visions of changes considering such things as agricultural practices, human actions and history within their local perspectives, aspects that scientists do not generally consider in their evaluations of change (Gray and Morant, 2003). However, it is equally important to critically assess local perceptions against scientifically accepted principles and knowledge.

### **Scientific assessment of the state of the environment**

There is a debate among scientists about the ecological dynamics and appropriate management of semi-arid rangelands (Sandford, 1983; Ellis and Swift, 1988; Illius and O'Connor, 1999; Sullivan and Rohde, 2002; Vetter, 2003). This debate has led to a challenge of received wisdoms of range management and pastoral development in dryland Africa, resulting in a critical scrutiny of the use of terms and concepts such as vegetation succession, carrying capacity and land degradation (Scoones, 1995; Dahlberg, 2000; Vetter, 2003). Central to the debate is the relative importance of biotic and abiotic factors driving primary and sec-

ondary production in rangelands, and the consequences of this regarding the potential for grazing-induced rangeland degradation (Vetter, 2003).

On the one hand there is the equilibrium model which has its roots in the Clementian school of plant ecology (Clement, 1916), based on ideas of succession and a climax state of vegetation, stressing the importance of biotic feedbacks between herbivores and their resource. On the other hand there is the non-equilibrium model, that sees stochastic abiotic factors, e.g. highly variable rainfall, as dominating vegetation and livestock dynamics (Behnke and Scoones, 1993; Vetter, 2003). The fundamental difference between predictions of the two models is that the equilibrium model sees drought as focusing the effects of herbivory (Illius and O'Connor, 1999), whereas the non-equilibrium model sees drought as relieving the pressure of high stocking densities, by making grazeable vegetation unavailable (Sullivan and Rohde, 2002), and by inducing livestock mortality, which reduces grazing intensity (Ellis and Swift, 1988; Behnke and Scoones, 1993). According to the latter, risks of environmental degradation in non-equilibrium systems are limited, as livestock populations rarely reach levels likely to cause irreversible damage (Ellis and Swift, 1988; Behnke and Scoones, 1993). However, recent studies suggest that most arid and semi-arid rangeland systems encompass elements of both these models at different scales (Vetter, 2003). Vegetation in areas with a higher degree of rainfall variability is more likely to be dominated by abiotic factors, while vegetation in less variable systems is more dominated by biotic factors, e.g. herbivory (Illius and O'Connor, 1999; Vetter, 2003).

Illius and O'Connor (1999) discussed the impact of herbivory on grazing resources in semi-arid environment with high climatic variability. They suggested that herbivores have an impact on resources over limited parts of these dry systems, i.e. in key resource areas and where herbivores have access to permanent water supply. Further away from these key resources the system is mainly driven by abiotic factors. Findings supporting the views of Illius and O'Connor (1999) have been presented by several authors, in Australia (James *et al.*, 1999), in South Africa (Thrash, 1995; Thrash, 1998; Todd and Hoffman, 1999; Thrash, 2000; Riginos and Hoffman, 2003; Todd, 2006) and in Namibia (Quan *et al.*, 1994b; Kuiper and Meadows, 2002; Getzin, 2005). On the other hand there are several examples of semi-arid rangelands assumed to have been degraded which have shown a dramatic resilience, recovering as soon as rainfall conditions improve (Hellden, 1991; Olsson, 1993; Agnew and Warren, 1996; Swift, 1996; Fynn and O'Connor, 2000; Sullivan, 2000; Ward *et al.*, 2000; Sullivan and Rohde, 2002; Leggett *et al.*, 2003). These findings are more in line with the non-equilibrium model, contradicting the importance given to livestock as the

main controller of rangeland conditions in semi-arid environments, i.e. overgrazing leading to degradation via undesirable vegetation change and loss of cover (Heady and Child, 1994; Tainton, 1999).

### **Satellite remote sensing to detect environmental changes in semi-arid environments**

Satellite remote sensing aimed at monitoring the surface of the earth has been pursued since the 1970s (Barrett and Hamilton, 1986) and has become a frequently used tool for ecological applications requiring data from broad spatial areas that can not be easily collected using field based methodologies (Kerr and Ostrovsky, 2003). For ecological applications one of the most commonly used satellite platforms is the Landsat sensor. Landsat data have been translated into useful ecological information for more than 30 years, with both the methods and applications growing increasingly in sophistication (Cohen and Goward, 2004). Information generated by remote sensing is commonly used for land cover classification and detection of natural and human induced changes within and across landscapes (Coppin *et al.*, 2004; Lu *et al.*, 2004).

Several change detection methods have been developed and are still being developed, e.g. algebraic operations and post classification comparisons (Lu *et al.*, 2004). Commonly used algebraic operations are image differencing, image regression, vegetation index differencing and change vector analysis (CVA). Post-classification comparison is based on a pixel by pixel comparison of independently produced spectral classification results to detect land cover changes over the time interval of interest. The main advantage of post classification comparison is the fact that the images are separately classified, thereby reducing the external impact from atmospheric and environmental differences between multi-temporal images (Coppin *et al.*, 2004). A second advantage of post classification methods is that by adequately coding the classification results, a complete matrix of change is obtained (Coppin *et al.*, 2004; Lu *et al.*, 2004). However, the accuracy of the post-classification comparison is totally dependent on the accuracy of the initial classifications. The final accuracy very closely resembles that resulting from the multiplication of the accuracies of each individual classification and may be considered intrinsically low (Coppin *et al.*, 2004). After assessing six different change detection methods Mas (1999) concluded that the highest accuracy was obtained using post-classification comparison based on supervised classification of two images. Image differencing and post classification was used by Petit *et al.* (2001) to detect land cover changes in south-eastern Zambia. By using these techniques they were able to quantify land-cover changes in terms of percentage of area af-

ected and rates of change, to quantify the nature of change in terms of impact on natural vegetation and to map the spatial pattern of land-cover change.

Calculation of vegetation indices derived from satellite data is one of the primary sources of information for operational monitoring of vegetation cover (Perry and Lautenschlager, 1984; Gilabert *et al.*, 2002). Most of these indices are based on algebraic combinations of reflectance in the red and the near infrared spectral bands (Bannari *et al.*, 1995). The most commonly used vegetation index is the normalized difference vegetation index (NDVI). However, in semi-arid and arid environments it has been shown that this index does not give a correct reflection of green biomass when green canopy cover is lower than 30% (Pech *et al.*, 1986). Due to the normally sparse to very sparse ground cover in these areas, the underlying soil influences the spectral signature to such an extent that it has to be compensated for (Rondeaux *et al.*, 1996; Schmidt and Karnieli, 2001; Gilabert *et al.*, 2002). Therefore several indices have been developed, of which the Soil Adjusted Vegetation Index (SAVI) is one of the most well known (Huete, 1988).

The papers that form the basis for this thesis elaborate on various aspects of the issues outlined here. The findings presented in paper I originate in an assessment of development and implementation of national level land degradation indicators under the umbrella of Namibia's Programme to Combat Desertification (Napcod). The monitoring system was created to determine the extent and rate of land degradation in Namibia. Acknowledging the potential of knowledge and experiences held by local land users, paper II presents an investigation of local peoples' perceptions about the state of the environment and causes and effects of changes in the environment. The findings were compared to results from the national level monitoring system discussed in paper I. In paper III a detailed vegetation survey, analysing distribution of grass species using ordination techniques in areas identified as degraded by interviewees in paper II was done, in order to assess the correspondence of local knowledge to independent scientific observations of environmental change. Finally, in paper IV the ability of satellite remote sensing to detect observed environmental changes in an important grazing area in semi-arid central northern Namibia was assessed in the light of results presented in the first three papers of this thesis.

## OBJECTIVES

The overall objective of this thesis is to assess to what degree have soil and vegetation resources deteriorated, if at all, and how do perceptions of environmental change held by local stakeholders correspond to scientific assessments of present and past environmental conditions in an important grazing area in central

northern Namibia, and how do these relate to national level assessments? Four specific objectives were defined:

1. to assess and discuss the process taken in Namibia to develop national level indicators for a land degradation monitoring system, to provide information to national and regional decision makers and for policy development (paper I).
2. to assess the correspondence of developed national indicators to conditions on the ground by investigating perceptions held by farmers about the present and past state of the environment in an important grazing area in central northern Namibia, identified as being at risk of land degradation by national indicators (paper II).
3. to conduct an independent survey of vegetation along transects radiating out from permanent water points in central northern Namibia in order to evaluate contradicting findings regarding the influence of livestock grazing around permanent water points in an important grazing area in central northern Namibia (paper III).
4. to assess the usefulness of satellite remote sensing in detecting identified environmental changes in central northern Namibia, presented in papers II and III (paper IV).

## STUDY AREA

### Namibia

Namibia covers an area of approximately 825 000 km<sup>2</sup> (Fig. 1). Much of Namibia consists of a wide, rather flat plateau that continues north, south and east into neighbouring countries. The height of the plateau is about 900 to 1300 m above sea level. To the west a pronounced escarpment rises from a coastal plain (Mendelsohn *et al.*, 2002). Mean annual rainfall follows a gradient from southwest to northeast with the far northeast receiving the most rainfall and the coastal areas receiving almost no rainfall (Fig. 2). Rainfall is highly seasonal in Namibia, with very well marked dry and wet seasons. In general the dry season extends from April/May to September/October, and the wet season over the rest of the year (Olszewski and Moorsom, 1995). The seasonality (summer rainfall) is consistent throughout much of Namibia. The exceptions to summer rainfall are in the very south west, experiencing winter rainfall, and the coastal areas where the wet season hardly exists (Hutchinson, 1995). Rainfall is naturally low with high inter-annual and intra-seasonal variability (Seely, 1978; Marsh and Seely, 1992). Temperature also shows a marked seasonality with the highest temperatures occurring just before the wet season in wetter areas and during the rain season in drier areas. Lowest temperatures occur in the dry season months of June, July and August (Hutchinson, 1995).

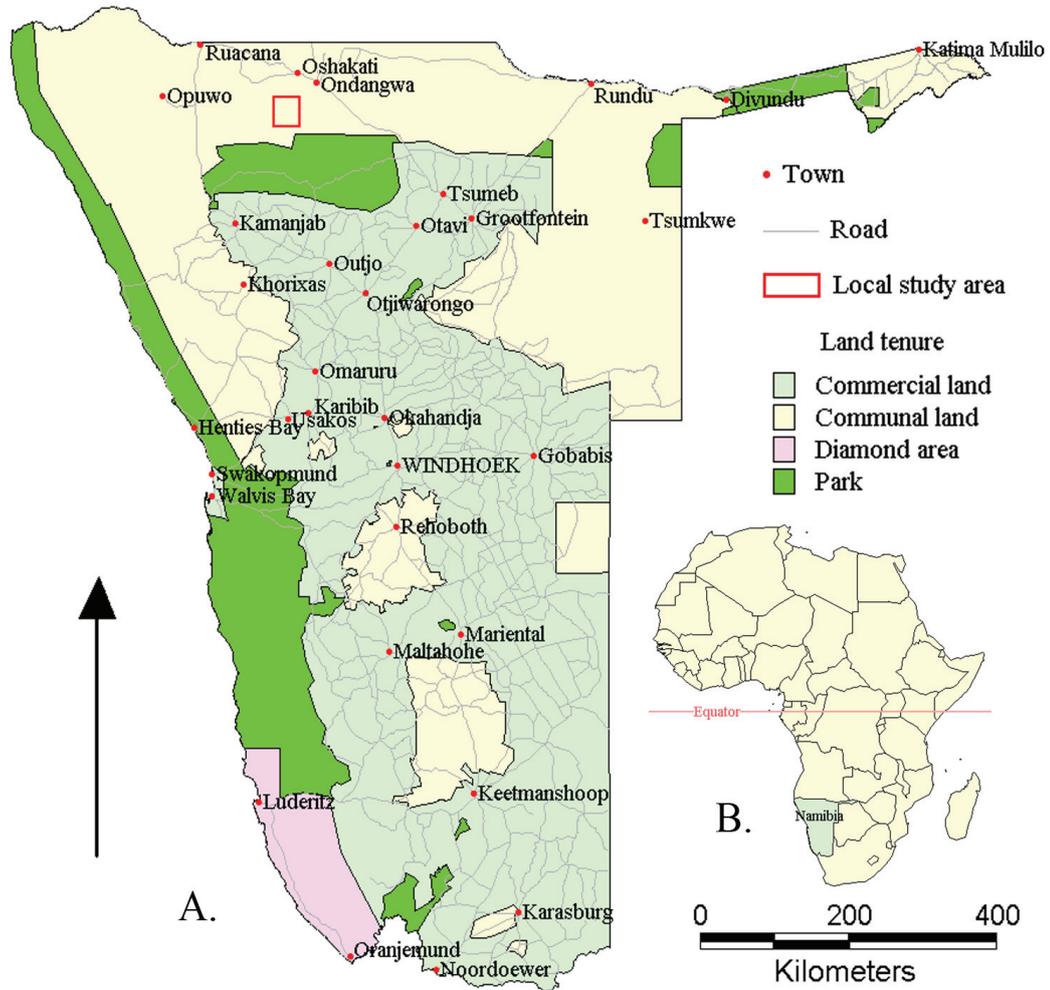


Figure 1. Map A shows the different tenure forms in Namibia together with main towns, and road network. Note that the location of the area being investigated in paper II, III and IV is indicated. Map B shows Namibia's location on the African continent.

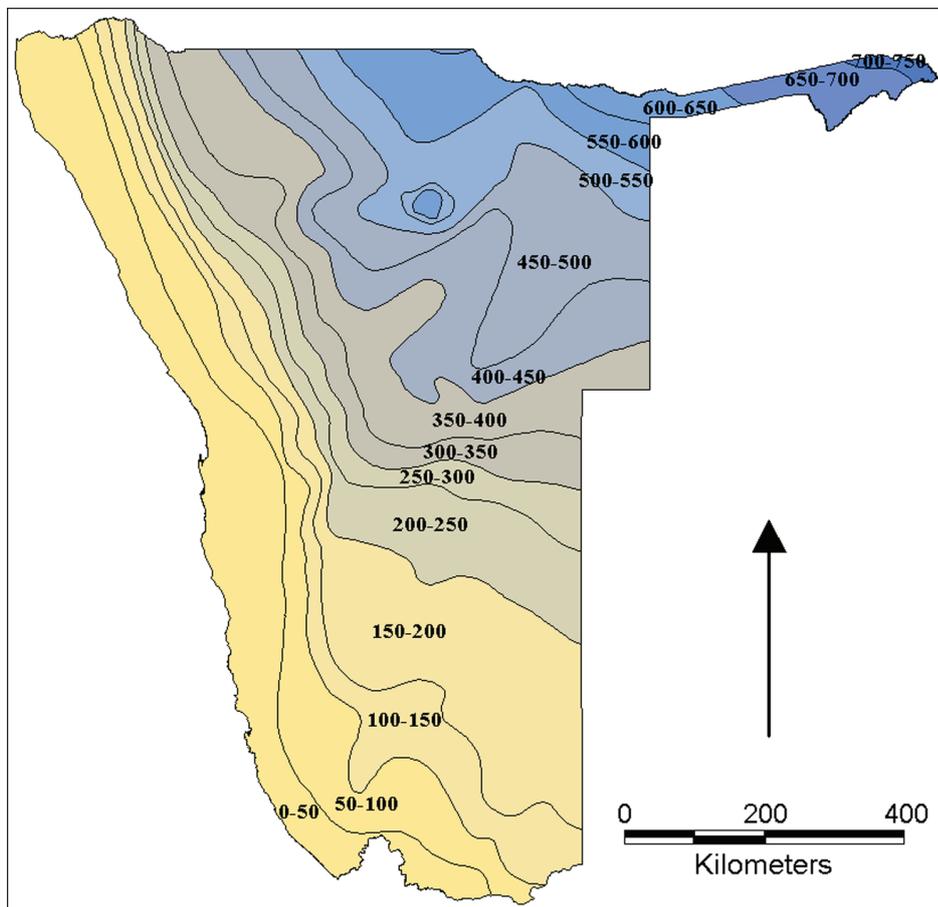


Figure 2. Mean annual rainfall. Interpolation of isohyets based on approximately 260 rainfall stations in Namibia.

Most soils in Namibia are unsuitable for crop growth. The most fertile soils are Cambisols and Calcisols. In the south Kalahari deep sands dominate, while central northern Namibia is characterised by clayey and salty soils, and in rocky areas, e.g. the escarpment, shallow, mica-rich soils are found (Mendelsohn *et al.*, 2002). Vegetation in Namibia is strongly influenced by rainfall. Most vegetation in the country consists of shrubland. Dwarf shrubs dominate areas in the southwest and at the eastern edge of the central Namib sand sea. Much of the Namib sand sea is characterised by a combination of dwarf shrubs in the dune valleys and gravel plains and grasses on the dunes. More and more trees replace shrubs from south to north in the eastern zone of the Kalahari sands, first as Kalahari shrubland, then as shrubland-woodland mosaic and, finally, as woodland in northern Namibia. The centre of the country has a moderate to dense cover of shrubs and small trees, particularly acacias (Mendelsohn *et al.*, 2002).

The total human population in Namibia is about 1.8 million, of which approximately 40 % are settled in the central northern regions (NPC, 2002), which comprise only 18% of Namibia's land surface. As a result of population growth and expanding human settlement during the past century, the natural resources of central northern Namibia are presently under high pressure (Quan *et al.*, 1994b). In 1994 an estimated 68 % of the Namibian population derived at least part of their livelihood from agriculture (Kruger, 2001). A comparison to the census conducted 1991 reveals that the population growth rate has decreased from 3.1 % to 2.6 % between 1991 and 2001. Furthermore, the ratio between urban and rural populations has changed from 28/72 to 33/67, indicating a slight tendency of urbanization over the time period (NPC, 2002).

Due to dry (arid and semi-arid) conditions, farmers rely predominantly on livestock for their livelihoods. Cattle dominate in central, north and north-east where the rainfall is highest, while sheep and goats are preferred in the western and southern parts of the country. Crop production is only possible in the northern parts of Namibia, except at a few locations with irrigation in the south (Balarrin and New, 1996; UNDP, 1996). Due to the more favourable natural conditions in north and northeastern Namibia, dense human and animal populations occupy these rural areas. High population pressure in these areas has had an adverse impact on natural resources, evident through deforestation, overgrazing and depletion of already scarce water resources (Adams *et al.*, 1990; Fuls, 1992; Quan *et al.*, 1994a).

## **The local study area: Ombuga grassland and surrounding mopane savanna**

This study was conducted in and around the Ombuga grassland in northern Namibia, one of three important grazing areas for about 600 000 people living in the four regions of northern Namibia encompassing about 85 000 km<sup>2</sup> (Mendelsohn *et al.*, 2000). The study area was selected as results from the national level monitoring system presented in paper I indicate that the risk of land degradation in the area is high. The local area investigated covers about 1600 km<sup>2</sup> and is referred to as the study area in this thesis (Fig. 3).

### *Geology*

Geologically the study area belongs to the Kalahari sequence, characterised by up to 500 m thick semi- to unconsolidated sediments (Thomas and Shaw, 1991). The study area is situated in a flat landscape at approximately 1100 m above sea level. Soils consist of clayey sodic sands in the lower parts of the landscape and sodic sands on surrounding relatively higher ground (Mendelsohn *et al.*, 2000). The area typically has infertile sandy topsoil, between 0 and 1 m thick, underlain by a saline hardpan forming very distinct prismatic structures (Marsh and Seely, 1992).

### *Climate*

In northern Namibia there are two climatic seasons, the dry season that lasts from May to October and the wet season, characterised by occasional rainfall, from November to April (Erkkilä, 2001). The climate is semi-arid and the area receives an average annual precipitation of approximately 350 mm in the southwest and 450 mm in the northeast (Fig. 4 and 5) (Hutchinson, 1995). Rainfall is patchy and highly variable in time and space (Mendelsohn *et al.*, 2000). Monthly mean temperature ranges from 26°C in November to 16°C in July. During the cooler period, June to August, the night temperature drops to 7°C while day temperature rises to 27°C or higher. The hottest period is from October to December, when maximum day temperature may reach 40°C (Hutchinson, 1995). Annual potential evaporation is estimated to exceed the annual precipitation by a factor of about five (Mendelsohn *et al.*, 2000; Erkkilä, 2001).

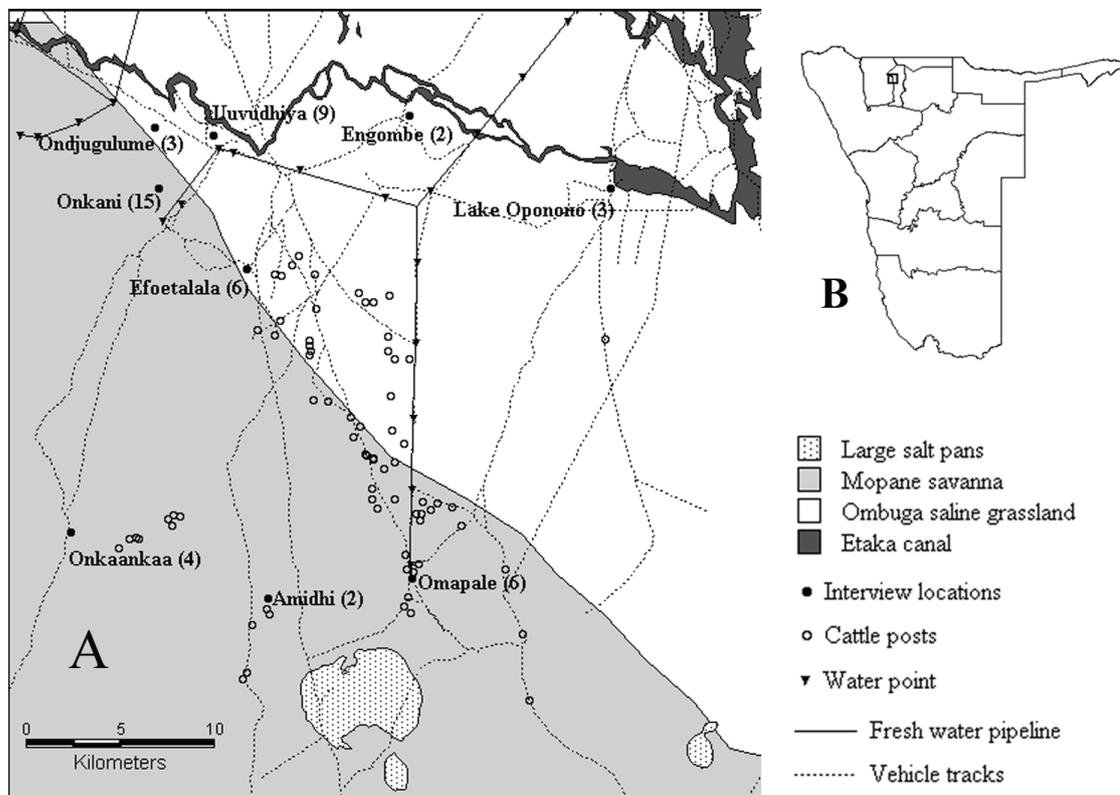


Figure 3. Map A: the extent of the study area, the Ombuga saline grassland, Mopane shrubland and location of settlements where interviews were made for paper II. Number of interviewees per settlement is indicated in parenthesis. Map B: location of the study area in Namibia.

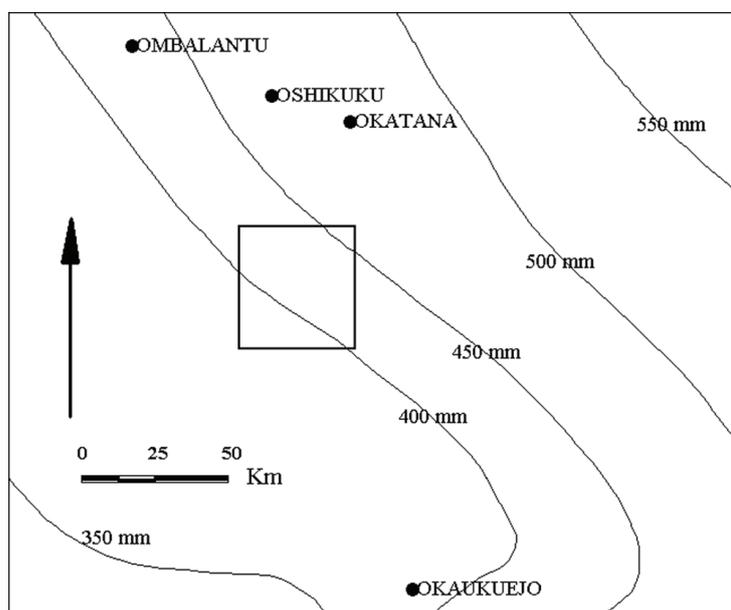


Figure 4. Map showing the location of rainfall stations referred to in the text. The square represents the extent of the local study area.

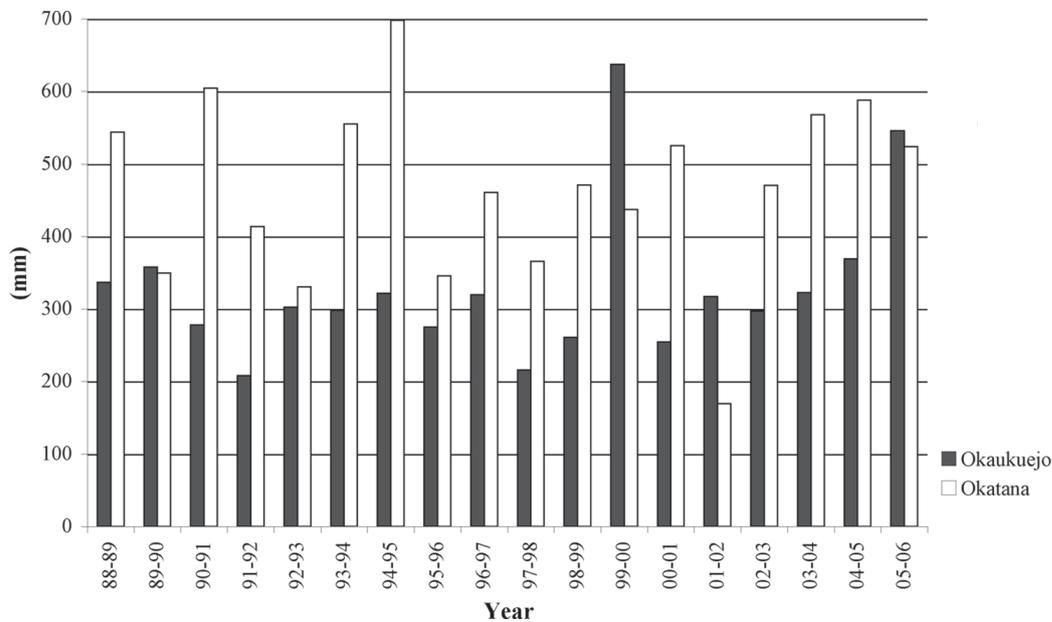


Figure 5. Rainfall map showing annual rainfall at Okaukuejo and Okatana for the period investigated in paper IV.

The use of a 9-years moving average to filter out year-to-year variations in rainfall data to reveal long-term trends has been described by Wheeler and Martin-Vide (1992) and Salinger *et al.* (1995). Applying this technique to the rainfall data recorded at four rainfall stations closest to the study area reveals that these stations have recorded two wetter and two drier periods since the 1930s (Fig. 6). The first dry period lasted from around 1960 to around 1970. The second dry period began in the later part of the 1980s and is still significantly different from the overall median (Mann Whitney U-test,  $p < 0.05$ ) at all stations except Oka-

tana. At Okaukuejo, Okatana and Oshikuku, rainfall below median was recorded during the first dry period of the 1960s while Ombalantu recorded “less” dry conditions. All four stations have recorded rainfall below median during the present dry period, starting with the 1984/85 season. The Ombalantu station recorded the largest negative deviation from the median rainfall and Okatana the least. However, the large negative deviation recorded at the Ombalantu station compared to the three other stations was treated with caution as it suggested a possible systematic measuring error or a faulty instrument.

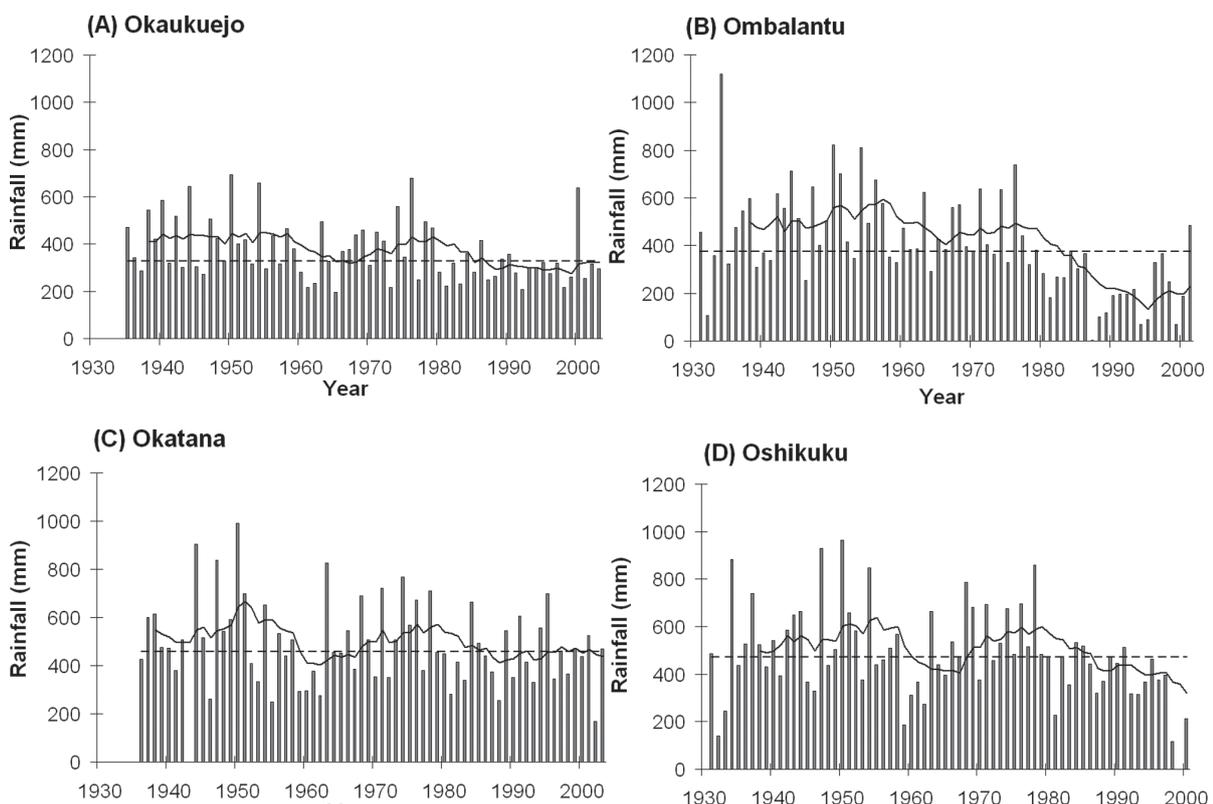


Figure 6. Graphs showing long term fluctuations in rainfall at the four rainfall stations illustrated in Figure 4.

## Vegetation

Two distinct vegetation types occur in the study area, saline grassland and mopane savanna (Giess, 1971) (Fig. 7). The saline grassland, named Ombuga grassland, is a flat plain covering an area of approximately 3000 km<sup>2</sup> with numerous pans. Perennial grasses are abundant in less disturbed parts of the landscape. Growth of woody species is prevented by the shallow depth of the salty soils underlain by a hardpan (Mendelsohn *et al.*, 2000). In the mopane savanna *Colophospermum mopane* is the dominant tree species and under well-developed stands grasses are

sparse. The height of mopane and other trees is related to soil depth, with dense stands of tall trees only occurring in areas with deeper soil (over 1 m sand on top of the hardpan). In the more populated areas the mopane savanna has been converted to agricultural fields (Verlinden and Dayot, 2005). Both these vegetation types are used for extensive grazing. The most common grasses in Ombuga grassland are *Odyssea paucinervis*, *Aristida stipioides* and *Schmidtia kalihariensis*. In the mopane savanna *Schmidtia kalihariensis*, *Pogonarthria fleckii* and *Stipagrostis uniplumis* are the most common grasses.

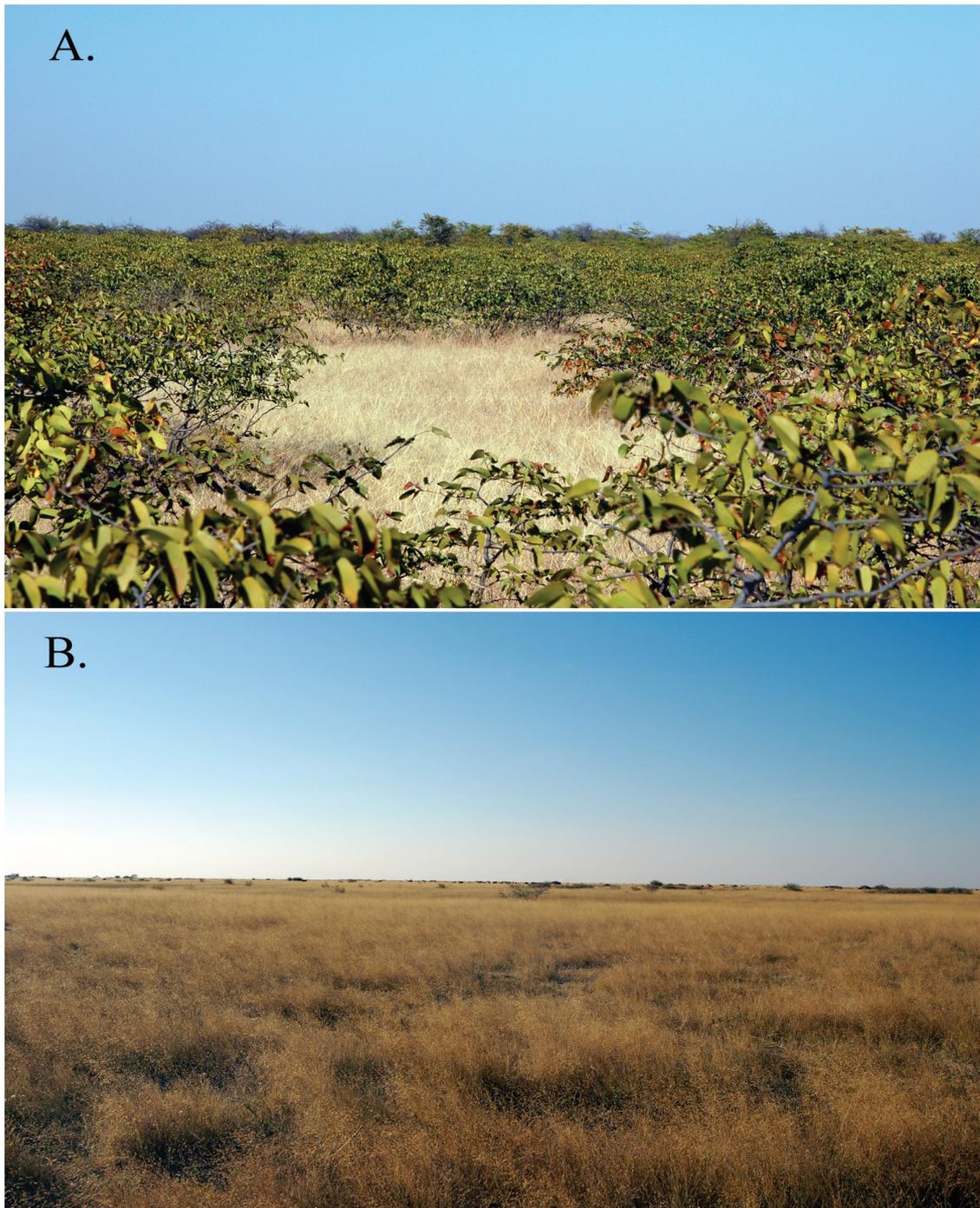


Figure 7. Illustrations of mopane savanna (A) and saline grassland (B). Photos by P. Klintonberg.

## Population and land tenure

In the past the Ombuga grassland was regularly visited by San hunter-gatherers and Ovahimba semi-nomadic pastoralists (Erkkilä, 2001). The grassland was crossed along traditional wagon tracks by missionaries and traders since the 1800s (Andersson, 1987). Since the 1940s the area was occasionally visited by Owambo people for hunting and grazing and crossed during salt collection expeditions to the salt pans in the southern part of the study area. The first permanent settlements in this part of central northern Namibia were established in 1968 (Christelis and Struckmeier, 2001) located around hand dug wells. By 1991 some 2000 individuals lived within the study area (Central Bureau of Statistics, 1994). By 2001, the population in the study area had increased to approximately 3300 inhabitants, living in about 670 households (NPC, 2002), which equals a population increase above 5 % per year.

The study area is under communal tenure system, i.e. land is owned by the government and is, in principle, accessible to anyone but with no exclusive rights. Traditional norms and rules still regulate use of land and resources, especially in areas where wells are still the main supply of water (Verlinden and Dayot, 2000). In the commons individuals are allowed to fence off an area of 10 ha for crop production and reserve grazing (if the entire 10 ha is not ploughed). Availability of grazing in the northern communal lands is decreasing due to extensive establishment of homesteads and crop fields. According to Mendelsohn *et al.* (2000) livestock numbers in central northern Namibia reached a peak between 400 000 and 600 000 head of cattle already in the 1960s and early 1970s. These numbers have been more or less maintained since then. However, the diminishing availability of grazing in more populated areas has led to an increased number of cattle grazing in the Ombuga grassland and establishment of a large number of new cattle posts (Low *et al.*, 1997; Denker and Schalken, 1998; Denker and Schalken, 1999). A cattle post is a temporary dwelling occupied by one or several herders, located in an area where livestock have access to both water and grazing (Fig. 8).

## Water supply systems

There are no perennial watercourses in the area (Erkkilä, 2001). Due to the flat character of the landscape in central northern Namibia and poor infiltration owing to shallow soils underlain by hardpans, a large number of shallow, ephemeral, poorly defined but interconnected flood channels (oshanas) and pans occur in the Cuvelai drainage system (Christelis and Struckmeier, 2001). During the rain season and early dry season oshanas serve as fresh water reservoirs, providing drinking water for humans and livestock (Marsh and Seely, 1992). These natural water sources

are complemented by hand-dug wells, which are dug mainly in the mopane shrubland in places where the groundwater is less saline. Due to population increase and the high salinity of the ground water, a pipeline system supplying purified water to local communities and to evenly spaced water points for livestock in both the Ombuga grassland and the mopane savanna was constructed in 1992/93 (Fig. 3) (Mendelsohn *et al.*, 2000; Christelis and Struckmeier, 2001; Directorate of Rural Water Supply, 2004).

## METHODS

Here the main methods used to meet the objectives of the thesis are presented. In paper I the process of developing a national level monitoring system is discussed. The basis of the study was stakeholder consultations in order to define and develop potential indicators useful for land degradation monitoring on a national scale. The actual development of indicators was done using three different GIS tools, MapInfo (MapInfo, 1997), ArcView (ESRI, 2001) and Idrisi (IDRISI, 1999). Semi-structured interviews with farmers in the study area in central northern Namibia provided the main source of information in paper II. The results were analysed using Mann-Whitney U-test, to determine if there were any significant differences between answers given by different groups of interviewees. In paper III vegetation sampling using a point step method was used to collect data along 7 – 10 km long transects radiating out from permanent water points and hand dug wells. Collected data were analysed by ordination techniques, i.e. DCA and CCA and species response curves using CANOCO software (Ter Braak and Smilauer, 2002). Finally, in paper IV supervised classification of Landsat TM imagery and calculation of vegetation indices were done using ER MAPPER (ER Mapper, 2005). Further analysis of the results was done using Idrisi (IDRISI, 1999).

## PRESENTATION OF THE PAPERS

### Paper I:

*Klintonberg, P. and Seely, M.K., 2004. Land Degradation Monitoring in Namibia: A First Approximation. Environmental Monitoring and Assessment, 99: 5-21.*

The process of developing land degradation indicators for a national level monitoring system under the umbrella of Namibia's Programme to Combat Desertification (Napcod) is presented together with an assessment of results generated by the indicators for two communal areas in Namibia. The purpose of the monitoring system is to provide information about extent and rate of land degradation in Namibia, contributing to informed decision-making on national level and policy development.



Figure 8. Illustration of cattle post in Omapale. The picture shows the craal where cattle is kept over night, Normally the herder releases the herd in the morning and brings the animals back to the craal at night fall. Photo by P. Klintenberg.

Involvement of representatives ranging from local rural communities to experts working on a national level was central in the process of identifying and developing indicators for the monitoring system. A consultative process involving these representatives resulted in the definition of four indicators: population pressure, livestock pressure, rainfall variability and soil erosion hazard. The four indicators were combined into an annual land degradation risk index for which maps were generated for the period 1971-1997. An evaluation of the behaviour of the developed indicators was done in two rural communities, Onkani in central northern Namibia, and Gibeon in southern Namibia. The purpose of this analysis was to identify if there are any trends in the time series and if the results correspond to actual local conditions.

The indicators suggest that Onkani in central northern Namibia experienced increased livestock numbers and decreasing rainfall since the early 1990s. On the other hand, at Gibeon in southern Namibia increasing rural population pressure and decreasing rainfall were factors causing increasing degradation risk there (Fig. 9). Independent studies in the Onkani area have shown that both human and livestock populations have increased rapidly since 1992 when a fresh water pipeline was installed providing people and livestock with a permanent supply of water (Akawa *et al.*, 2002).

Based on the experiences gained through the process of developing the Namibian national level monitoring system a number of conclusions of broader applicability could be made:

1) Those involved in identifying indicators for land degradation monitoring are required to have an overall

understanding of both socio-economic and biophysical key elements of land degradation impacts.

2) To ensure that developed indicators are relevant and useful, a set of well-defined criteria is required. It was 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.

3) Accessibility of data is fundamental for the functioning of any monitoring system. Many indicators proposed by Namibian stakeholders were inappropriate as data were not being collected or could not be collected for various reasons involving funding, manpower and inflexible sectoral programmes.

At the time when the Namibian national monitoring system was developed there was a major thrust within

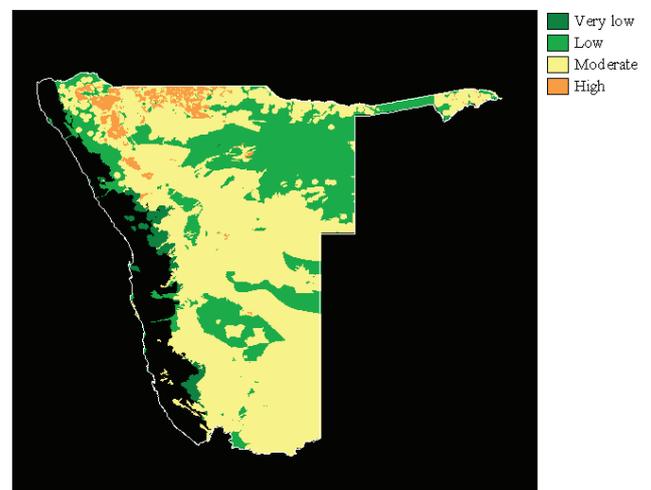


Figure 9. National land degradation risk map for year 1997 (Bethune and Pallett, 2002). The map is based on the four indicators presented in the text.

the United Nation's Convention to Combat Desertification (UNCCD) to develop a set of core indicators that would be universally applicable. The Namibian experience however, underlines the importance of developing specific indicators applicable on a national level. There are several reasons for this:

1) There are no universal causes and effects of land degradation.

2) In Namibia the participatory approach gave stakeholders ownership of the process and the resulting indicators, and led to an increased understanding among involved stakeholders of the concept of environmental monitoring, something that would not have been achieved if indicators were provided from the 'outside'.

3) A common platform was established for stakeholders from various sectors, leading to an increased interaction between sectors, an important aspect in most developing countries, where sectoral approaches predominate.

Finally, it was concluded that land degradation is a multi-faceted phenomenon with many causes and effects. Therefore, it is clear that the four indicators developed for the Namibian monitoring system are not sufficient to provide a complete picture of land degradation in Namibia. The first approximation presented in paper I should rather be seen as a first national monitoring system developed in a fully participatory manner, involving stakeholders from all levels. To improve the monitoring system, the four indicators have to be tested and evaluated in the field and additional indicators developed.

## PAPER II

*Klintonberg, P., Seely, M.K. and Christiansson, C., 2007. Local and national perceptions of environmental change in central northern Namibia: Do they correspond? Journal of Arid Environments, in press.*

The study presented in paper II compares results from the national level monitoring system discussed in Paper I with those obtained from interviews of local farmers about their perceptions of past and present states of the environment in and around Ombuga grassland in central northern Namibia. Semi-structured interviews were conducted with 50 representatives (12 female and 38 male) representing 50 homesteads in nine villages in the study area (Fig. 3). Five key questions were asked: 1) When and why did you first come to this area? 2) What was the condition of the environment when you first came here? 3) Have you noticed any changes in the state of the environment since you came here, and if so, can you describe them? 4) Where have you observed these changes? 5) What are the causes of these changes?

Results were analysed by dividing the interviewees in the following groups: 1) All interviewees, 2) Interviewees that arrived in 1990 or before and interview-

ees arriving after 1990; and 3) interviewees depending on pipeline water for all their needs and interviewees less dependent on pipeline water, also using hand dug wells. Separation of farmers arriving before or after 1990 was used as Namibia became independent this year and 1991 was the year when the construction of a fresh water pipeline, providing permanent access to water for people and livestock in the area, was initiated.

The most common changes observed by the interviewees were those related to abundance and quality of grasses. Regardless of time of arrival to the area, interviewees said that palatable perennial grasses were plentiful when they first arrived. However, as many as 86% of the respondents stated that the abundance of these desirable grasses has decreased in the area since they first came there. Further, as many as 66% of respondents said that the quality of grasses has decreased; grasses were said to be weaker and shorter now. Twenty-eight per cent of the interviewed farmers had noted that palatable perennial grasses had disappeared from the area. Answers related to quality of grazing given by farmers depending on pipeline water and farmers having access to other water sources show that mainly farmers depending on pipeline water referred to grazing related changes. This suggests that grazing quality has decreased more around water points along the pipeline than around traditional wells.

Seventy six per cent of the respondents stated that overgrazing is a cause of perceived environmental changes. Decreasing rainfall was another cause mentioned by more than half of the respondents as causing observed changes. Apart from these, construction of the water pipeline, building of homesteads, fencing of large parts of the commons and improved access to the area were other causes mentioned. Overgrazing and decreasing rainfall were factors identified as causing increased risk of land degradation in the Onkani area by the national level monitoring system discussed in paper I above. However, results from interviews with local farmers revealed a more complex picture of causes and effects leading to environmental changes in the area compared to the one given by the national level monitoring system (Fig. 10). Results presented in paper II suggest 1) decreased availability of palatable grasses in areas north of Ombuga grassland, 2) improved access to the area, 3) permanent access to water after the water pipeline was constructed making it possible for more farmers to settle in the area, leading to increased numbers of livestock and extensive grazing in areas that previously only were used when surface water was available, and 4) fencing of large areas of the commons, are major factors causing the environmental changes referred to by the interviewees. Results suggest that introduction of permanent water supply was the single most important factor, allowing more people and livestock into the area.

The results presented reflect the conditions in the study area but the factors identified by the interviews as causing environmental changes are most likely also applicable for other semi-arid areas where inhabitants

rely on natural resources. This suggests that assessments of local knowledge in a relatively small area can provide a valuable contribution to development and assessment of national monitoring initiatives.

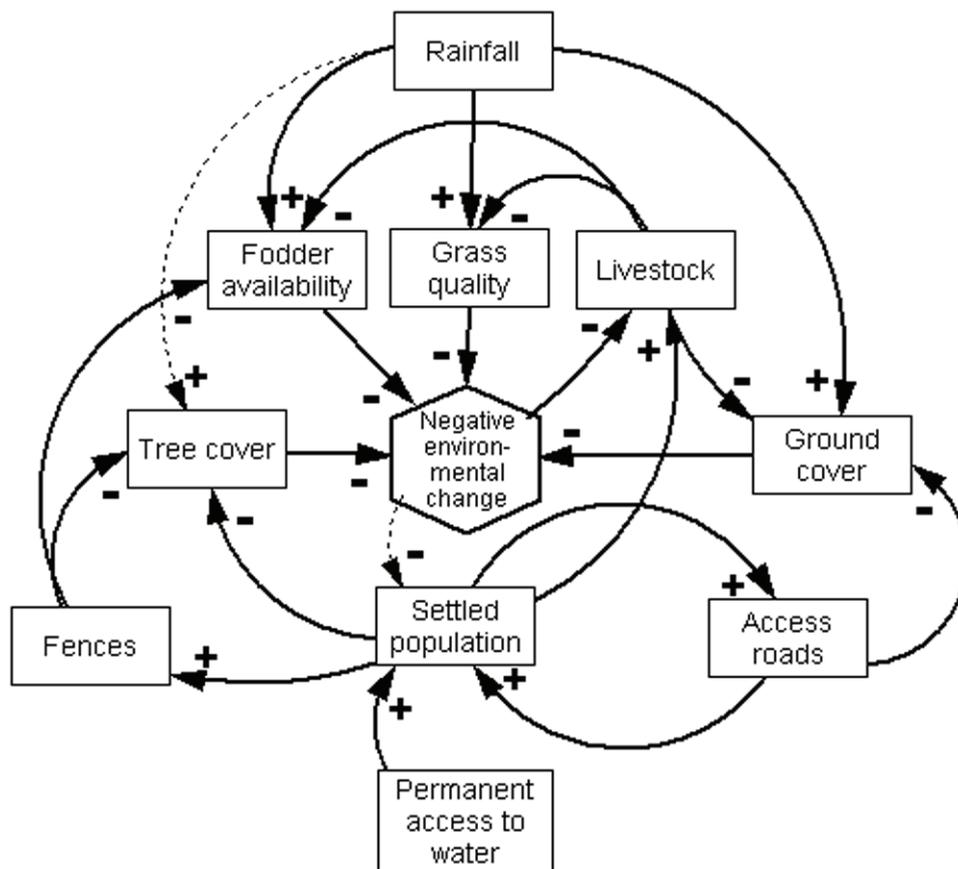


Figure 10. Relationships between manifestations and causes of perceived land degradation in the study area according to interviewed farmers. Thick lines indicate strong relationships between variables, while dashed lines indicate weaker relationships. Variables responding in similarly, i.e. an increase of variable A leads to an increase in variable B, are linked with (+) and variables responding opposite to each other, e.g. an increase in variable A leads to a decrease in variable B, are linked with (-).

### PAPER III

Klintonberg, P., Verlinden, A., submitted. Water points and their influence on grazing resources in central northern Namibia. *Land Degradation and Development*.

The study presented in Paper III investigated impacts of grazing on grass composition around permanent water points along a water pipeline and around a traditional hand dug well in the same area that was investigated in paper II above. Grass species abundance and selected environmental variables sampled along transects radiating out from these water points were analysed using Canonical Correspondence Analysis (CCA).

The results show a high frequency of grazing tolerant species, mainly annual grasses compared to more palatable, perennial grasses. This suggests that there is a fairly high grazing pressure throughout the area. A comparison between the influence of grazing around the permanent water points in the Ombuga grassland

and a traditional hand dug well shows that grazing around the water points has resulted in significant changes of the grass species composition. This was manifested in the dominance of *Schmidtia kalihariensis* and *Aristida stipioides* closest to the water points, and more palatable perennial grasses, i.e. *Stipagrostis uniplumis*, *Antephora pubescens* and *Eragrostis trichophora*, further away from the water points. The impact of grazing could be seen as far as 6-8 km from these water points. In contrast to the Ombuga grassland, no grazing related changes in grass composition could be shown around hand dug wells in the mopane savanna.

Several factors seem to contribute to the higher impact of grazing around permanent water points along the water pipeline in Ombuga grassland compared to around hand dug wells in the mopane savanna. It is argued that the provision of artificial permanent water points makes livestock more sedentary, resulting in unnaturally constant and heavy grazing pressure on grass resources, compared to a system where rainwater is the only source of water. Under such condi-

tions livestock movements are driven by the irregular distribution of rainfall characteristic of semi-arid environments (Marsh and Seely, 1992; Tainton, 1999). Another factor that has led to additional pressure on the grass resources is the accelerated immigration of humans and livestock to the area that apparently has taken place since the introduction of freely available water in the Ombuga grassland. On the other hand, private ownership of the traditional hand dug wells seems to result in stronger control of use and therefore a lesser impact of herbivory compared to the open access situation along the water pipeline in Ombuga grassland.

#### PAPER IV

*Klintonberg, P., Niipele, N., Kleman, J., manuscript. Can remote sensing detect environmental changes in an important grazing area in northern Namibia?*

In Paper IV the usefulness of satellite remote sensing in detecting environmental changes around permanent water points in Ombuga grassland referred to in the previous papers was investigated. Landsat TM data recorded after the rainfall season (March – April) 1989, 1991, 1993, 1997, 2000 and 2005 were used for the analysis. Land cover classification was done based on supervised classification applying maximum likelihood classification and a nearest neighbour algorithm, using bands 1-5 and 7. The following land cover classes were identified: woodland, shrubland, grassland, water, saltpan and bare ground. To assess changes in green biomass during the time series the soil adjusted vegetation index (SAVI, L-factor=0.5) was calculated for each of the scenes. Changes in SAVI over the time series were analysed by re-classifying images into 0 (SAVI<0.15) and 1 (SAVI >=0.15). All six scenes were combined into a composite map showing how many times each pixel had SAVI values above 0.15. SAVI values for each scene were also compared along two transects radiating 7 km to the west and east of two of the water points in the study area (Fig. 11).

Results of the land cover classification show 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. Before the water pipeline was operational, i.e. 1989 and 1991, bare ground mainly occurred in the saltpan in the south and in a limited area in the northeast corner around Lake Oponono, a central source of water in that part of the study area. Already in the satellite scene of 1993 the impact of the newly established permanent water points on the environment can be seen. The most striking change is the occurrence of bare ground, so called sacrifice zones resulting from concentrated trampling and grazing by graziers (Thomas *et al.*, 2000), around the water points. At that time the extent of bare ground had

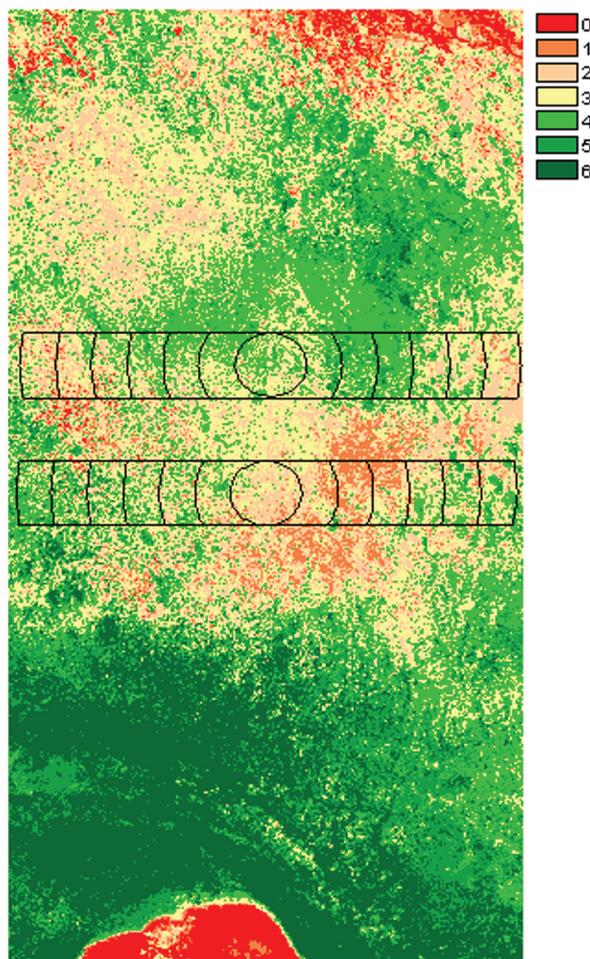


Figure 11. The map shows the resulting SAVI composite map illustrating the number of occasions the satellite images recorded SAVI >= 0.15 over the time series. The two transects which were used for assessment of variations in green biomass over the time series are also indicated.

increased in the north, occurring throughout that part of the study area. The following years bare ground mainly occurred around the water point and in the northwest part of the study area. Similar changes are revealed after analysing how SAVI varied during the time series. Results show that the areas with the lowest SAVI over the time series are in the northern part of the study area, which corresponds to the land cover classifications. The occurrence of bare ground in the northern part of the study area is most likely a consequence of the higher population pressure there, leading to clearing of land for cultivation and continuous heavy grazing and trampling by both large and small stock. An assessment of variation of SAVI along the two transects (Fig. 12) based on approximately 200 points sampled from each satellite scene shows that the highest SAVI values were recorded in 1989 which was a relatively good rainfall year. Results show that SAVI have changed substantially over the time series. In the later part of the time series, i.e. 2000 and 2005, when rainfall was even higher than 1989, SAVI did not respond accordingly, suggesting that, even during years of plentiful rainfall the vegetation does not recover to the same levels recorded in the beginning of the time series. This indicates that the increasing num-

bers of people and livestock in the area after the water pipeline was installed have had a negative influence on the resilience of green biomass in the area. However, a statistical assessment of the fluctuations of SAVI values along the two transects radiating out from two water points along the pipeline reveals that most of the fluctuations in greenness are not significant. This suggests that natural fluctuations of green biomass caused by high spatial and temporal variability of rainfall, regardless of distance to water points have a stronger influence on the greenness of the vegetation

than intensity of grazing has. It is important to note that this does not mean that grazing does not influence the vegetation around water points. The findings show that greenness of vegetation is more responsive to rainfall than grazing. Grazing around the water points has been shown to cause a change in vegetation composition, e.g. from palatable perennial grasses to less palatable annual once. However, these changes will most likely not be detected by using SAVI as it only gives a measure of greenness and not quality of the vegetation.

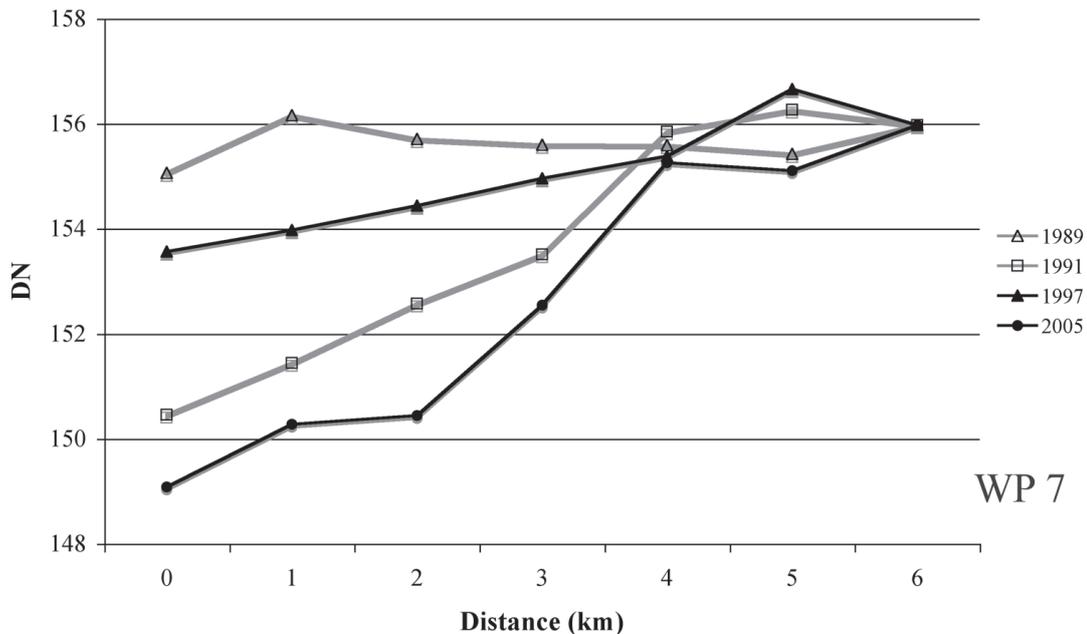


Figure 12. SAVI values recorded 0-7 km east and west from water point 7 (WP 7). Note that each value is an average value of the eastern and western part of the transect. Values were adjusted to be equal at 6 (6 to 7 km from the water point) where the impact of grazing was assumed to be non-significant.

## GENERAL DISCUSSION

The four papers forming the core of this thesis present four different approaches related to environmental monitoring, ranging from national level monitoring based on indicators, local perceptions of environmental changes held by farmers in central northern Namibia, detailed assessment of the state of the environment surrounding permanent water points in the same area, and finally the use of remote sensing to investigate environmental changes over time also in central northern Namibia. In this general discussion these four approaches are examined in light of other relevant investigations.

### The development of national level land degradation indicators

Several important factors required for successful development of national level indicators were identified in paper I. First, an obvious fact, the importance of those involved in developing indicators having an overall understanding of causes and effects of the

processes to be monitored. Based on the Namibian experience it was shown that the involvement of representatives from a large number of different disciplines and institutions often led to misunderstandings between involved groups due to sectoral thinking. At the onset of the project it was clear that there was no common understanding among the representatives from these different institutions about causes and effects of land degradation in Namibia. The most obvious problem was the lack of understanding among biophysical scientists towards socio-economic factors contributing to land degradation and being affected by land degradation. Similar problems were identified by reviewing indicators developed for Namibian state of the environment reporting (Klintonberg, 2001). After assessing 99 indicators developed for Namibian state of the environment monitoring Klintonberg (2001) showed that only 67% of the indicators fulfilled the criterion of perceived scientific relevance by reflecting what could be argued to represent “current received wisdom”. Furthermore, only 25 of the 99 indicators were considered to be potentially useful for practical environmental monitoring. The low useful-

ness of indicators developed for the Namibian state of the environment monitoring programme suggests that there was limited understanding among involved parties towards what to monitor and what requirements a functional indicator has to fulfil. To guide the development of indicators, it was suggested in paper I that a set of well-defined criteria that have to be fulfilled by developed indicators was required. Further, it was suggested that this should be a globally accepted set of criteria, ensuring equal quality requirements for different indicators independent of where the indicator is used. The need for criteria to assess the quality of suggested indicators has been suggested by several institutions and authors, e.g. (OECD, 1993; Denisov *et al.*, 1998; Rubio and Bochet, 1998; OECD, 2001).

Furthermore, it was stated in Paper I that there are no universal causes and effects of land degradation. This was also shown in an assessment of the state of the art of land degradation indicators identified and developed by the SADC countries in southern Africa as part of their commitments to the UNCCD (Klintonberg and Seely, 2005). Their review identified approximately 225 unique indicators related to land degradation monitoring or to the implementation of national action plans (NAPs) under the UNCCD. It was shown that even though monitoring of various aspects of rainfall and soil properties was most common, the same indicators are seldom used in more than one country. This suggests that issues related to land degradation differ widely between different countries in southern Africa, which makes it difficult to develop a universal core set of land degradation indicators (Klintonberg and Seely, 2005). On the contrary, paper I suggests that the development of country specific indicators through a participatory process involving representatives from all relevant disciplines and institutions, would be more useful than striving towards the creation of a globally accepted set of indicators. The same recommendation emerged from a discussion among international experts, arranged by FAO, where it was recommended that end users, e.g. national decision makers, should identify and prioritize key issues and questions that form the basis for indicators to be developed (Snel *et al.*, 2003). The Namibian experiences showed that the participatory approach led to better understanding of concepts of indicators and environmental monitoring among the participants. Secondly, through the process a common platform was established for stakeholders from various sectors, e.g. environment, agriculture, finance NGO and private, promoting an increased interaction among sectors, an important aspect in most developing countries, where sectoral approaches predominate.

Regardless of the benefits of the participatory approach taken to develop national land degradation indicators in Namibia, there are a number of issues that still need to be dealt with. A closer look at the indicators developed for the Namibian national level

monitoring system reveals a number of limitations. First, the indicators are based on a large number of assumptions. For instance the population pressure index relies on population figures from only one national census carried out in 1991. A constant growth rate of 3.1% per annum was assumed (growth rate 1991), which is an oversimplification of the actual situation, as growth rate might be higher or lower in different parts of the country. The livestock index is based on annual summarised livestock counts in the 15 state veterinary districts. It was assumed that all livestock are found within 10 km from any permanent water source and that they are evenly distributed within these areas. All these assumptions reflect a poor availability of data with high enough resolution as commonly found in a developing country. This is also reflected by the fact that annual risk assessment maps have only been produced for the time period 1971-1997 due to lack of rainfall data. After 1997 there was not enough rainfall data available to calculate the rainfall index. The number of operating official rainfall stations decreased from approximately 265 to about 115 just after Independence in 1990. A drastic reduction in data accessibility from 1997 onwards is related to slow data processing. Based on these considerations it is clear that the four indicators presented in Paper I are not sufficient to provide a complete picture of land degradation risk in Namibia. After taking these limitations into consideration the need for an assessment of the accuracy of the indicators developed and the resulting land degradation risk maps became obvious. This was the starting points for the study presented in paper II, the comparison of results generated by the national level monitoring system and perceptions held by interviewed farmers.

### **Local and national perceptions of environmental change in central northern Namibia**

According to results based on interviews with farmers presented in paper II, the quantity and quality of grazing has decreased in the area being investigated. Farmers stated this regardless of when they first arrived to the area. However, one of the most significant findings in paper II is that according to interviewed farmers, the degradation of grazing resources in the area started after the construction of a water pipeline in 1992/93, providing permanent access to water. This was further confirmed by interviewees stating that the degradation was more extensive around free access water points along the water pipeline, compared to around privately owned hand dug wells.

When asked about the causes of observed environmental changes in the area, interviewees responded that main causes are: overgrazing, decreasing rainfall, extensive use of wood for construction, illegal fencing and increasing number of regularly used informal

vehicle tracks. This corresponds to two of the main factors identified by the national level monitoring system discussed in paper I, which indicated that increasing livestock numbers and below average rainfall are main causes of environmental change in the Ombuga grassland. The suggestion made by the interviewees that decreasing rainfall is a cause of environmental changes in the area was compared to rainfall records from four stations surrounding the study area. These records suggest a periodicity of drier and wetter conditions, similar to the southern African 18 year rainfall cycle described by Tyson (1986, 1991). However, the rainfall records presented in Figures 5 and 6 show that the drier conditions that prevailed when the interviews were made are not unique and that drier periods are part of normal conditions in northern Namibia. This does not support the notion that decreasing rainfall alone is a cause of observed environmental changes. This corresponds to findings by Ward *et al.* (2000) who concluded that perceptions held by farmers in Otjimbingwe about decreasing rainfall causing environmental changes in that area were not consistent with scientific records. Therefore it is more probable that non-adaptive management during prolonged dryness, allowing cattle to continuously graze the area along the pipeline is causing perceived environmental change in the study area.

The construction of the water pipeline is central in the development of the study area. According to interviewees the provision of permanent water supply allowed cattle to graze permanently in areas that previously were used only when rainwater was available. The relationship between grazing and negative environmental changes around permanent water sources in Ombuga grassland along the water pipeline was shown by Langanke (2000) and Larsson (2003). Larsson's investigation of 2003, based on remote sensing and field observations, concluded that intensive grazing around permanent water points in Ombuga grassland has a negative effect on the rangeland. Vegetation was shown to gradually decline with 1) proximity to water point, 2) length of period of use and, 3) increased grazing intensity. Similar findings have been reported by Susco *et al.* (1995), Dougill *et al.* (1999) and Nash *et al.* (1999). However, after investigating if grazing had caused change from perennial to annual grasses in the Ombuga grassland by sampling vegetation along transects radiating from water points along the pipeline, Nangula and Oba (2004) concluded that no change from perennial to annual grass species due to increased grazing pressure could be detected.

The findings from the interviews of farmers in the study area, together with contradicting results by other scientists regarding the impact made by grazing livestock on the vegetation surrounding the permanent water points in the study area, led to the in depth assessment of grass species composition in areas surrounding permanent water points presented in paper III.

## **Vegetation survey to assess impacts of grazing by domestic large stock around permanent water points in Ombuga grassland and surrounding mopane savanna**

A key finding from this investigation is that the grass species composition has changed significantly around permanent water points along the water pipeline in Ombuga grassland. The ordination analysis based on detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) suggests that there is a grazing gradient radiating out from the permanent water points along the water pipeline. However, no grazing related changes in grass species composition could be shown around hand-dug wells in the mopane savanna. This suggests that grazing does not have a significant effect on the distribution and abundance of grass species along transects radiating out from these.

Results presented in paper III correspond to information provided by interviewees in paper II, who observed decreasing quality of grasses around water points along the pipeline. Further, the species composition along the transects surveyed in paper III corresponds to findings by Thrash *et al.* (1993) who show that heavy grazing around water points in Kruger national park led to selective removal of perennial grass species, promoting the growth of annual grass species. In the Kalahari of Botswana, Thomas *et al.* (2000) showed that sacrifice zones were formed and palatable grass species were replaced by unpalatable ones around water points. James *et al.* (1999) described a radial pattern in vegetation surrounding permanent water points generated by increasing grazing and trampling intensity towards water points. Similar impacts of heavy grazing were reported from South Africa around animal kraals in succulent Karoo (Riginos and Hoffman, 2003), in Nama-Karoo shrublands (Todd, 2006) and in communal grazing areas dominated by leaf succulents (Todd and Hoffman, 1999). In northern Namibia Kuiper and Meadows (2002) observed a change in vegetation composition in communal grazing areas, from predominantly perennial to unpalatable annual grasses. In central Namibia Getzin (2005) identified a grazing gradient around artificial water sources in a game reserve. In the study presented in paper III, perennial and more palatable species were shown to have their maximum as far as 6 to 8 km from the water points in the Ombuga grassland. Dougill *et al.* (1999) observed grazing induced vegetation changes as far as 8 km from permanent water points in the Kalahari of Botswana.

However, as was indicated already in paper II, findings presented in paper III disagree with findings reported by Nangula (2001) and Nangula and Oba (2004) regarding impacts of grazing on occurrence and abundance of grass species around permanent water points in Ombuga grassland. According to their findings many differences in vegetation compo-

sition and abundance were explained by differences between landscape types, e.g. deep sandy soils vs. shallow silty soils, pans and shallow depressions. The influence of differences in landscape types on vegetation was confirmed in paper III. However, even after taking this into consideration it is clear that the results differ when it comes to impacts of grazing. One likely explanation to this is the different distances from water points where data was collected. The study by Nangula and Oba (2004) investigated grazing impacts to a distance of 1 km from water points in the Ombuga grassland. These results were compared to benchmark sites less than 5 km from water points. However, results presented in paper III indicate that the impact of grazing livestock reaches as far as 6 to 8 km away from permanent water points in this area. This suggests that both the samples collected within the distance of 1 km from the water points and the samples at benchmark sites by Nangula and Oba (2004) might have been located within the disturbed zone around the water points, making the identification of a grazing gradient less obvious.

The fact that findings in both paper II and III suggest that the grass species composition around privately owned hand dug wells do not show the same negative changes as observed around freely accessible water points in Ombuga grassland is interesting. This suggests that private ownership allows a stronger control of use, which seems to lessen the impact of herbivory compared to the open access situation along the pipeline. This scenario is similar to what was termed as the tragedy of the commons by Hardin (1968). In his rather controversial paper Hardin illustrates the tragedy of the commons with a hypothetical example from a pastoral open access system, similar to the pastoral system in the study area. Each individual using Hardin's 'commons', (more commonly termed 'open access') is assumed to wish to maximize his yield, and will therefore increase his herd size when ever possible. This has both positive and negative consequences for the individual. The owner receives all benefits of each animal he adds to his herd. However all pastoralists share the environmental impact of each animal added to the commons. As the gain is higher than the losses the rational for the individual would be to keep adding animals to his herd. However, since all pastoralists reach the same conclusion the consequence will be overgrazing and degradation of the pasture (Hardin, 1968).

Before the water pipeline was constructed in the study area access to water and grazing was ultimately controlled by the amount and distribution of rainfall. The lack of permanent water supply limited the use of the area to the few months when rainwater was available. Furthermore, the high spatial variability of rainfall led to a natural rotation of grazing, as cattle would follow the rain in search of grazing. However, since permanent water supply was provided more and

more people are moving in to the area. Interviewees in paper II confirmed the increased immigration to the area after the pipeline was put in place. Most of these new arrivals establish cattle posts, of which some are turned into permanent homesteads occupied by entire families and with permanent crop fields, close to the water pipeline. A common critique of Hardin's scenario is that even the commons have regulatory systems in place aimed at preventing maximization of the individuals gain on the expense of the common good. In the study area there are traditional authorities represented by a senior headman and several headmen and there are a number of customary laws in place aimed at preventing the over use of common resources. These laws apply to the individually owned hand-dug wells. However, in the case of the water pipeline there are presently no control functions in place, making this an unmanaged common (Hardin, 1998). As the results presented in paper III suggest, the lack of management of water and grazing around open access water points has resulted in degradation of the grass resources there. The fact that this does not take place around the privately owned wells suggests that the "tragedy of the commons" is a reality around open access water points in Ombuga grassland.

The question if the grazing area is an equilibrium or non-equilibrium system is also interesting. The findings presented clearly show that herbivory has influenced grass species composition around permanent water points along the water pipeline. This supports the argument of Illius and O'Connor (1999) that key resources and water points create hot spots in semi-arid rangelands where herbivory does have an effect on grass species composition. According to Vetter (2003) it is likely that areas further away from the water points, which can only be grazed as long as there is surface water available in the rangeland, are more driven by abiotic factors, e.g. rainfall and less influenced by cattle grazing. However, findings presented in paper III do not give a clear indication if this is the case.

### **Using remote sensing to identify environmental changes in the study area**

In paper IV the usefulness of satellite remote sensing for detection of environmental changes recorded in the field was tested. A key finding is that it was possible to detect an increase of bare ground around permanent water points and in the northern, more populated part of the study area, after the construction of the water pipeline 1992/93. These findings were supported to some extent by an analysis of the soil adjusted vegetation index, indicating that the northern parts of the study area showed the lowest SAVI values throughout the time series, suggesting that the higher population pressure in that part of the study area has resulted in

less green biomass there. As was discussed above, the occurrence of sacrifice zones around permanent water points in semi-arid environments have been reported by several authors (Thrash *et al.*, 1993; James *et al.*, 1999; Nash *et al.*, 1999; Todd, 2006) and specifically in Namibia (Kuiper and Meadows, 2002; Getzin, 2005) and in the study area (Larsson, 2003). Results show that the number of pixels classified as woodland, shrubland and grassland fluctuated largely over the time series. A steady decrease of woodland could have been explained by the rapid population increase that took place in the area after the introduction of the permanent water supply, but fluctuations between high and low abundance of woodland most likely illustrates a difficulty in separating woodland from other woody vegetation. Shrubland on the other hand could increase due to the increased grazing pressure, as it has been shown that increasing grazing pressure might stimulate the encroachment of bush (De Klerk, 2004). In the study area it has been observed that the density of bitter bush (*Pechuel-Loeschea leubnitziae*) has increased in areas under heavy grazing and trampling pressure. However, if that is the cause of increasing number of pixels being classified as shrubland then the abundance would be increasing most around the water points towards the end of the time series, something that is not evident. It is most likely that the fluctuating number of pixels classified as shrubland and woodland illustrate a difficulty in separating these two classes from each other in this environment. A reason for this could be the generally sparse canopy cover of woody vegetation in this part of central northern Namibia (Mendelsohn *et al.*, 2000).

The number of pixels classified as grassland was at their maximum in 1989 and 1991, after which the numbers dropped significantly. This corresponds to the number of pixels classified as bare ground, which was at a minimum for the first two years and then increased after 1991. This could be an effect of the increased grazing pressure associated with the introduction of permanent water supply. However, decreasing rainfall during the same period could also cause the increasing occurrence of bare ground. An examination of the rainfall during the time series reveals that rainfall was low in 1993 and relatively good rainfall was received in 2000 and 2005 (Fig. 5). This contradicts the expectation that decreasing rainfall would cause the increased occurrence of bare ground. However, the rainfall records used are recorded northeast and southwest of the study area. Knowing that rainfall is highly variable both in time and space in semi-arid environments, this might not be the best data to use for this assessment. However, the amount of water in the saltpan in the southern part of the study area, closer than either of the rain gauges, could serve as a valuable indicator of how much rainfall was received in the area. An assessment of the land cover maps reveals that the years with most water in the saltpan

were 1993, 2000 and 2005, indicating that at least the southern part of the area received plenty of rainfall these three years. This supports the argument that the increased occurrence of bare ground could be caused by increasing grazing pressure around the permanent water points in the area, which has been proposed by Niemann, (2002), Larsson (2003), Klintonberg and Christiansson (2005) and in paper II and III presented here.

Findings presented in paper IV show that satellite remote sensing based on Landsat TM data can detect some of the environmental changes identified during previous field based assessments in the study area, e.g. sacrifice zones around water points. However, the difficulties of separating woodland and shrubland and the low accuracy of some of the land cover classes illustrated the importance of timely collection of control points used for the evaluation of results (Congalton, 1991; Fitzgerald and Lees, 1994; Congalton and Green, 1999). In this study it was shown that the timing of collection of ground control points strongly influences the result. The relatively high abundance of mopane shrubs in the western part of the study area illustrates another complication of using satellite data. It is difficult, and sometimes even impossible for the satellite to record what hides under the leaf cover of shrubs, in other words, it is not possible to see if there are any grasses under the shrubs, which therefore makes satellite remote sensing less useful to detect grazing induced changes in shrubland.

## CONCLUSIONS

Here the most important conclusions of this thesis are presented. The conclusions are based on findings from the four papers, summarized above. Conclusions based on studies in and around the Ombuga grassland reflect the conditions there but are most likely also applicable to other semi-arid environments where inhabitants rely on natural resources to a similar extent.

The analysis of the process of developing national level indicators for monitoring of land degradation concluded that specific indicators should be developed on national level, and in some instances even on a regional and local level, instead of the often proposed development of a global set of indicators to be used everywhere. The reason for this is that 1) there are no universal causes and effects of land degradation. 2) the participatory approach, involving stakeholders on both local and national levels gave them ownership of the process and the resulting indicators, and led to an increased understanding of the concepts of environmental monitoring. 3) the participatory process of developing national indicators taken in Namibia created a common platform for representatives from various sectors, leading to increased interaction among sectors, an important aspect in most developing coun-

tries, where sectoral approaches predominate.

The four indicators developed in Namibia do not provide a complete picture of land degradation in Namibia. To improve the system further, these indicators have to be tested and most likely adjusted and additional indicators have to be added. The strength of the findings in paper I is not so much the results of the indicators but the manner in which these indicators were developed, promoting participation, creating ownership and a platform for further development of monitoring systems.

The assessment of local perceptions of land degradation in and around Ombuga grassland showed that farmers there claimed that overgrazing and low rainfall since the beginning of the 1990s cause negative environmental changes in the area, which corresponds to the results of the national level monitoring system discussed in paper I. However, results from the interviews reveal a more complex picture of causes and effects leading to environmental changes in the area compared to the one given by the national level monitoring system. These results suggest that 1) decreasing availability of grazing outside the study area, 2) improved access to the area, 3) provision of permanent water supply after the water pipeline was constructed, and 4) fencing of large areas of the commons, are major factors contributing to environmental changes in the area. The results suggest that introduction of permanent water supply was the single most important factor, allowing more people and livestock into the area.

The results suggest that assessments of local knowledge in a relatively small area can provide a valuable contribution to development and assessment of national monitoring initiatives.

The investigation of impacts of permanent water points and their influence on grazing resources in Ombuga grassland and surrounding mopane savanna showed that significant grazing induced changes, manifested by palatable perennial grasses being replaced by less palatable annual grasses, were identified around water points along the water pipeline. The annual grasses *Schmidtia kalihariensis* and *Aristida stipioides* dominate the vegetation as far as 6 km from the water points. However, no significant grazing induced changes in grass composition were observed around privately owned hand dug wells. Private ownership leading to stronger control of access to traditional wells compared to open access water points along the pipeline seems to be a key factor preventing over-utilization of grazing resources around the former.

The assessment of the usefulness of satellite remote sensing in detecting environmental changes in and around Ombuga grassland shows that the Landsat TM sensor is capable of identifying the bare ground, grassland and pan with a fair accuracy, while water, shrubland and woodland were classified with lower

accuracy, caused by difficulties in separating different classes of woody vegetation from each other and also from grassland in some instances, using supervise classification. Woodland and shrubland are most likely difficult to separate due to the similarities in canopy cover and spectral signature from green leaves, making height of the woody vegetation the main factor separating the two classes. The difficulty of separating shrubland from grassland mainly occurs in the transition between the two main vegetation types, mopane savanna and open grassland, where the density of shrubs decrease gradually towards the east, into the grassland.

The results suggest that the use of the soil adjusted vegetation index (SAVI) provides valuable information about variations of green biomass over time in semi-arid environments. However, because of the strong influence of underlying soil related to the relatively sparse ground cover in semi-arid environments, it is suggested that any investigation based on satellite remote sensing in dry environments be supported by a thorough ground based assessment, taking into account the high spatial and temporal variability of rainfall in these environments.

## SUGGESTED FUTURE RESEARCH

The results emerging from this thesis reveal that there is a need for future research within a number of fields related to environmental monitoring. However, seen from the authors perspective there are two fields in particular that would require further research. First the aspects related to open or free access to natural resources versus private ownership and what influences this has on the use of the resource base. This is a topic that has been discussed and debated for many years but given a lot of interest after Hardin's text in Science in 1968, where he discusses aspects of uncontrolled access to a common resource. The investigations in Ombuga grassland clearly show that, perhaps not ownership, but at least controlled use of natural resources in the commons is very important. Secondly, the contributions of local knowledge to improve our understanding of the dynamics of the natural resource base, and the management and use of these resources by local land users was identified in paper II. This is a field that is receiving increasing attention from the scientific community. In Namibia a number of studies in the central northern part of the country have been published, but there are still many aspects of local knowledge and its contributions to science to explore. It would therefore be interesting to carry out a focused investigation into these issues, not only in the Ombuga area but throughout the entire Cuvelai basin, starting in southern Angola and ending south of Etosha national park in Namibia. By extending the investigation to the entire Cuvelai basin a wider variety of conditions, e.g. the higher population pressure

towards the Angolan border in Namibia and its influence on the management of natural resources and the present state of these resources could be compared to the conditions observed in Ombuga grassland, which still has a relatively low population density. Furthermore, to also include the Angolan part of the basin would provide information about conditions in areas that have been very little utilized and which so far, in parts, have seen little development in the form of improved infrastructure. These less developed areas are therefore most likely still managed in a more 'traditional' way, without provision of permanent water and other development initiatives.

Finally, a different field of research, but not less important, is the study of information sharing. Research findings like these presented in this thesis are seldom communicated to the people that are being researched. Seen in a more general perspective, there seems to be a need to investigate how scientific findings can better contribute to the general public and decision makers. Presently there are few incentive systems in place within the academic world, promoting the scientist to communicate findings outside this world. However, this is a field that would be worthwhile to research.

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