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Mapping and Modelling of Vegetation Changes in the Southern Gadarif Region, Sudan, Using Remote Sensing

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Land-Use Impacts on Biophysical Processes

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Preface

Presently there is a global increase in the recognition of environmental, social and economic values of native vegetation, particularly in terms of both sustainability of agricultural production and maintenance of natural resources. Land-use/land-cover (LULC) changes are among the most important human alterations affecting the ecosystems of the earth. Their direct impact on biological diversity, their contribution to local and regional climate changes as well as to global climate warming is well documented. Also LULC change is one of the main triggering factors for local resource conflicts in third-world countries like Sudan. However, balancing human needs and ecosystem functions requires quantitative knowledge about ecosystem responses to land-use. These responses vary according to the type of land-use change and the ecological setting, and have local short-term as well as global long-term effects.

The Gadarif Region in Sudan underwent wide-spread deforestation due to mechanized rain-fed agricultural expansion for the last fifty years from 500 ha in the 1940s to about 2.3 million ha in 2006. Nearly one third of Sorghum (*Sorghum bicolor;* the primary stable crop) and Sesame (*Sesamum indicum*) produced in Sudan are cultivated in this region. The conservation and sustainable management of natural resources in the Gadarif Region needs a holistic approach: in addition to ecological concerns, socio-economic, agricultural issues including cultural aspects must be taken into consideration. The rapid expansion of mechanized rain-fed agriculture in the region has resulted in dramatic vegetation clearing.

Following the aforementioned considerations, the aim of the present study is to reveal the influences of the introduction of mechanized rain-fed agriculture and its rapid expansion on the natural vegetation in the southern Gadarif Region from different perspectives. To achieve these objectives the study utilized a series of techniques to map and model the vegetation changes in the study area within the last four decades. Besides the intensive use of remote sensing imagery, interviews with key informants and farmers and detailed field surveys were conducted.

The thesis organization follows the logical sequence of events from the 1972 up to 2006, this means from the introduction of mechanized rain-fed agriculture (MRA) to the degradation and abandonment of agricultural land in the study area. The thesis consists of six major chapters, which can be read independently like journal publications and a last chapter as overall summary and conclusions. When appropriate, additional explanation was given to illustrate some technical procedures. Although such procedures were mentioned in many reference books, stepwise illustrations are believed to be useful for readers in areas such as the Gadarif Region where remote sensing and GIS is still a young science.

Chapter 1 introduces the reader to the study area and gives an overview for the beginning of MRA. Chapter 2 deals with vegetation clearing due to the expansion of the MRA in the Gadarif Region. The identification and analyses of some agricultural, social and ethno-botanical aspects of degradation and abandonment of agricultural land by interviewing two groups of respondents is presented in Chapter 3. Mapping of abandoned agricultural land is intensively investigated in Chapter 4. Chapter 5 shows the effects of previous land-use and the age of fallow on vegetation composition and structure of abandoned agricultural land. The modelling of the restoration potential of some abandoned agricultural land is depicted in Chapter 6. An important reason for developing the model is to link the remotely sensed data (e.g. satellite imagery) and the digital elevation model with field data containing site-specific data relevant to the land-use. Chapter 7 contains overall conclusions and recommendations of the study. At the end of the thesis an English Summary and a German Zusammenfassung is given. Parts of the work were presented at international conferences and workshops and published in reviewed proceedings[1].

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1) Publications:

Sulieman, H. M. and Buchroithner, M. F. 2005. Assessment of the Restoration Potential of the Abandoned Agricultural land in Doka Area, Eastern Sudan Using Remote Sensing Imagery and GIS. *Proceedings of International Workshop for Sustainable Development,* 14 – 16 November 2005, Institut Scientifique Universte` Mohammed *V* Agdal, Rabat, Morocco.

Sulieman, H. M. and Buchroithner, M. F. 2006. Assessment of Natural Vegetation Clearing and Re-Growth in Southern Gadarif (Sudan) Using Change Vector Analysis Based on Remote Sensing and Field Data. *ISPRS Commission VII Mid-term Symposium "Remote Sensing: From Pixels to Processes"*, 8-11 May 2006, Enschede, the Netherlands.

Sulieman, H. M. and Buchroithner, M. F. 2007. Multi-Temporal Classification of Abandoned Agricultural Land in Gadarif Region, Sudan, Using Original Bands, Indices and Feature Components of Spaceborne Imagery. *IEEE Proceedings for Fourth International Workshop on the Analysis of Multitemporal Remote Sensing Images*, 18-20 July 2007, Leuven, Belgium.

The completion of this work would not have been possible without the support from various people and institutions which made `the journey´ possible and worthwhile. First of all, I wish to express my sincere thanks to Prof. Manfred F. Buchroithner for the privilege to carry out this study under his supervision. The study considerably benefited from his admirable scientific insight as well as from his kind support. His encouragement to participate in numerous local and international scientific events is very much appreciated. I wish to express my gratitude to my second supervisor Prof. Peter A. Schmidt for his significant inspections and constructive discussions. My gratitude also goes to Prof. Dr. Hartmut Kenneweg for spending his valuable time on the evaluation of this thesis.

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Without the generous financial support of the German Academic Exchange Service (DAAD) it would not have been possible for me do this work. The finical support of the

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My profound gratitude goes to my family, to my mother, father and siblings for their merciful prayers and sympathetic support. Last, but certainly not least, my wife Amna and my kids Mohamed, Maab and Sara deserve special thanks for their endless support and infinite understanding. To you I dedicate this work.

Table of Contents

1 Mechanized Rain-Fed Agriculture in the Gadarif Region: An Overview

1.1 Introduction

The Gadarif State is located in the eastern part of the Sudan between 33 – 37° E Longitudes and 12 – 16° N Latitudes with an area of approximately 78,000 km^2. It is bounded in the north by Kassala and Khartoum States, in the west by Gezira, in the south by Blue Nile State and shared boundary with Ethiopia from the east. The Gadarif State is divided into four provinces. The town of Gadarif is the State's capital. The current study was conducted in Galabat Province, which is located in the southern part of the state, and its capital is Doka (Figure 1.1). It is widely recognised in Sudan that the Gadarif Region in the land of sorghum and for many local peoples in other parts of Sudan the situation of the rainfall and sorghum productivity in the Gadarif Region is a source of reassurance. This is because agriculture is still the mainstay of social and economic stability in Sudan and the Gadarif Region produces about one third of the national production of sorghum – the principle food stuff.

1.2 Study Area

1.2.1 Geographical Location

The study site covers an area of about 55 x 40 km^2 in the vicinity of the rural town of Doka to the south (Figure 1.1). The selection of this area has been based on many arguments. This is the area where mechanized farming was introduced for the first time in southern Gadarif Region. The prosperity of the mechanized farming has attracted many people to the area. Because of that the area was surrounded big villages beside the Doka town. A good proof for that is the rapid population development of the town of Doka which was depicted in Table 1.1. This situation makes the area suitable for research because it offers a combination of physical, ecological and social dimension of the mechanized rain-fed agriculture after around fifty years of its introduction.

1.2.2 Geology and Soil

The dominating rock is a black basaltic rock with many druses which are partly filled up by secondary crystallization products such as zeolites, thus giving the rock a black-white dotted appearance. This basaltic rock is the parent material of the clay. From the common occurrence of rock fragments on the surface of nearly the whole area and the presence of rock in many soil pits it becomes evident that the clay layer is generally not very thick. Being a weathering product of a very fine grained material no quartz pebbles or coarse sand grains are found in the clay.

Soils in the study area are dominated by dark, heavy cracking *vertisol,* formed on colluvio-alluvium derived from the basaltic rocks of the Gadarif-Galabat ridge and basement complex rocks. The typical characteristics of the soil exhibited the area are a high content of expanding lattice clay (average clay content ca. 70 %), a high cation exchange capacity and an intense and deep cracking down to ca. 1.50 metres. The nutrients status of the soil is marked by low nitrogen and potassium contents and high phosphorus contents. The soils have a high water holding capacity coupled with poor permeability, which consequently induces erosion. They are also characterised by unfavourable texture and high bulk density (Knibbe *et al*., 1964; Blokhuis, 1993).

1.2.3 Topography and Drainage System

The topographical features of the study area are undulating relief with several major drainage systems. The undulating relief with its poorly drained and well drained sites causes an irregular water regime which may be reflected in crop production. Moreover, corresponding with the relief – the most severe limitations arise from shallowness and stoniness. However, the overall relief of the area is gently down-sloping from the Gadarif-Galabat ridge to the river Rahad. Inselbergs, rocky hills, gentle ridges modify this contour pattern locally.

1.2.4 Climate

Annual rainfall is concentrated in a single relatively short summer season during June to September, and amounts to around 670 mm per annum in Doka. The period of observation is not yet long enough for more detailed data but according to the rainfall map, prepared by the Sudan Meteorological Service, the probable error is about 80 mm. Remarkable, however, is a higher rainfall in July and August (Figure 1.2). Figure 1.3 depicts a comparison of long term and 2003 season rainfall and Normalised Difference Vegetation Index (NDVI) for area of 20 x 20 Km around Doka. Remaining gross atmospheric interference (large temporary drops in NDVI) is smoothed out. In general terms, the initial development of vegetation denoted by the rise in the NDVI curve, usually follows the arrival of significant rainfall with a delay related to the characteristics of the landscape (soil, vegetation type, topography). These also control the shape of the NDVI curve through the season (SEWS, 2003). Temperature ranged from a mean minimum of 21° C in January to a mean maximum of 36.4° C in April and May. The mean annual temperature is about 28.7^{o} C (Figure 1.4).

1.2.5 Vegetation

Harrison and Jackson (1958) classified the natural vegetation of the study area as an *Acacia seyal* and *Balanites aegyptiaca* woodland Savannah. On the clay plain *Acacia seyal*, *Balanites aegyptiaca*, *Ziziphus orthacantha* and *Acacia senegal* are the dominant trees. Common grasses include *Cymbopogon nervatus*, *Aristida mutabilis* and *Ctenium elegans*. In the drainage depressions also *Hyparrhenia rufa*, *Hyparrhenia hitra* and *Longohocarus laxiferrus* occur. The vegetation on the higher stonier land is less affected by human influences. On shallower soils the trees of *Lannea stumper*, *Acacia campyla-cantha* and *Combretum hartmannianum* are grown. Sorghum grasses, *Cymbopogon spp.* and *Sporobolus* grass species dominate areas of fallow or abandoned crop-land (SKAP, 1992).

This natural vegetation has largely been destroyed in the course of widespread clearance for mechanized crop cultivation, extensive burning and shifting cultivation, and only scattered fragments remain. The vegetation is marked by clear intra-annual changes. There is no recent reliable and comprehensive data for the vegetation of the study area and the few surveys carried out in the past have become outdated because of the dramatic changes in the area. However, despite these changes sufficient traces of the natural vegetation remain (e. g. tracks between farms, abandoned farms, areas around water courses) to permit a description of the dominant plant communities in the region.

1.3 Human Population

The annual population growth rate in Gadarif state is 2.6 % which is higher than the national growth rate (2.2 %; UNFPA, 2003). Table 1.1 shows the population of the town of Doka, the headquarter of the Galabat Province (World Gazetteer, 2007). It is clear that the town gained rapid population increase.

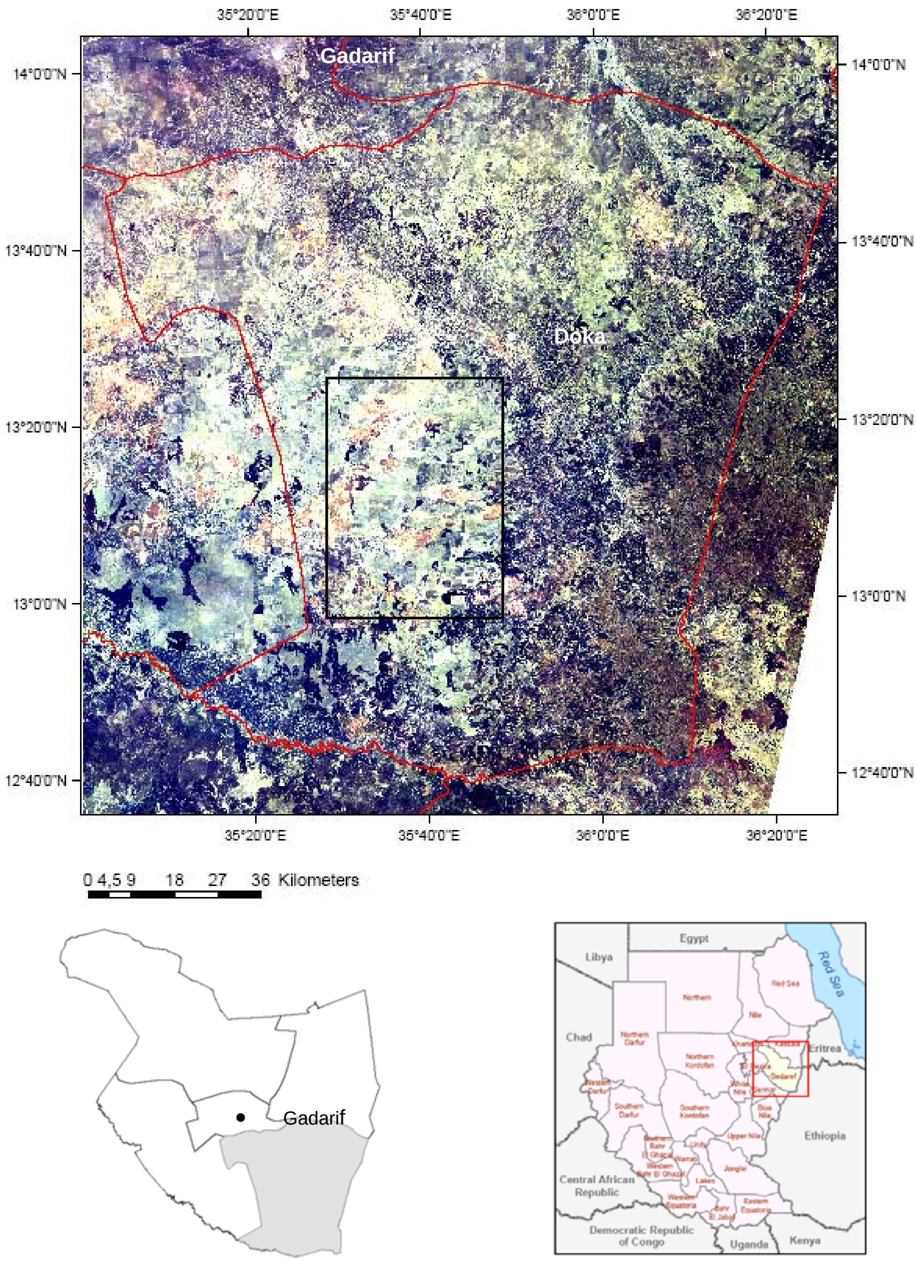

Figure 1.1: Location map of the study area. The background is Landsat ETM image (March 2003).

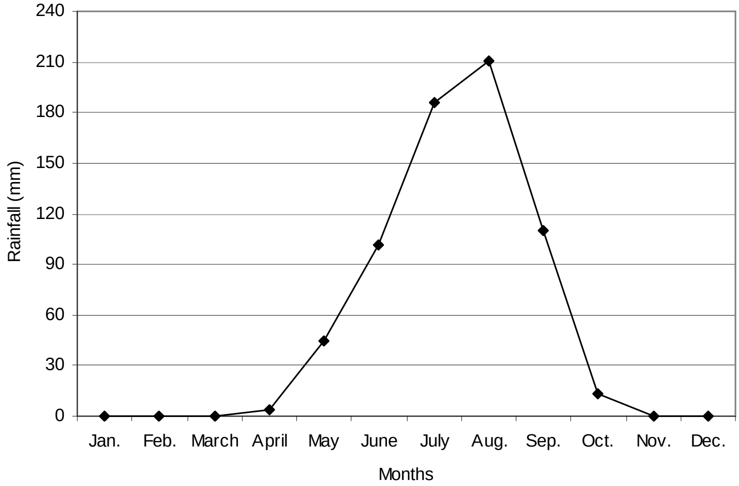

Figure 1.2: Mean monthly rainfall distribution pattern in the Doka Area. Source: MFC (2007).

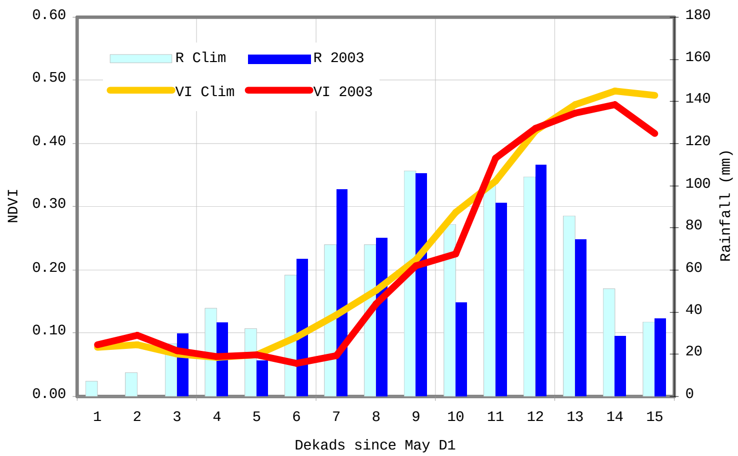

Figure 1.3: Rainfall and Normalised Difference Vegetation Index for 2003 rainy season in an area around Doka. 2003 decadal actual rainfall as dark blue bars, long term average decadal rainfall as light blue bars, 2003 decadal NDVI as a red continuous line, long term average decadal NDVI as an orange continuous line. Source: SEWS (2003).

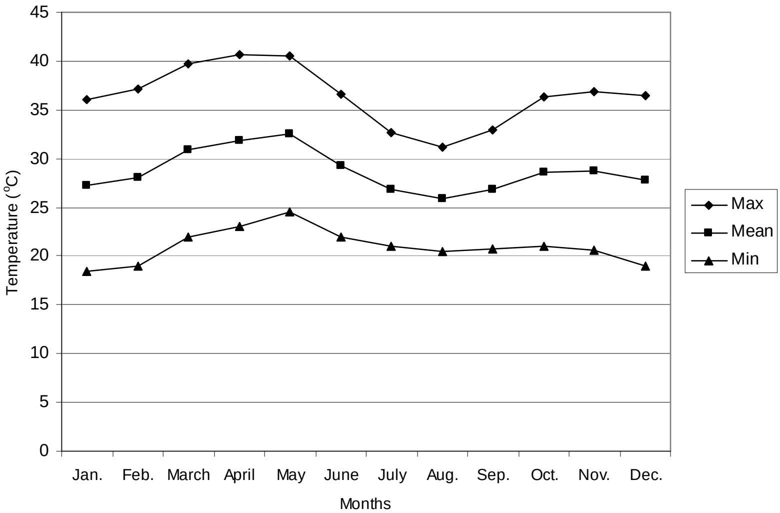

Figure 1.4: Mean, minimum and maximum temperature patterns in the Doka Area. Source: FAO (1997).

Table 1.1: Population growth rate for the town of Doka.

year	population
1973	4 857
1983	12 218
2006	20 232

Source: World Gazetteer (2007).

1.4 Land-Use Types

Agriculture is the main economic activity, followed by livestock raising in the traditional seasonal transhumance pattern (Figure 1.5), village livestock raising and, as a recent element, livestock raising by large-scale mechanized merchant-farmers investing surplus wealth in cattle. Gum tapping, collecting and trading forest products and charcoal burning are other traditional forms of economic activity. Thus, the people derive their income from various combinations of the three main forms of land-use: agriculture, grazing, and forest exploitation. Mechanized rain-fed crop production, has considerably reduced the land available for small-holder farming and for grazing (Glover, 2005). Elmoula (1985) stated that the traditional pattern of land-use has been profoundly changed by population growth,

Figure 1.5: Livestock raising in the traditional seasonal transhumance. South west of Doka. Photographs by the author. July 2006.

the influx of refugees from Ethiopia, a succession of drought years and more than anything else, the unbridled expansion of large-scale mechanized farming since the 1940s.

By blocking the extension of traditional shifting cultivation as the population grows, the expansion of large-scale mechanized farming has gradually reduced the soil-restoring fallow period to zero, while creating landless peasants in the process. Continued mono-cropping on traditional and large scale mechanized agriculture has caused a decline in crop yields and an increase in infestation of cropland by the hemi-parasitic plant *Striga hermontheca*. Mechanized farming has taken over nomads' traditional grazing lands and blocked traditional migration routes (Glover, 2005).

1.5 Mechanized Rain-Fed Agriculture in the Gadarif Region

1.5.1 General

Large scale mechanized agriculture (using tractors, disc harrows and seed threshing) is the driving force for land-use/and-cover (LULC) change in the study area. Clearance of natural vegetation to provide new agricultural land has caused dramatic changes in the natural resources in the area and subsequent land degradation. Agricultural mechanization was introduced in the Gadarif Region since 1944, when a government project was started to meet the food needs of army units stationed in the British colonies in eastern Africa (present-day Kenya, Tanzania, and Uganda). An average of about 6,000 hectares per year was cultivated between 1945 and 1953, producing mainly sorghum, under a sharecropping arrangement between the government and farmers who had been allocated land in the project. In 1954 the government began encouraging the private sector to take up mechanized farming in the area, a policy that continued after Sudan gained independence in 1956. Under the new approach, the government established several state farms to demonstrate production methods and to conduct research. The private sector response was positive, and by 1960 mechanized farming had spread into other areas of the Gadarif Region and other parts of the central clay plains (e.g. Damazin). The government set aside rectangular areas that were divided into plots of 420 hectares each. Only a few crops had been found suitable for cultivation in the cracking clay area. Sorghum had been the principal one followed by Sesame and Cotton.

1.5.2 Expansion of Mechanized Agriculture and Vegetation Clearing

LULC changes are always caused by multiple interacting factors originating from different levels of organization of the coupled human-environmental systems. The mix of driving forces of LULC change varies in time and space, according to specific human-environment conditions. Driving forces can be slow variables, with long turnover times, which determine the boundaries of sustainability and collectively govern the land-use trajectory, or fast variables, with short turnover times (Lambin *et al.*, 2003). However, the current study emphasizes on agricultural expansion because it is generally recognized as a primary driver of LULC change in the Gadarif Region. Agricultural expansion is important for two reasons: intensification of agriculture can result in higher rates of carbon sequestration (Woomer *et al*., 1997), and also considered to be a key driver for removal of natural vegetation which is the major carbon stock in many regions, especially in sub-Saharan Africa (Wood *et al*., 2004). Other major natural vegetation losses in the Gadarif Region are due to over-grazing, fuel-wood harvesting, charcoal and building material production.

Although Sudan is one of the wealthiest countries of Africa in terms of natural resources, the conflicting goals between increased production and sustainable resource management became evident in the rain-fed agriculture, particularly in the large-scale mechanized farming. After over half a century of unsustainable use, studies indicate that considerable amount of land are degraded to varying degrees (Ayoub, 1999). The rapid growth of the population in Sudan (2.6 %; UNFPA, 2003) stimulated the evolution of mechanized rain-fed agriculture in the Gadarif Region from 500 ha in the 1940s to about 2.3 million ha in 2003 (Figure 1.6). Nearly one third of Sorghum (*Sorghum bicolor*) (the primary stable crop) and Sesame (*Sesamum indicum*) produced in Sudan are cultivated in this region. Like most developing countries, Sudanese economy depends largely on agriculture. In order to achieve sustainable agricultural development, priority has to be put on maintaining and improving the capacity of the higher potential agricultural lands to support the expanding population and on conserving and rehabilitating the natural resources on lands with a lower agricultural potential (Hassan, 2002).

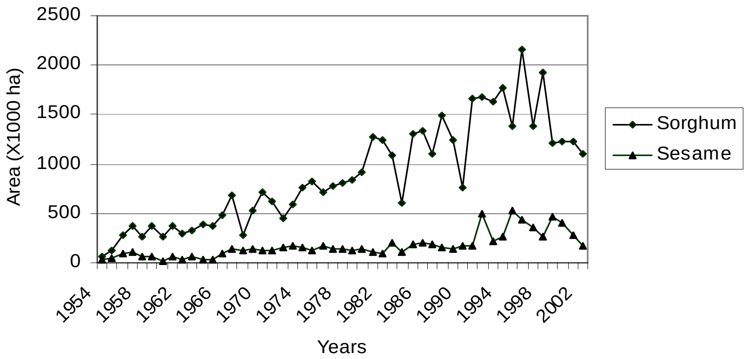

Figure 1.6: Total area of the two main crops in the Gadarif Region for the period 1954 – 2003. Source: MFC (2007).

The Global Forest Resource Assessment (FRA, 2005) Report showed that 28.4 % (67 546 000 ha) of Sudan is forested. The change in forest cover between 1990 and 2000 averaged to 589 000 hectares of forest per year, which amounts to an average annual deforestation rate of 0.77 %. Measuring the total rate of habitat conversion for the 1990 – 2005 intervals, Sudan lost 11.6 % of its forest and woodland habitat. According to SCSB (2001) there are 112 plant species of which 91 species are endangered and three species almost extinct in the study area.

Land-cover mapping using remotely sensed data not only provides a current inventory of resources and land-use, but also provides an opportunity to identify and monitor changing patterns of LULC (Peterson *et al*., 2004). For relatively large areas traditional methods for monitoring such changes relying on field data and aerial photography can be costly and time-consuming. The cost of such traditional field surveys could be one of the limiting factors for countries like Sudan. However, satellite imagery gives unique and indispensable capabilities for assessing and monitoring natural resources at comparatively moderate costs.

1.6 Land Degradation

Land degradation is the deterioration in quality of land brought about by human activity, usually a change or intensification of land-use without due care (Ayoub, 1999). Land degradation is most severe and widespread in semi-arid regions and measuring rates of dry land degradation is a much more complex challenge considering the strong interaction between natural environment (climatic factors) and anthropogenic changes. The interactions between the physical and anthropogenic processes leading to dry land degradation are more complex than in the case of forest clearing. One of the important research areas in LULC change is the integration of human activities (Lambin and Ehrlich, 1997).

Despite the acknowledgment of land degradation as a major bottleneck of agricultural productivity and natural resources management by farmers and policy makers, the issue of land degradation was not considered as a top priority in the national policy of poverty alleviation in Sudan (Glover, 2005). Sole cropping and the absence of fertilizer use have caused a decline in yields and degradation of the soils. The main problems at present are difficulties in land preparation and timely sowing, lack of fertilizer inputs and crop rotation, and inadequate control measures of pests and diseases (Babiker, 1989).

The SKAP (1992) Report – which is the only relatively recent comprehensive document for the study area - stated: ´´The cultivable land is now almost entirely used up in ways which neither conserve the natural resources, nor sustain production from them, nor maximise their potential´´.

1.7 Conflicts on Natural Resources Use

Environmental degradation is among the root causes of decades of conflict in Sudan a new UNEP (2007) report argues, warning that the country is unlikely to see lasting peace unless it is addressed. The most serious concerns are land degradation, desertification and the spread of deserts southwards. These are linked with factors including overgrazing of fragile soils by a livestock population that has exploded from close to 27 million animals to around 135 million now. Many sensitive areas are also experiencing a deforestation crisis. Indeed, some areas may undergo a total loss of forest cover within the next decade. Meanwhile, there is mounting evidence of long-term regional climate change in several parts of the country.

The rapid and extensive expansion of rain-fed mechanized farming schemes in the Gadarif Region has meant that nomadic herders lost a large share of their traditional grazing areas and migration routes. Moreover, the expansion in large-scale mechanized farming came at the expense of traditional rain-fed agriculture, which consequential caused conflicts between alternative land uses and users. Primary participants in these conflicts included traditional farmers, nomads, large-scale mechanized farmers, forestry officials trying to protect forest reserves, fuelwood sellers, and charcoal-makers. These conflicts were - and remain - difficult to resolve because of the vast areas of the country covered by mechanized agriculture (Elnagheeb and Bromley, 1992). Demands on both arable land and grazing areas tend to be too heavy and physical and chemical soil deterioration are serious threats (Blokhuis, 1993).

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2 Multi-Temporal Analysis of Vegetation Clearing and Expansion of Mechanised Rain-Fed Agriculture

2.1 Abstract

The study is an effort to produce synthetic knowledge on the rapid land-use/land-cover (LULC) changes and on the integrating rates of change with fundamental patterns in the southern Gadarif Region, Sudan, for the period 1972 - 2003. Agricultural expansion is widely documented as one of the major drivers of theses changes. Comparisons of LULC changes showed that the land-cover of the southern Gadarif Region has changed drastically since the introduction of mechanized rain-fed agriculture in the area. The average natural vegetation clearing rate was around 0.8 % per year, and the most rapid clearing occurred during the seventies when conversion rates increased to about 4.5 % per year. Both the largest and average rate of vegetation clearing exceeds the average rate of deforestation for the entire country. Recently, the conversion of natural vegetation to agricultural land has slowed down. Information about patterns of LULC changes through time in the southern Gadarif Region is important not only for the management and planning of these areas, but also for a better understanding of the human dimensions of environmental changes at regional scale.

2.2 Introduction

2.2.1 General

Presently a global increase in the awareness of environmental, social and economic values of native vegetation, particularly in terms of both sustainability of agricultural production and maintenance of natural resources can be noticed. The relationship between agricultural productivity and economics has driven patterns of human land-use and population distribution throughout the history. This close relationship has only recently been disturbed by potentially motivated economic subsidies (Huston, 1995).

LULC change detection analysis has become a major application of remote sensing technology in recent decades. Thus remotely sensed data represents a viable source of LULC information which can be efficiently and cheaply extracted in order to assess and monitor these changes effectively, because of repetitive coverage in short intervals and consistent image quality (Mas, 1999). Nevertheless, timely and accurate change detection of Earth surface features is extremely important to understand relationships and interactions between human and natural phenomena in order to promote better decision making (Lu *et al*., 2004).

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). It involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the phenomenon. Due to the advantages of repetitive data acquisition, its synoptic view, and digital format suitable for computer processing, remotely sensed data have become the major data sources for different change detection applications during past decades. A proper change detection research should provide the following information: area change and change rate; spatial distribution of changed types; change trajectories of land-cover types; and accuracy assessment of change detection results (Lu *et al*., 2004). However, many factors are affecting multi-temporal analysis. Coppin *et al*. (2004) stated that all digital change detection methods are affected by spatial, spectral, temporal and thematic constraints. In the same environment, different approaches may yield different change maps. Moreover, because of the impacts of complex factors, different authors often arrived at different and sometimes controversial conclusions about which change detection techniques are most effective. In practice, it is not easy to select a suitable algorithm for a specific change detection project. Hence, a review of change detection techniques used in previous research and applications is useful to understand how these techniques can be best used to address specific problems. When study areas and image data are selected for research, identifying a suitable change detection technique gains importance for good-quality change-detection results (Lu *et al*., 2004).

LCLU change detection provides fundamental input for planning, management and environmental studies, such as landscape dynamics or natural risks and impacts (Serra *et al*., 2003). Due to its temporal resolution, remotely sensed data provides an excellent historical framework for estimating the spatial extent of LULC changes and in this respect remotely sensed data represents the solely source of such information in many parts of the world, specially in developing countries. Singh (1989) classified change detection into two basic approaches: Comparative analysis of independently produced classifications from different dates (post-classification comparison: map-to-map comparison) and Simultaneous analysis of multi-temporal data (multi-date classification and others: image-to-image comparison). Both approaches have advantages and disadvantages. Moreover, if the images used for each classification are from different seasons of the year, the comparison can be more difficult, especially for some legend items which are based on vegetation phenology (Serra *et al*., 2003).

2.2.2 Post-Classification

Post-classification is a term describing the comparative analysis of spectral classifications for different dates produced independently (Singh, 1989). The technique compares, on a pixel-by-pixel basis, multiple maps created from remotely sensed data collected at different times (Peterson *et al*., 2004). It identifies not only areas of change, but also provides directional information of the observed change (Jensen, 1996). By adequately coding the classification results, a complete matrix of change is obtained, and change classes can be defined by the analyst. The principal advantage of post-classification lies in the fact that the two dates of imagery are separately classified; thereby minimizing the problem of radiometric calibration between dates (Coppin *et al*., 2004). Through choosing the appropriate classification scheme, the method can also be made insensitive to a variety of types of transient changes in selected terrain features that are of no interest. The final accuracy very closely resembles that resulting from the multiplication of the accuracies of each individual classification and may be considered intrinsically low. Foody (2001) sated that accurate classifications are vital to insure precise change-detection results. Miss-classification and miss-registration errors that may be present in the original images are compounded and results obtained using post-classification comparison are therefore frequently judged unsatisfactory (Howarth and Wickware, 1981).

In a variety of studies, the post-classification change detection method was found to be the most suitable one for detecting LULC change (Howarth and Wickware, 1981; Mas, 1999; Serra *et al*., 2003; Peterson *et al*., 2004). Mas (1999) compared six change detection procedures using Landsat MSS images for detecting areas of changes in the coastal region of the State of Campeche, Mexico. The change detection techniques used were image differencing, vegetation index differencing, selective principal component analysis, direct multi-date unsupervised classification, post-classification change differencing and a combination of image enhancement and post-classification comparison. Post-classification comparison was found to be the most accurate procedure and presented the advantage of indicating the nature of the changes. Methods based on classification were found to be less sensitive at these spectral variations and more robust when dealing with data captured at different times of the year. Peterson *et al*. (2004) stated that the use of co-occurrence matrices and post-classification change detection analysis successfully identified historical and recent land-cover change in Kansas, USA, using Landsat TM data. They found that conversion of grassland to cropland was the most prominent historical land-cover change and some prairie types have been reduced in area more dramatically than others. García-Aguirre *et al.* (2005) evaluated changes in forest cover during a 16-year period by means of a post-classification technique at a site to the southwest of the Basin of Mexico City. The overall classification accuracy ranges from 59.8 % to 70.2 %. They stated that the technique was preferred over other change detection methods since it offers the advantage of indicating the nature of changes, such as forest to shrub-land, cropland or other land uses.

2.2.3 Motivation of Study

After about fifty years from the introduction of mechanized rain-fed agriculture in the southern Gadarif Region, it is essential to assess the impact of this introduction on the natural resources, namely natural vegetation, so as to have a clear vision of sustainable management and utilization of this vital resource for its present use and future perspectives. Analysis of the recent history of LULC offers a present-day baseline for assessing future landscape patterns and their consequences (Zheng *et al*., 1997). Recently, remote sensing and GIS have significantly improved the capability to monitor processes of LULC change and therefore become fundamental tools for understanding and monitoring of deforestation and secondary succession processes, particularly in the tropics, the area with the most promising research opportunities (Westman *et al*., 1989).

2.2.4 Objectives

Within this context, the objectives of the study are to identify changes in the spatial and temporal pattern of the natural vegetation due to the expansion of mechanized rain-fed agriculture and to quantify rates of change in LULC for the period 1972 – 2003.

2.3. Data Sets

Cloud-free Landsat Multi-spectral Scanner (MSS) and Enhanced Thematic Mapper (ETM) imagery have been utilized for the multi-temporal change detection (Table 2.1). Due to the unavailability of other sources of data Landsat imagery represents the only available data source for detecting historical LULC changes in the study area. Moreover, its consistency of acquisition over the last four decades and reasonable spatial resolution make it an indispensable means for LULC classification world-wide.

Table 2.1: Satellite imagery used for the multi-temporal change detection.

Satellite	Sensor	Path/row	Acquisition date	Spatial resolution (m)
Landsat 1	MSS	184/51	1972-12-11	60*
Landsat 3	MSS	184/51	1979-11-23	60*
Landsat 4	MSS	171/51	1989-12-12	60
Landsat 7	ETM	171/51	1999-11-06	30
Landsat 7	ETM	171/51	2003-03-22	30

*****Resampled resolution.

2.4 Methodology

When implementing a change detection project, three major steps should be involved: 1) image pre-processing including geometrical rectification and image registration, radiometric and atmospheric correction, and topographic correction if the study area is located in relief terrain; 2) selection of suitable techniques to implement change detection analyses; and 3) accuracy assessment (Lu *et al*., 2004).

2.4.1 Pre-Processing

Even for the new generation of space sensor systems image pre-processing remains an essential initial step for any remote sensing application. Image corrections are also necessary for the current study for many reasons. Multi-sensor imagery (four different sensors) will be utilized, namely Landsat 1, 3, 4 and 7. Moreover, the temporal range of the imagery set is about 30 years (1972 to 2003) using scenes from five dates. For sure, during this relatively long period, many factors changed. Not only atmospheric and radiometric differences but also sensor degradation and sometimes mal-function could happen. However, because of non-availability of field measurements and data that could be used for absolute image corrections, relative corrections were always followed based on information either extracted from the image itself or on the accompanying metadata. Moreover, the result of image pre-processing is crucial for the subsequent selection of the change detection method. Song *et al*. (2001) stated that when and how to apply atmospheric corrections depends on the remote sensing and atmospheric data available, the information desired, and the analytical methods used to extract the information. In many applications involving classification and change detection, atmospheric correction is unnecessary as long as the training data and the data to be classified are at the same relative scale. In other circumstances, corrections are mandatory to put multi-temporal data on the same radiometric scale in order to monitor terrestrial surfaces over time. Precise geometrical registration and atmospheric correction or normalization between multi-temporal images is prerequisites for a change detection project. Identifying a suitable change detection technique has considerable significance for a study area to produce good change detection results (Lu *et al*., 2004). To what extent the pre-processing results of the current study fits to pre- or post-classification change detection techniques will be discussed later in this chapter.

2.4.1.1 Radiometric and Atmospheric Correction

Improved Image-Based Model (COST Model)

To correct both solar and atmospheric effects at-satellite radiance must be converted to surface reflectance. To achieve this goal Chavez's (1996) COST Model was used. The method is quite useful, especially when the absolute atmospheric parameters are not available like in our case. COST is a widely used method of reducing haze within an image and is done for each band individually. The concept of the model relies on dark object subtraction. It is assumed that there are pixels within each band of a multi-spectral image that have very low or no reflectance on the ground and that the difference between the brightness value of these pixels and zero is due to haze (Chavez, 1996; Moran *et al*., 1992). This estimated difference is subtracted from each band of the image (Chavez and Bowell, 1988). However, this relative normalization method assumes that the effects of haze are distributed evenly across the entire image, which may or may not be the case (Callahan, 2003). The main advantage of this model is that it is a strictly image-based procedure and therefore, does not require *in-situ* field measurements and it is simple and straightforward to apply (Rahman, 2004). The main disadvantages are that for reflectance values greater than about 15 percent the accuracy is often not acceptable and that the selection of the haze values must be done with care (Chavez, 1996).

The COST model which uses dark object subtraction can be written as:

$$REF = \frac{PI \times (L_{sat\lambda} - Lhaze_{\lambda})}{(TAUv \times (Eo \times Cos(TZ) \times TAUz + Edown))} \qquad [2.1]$$

where:

REF = Spectral reflectance of the surface

$L_{sat\lambda}$ = At-sensor solar radiation for band λ enumerated from the Markham and Barker (1987) equation (Equation below).

$Lhaze_{\lambda}$ = Atmospheric-scattered path radiation for band λ.

TAUv = Atmospheric transmittance along the path from the ground surface to the sensor.

Eo = Solar spectral irradiance on a surface perpendicular to the sun's rays outside the atmosphere. Eo contains the Earth-sun distance term imbedded and is given in astronomical units.

TZ = Angle of incidence of the direct solar flux onto the Earth's surface (solar zenith angle = 90 – solar elevation angle).

TAUz = Atmospheric transmittance along the path from the sun to the ground surface.

Edown = Down-welling spectral irradiance at the surface due to scattered solar flux in the atmosphere.

At-Satellite Reflectance

The Markham and Barker (1987) equation to convert satellite DNs to at-satellite radiances was applied. It writes:

$$L_{sat\lambda} = (DC_{\lambda} - Offset)/Gain \qquad [2.2]$$

Alternatively this can also be calculated using the following equation:

$$L_{sat\lambda} = LMIN_{\lambda} + \frac{(LMAX_{\lambda} - LMIN_{\lambda})}{DCMAX} x DC_{\lambda} \qquad [2.3]$$

Where:

DC_{λ} = Calibrated and quantized scaled radiance in units of DN, digital number for band λ

$L_{sat\lambda}$ = At-sensor solar radiation for band λ

$LMAX_{\lambda}$ = Spectral radiance at maximum DC (255) for band λ

$LMIN_{\lambda}$ = Spectral radiance at minimum DC (255) for band λ

MCMAX= Range of rescaled radiance in DN = 255

However, both equations determine the same, only the coefficient factors are different. The values for $LMAX_{\lambda}$ and $LMIN_{\lambda}$ were enumerated according to Markham and Barker (1987) and Irish (2004) and they are always included in the metafile of imagery.

2.4.1.2 Temporal Rectification

Before a time series of remotely sensed imagery can be used for change detection, a common radiometric response is required for quantitative analyses of multiple satellite images of scenes acquired on different dates with different sensors. Due to the scarcity of historical atmospheric and ground reflectance data, researchers often decided for a normalization method that corrects a set of images relative to a reference image. In this study the methods developed by Hall *et al*. (1991) will be followed in order to fulfil the temporal rectification. They described a technique to "radiometrically rectify" multiple Landsat images to a reference image. The radiometric rectification algorithm they developed consists of two major components. First, radiometric control sets that have little or no variation in their mean surface reflectance between images. The members of these sets are not necessarily the same pixels from image to image. The second component radiometrically rectifies the images using a linear transformation with coefficients calculated to equalize the individual band means (in raw digital counts) of the radiometric control sets in each image using the following equation as example:

$$ETM_{t=1}\ (DN) = slope * ETM_{t=2}\ (DN) + intercept \qquad [2.4]$$

The target brightness values from the scenes to be normalized (as independent) were regressed against the target brightness of the reference image (as dependent). This is a linear regression model relating each band of each pairing of images, consisting of an additive component (*intercept*) which accounts for the difference in path radiance, and a multiplicative component (*slope*) which corrects for differences in detector calibration (Callahan, 2003).

Water ponds were used as radiometrically stable objects. Relative temporal normalisation is based on the assumption of a linear relationship between image bands across time. The linear relationship can be determined from radiometric measurements over pseudo-invariant features in the images which are objects spatially well defined and radiometrically stable such as clear deep lakes, dense homogeneous mature forests, gravel-covered area (Song *et al*., 2001). Due to the lack of objects radiometrically stable over addressed period the coefficient of fit for the regression model was not as high as the usual value suggested by Vogelmann *et al*. (2001). The highest value of R^2 was 0.68. Based on the results it was not advisable to use a direct change detection technique. This could be due to relatively small size and shallow water Ponds. The ponds on Figure 2.1 show clear changes over time.

2.4.1.3 Geometric Rectification and Georeferencing

Geometric corrections are critical to enable accurate multi-temporal imagery analysis and vegetation mapping. Scene to scene registration to sub-pixel accuracy is required for multi-temporal analysis. Image co-registration was based on 7 to 20 GCPs which were manually placed or automatically matched using image-to-image registration technique in ERDAS Imagine. Landsat ETM+ March 2003, the most recent in the image set, was taken as reference image for the co-registration. The reference image rectification is achieved using 1:100 000 topographic map dated to 1983. However, during this time lag of 20 years the area underwent significant changes. Therefore, it was hard to fulfil the recommended accuracy of less than one pixel for the rectification process due to the recent changes in the area and lack of man-made features. However, the geometric lines of the farm boundary which can easily be detected in the raw images are also changing every few years if not from season to season due to agricultural practices or abandonment. To improve the accuracy ground control points (GCPs) were collected using a handheld GPS which provides 15 m real-time accuracy. This implies also another source of error.

A real challenge was to co-register the Landsat 1 MSS 1972 and Landsat 3 MSS 1979. Due to the moderate resolution combined with the lack of man-made features it was very difficult to fulfil the recommended accuracy. After a careful search it was possible to find 7 GCPs. Figure 2.2 illustrates the location of some GCPs which were just some acute angles in the courses of small rivers which exist in both images and they look similar. Nevertheless, locations of some of these points are changed through time. Gully erosion after heavy rain storms and vegetation clearing are the main causes of small rivers and seasonal water courses to change their direction (Figure 2.2C).

A common approach to compensate the miss-registration is to aggregate pixels of the multi-temporal image data set to yield image arrays with larger ground resolution elements. The rationale is that the magnitude of miss-registration between the multi-temporal images will be minimized relative to the larger land area represented by aggregated pixels (Justice *et al*. 1989). Nevertheless, the disadvantage of this approach is that land cover changes that occur at or below the size of the original ground resolution element may not be detected after the images are aggregated (Stow, 1999).

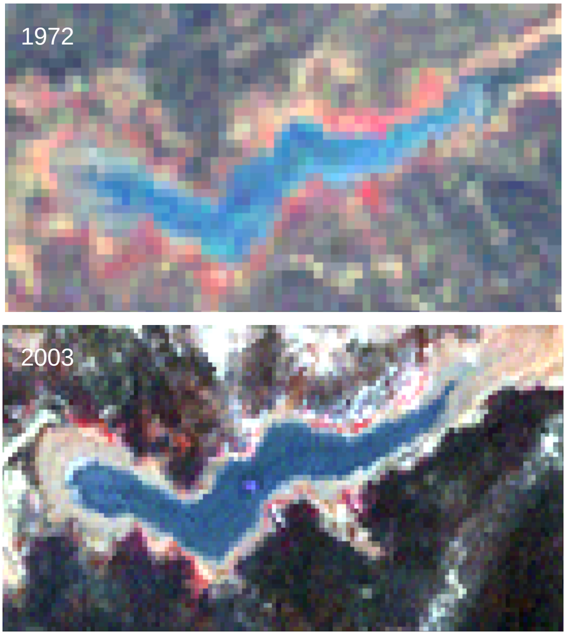
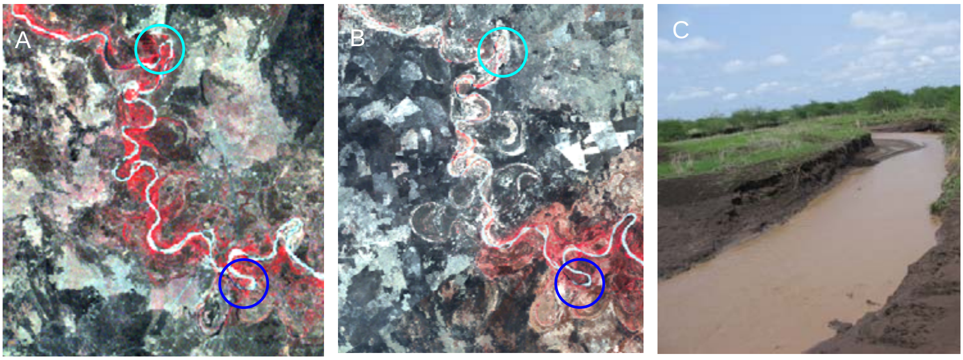


Figure 2.1: Water ponds used as radiometrically stable objects were small (ranging between 2.4 – 2.8 km in length) to calibrate the whole scene.



A

Location of some GCPS on Landsat MSS 1972 (A) and Landsat ETM 2003 (B) (reference image). It is easy to observe how the location changed after 30 years.

C: Gully erosion after heavy rain storms.

Figure 2.2: Illustration for the location of some GCPs and how they are subjected to changes.

2.4.2 Processing

2.4.2.1 Land-Use/Land-Cover Types

The determination of LULC classes was based on field survey, interviews with farmers and visual comparison of the original images. Thus, the major LULC classes were bare land, natural forest, cultivated agricultural land, abandoned agricultural land and secondary forest on abandoned agricultural land. However, the last two classes only appeared after the seventies. It is worth to mentioned that it was meant by natural forest the areas managed by the Forest National Corporation as protected forest land.

2.4.2.2 Supervised Classification

The major step in a straightforward supervised classification is the selection of training pixels. Prior to the identification of training pixels an intensive field survey (March and April 2005) was carried out and historical land-use information was collected from pioneer farmers who were among the first group to invest in mechanized farming in the area. The second group interviewed was the staff of the Forest National Corporation. There exist no recent maps and records documenting the land-use activities for the study area. For the visual comparison with the original images, different viewing utilities and the signature editor of ERDAS Imagine (Version 8.7) were used.

2.4.2.3 Accuracy Assessment

Unfortunately, neither aerial photographs nor ground data could be used to conduct an accuracy assessment of the 1972 and 1979. Due to drastic changes of the LULC in the study area the 1:100 000 topographic map from 1983 was not valid. Instead, the accuracy of the classified image was assessed by visually interpreting the unclassified satellite images. Random samples of 320 points were obtained across each scene. Identification of LULC types of the sampling points for each scene was based on image interpretation and was then recorded for comparison with the results obtained from the classified maps (ERDAS, 2003).

2.5 Results and Discussion

2.5.1 Visual Interpretation

Visual interpretation by displaying the raw image could give a first glance for the LULC changes due to the introduction of the mechanized rain-fed agriculture and how it moved southwards (Figure 2.3). This highly agrees with what has been mentioned by the interviewed farmers. They stated that the first mechanized rain-fed agriculture was practiced in the area around Doka and Kafay and then spread elsewhere, mainly directed towards remote areas in the south. By the mid-eighties all suitable land in the area was under cultivation. Figure 2.3 shows the area which was covered by natural vegetation in 1972 gradually changed to mechanized rain-fed agriculture land in 1989 to 1999 and recently (i.e. 2003) to abandoned agricultural land.

2.5.2 Training Data Evaluation

It is important that training samples are representative of their class. This does not necessarily mean that they contain a large number of pixels or are dispersed over a wide region. The selection of training samples largely depends upon the knowledge about the data of the study area and about the classes you want to extract (ERDAS, 2003). Selecting training samples is often an iterative process. The selection of signatures that accurately represent the classes was carried out using a contingency matrix. Contingency matrices perform a quick classification of the pixels in a set of training samples. This allows getting an impression of considering what percentages of the sample pixels are actually classified as expected. In order to obtain an appropriate level of classification accuracy, contingency of training data were tested prior to the classification using the ERDAS Imagine signature evaluation tools.

The contingency matrix utility allows the evaluation of signatures created from different areas of interest (AOIs) in the image. This utility classifies only the pixels in the AOI training samples based on the signatures generated from these AOIs. The output of the contingency matrix utility is a matrix of percentages and/or pixel numbers that allow seeing how many pixels in each training area were assigned to each class. A perfect set of training data would result in a contingency utility only along the diagonal (Appendix 2.1).

2.5.3 Accuracy Assessment

Based on the comparison with 320 points, overall classification accuracies were estimated to be 88.50 %, 85.19 %, 89.90 %, 92.12 and % 90.71 for 1972, 1979, 1989, 1999 and 2003 respectively. Standard errors obtained from the accuracy assessment performed were ranged between 1.4 % for bare land and 6.8 % abandoned agricultural land. While the purpose of this study was to detect major changes in land cover over the last thirty years rather than to develop a detailed classification of the LULC, the accuracy gained and its standard deviation seem to be sufficient. Moreover, comparisons of unclassified and classified sub-areas from 1989 show a good agreement (Figure 2.4). Zheng *et al*. (1997) performed a comparison with 345 visually interpreted points from each image; the overall classification accuracies were estimated to be 81.9% and 91.8% on the 1988 and 1972 land-cover maps, respectively in Changbai Mountain area of China and North Korea.

It was observed that it was not always like this that the higher resolution imagery has grater classification accuracy. Though containing more detailed ground information, the images of finer spatial resolution do not necessarily achieve higher classification accuracy (Hsieh and Lee, 2000; Huiping *et al*., 2003).

2.5.4 Maximum Likelihood Classification

The results of the maximum likelihood classification are shown in Table 2.2, while Figure 2.5 depicts the visual display. During the seventies the LULC consisted of three classes: bare land, natural forest and cultivated agricultural land. Later abandoned agricultural land and secondary forest on abandoned agricultural land appeared. The area under cultivation was drastically expanded on the expenses of the natural vegetation cover. During 1980s, however, farmers began to abandon their land. Land abandonment was detected in many areas, even in the newly cultivated land in the southern part. This may be due to the problem of accessibility where there is no paved road and especially after the establishment of the rainy season (e.g. July – August) the sticky heavy clay soil was very difficult to be crossed even for 4-wheel vehicles (Appendix 2.2). Therefore most of these areas are now covered by secondary forest (Figure 2.5). This rapid regrowth of forest could be, beside the inaccessibility for illicit felling, due to short period of cultivation which has significant effect on the soil seed bank and nutrients. Accessibility has to be considered as one of the most important driving factors of LULC change (cf. Geist and Lambin, 2002). The possibility for people to reach desired locations, such as a market or forest land, can influence both the extent and the location of land-use conversions (Verburg *et al*., 2004).

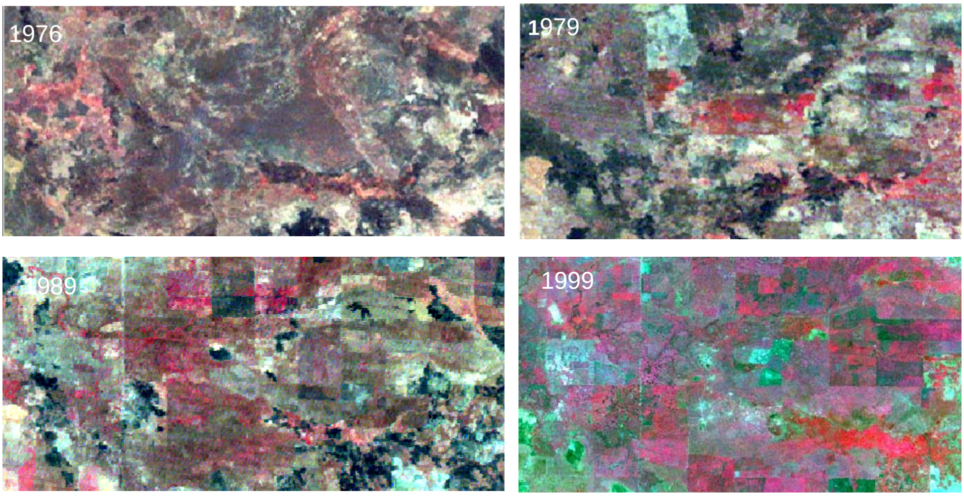
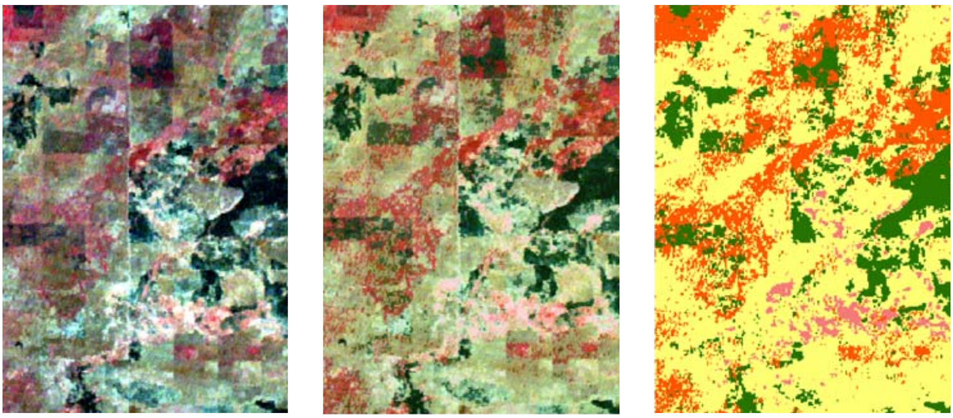


Figure 2.3: Visual interpretation of LULC changes from raw imagery sets. On 1979 image and thereafter it is easy to observe the mechanized rain-fed agriculture expansion from the geometric forms of agricultural land parcels. ☐ Location of the sub-scene in the study site.



A: Unclassified B: Blending of raw and classified C: Classified

Figure 2.4: Comparison for unclassified (raw) (A) subset of 1989 and after classification (C). B: Shows high degree of agreement by overlaying of A and B using blend utilities of ERDAS Viewer.

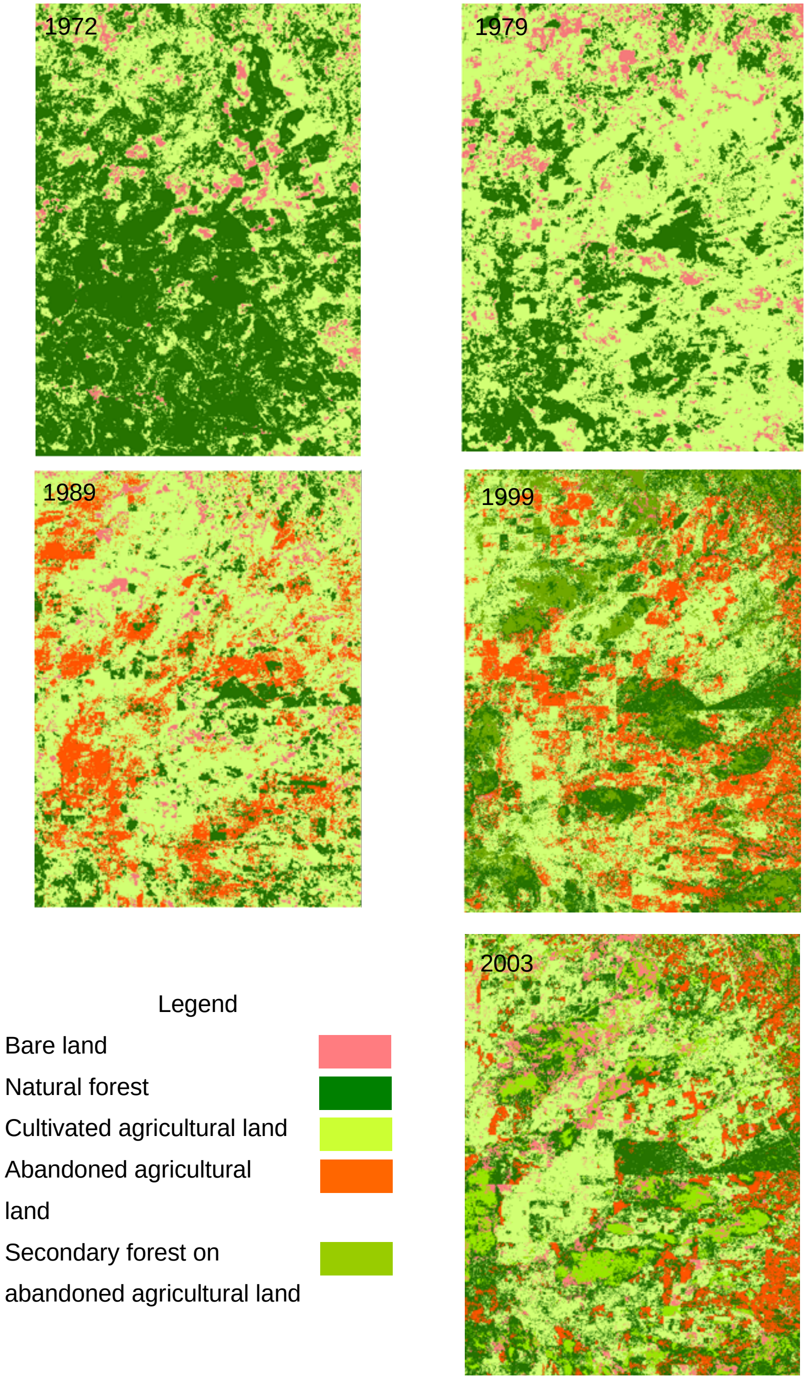


Figure 2.5: Maximum likelihood classification showing LULC through the period 1972 – 2003.

Table 2.2: Area (ha) and percentage of LULC classes during the study period 1972 – 2003.

Class	1972		1979		1989		1999		2003	
	Area	%	Area	%	Area	%	Area	%	Area	%
1	8235	06	13053	07	8164	05	2027	01	13874	07
2	107102	58	49346	27	26305	14	46243	25	56631	31
3	67239	36	120178	66	113824	62	73609	40	69055	38
4	NO*		NO		35472	19	38251	21	21548	12
5	NO		NO		NO		22222	12	21318	12

Where 1: Bare land, 2: Natural forest, 3: Cultivated agricultural land, 4: Abandoned agricultural land and 5: Secondary forest on abandoned agricultural land. *NO: LULC class not existed.

2.5.5 Land-Use/Land-Cover Change Rates

Post-classification comparisons provides "from-to" information. Actual change can be obtained by a direct comparison between classified images from one date with that from the other date. Temporal changes that have occurred between the two dates can be measured by performing a change matrix (Appendix 2.3).

The period 1972 to 1979 shows an intensive clearance of natural vegetation due to a dramatic expansion of mechanized rain-fed agriculture. It reached to 4.52 % per year and the total area under the plough was about 120178.30 ha (65.9 %). According to the information collected from the farmers, the seventies were the golden time of the rain-fed mechanized agriculture in the region, and the high initial profitability encouraged many farmers to clear new areas from its natural vegetation. Moreover, opening new areas has double benefit, gaining a new fertile agricultural land and at the same time selling the harvested wood at local market as fire wood and or building materials. Woody materials are still the main building material in the region. Abandoned agricultural land could not been detected during this period.

The LULC changes for the period 1979 – 1989 show also a decrease of the natural vegetation and also of the abandoned agricultural land appeared during this period (represent 10.8 %). It is clear that the agricultural expansion reached its culmination during this period, and farmers started to abandon parts of their land due to drops in crop yield or weed invasion. Later, during the period 1989 – 1999, the conversion of natural vegetation to agricultural land has slowed down and abandoned land increases. Only about 40 % of the area was under cultivation, whilst the natural vegetation (the already existing one and the parts which could naturally re-establish) makes up about a quarter of the area.

The abandoned agricultural land could be managed as natural restoration sites by following appropriate silvicultural strategies. This could enhance the productivity of abandoned areas for producing firewood or building materials, whilst enhancing the conservation value of the natural regrowth. Asefa *et al*. (2003) stated that land abandonment is the common conservation strategies to promote restoration of biodiversity in degraded agricultural and grazing lands.

The average natural vegetation clearing rate during the study period was around 0.79 ha per year. Both the average and largest rate of deforestation exceed the average rate of deforestation for the entire country (FRA, 2005). The magnitude of increases in natural vegetation during the nineties was questionable. However, this may be due to registration errors and classification methodologies used to generate the LULC maps. Land-use change patterns in the study area have been caused by two different contradicting agents: vegetation clearing for mechanized rain-fed expansion and abandonment of agricultural land after degradation.

Digital change detection allows quantification of temporal phenomena in multi-date satellite imagery (Coppin and Bauer, 1996). In spite of numerous estimates of deforestation using satellite imagery and other sources, several uncertainties exist, including estimates of the rates and extent of deforestation and land-uses mapped with satellite imagery. Generally, forest clearing and vegetation regrowth can be distinguished visually in Landsat data. It is difficult, however, to differentiate land cover types exhibiting vegetation regrowth in its early successtional stage. Deforestation of primary and regenerating forest in Rondônia, Brazil was easily detected in the 30m resolution classification of the multi-date composite by Guild *et al*. (2004). Most of the inaccuracy of the classification was associated with spectral confusion of some regrowth areas that were classified as being in a cleared state.

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2.7 Appendix

Appendix 2.1: Contingency matrix of training data for the maximum likelihood classification.

Year	Classified data	Reference data (%)					Total pixel
1972		1	2	3			
	1	**100**	0.00	0.52			1733
	2	0.00	**99.55**	0.78			11739
	3	0.00	0.45	**98.70**			6264
	Total pixel	1700	11743	6293			19736
1979		1	2	3			
	1	**100.00**	0.02	0.19			1388
	2	0.00	**93.51**	1.41			16076
	3	0.00	6.46	**98.39**			11204
	Total pixel	1364	17036	10268			28668
1989		1	2	3	4		
	1	**99.97**	0.03	0.33	0.00		
	2	0.00	**91.58**	1.99	0.40		
	3	0.03	6.83	**96.58**	1.66		
	4	0.00	1.56	1.10	**97.94**		
	Total pixel	2905	35353	35111	19294		
1999		1	2	3	4	5	
	1	**99.38**	0.01	0.00	0.00	0.34	509
	2	0.00	**93.87**	2.32	0.24	1.91	23430
	3	0.00	2.87	**96.95**	0.20	0.03	8146
	4	0.00	0.59	0.56	**99.56**	0.00	2656
	5	0.62	2.66	0.17	0.00	**97.73**	7373
	Total pixel	486	24625	7667	2478	6858	42114
2003		1	2	3	4	5	
	1	**99.82**	0.04	2.08	0.00	0.48	2517
	2	0.00	**95.63**	1.05	2.60	1.48	25548
	3	0.09	2.02	**96.71**	0.02	0.11	12410
	4	0.00	0.83	0.06	**97.38**	0.00	4908
	5	0.09	1.48	0.11	0.00	**97.92**	6672
	Total pixel	2224	26351	12272	4809	6399	52055

2.2 Appendix: Field trip try to southern part of the study area during the second week of July 2007. The sticky heavy clay soil was very difficult to be crossed even for a 4-wheel vehicle. Photographs by the author.

2.3 Appendix: LULC change matrices for the period 1972 – 2003.

	1972	1979			Total 1972
Matrix 1	Class	1	2	3	
	1	847.10	1589.55	5798.75	8235.40
	2	5900.98	34064.27	67136.54	107101.80
	3	6304.54	13691.77	47243.00	67239.31
	Total 1979	13052.62	49345.59	120178.30	

	1979	1989				Total 1979
Matrix 2	Class	1	2	3	4	
	1	1158.46	1543.65	8828.63	1600.97	13131.71
	2	1710.75	9042.31	27891.15	11023.80	49668.01
	3	5294.70	15717.54	77104.22	22847.72	120964.20
	4	0.00	0.00	0.00	0.00	0.00
	Total 1989	8163.92	26303.50	113824.00	35472.49	

	1989	1999					Total 1989
Matrix 3	Class	1	2	3	4	5	
	1	256.52	2495.08	1726.13	1420.04	2203.48	8101.25
	2	321.85	9389.06	8105.40	4898.79	3386.45	26101.55
	3	1174.25	28745.28	45422.83	22565.51	15042.24	35200.16
	4	274.43	5613.94	18355.11	9366.59	1590.09	112950.10
	5	0.00	0.00	0.00	0.00	0.00	0.00
	Total 1999	2027.05	46243.36	73609.46	38250.93	22222.26	

	1999	2003					Total 1999
Matrix 4	Class	1	2	3	4	5	
	1	319.51	628.28	428.58	297.57	353.11	2027.05
	2	3493.44	18496.58	10767.71	5055.90	8429.73	46243.36
	3	4470.88	18644.83	37979.18	8597.10	37979.18	107671.20
	4	1869.28	12353.97	14953.09	6215.73	2858.86	38250.93
	5	3725.68	6493.84	4879.74	1372.21	5750.79	22222.26
	Total 2003	13878.79	56617.50	69008.30	21538.50	55371.68	

Where 1: Bare land, 2: Natural forest, 3: Cultivated agricultural land, 4: Abandoned agricultural land and 5: Secondary forest on abandoned agricultural land.

3 Degradation and Abandonment of Mechanized Rain-Fed Agricultural Land Based on the Farmers' Perception

3.1 Abstract

The main objectives of this study were to identify and analyze the farmers' attitudes and perceptions towards agricultural land degradation and abandonment and to examine the impact of land-use history on floristic and structural attributes of the vegetation on the degraded and abandoned agricultural land. The narrative perceptions of the key informants give a clear picture of different historical changes from the introduction of the agricultural mechanization in the Doka area, southern Gadarif. At the same time they succeed to give a good analysis of different aspects concerning plant species changes in the area. The cross-sectional data collection from 41 large-scale farmers using pre-constructed questionnaires was focussed on the personal characteristics of the respondents, on agricultural land, land degradation, abandoning of agricultural land and ethno-botanical information concerning the vegetation cover on cultivated and abandoned agricultural land. The results of the study show that the respondents were aware that soil degradation in various forms taking place on their cultivated agricultural land. This is based on their perception and interpretation of indicators such as weed infestation, reduced soil fertility and soil compaction. Continuous cropping, mono-cropping, rainfall shortage and the use of inferior seeds were the main reasons of land degradation indicated by the farmers. The mitigation measures carried out by farmers to improve land productivity were repeated ploughing, land abandonment, crop rotation and fertilizing. Respondents acknowledged two types of indicators they used to assess the restoration of their abandoned land, e.g. plant species and soil indicators. Farmers prefer to retain certain trees and shrubs species in the cultivated land. They believe that grazing, duration of abandonment, length of previous cultivation, rainfall, fire events and weed composition, are the major factors determining plant species composition and succession on fallow land.

3.2 Introduction

3.2.1 General

Observational and theoretical studies have proved that the destruction of the natural vegetation cover for agricultural expansion and over-cultivation is one of the major causes for the degradation of renewable resources and the environment in tropical Africa and especially in the Sahel Region. Different factors are lying beyond this phenomenon. Identifying the human and social causes of land-use change requires an understanding of how people make land-use decisions and how various factors interact in specific contexts to influence decision making on land-use (Lambin *et al.*, 2003). These causes are formed by a complex of social, political, economic, demographic, technological, cultural and biophysical variables. The analysis of changes in cultural landscapes requires the consideration, and possibly the quantification, of the human impact (Bürgi and Turner, 2002). The role of human activities in land degradation is well documented in the tropics (i a. Ibrahim, 1982; Ayoub, 1992; SKAP, 1992; Larsson, 1996; Lambin, 1997; Ayoub, 1999; Lambin *et al.*, 2003; Sulieman and Buchroithner, 2006).

Since people are the key drivers of disturbances and the subsequent ecosystem attributes in agricultural landscapes, anthropogenic disturbance history is a primary determinant of past, present and future landscape patterns and elements (Lunt and Spooner, 2005). Therefore, it is important to explore and understand land users' attitudes, values, beliefs, individual perceptions, personal histories because all these play a vital role for any restoration activities. Lunt and Spooner (2005) stated that not all human activities lead to degradation, and that humans are an integral component of landscape dynamics. By detailing the history of human activity and the resulting changes in vegetation structure, composition and pattern, we can examine biotic responses to anthropogenic disturbance processes and devise appropriate conservation strategies which allow changes in vegetation to be viewed in a longer perspective (Larsson, 1995).

3.2.2 Motivation of Study

Since land degradation is a complex phenomenon affected by biophysical and socio-economic factors, it became relevant to understand the causes that play a major role in degradation and abandonment of mechanized rain-fed agricultural land. A multitude of human causes may contribute to land degradation. Their contributions are significance varies from one place to another and from one time to another, which makes it difficult to create general explanatory models of land degradation. Meanwhile, comparative analyses of case studies of land-use dynamics will help to improve the understanding of the causes for land-use change (Lambin *et al.*, 2003). Ibrahim (1982) stated that land degradation and diminishing productivity, are the major problems in the semi-arid areas of Sudan, and the actual causes of degradation are human activities. Glover (2005) considered land resource degradation to be one of the major threats to food security and natural resource conservation in the Gadarif Region. Therefore, it is important to conduct studies that tackle the social aspect of land-use/land-cover (LULC) changes and their environmental consequences in this region.

3.2.3 Objectives

The main objectives of this study were to: identify and analyze farmers' attitudes and perceptions towards agricultural land degradation and abandonment and to examine the impact of land-use history on floristic and structural attributes of the vegetation on the degraded and abandoned agricultural land.

3.3. Study Area

The survey was conducted in the rural town of Doka where mechanized farming has been introduced to the southern part of Gadarif Region for the first time. The total population was recently estimated to be at about 20232 inhabitants (World Gazetteer, 2007). Figure 3.1 shows the housing pattern in Doka. After the introduction of mechanized agriculture in the northern parts of the Gadarif Region during the mid of 1940s, the process began to encroach southwards and before the end of the fifties it was practiced in the area around Doka. By the end of eighties there were no more areas for further agricultural expansion, except some protected forests or unsuitable hilly or eroded areas around some seasonal water courses.

3.4. Methodology

3.4.1 General

To fulfil the above mentioned objectives, a range of techniques was used to collect information based on questionnaires for two groups of respondents: key informants and large-scale farmers. Also transect walks and discussions with farmers were repeatedly conducted. The interview was carried out during June and July 2006 concurrently with the second phase of vegetation sampling.

Figure 3.1: Overview of housing pattern in Doka. Doka is an old settlement in-between a big village and a small town. Beside its agricultural importance it is located along an old and important commercial road which links Gadarif with Metemma in Ethiopia. The white coloured buildings in the centre of Figure A show the centre of the town. Figure B shows the housing pattern in Doka. The town is mostly built from wooden material. Photographs taken by the author. July 2006.

3.4.2 Key Informants Interview

To get information on historical changes in the study area, an interview (Appendix 3.1) was held with ten elderly farmers with regard to changes in LULC, crop productivity, cultural practises and plant species composition (e.g. disappeared, decreased, increased and invader plant species). Ibrahim (1982) stated that in order to monitor the complex process of degradation with its ecological and socio- economic aspects, an attempt should be made to re-construct the pre-degradation conditions. This could partially be achieved through the assessment of ecological and human preconditions. Moreover, such a landscape history provides valuable information about the management of cultural landscapes, land-use planning and restoration ecology (Bürgi *et al.*, 2004). Historical perspectives increase the understanding of the dynamic nature of landscapes and provide a frame of reference for assessing modern patterns and processes (Lambin *et al.*, 2003).

There is a lack of recorded information concerning the historical development of mechanized agriculture in the area of Doka. The information available from the head-quarters of the Mechanized Farming Corporation (MFC) at Gadarif is based on regional estimates. In such situation, key informants were the only available source of information.

Further benefit from key informants is the recording of valuable ethno-botanical information concerning the local knowledge of extinct and endangered plant species and their uses. However, in the local community, narration is the only means for documenting such information from generation to generation, and this knowledge will be disappeared with the death of the knowledgeable elderly persons, if other means of documentations were not carried out. This information can play an important role for restoring the degraded agricultural land. According to Robertson *et al.* (2000) the potential for the ecological restoration can be enhanced through the use of local environmental narratives. Local people observation and experience of environmental degradation can be vital to restoration efforts, particularly for regions where the degradation has occurred within the memorable life time of local residents.

3.4.3 Large-Scale Farmers

3.4.3.1 Questionnaire

Cross-sectional primary data were collected using a pre-constructed questionnaire (Appendix 3.2) which was designed to obtain, among other things, the social characteristics of the respondents, agricultural land, land degradation, abandonment of agricultural land and ethno-botanical information concerning the vegetation cover on cultivated and abandoned agricultural land. The questionnaire was built on experience gained from the first phase of the field survey (March and April 2005), group discussions with the key informants, numerous questionnaires completed during previous research in the region and the author's background knowledge of the area. Moreover, a pre-test with 3 farmers was carried out for further improvement of the questionnaire. Key informants were asked whether the questions were clear and their interpretations were explored to see whether the intended meaning was clear. At the same time they provided multiple choices to open questions. The interviews were carried out by personal contact.

3.4.3.2 Sampling Procedure

Population

The target group of large-scale farmers[1] is specified by those whose agricultural land is located within and/or in the vicinity of the study area, which corresponds to an area of about 55 x 40 km^2. This relatively small area was selected so as to collect in-depth and

1) According to MFC the minimum land size is 500 feddans (210 ha) for framer to be classified as large-scale farmer. Feddan: a non-ISU of land area used in Sudan and also in Egypt. 1 feddan = 1.038 acres = 0.42 ha.

detailed information for the whole study area and at the same time farm-level data.

Sampling Frame

There is no official record from the MFC Office or any other sources, which could show the exact number of large-scale farmers for the study area. Although it is possible to detect the farm boundaries from ASTER 2005 imagery (see Chapter 4), many farmers have more than one farm and some times two farmers share one farm. After long discussions with the key informants the total number of farmers was estimated to be around 450.

Sample Size

The sampling percentage taken amounts to 9 %. Mustafa (2006) randomly selected 100 respondents to represent the farmers of the Gadarif Region, while Glover (2005) took 17 % in a study carried in Elrawashda (Northern Gadarif Region). Hinton (1995) argued that 25 respondents successfully represent the population in social studies.

Survey

The survey was executed by three enumerators[2]. The interview was conducted in Arabic.

3.4.4 Data Analysis

Data collected from interviews were coded, computerised and analysed using the Statistical Product and Service Solutions (SPSS) version 11.5. Descriptive statistics were used to explain the demographic characteristics of respondents and to find out the farmers attitude and perception towards land degradation and abandonment and ethno-botanical knowledge. Frequencies for different variables were computed together with their percentages.

3.5 Results and Discussion

3.5.1 Key Informant

3.5.1.1 General

The author is well aware that the accuracy of this information source is limited. In the absence of any records, however, it was perhaps the only method/approach which could

2) The first one is an agricultural economist with long experience in social surveys and good knowledge in social statistics, the second one is an agricultural engineer and the third one is the author himself.

be followed to collect and document information on the development of the mechanized farming and plant species prevailing in the area in the last few decades. After filling the questionnaire all key informants were invited for discussion. The objective of this exercise was to quantify and verify the information collected by individual cover. The age of key informants ranged from 60 to 82 years and all of them were literate.

3.5.1.2 Historical Overview of Some Agricultural Practices and Crop Yield

The key informants agreed that the mechanization of agriculture was first implemented in the area in the 1950s at Kafy and Gereeb. Farmers started to leave part of their mechanized agricultural land abandoned during the 1980s. Table 3.1 reflects changes in yield, times of ploughing and times of weeding for the two main crops, sorghum (*Sorghum bicolo*r) and sesame (*Sesamum indicum*.), in the last five decades. The key informants stated that crop yield has declined substantially. Concerning the weeding, presently they practice it two times for sorghum instead of one in the past and up to three times for sesame instead of two in the sixties. Nowadays they have to plough two to three times to prepare the soil for seeding. Recent regional study, based on farmers interviews, carried out by Mustafa (2006) found that the yield of sesame and sorghum is declining considerably throughout the Gadarif Region. Despite the introduction of mechanization, weeding is practiced manually and considered to be the most costly operation in the crop production budget. Mustafa (2006) estimated the cost of manual weeding to reach 26 % and 16% of the total production cost for sorghum and sesame respectively. Recently, for the last four seasons, some farmers started to apply herbicides.

Table 3.1: Yield estimation and changes of weeding and ploughing times in the last five decades for sorghum and sesame cultivated in the study area.

Decade	Sorghum			Sesame		
	Yield (kg / feddan)	Times of weeding	Times of ploughing	Yield (kg / feddan)	Times of weeding	Times of ploughing
1960s	800	1	1	440	2	1
1970s	740	1	2	450	2	1
1980s	400	2	2	330	2 – 3	2
1990s	325	2	3	235	2 – 3	2
2000s	325	2	3	180	2 – 3	2

3.5.1.3 Changes in Plant Species Composition

Regarding their opinion of changes in plant species composition in the study area, the key informants gave several reasons: vegetation clearance for agricultural expansion, charcoal and firewood production, cuttings for building materials, grazing, and recently herbicides applications. In order to assess the changes of plant species composition the key informants were asked to mention disappeared, decreased, increased and invader plant species and their local use (Table 3.2). Local people reported 32 species belonging to 17 families. Out of these, 4 were annual herbs, 2 perennial grasses, 4 shrubs and 16 trees. According to the key informants, 8 of the 20 tree/shrubs species were considered to have almost disappeared from the study area, 11 decreased in abundance; no tree or shrub species are thought to have been increased in abundance, and one tree species has been classified as disappeared and decreased at the same time. Perception of more decreasing than increasing species is coherent with the results of many studies where a decline of vegetation cover is documented (SCSB, 2001). An old man expressed his feeling for the indigenous medical plants: ‘‘before we did not have to rely on medicines from pharmacy, we were depending on herbs for most kinds of treatments. Nowadays the majority of those plants disappeared from the vicinity of Doka and for long time I have been missing to see them during my field trips’’.

However, an increase of species can be caused by various factors. Wezel and Haigis (2000), for example, mentioned that species well adapted to the environment and species experienced certain degrees of protection are increasing in the semi-arid region of Niger. Nevertheless all increased plant species were herbs and grasses. There were closer relations between the types of use and the changes in species abundance: those species used for live fences, firewood and as fodder were considered to have declined most. In Chiapas, Mexico, Hellier *et al.* (1999) found that, although there was no overall relation between trends in species abundance and particular vegetation types, the decline in species appeared to be related to their pattern of use.

Hellier *et al.* (1999) concluded that rapid surveys of indigenous knowledge may be used as a source of information about trends in biodiversity, including both changes in abundance of particular species and the dynamics of different vegetation types. Because indigenous knowledge of farmers is one of the major factors contributing to conservation of agro-biodiversity (Upreti and Upreti, 2002). However, the value of indigenous knowledge clearly depends on its accuracy, an aspect not easily addressed without independent sources of

Table 3.2: Key informant observations on plant species changes in the last five decades (1960s – 2000s) in the Doka Area.

Family name	Scientific name*	Vernacular name	Changes	Life form	Local uses**
Anacardiaceae	*Lannea fruticosa*	layon	De	Tr	Fg, Bm
	Lannea schmperi	Galob	Di De	Tr	Wd
	Sclerocarya birrea	Homeid	Di	Tr	Wd, Md
Balanitaceae	*Balanites aegyptiaca*	Hegleg	De	Tr	Fo, Ft, Md
Burseraceae	*Boswellia papyfifera*	Gafel	De	Tr	Incense
Caesalpiniaceae	*Tamarindus indica*	Aradeb	Di	Tr	Fg, Md,
Capparidaceae	*Cadaba farinose*	Soreh	Di	Sh	Fg, Md
Combretaceae	*Anogeissus leiocarpus*	Saheb	De	Tr	Wd
	Combretum glutinosum	Habeel	De	Tr	Wd
	Combretum hartmannianum	Sobag	Di	Tr	Wd, Fl
	Terminalia laxiflora	Darot	De	Tr	Bm
Commelinaceae	*Commelina imberbis*	Bowed	In	aH	Fd
Convolvulaceae	*Ipomoea cordofana*	Taber	De		Fd
Ebenaceae	*Diospyros mespiliformis*	Gogan	Di	Tr	Wd
Gramineae	*Aristida adscensionis*	Denbalab			Fd
	Cymbopogon nervatus	Nal	Di	pG	Bm
	Dinebra retroflexa	Mamilha	De		Fd
	Hypharrhenia pseudocambaria	Anzora	De		
	Ophiuros papillosus	Abgenger	De		Fo
	Sorghum arundinaceum	Adar	In	pG	Bm
Lamiaceae	*Ocimum basilicum*	Rehan	In	aH	Aromatic
Mimosaceae	*Acacia mellifera*	Kiter	De	Sh	Hg, Fl
	Acacia senegal	Hashab	De	Tr	Gum, Fd
	Acacia seyal Var. fistula	Sofar	De	Tr	Fg, Wd
	Acacia sieberana	Kuk	Di	Tr	Wd. Fg, Fl
Moraceae	*Ficus sycomorus*	Gimeiz	Di	Tr	wd
Papilionaceae	*Dalbergia melanoxylon*	Abanos	Di	Sh	Carving
Rhamnaceae	*Ziziphus spina-christi*	Sider	De	Sh	Ft, Wd
Scrophulariaceae	*Striga hermonthica*	Buda	In	aH	
	Veronica sp	Abumorowa	In		
Sterculiaceae	*Sterculia setigera*	Rareb	De	Tr	Wd, Gum
	Schizachyrium exile	Himera	De	aH	Fd

Short abbreviations stand for: Tr: tree, S: shrub, aG: annual grass, pG: perennial grass, aH: annual herb, pH: perennial herb, Tm: timber, Bm: building material, Cl: Clean, Md: medicine, Fg: forage, wd: wood, Fd: fodder, Fl: fuel, Ft: fruit, Hg: hedge, Fo: food, De: decrease, Di: disappear, In: increase.

* Scientific nomenclature follows Hutchinson and Dalziel, 1954.

** References: von Maydell,1990; El Almin, 1990; Vogt, 1995; Braun *et al*., 1991; Bebawi and Neugebohrn, 1991 and farmers' knowledge.

information with which indigenous knowledge may be compared. In the case of individual species, such a comparison would require data from formal monitoring programmes collected over a number of years, information which is usually lacking in rural tropical areas (Hellier, 1999). Nevertheless, the use of remote sensing imagery and GIS tools can potentially provide an independent basis for the evaluation of indigenous knowledge on patterns of change in land-use and vegetation type.

3.5.2 Large-Scale Farmers

3.5.2.1 Personal Information

The interviews took place in the rural town of Doka. All of the 51 (41 large-scale farmers + 10 key informants) farmers interviewed were men. There were no women among large-scale mechanized farmers in the study area. Women are mainly responsible for household work but they are actively involved in small-scale farming and home-gardening. In other agricultural sectors of Sudan the situation is totally different. In the traditional sector women constitute 80 % of the farmers and approximately 49 % of the farmers in the irrigated sector. 30 % of the food in the country is produced by women (FAO, 1995).

The age of the respondents ranged from 32 to 82 years, the average age being 51.6 years and the age distribution relatively even (Appendix 3.3). Concerning the farmers' age it is often hypothesized that increasing age reduces the probability of adoption. Younger farmers tend to have a better education and are often expected to be more willing to innovate. It seems not only to be a matter of co-incidence that the youngest farmer among the respondents (32 years) is the only one who leaves 40% of his land under *Acacia senegal* trees to restore the soil fertility and for gum Arabic production.

The level of education among respondents is relatively high (Table 3.3). All of respondents are literate. About 44 % of respondents have finished the secondary school and 15 % were graduates. A significant number of respondents (17 %) had not attended formal schooling except *Kalwa*[3]. Mustafa (2006) found that most of the respondents have been attaining some sort of education (97%). Glover (2005) mentioned that in Elrawashda (Northern Gadarif Region) 38 % of respondents were illiterate. This lower percentage found by Glover (2005) could be because he includes, besides the large-scale farmers, small-scale farmers, who are expected to be have poor livelihood, and possibly they have difficulties in schooling. However, the very high percentage of literacy recorded by the current work and the work of Mustafa (2006) does not reflect the actual situation of literacy in Sudan, where the national average for literacy rate is 60.9 % (UNESCO, 2006). Nevertheless, since farming in the Gadarif Region is considered as a type of business investment, the area attracted many investors from urban areas who attained some sort of education before they joined farming activity (Mustafa, 2006). Investments in education widen horizons, make it easier for people to take advantage of new opportunities and help them to participate in social and economic life (Glover, 2005). Age composition and the level of education are indicators of the farmers' level of awareness and their abilities of taking decisions (Mustafa, 2006). In comparison to uneducated people it was found that the educated group had a better perception, more detailed knowledge, greater awareness, a better attitude regarding environmental problems (Sudarmadi *et al.,* 2001), and a faster adoption of new technologies (Lin, 1991; Alonge and Martin, 1995).

The respondents show a wide range of experience in agricultural work (8 to 60 years) (Appendix 3.3) with an average of about 28 years of experience. 34 % of the respondents' experience fall within 8 to 20 years and the same percentage into the range of 21 to 30 years. Only very few farmers have more than 40 years of experience. Possible explanations for this long experience could be that the farmers accompany their fathers from relatively early ages to the field. Some farmers mentioned that they started to joint their fathers before the age of ten. In order to determine the factors that best predicted a farmer's adoption of sustainable agricultural practices, Alonge and Martin (1995) found that there is a positive relation between the adoption of sustainable agricultural practices and variables like education, age, and years of farming experience.

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3) *Khalwa*: Religious school in which Quran and Islamic sciences are taught. It also provided some instruction in reading and writing of Arabic.

Table 3.3: Level of education as indicated by respondents in the Doka Area.

Level of education	No.	%
Illiterate	0	00.0
Kalwa	7	17.1
Primary	10	24.4
Intermediate	1	02.4
Secondary	18	43.9
Graduate	7	17.1
Total	41	100.0

3.5.2.2 Agricultural Land

The total land held by respondents amount to 67200 feddan (28222 ha). The area held per farmer ranges between 16000 and 500 feddan with an average land size of 1639 feddan. 17 % of respondents hold the minimum land size for a large scale-farmer (Appendix 3.3). 20 % of the respondents hold one scheme[4]. Officially land is allocated to farmers on a 25-years lease-basis from the state through the Office of MFC in Gadarif. Most of the land (70.7%) has been cultivated for more than 20 years (Appendix 3.3).

3.5.2.3 Main Crops

The main crops cultivated in the area are sorghum (*Sorghum bicolor*), sesame (*Sesamum indicum*) and millet (*Pennisetum americanum*). Sorghum is the main food stuff in the region, while sesame is the most important edible oil Cash-crop. All farmers except two cultivate at least two crops in spatial and temporal sequences (table 3.4). 80 % of the farmers cultivate sorghum and sesame alternatively, according to rainfall conditions and the crop prices. Previously, as late as the seventies, 15 % of the farmers were also cultivating cotton (*Gossypium spp.*) besides the other two main crops. According to Glover (2005) in the Elrawashda Area, northern Gadarif, 86 % of all farmers practiced only mixed cropping, while 14% had adopted mono-cropping of sorghum. The respondents mentioned that in order to cope with the problems of rainfall and price fluctuations it is wise to be in the save side and cultivate more than one crop. Mustafa (2006) concluded that the agricultural production in the Gadarif Region is associated with high degree of uncertainty.

4) Scheme is a local official name for the principal farm size of one thousand feddans.

The uncertainty arises from the dependency on the agricultural production on uncontrollable weather conditions (erratic and variable rainfall) which cause big fluctuations on crop yield on one hand, and strong fluctuations in input and output-prices which, on the other hand restrict the reliability of price predictions. Glover (2005) stated that farmers in Elrawashda (Northern Gadarif Region) divided the agricultural risks over two or more crops instead of one, so as to increase their chances of food security. Empirical evidence by Elnagheeb and Bromley (1994) shows that sorghum cultivation increased with sorghum's expected price or expected yield and decreased with costs of production. Sesame prices were not found to influence sorghum cultivation. Larsson (1996) found that the correlation coefficient was high for sorghum yield against mean annual rainfall, while the sesame correlation was low and not significant in the Gadarif Region. Although the study area has favourable conditions for rain-fed cotton production (Beinroth and Duemmler, 1964), cotton is no longer cultivated as it is considered to be uneconomical due to high labour costs and difficulties in the use of mechanisation (Larsson, 1996). Other crops such as tobacco were also cultivated once in the area (Wingate, 1892; cited by Larsson 1995).

3.5.2.4 Land Degradation

Putting in mind that land degradation is a human activities caused negative environmental changes with reference to specific socio-economic contexts (Chanda, 1996), farmers are aware that soil degradation, in various forms, is taking place on their land. This is based on their perception and interpretation of indicators that reveal certain conditions regarding to crop yield and weed infestation. 59 % of respondents classify the yield of their land as poor (Appendix 3.3) and most of them (85 %) acknowledged instances of degradation (Appendix 3.3). Ayoub (1999) mentioned that per unit yields of all crops in the mechanized large scale rain-fed farming in Sudan are steadily decreasing; reaching rates far below their genetic potential and loss of soil fertility and rainfall variability are among responsible factors. Farmers cited several ways in which they experience land degradation.

Table 3.4: Main crops cultivated in the Doka Area as indicated by farmers.

Cultivated crop	No.	%*
Sorghum	2	04.88
Sesame	0	0.00
Sorghum and sesame	33	80.49
Sorghum, Sesame and millet	6	14.63
Cotton (Previously 1970s)	6	14.63

* Due to none and/or multiple responses, the percents given will not add up to 100%

3.5.2.5 Major Indicators of Degradation

The major indicators of degradation mentioned by the farmers can be ranked as follow: weed infestation (73 %), reduced soil fertility (63 %), and soil compaction (5 %) (Table 3.5). In recent work conducted in the northern part of the Gadarif Region, the respondents ranked the indicators of the occurrence of land degradation in the following order: reduced soil fertility/soil erosion/prevalence of pests, soil erosion/pests, reduced soil fertility/soil erosion, and reduced soil fertility (Glover 2005).

Table 3.5: Indicators of land degradation mentioned by the farmers.

Instances of degradation	N0.	%*
Poor soil fertility	25	62.5
Weed invasion	29	72.5
Soil compaction	2	05.0
Others	2	05.0

Weed Infestation

Weed infestation in the Gadarif Region is one of the most serious problems which faces the mechanized rain-fed agriculture. The most important weed affecting the crop yield, sometimes even leading to a complete crop filature in the area, is Witch Weed (*Striga hermonthica*) and Wild Sorghum (*Sorghum arundinaceum*). *Striga* is a sorghum-associated weed parasite belongs to the genus *Striga.* It contains some of the most damaging plant species of the world (Kuiper *et al*., 1998) which do substantial harm to cereals, especially sorghum and millet. However, with no fertilizer application, poor weed control, no crop rotation, and continuous cultivation of cereals, *Striga* becomes devastating. In a previous study carried out by Bebawi *et al*. (1985) they mentioned that most of the farmers stated that they do not know of any method of combating *Striga*, and they also complained that they found no help from the Agricultural Extension Service. However, a small number of farmers from the Gadarif Region had tried fallowing as a possible means of reducing *Striga* infestation but found it ineffective. Although this has been cited before 20 years, it still reflects the situation nowadays where no significant work has been carried out to control this weed. Wild Sorghum, as it is clear from the name, is a wild species of sorghum which is very difficult to control. In the emergence stage it confused the farmers with the cultivated sorghum crop and they could not get rid of it during the first weeding and in the later stage it is difficult to cut manually, because this would be well established. Even when the farmers recently have started to apply selective herbicides it was not possible to control Wild Sorghum species for it close genetic constituent with sorghum. The problem of confusion is under control when they cultivate sesame and apply timely weeding.

The processes that determine weed shifts are complex: Long term changes in weed flora will be driven by the interaction of tillage, soil type and moisture, crop rotation, crop type and method and timing of weed management practices (Shrestha *et al.,* 2002).

Reduced Soil Fertility

Overexploitation of land resources without returning the basic nutrients to the soil is also an important factor that contributes most to the soil fertility decline in the region. The decline in soil fertility has been accelerated by the desertion of the fallow system. Chanda (1996) mentioned that the local populations seem to be keenly aware of the environmental crisis and have a good sense for its temporal and spatial dimensions. However, they were generally concerned about the low productivity of the land. The most widely recognized are crop failures. The rain-fed agriculture production system in Sudan is however, heading for a total collapse, if this attitude to soil mining does not change (Ayoub, 1999).

Soil Compaction

Large-scale farmers commonly identified the existence of a hardpan as an impediment to crop root development. Evidence was obtained by farmers from examining plant roots (Glover, 2005) and it is very clear from the distortion of sesame tap root. Ayoub (1999) stated that mechanized rain-fed agriculture in the Gadarif Region experiences high physical deterioration due to the use of heavy machinery and mono-cropping. Physical degradation is the least common among other types of soil degradation as acknowledge by respondents, but it could spread if such inappropriate management practices continue. According to El Moula (1985) there was a direct positive correlation between ploughing frequency and the development of compaction layer. A range of solutions has been suggested by the Agricultural Research Corporation, which ranged between deep ploughing and zero tillage.

3.5.2.6 Reasons for Land Degradation

The interaction between the physical and anthropogenic processes leading to agricultural land degradation is complex. Table 3.6 illustrates that 24 farmers (59 %) considered continuous cropping as the main reason for land degradation. The second reason is mono-cropping (18 farmers, 44 %) followed by rainfall shortage (16 farmers, 39 %) and the use of inferior seeds (13 farmers, 32 %). An elderly farmer mentioned that ‘‘for the last four decades we are cultivating the same land using wide disc harrows to plough the top layer of the soil. Although we are giving the land some period of rest, I believe that our land is totally exhausted’’.

Table 3.6: Farmers’ perceptions for reasons of land degradation in the Doka Area.

Reason of degradation	No.	%*
Rainfall shortage	16	39.0
Continuous cultivation	24	58.5
Mono-cropping	18	43.9
Inferior seeds	13	31.7
Others	7	17.1

Continuous Cropping

It is clear that continuous long-term cropping (average farm age 31.7 years) without any nutrients input has resulted in adverse effects to the physical, chemical and biological soil properties. It is well documented that continuous cropping, even with the rotation of leguminous crops has an adverse effect of soil properties and crop yield. The results of an experiment conducted by Horst and Härdter (1994) in Ghana showed that maize grain yields were significantly higher for maize in rotation with cowpea than for maize mono-cropping. However, sequential cropping of maize and maize/legume intercropping over a period of several cropping seasons led to significant depressions of maize yields. Juo *et al.* (1995) stated that continuous maize cropping, even under no-tillage with crop residues returned as mulch, the soil may become acidified. The biological activity deteriorated in all the cultivated (8 – 50 years) *vertisols* in the Walgett area, north-western New South Wales when compared to adjacent uncultivated soils (Chan *et al.*, 1988).

Mono-Cropping

While economically a very efficient system allowing for specialization in equipment and crop production, mono-cropping is also controversial, as it often leads to a depletion of soil nutrients of the soil and problems with weed infestation. The traditional cultivation system in the area before the introduction of mechanization is a shifting cultivation system. Reasons to favour mixed cropping are to reduce the risk of crop failure caused by unfavourable patterns of rain as well as pests and diseases. Further advantages are seen in a diversified food supply and a more equal distribution of the work which comes up during the cropping season (Sauerborn *et al.*, 2000).

Rainfall

The correlation of amount of rain and yields of sorghum and sesame in the Gadarif Region is found to be weak (SKAP, 1992). This is not surprising because rainfall varies considerably over short distances and the available data are generalised from a large area. Also, factors other than rainfall, for example weeds, lack of input and poor husbandry can be more important than rainfall or superimpose themselves on productivity (SKAP, 1992). In this sense, data collected through interviews of farmers serve as the only available way to shade light onto the productivity/rainfall relations for the study area on the farm level. The negative productivity trend could have its reason in less rainfall or in soil mining. Both factors probably influence the productivity (Larsson, 1996).

Using Inferior Seeds

Farmers are using their own seed collection and sometimes exchange collections with other farmers. Normally they collect the next-year seeds from the more vigour, healthy and early maturing harvest. Farmers have long experience in seed collection. Nevertheless some wealthy farmers are sometimes using cleaned seeds produced by local seed production companies and only very limited number of farmers are using certified seeds. Repeatedly used seeds from the same field can lead to inbreeding depression[5], a phenomenon which is more common in populations with a wide genetic base like sorghum. Also, the collection of such a mass of seed is not an easy task to be correctly handled by the local farmers. Many of them told that sometimes they also unconsciously collect weed seeds during the process. In order to minimize this problem some farmers sieve the collected seeds before storage to avoid weed seed contamination.

3.5.2.7 Mitigation/Improvement of Land Productivity

A number of measures have been practiced by the respondents to mitigate/improve their land productivity. Theses measures ranged from repeated ploughing to the application of mineral fertilizers (Table 3.7). The results of the interview show that all farmers follow one or more mechanical or biological ways to mitigate their land productivity.

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5) Inbreeding depression is reduced fitness in a given population as a result of breeding of related individuals (self- or within-family fertilization; Charlesworth and Charlesworth, 1987).

This clearly illustrates a high degree of awareness representing the land degradation problem among the respondents and their ability to address the problem. This coincides with the findings of Glover (2005). He mentioned that empirical evidence shows that the decision whether or how to manage land depends on the farmers' perception of land degradation as well as on their own personal characteristics, socio-economic condition, institutional support provided and biophysical characteristics of land holdings.

Table 3.7: Measures practiced by respondents to maintain and improve land productivity in the Doka Area.

Mitigation measures	No.	%*
Mineral fertilizers	3	07.3
Crop rotation	18	34.0
Double / triple ploughing	31	75.6
Prescriptive fire	4	09.8
Abandonment	28	68.3
Removing crop residue (dry season cleaning)	10	24.4
Using improved seeds	4	09.8
Others	4	09.8
Nothing	0	00.0

Repeated Ploughing

The commonly most appreciated method of mitigation by the respondents was repeated ploughing (76 %). Repeated ploughing is one of the common methods followed by farmers in the study area for more than one purpose: to control the newly emerged weeds after the first rain showers and this could be repeated several times (two or even three times) in about two to three week intervals depending on the rain intensity and the weed density. Moreover, repeated ploughing improves the soil moisture content of the heavy clay, breaks the hard pan in areas where there are problems of soil compaction. Until 2003 and before the recent introduction of herbicides, manual weeding used to be the only means of weed control in the study area. Farmers believe that repeated ploughing reduces the times of needed weeding to only one time for sorghum and two times for sesame. Although it could be considered as waste of valuable time – putting in mind the relatively short rainy season

– and resource, it is more economically than the expensive laborious hand weeding, especially for areas heavily infested by weeds.

Land Abandonment

About 68 % of the respondents practice land fallowing/abandonment to restore the soil fertility and to control weeds. Fallowing/abandoning of mechanized agricultural land is a relatively common practice in the area in comparison with other regions in the Sahel of Africa. This could be due to the relatively large areas held per farmer, which allow them to leave part of their land abandoned. Abubaker (1996) argued that fallowing helps in the rehabilitation of degraded lands (North Nigeria), but it is obvious that short periods of fallow are less effective than long periods. Even after about 15 fallow years, no significant changes were observed in the base elements. In order to achieve the maximum benefits from short fallow periods, more human interference in the fallow ecosystem would be necessary in order to improve its restorative capacity. This practice is very difficult to be followed in many other regions in the Sahel zone of Africa, where the problem of high population growth is always combined with a shortage of agricultural land. Amede (2003) gives a detailed description of the situation in a near-by region in Ethiopia just across the boarder: In earlier days, fallows were used to restore soil fertility mainly in the cereal-based highlands of Wollo and Gonder. However, due to the increasing demand for land as a result of population pressure, long duration fallows are no longer a viable option for the improvement of soil fertility. It has been recognized that fallow requires a longer time to achieve the required level of soil fertility that can lead to optimum crop yields. Short-duration fallows are now becoming more appreciable, though short-duration fallows do normally not maintain soil fertility at levels similar to those achieved under long fallows (Aweto *et al.,* 1992). However, wealthy farmers in the mechanized rain-fed agriculture in central Sudan can afford to buy many farms and shift among them as productivity decreases. Abandoned farms can be returned to after a period of time sufficient to allow for restoration of soil fertility (Elnagheeb and Bromley, 1992). In contradiction to the findings of the current study, Mustafa (2006) has found that only 7 % of the farmers left a small part (less than 250 feddans) fallow in the Gadarif Region and this is only, because they have not enough funds to cultivate the whole scheme area.

Crop Rotation

Another highly appreciated mitigation strategy practiced by farmers is the crop rotation. Although 34 % of the respondents mentioned that they are following a crop rotation to mitigate their land, this should be seen in the light of what has been raised from the group discussion. The driving forces for selection of crops to be cultivated are market prices, rainfall conditions and availability of finance (e.g. Bank credit). Moreover, the sorghum-sesame cycle should not be considered as a sound crop rotation. Previously the recommended rotation by MFC is cotton-sorghum-sesame-fallow (Larsson, 1996). In 1997 a specific rotation was imposed by the Ministry of Agriculture with the aim of arresting the environmental deterioration and maintaining sustainable agriculture in the region. The rotation includes cultivation of 50 % of the land by sorghum, 25 % by sesame and the rest 25 % is under forest and fallow (Mustafa, 2006). However, neither the previous nor the recent crop rotation is adopted or applied by the farmers in the area.

Fertilization

Only three farmers were cited that they use mineral fertilizers. Using mineral fertilizer in the rain-fed mechanized agriculture in Sudan is still a very limited practice and mostly confined to some pilot or experimental areas. It is clear that the high risk and uncertainty accompanying the production system in the study area would not encourage the farmers to invest more money. Farmers in the rain fed mechanized farming were found to be responsive to risk in prices and rainfall (Mustafa, 2006). Van Duivenbooden *et al.* (1996) stated that despite national fertilizer recommendations in many developing countries chemical exhaustion of soils still continues, as the use of inorganic fertilizers is restricted by factors such as marketing constraints and long distances from importers to farmers. Ayoub (1999) cited a figure showed that the use of fertilizers in Sudan is 5 kg per ha of nutrient which is disturbingly low. This is less than one fifth of the world average, a quarter of that of Africa and less than half of that of sub-Saharan Africa. Under such agricultural practices that dominated the study area, it has become unfeasible to maintain soil fertility by means of long-term fallows. The need to use inorganic fertilizer to achieve and sustain adequate soil fertility therefore becomes important or evens an unavoidable choice.

3.5.2.8 Abandonment and Restoration of Degraded Agricultural Land

There exits a very high acknowledgement of abandoning degraded agricultural land in the study area (Appendix 3.3). Thirty nine out of 41 – the total number of respondents – (95 %) left part of their land abandoned in the last five seasons. In average they left 37 % of their total land, and the range is from 15 % to 75 %. The most accepted percentage lies between 15 % and 30 % of the total land, as cited by 22 of the respondents. The average period of abandoning applied by the farmers is 4.7 years but the majority of them (87 %)

abandoned their land less than 6 years. However, when asked about the optimum abandoning/fallowing period they gave different answers. 32 farmers said that the optimum period ranged between 5 to 10 years. Nevertheless, 3 farmers only followed the optimum period suggested. In average the farmers started to abandon their land after 9 years of cultivation, some of them started even earlier, after 4 to 6 years of cultivation. However, 10 % of the respondents delayed the abandonment to 15 years of cultivation (Appendix 3.3).

Wezel and Haigis (2002) have given another different system practiced in southern and central Niger. They mentioned that farmers cultivate their fields on average up to 5 years until they are left fallow, few farmers crop them between 6 and 20 years. Most farmers use short fallow periods of 1 – 5 years, some cultivate their fields permanently. Only very few farmers used an average fallow period of more than 5 years.

Abandoning agricultural land is a well known practice in the traditional shifting cultivation in many regions of the tropics and particularly in the Sahel of Africa. It is generally accepted by the local and scientific communities to be an effective way of restoration (Abubaker, 1996; Wezel and Haigis, 2000; Wezel and Haigis, 2002). However, the southern Gadarif Region receives relatively much rainfall in comparison to the central and northern part of the region. At the same time the area hold per farmer is relatively large. This encouraged the farmers to abandon parts of their land. Although the length of abandoning periods was short and could be insufficient to restore the soil fertility. Nevertheless, farmers mentioned that they always have a good yield in the first three years after the abandonment, and that they can even cultivate sesame in the first season. Because they are sure that they will get a high profit, although they invest more in clearing and weeding. Mertz (2002) argued that the impact of the length of the fallow may be very difficult to determine in the first year of cultivation. It is obvious that fallow impact on yields in the following years will be more complex. Shorter fallow periods are believed to cause environmental damage in the form of soil properties. Glover (2005) mentioned that farmers in Elrawashda Area (northern Gadarif) shortened the fallow period from 25 years to 3 to 6 years, and presently there is no more fallow land. Mertz (2002) further stated that the correlation between shortened fallow periods and yield decline in shifting cultivation is questionable. This relation appears to have been taken for granted and farmers have in some cases confirmed that they prefer long fallow. Mertz argued that yield levels in shifting cultivation are influenced by a wide range of biophysical, socioeconomic, and cultural factors and that it is difficult to isolate the length of the fallow as a single determining factor. To rely on the farmers’ statements and to conclude that yields decline with decreasing fallow is a more valid approach than some of the quantitative studies which are often forced to simplify the circumstances of production.

Many studies (Nye and Greenland, 1960; Ruthenberg, 1980; Mertz, 2002) concluded that it is difficult to give an optimum period of fallow, because it mainly depends on the site conditions and circumstances prevailing in the area. Vasey (1979) concluded that ten years fallow would be sufficient. Volcanic soils in central Africa may only need two to three years of fallow (Ruthenberg, 1980).

A combination of several factors has been involved in this high acknowledgement towards abandonment of agricultural land amongst the respondents (Appendix 3.3): to restore soil fertility (29), to control weeds (25), financial shortage (12) and rainfall (10 farmers). Weed suppression and soil fertility are the two major reasons for fallowing (Mertz, 2002). Concerning the financial shortage, Mustafa (2006) showed that around 48 % of farmers she interviewed, used their own savings which indicates the economic sustainability of this farming system or the contribution of off-farm activities in financing the agriculture. On the other hand, it has been noticed that during the last few years farmers who obtain loans from banks have experienced severe indebtedness problems, rendering the credit from banks being a non-preferable option to them.

The average annual precipitation in the Doka Area is about 670 mm/year which is a sufficient amount for the two cultivated crops. Recently most of the seasons are above the long-term rainfall average. In such short rainy season (June to Sep.), timely operation is very important. However, rainfall shortage could be a problem for farmers who started their field operation late. The agreement of all respondents that they do not see any disadvantages of abandoning their land is a little bit surprising. Contradicting results have been stated by many other authors (Johnson *et al.,* 1991; de Rouw, 1995; Dingkuhn *et al.*, 1999; Mustafa, 2006;). Mustafa (2006) mentioned that farmers believe that fallow gives weeds a good chance to grow and to reproduce. This means that more efforts to get rid of them which involve additional costs. Moreover, fallow could provide a suitable environment for insects and birds and attracts other animals which can be harmful to the neighbouring crops. Nevertheless, in this study farmers mentioned that they do not consider the intensive preparation, e.g. vegetation clearing and frequent weeding, as a serious problem when they compare it with the profit they are expecting from the increased crop yield. Moreover, in recent years a significant improvement in prices of crops in the local market has been occurred.

Benefits from Abandoned Agricultural Land

Only 10 respondents (24 %) are practicing nothing in their abandoned agricultural land, while the others have different benefits (Table 3.8), e.g. grazing (73 %), firewood collection (32 %) and/or wood-cutting (7 %). Animal herding is the second important human activity following agriculture in the study area. Due to the drastic agricultural expansion animal herders were expelled from the area, and shortages of grazing lands exist. Abandoned lands and the crop residue after harvesting provide excellent sources of grazing in the area. The crop residues, fallow fields and failed crops of the area provide four fifths of the available grazing and forage resources of the entire Gadarif Region (SKAP, 1992). Moreover, grazing could play an important role in restoring the degraded agricultural lands by different means, by enriching the seed bank and the nutrients of the soil in the grazed area. However, this might be a controversial means towards the restoration of abandoned agricultural land. Farmers mentioned that while they consider the grazing of goats, sheep and camels to have positive impact on the soil nutrients and physical properties, they do not prefer to let cattle graze on their land because they negatively affect the soil and lead to more soil compaction. Plant-animal relationships are complex and the influence of livestock grazing on species composition of pastures strongly depends on intensity, duration and frequency of grazing as well as on the herd composition (Hiernaux, 1998; Kuiters and Slim, 2003). Wezel and Schlecht (2004) experimentally proofed that the comparison of the grazed sites with protected sites clearly show that protection of a site from grazing reduces the number of species showing variable occurrence, while inter-annual variation in species abundance still takes place. The young trees and shrubs naturally regenerated on the abandoned land are one of the valuable sources of firewood for the farmers and their labourers, especially during weeding and harvesting time. Wood-cutting is not common because the short fallow periods do not allow a vigour growth of trees and shrubs to produce poles large enough to be commercially utilized (e.g. as building material).

3.5.2.9 Restoration Indicators

Farmers acknowledged two types of indicators they used to assess the restoration of abandoned land, e.g. indicator plant species (95 %) and soil indicators (29 %; Appendix 3.3).

Table 3.8: Farmers' activities and benefits from their abandoned/fallow land.

Activity	No.	%*
Grazing	30	73.2
Firewood	13	31.7
Wood cutting	3	07.3
Others	0	00.0
Nothing	10	24.4

Indicator Plant Species

Table 3.9 elicits a list and frequencies of indicator plant species mentioned by farmers. Respondents mentioned that as soon as *Sorghum purpureorsericerum* (66 %), *Aristida adscensionis* (54 %) and/or *Hypharrhenia pseudocambaria* (51 %) appeared and dominated the abandoned land, that means the cycle of plant species (herbs and grasses) was completed, they started to re-cultivate the land.

Biological indicators are readily measured components that can be used to provide general information about the complex ecosystems in which they occur, and they play key roles in conservation planning and management (Andersen, 1999). Indicator species, i.e. species that indicate particular environmental conditions (Ellenberg *et al*. 1991), are thought to be sensitive to serve as an early warning indicator of environmental changes (Parsons, 1991). Dufrêne and Legendre (1997) defined indicator species as the most characteristic species of each group. The use of plants as indicators of site quality has been recognised for many

Table 3.9: Plant species mentioned by farmers as restoration indicators.

Family	Scientific name	Vernacular name	Life form*	%
Gramineae	*Aristida adscensionis*	Dembalab	aG	22
	Brachiaria obtusifolia	Um Girr	aG	2
	Cymbopogon nervatus	Nal	aG	3
	Hyparrhenia pseudocymbaria	Anzora	aG	21
	Ischaemum brachyatherum	Boos)	pG	15
	Ophiuros papillosus	Ab Genger	aG	8
	Sorghum purpureosericeum	Anees	aG	27

* Abbreviations stand for: aG: annual grass, pG: perennial grass.

years. Godefroid and Koedam (2003) assessed site quality using indicator plants. They identified 14 indicators species in terms of species richness and/ or commonness and they used them to evaluate the nature quality across time and space in forests in North Belgium. With these indicators, which are rather common species in the study area, any forest compartment can be evaluated.

Soil Indicators

Concerning the soil indicators farmers expressed that the soil surface changed from hard black to friable brownish. Friable[6] soil crumbles easily, allows water and oxygen to reach plant roots. The brownish colour could be due to accumulation of organic matter from the decomposition of dead vegetation materials. One farmer describes that ‘‘you feel as if you are walking on a comfortable surface’’. This could be due to improvement in soil bulk density after the stopping of the soil working for some years and also could be as a result of soil shrinkage and swelling with changes in moisture content. During dry periods, the soil volume shrinks, and deep wide cracks form. Surface material is more accumulating in these cracks during the dry season and creating the self-mixing action of *vertisols* as a kind of self-mulching. This phenomenon led to improvements of soil organic matter and soil bulk density.

Usually local communities have a sound knowledge and understanding of their environment, and they are able to interpretate their knowledge regarding appropriate managerial skills and adaptive strategies for land-use decisions. Desbiez *et al.* (2004) found that farmers perceptions of soil fertility were found to be more holistic than those of the researchers, as they included factors which in their opinion influenced the soils and the crop growth in their fields. However, due to lack of baseline data from soil survey, the only available information on changing soil characteristics in the study area is the farmers.

3.5.2.10 Plant Species Composition on Cultivated Land

Trees and Shrubs

Most of respondents (83 %) prefer to leave some of the naturally regenerated trees and shrubs on the cultivated part of their land but not all, and only few of them (% 17) remove all (Appendix 3.3). Table 3.10 shows the farmers’ preferences for retaining certain species in the cultivated land. *Acacia senegal*, *Acacia seyal* var. *seyal* and *Balanites aegyptiaca* are

6) Friability: is a characteristic of good soil positively correlated with the organic content of the soil.

the most preferred by farmers. While *Acacia senegal* produces gum Arabic, *Acacia seyal* var. *seya*l is an excellent source of firewood, charcoal and building material. *Balanites aegyptiaca* is mainly left for its shade, cultural believes (taboo; common believe by local population is that if somebody cuts this tree he/she will be attacked by devils) and fruits. Moreover, *Balanites aegyptiaca* is an ever-green tree and a unique place for a rest and camping, too. The three species have relatively long stems which do not hinder mechanical soil working.

Trees in agricultural fields are a distinctive feature of the Sahelian and Sudanian landscape (Gray, 1999). For Example *Acacia albida, Balanites aegyptiaca, Guiera senegalensis* or *Piliostigma reticulatum* experience a certain degree of protection because they are among the ones that farmers prefer to be left in their fields in the semi-arid region in Niger. Buhkari (1998) mentioned that *Acacia seyal* and agricultural crops are sequentially rotated in traditional farming systems on clays of central Sudan.

Concerning the methods of trees and shrubs clearing, respondents followed up-rooting (90%), burning (22%) and cutting the stem (20%; Appendix 3.3). When they apply up-rooting they are in the save side regarding the impact of the stump which could cause mechanical damage for the plough disc and tires. The method of tree/shrub removing plays an important role in the regeneration process especially for those species which have a coppicing capacity (Figure 3.2). *Acacia senegal* is very sensitive to fire while *Acacia seyal* var. *seyal* shows a good coppicing after stem cutting or fire. This has been also recorded by Vogt (1995).

Table 3.10: Farmers' preferences for retaining certain species in the cultivated land.

Scientific name	Reason						
	Cultural value	Shade	Fire wood	Charcoal	Construction	Gum	Fruits
Balanites aegyptiaca	●	●	●	●	●		●
Acacia senegal						●	
Acacia seyal var. seyal		●	●	●	●	●	

●: Means indicated by more than three farmers.

Herbs and Grasses

Respondents easily named the herbs and grasses (weeds from the farmers' point of view) germinating on their land and mentioned at which time of the rainy season they emerge (Table 3.11). It is clear that *Evolvulus alsinoides*, *Desmodium dichotomum, Sorghum arundinaceum, Ischaemum afrum* and *Veronica sp.* are prevailing the area during the whole rainy season, while *Hyprrhenia pseudocymbaria* are dominating at the beginning of the rainy season. *Denebra retraflexa* however, is a late emerging speices. *Sonchus cornutus* emerges at the beginning and in the middle of the rainy season. S*triga hermonthica, Schizachyrium exile* and *Ocimum basilicum*, tend to emerge in the mid and late rainy season.

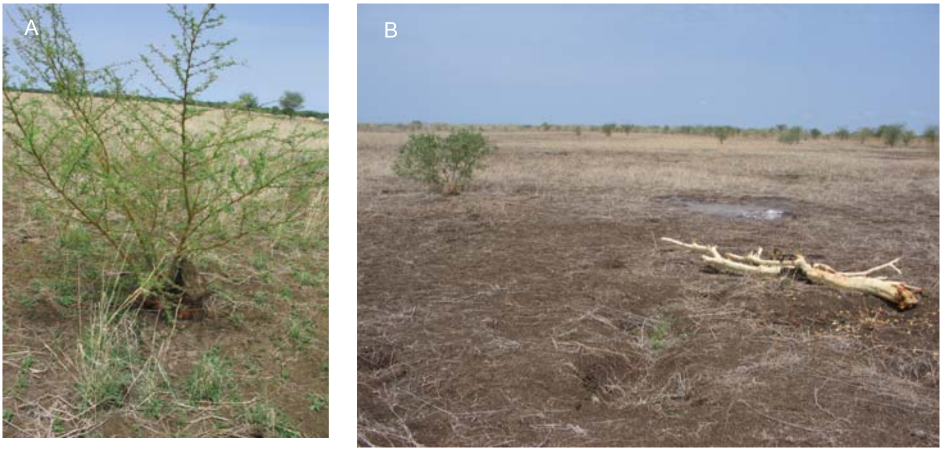

Figure 3.2: The effect of method of tree removing on trees/shrubs regeneration. A: *Acacia seyal* var. *seyal* regenerated from coppice, B: up-rooting and burning at the same time to avoid any future coppicing from the stumpage. Photographs taken by the author. June 2006.

Table 3.11: Herbs and grasses prevailing cultivated agricultural land and their seasonal emergence.

Family	Scientific name	Vernacular name	Life form	Time of emergency		
				Early	Mid	Late
Amaranthaceae	*Achryanthes aspera*	Fakha	aH	●	●	●
	Digera muricata	Daneb Elkalib	aH			●
Asteraceae	*Sonchus cornutus*	Moleta	pH	●	●	●
Capparidaceae	*Gynandropsis gynandra*	Tamaleka		●		
Commelinaceae	*Commelina imberbis*	Bowed	aG	●		●
Convolvulaceae	*Evolvulus alsinoides*	Deria		●	●	●
	Ipomoea cordofana	Taber	pH	●		●
Fabaceae	*Desmodium dichotomum*	Abu Arida	aH	●	●	●
	Tephrosia uniflora	Um Ragega	aH	●		●
Gramineae	*Aristida hordeacea*	Daneb Elkades	aG	●		●
	Brachiaria obtusifolia	Um Gir	aH	●		
	Dinebra retroflexa	Um Mamleha	aG	●	●	●
	Echinochloa colona	Difra	aH	●		
	Hyparrhenia pseudocymbaria	Anzora	aG	●	●	
	Ischaemum afrum	Boos	pG	●	●	
	Ophiuros papillosus	Ab Ganger.		●		●
	Sorghum arundinaceum	Adar	aG	●	●	●
	Schizachyrium exile	Himera		●	●	●
	Sorghum purpureosericeum	Anees	aG	●	●	
Lamiaceae	*Ocimum basilicum*	Rihan	aH	●	●	●
Malvaceae	*Abelmoschus esculentus*	Weka	aH	●		
Scrophulariaceae	*Striga hermonthica*	Boda	aH	●	●	●
	Veronica sp.	Abu Morowa	aH	●	●	●
Tiliaceae	*Corchorus spp.*	Khodra	aH	●	●	

* Abbreviations stand for: aH: annual herb, pH: perennial herb, aG: annual grass, pG: perennial grass.

●: Means indicated by more than three farmers.

3.5.2.11 Plant Species Composition on Degraded Agricultural Land

Grasses and Herbs

Weed infestation (according to their composition and intensity) is the major indicator of land degradation cited by the farmers, as it has been discuss previously. The reason for using wild plant species as indicators of change in soil fertility or soil degradation is that plants are sensitive to soil conditions, and because farmers are knowledgeable of which wild plants indicate good or bad soil fertility (Wezel and Haigis, 2000; Olson *et al*., 2004). Table 3.12 shows the common grasses and herbs appeared on the degraded agricultural land. *Striga hermonthica*, *Veronia sp.*, *Evolvulus alsinoides*, *Desmodium dichotomum*, *Sonchus cornutus*, *Sorghum arundinaceum*, *Ocimum basilicum* and *Schizachyrium exile* are the more common. Ten out of the 13 species are annual herbs and two are grasses. *Ischaemum brachyatherum* is the only perennial species. The domination of annuals for specific vegetation is indicator of deterioration. Corbeels *et al.* (2000) stated that farmers use the appearance of specific weed species, like *Echinops hispidus* and *Xanthium spinosum,* in Tigray, Ethiopia as indicators of declining soil fertility. As individual weed species or communities adapted to particular habitats, their presence may indicate problems with the soil's nutrient status or structure. However, the ability of weed species to act as unambiguous indicators is limited, because their presence may reflect cropping practices rather than soil conditions.

Table 3.12: Grasses and Herbs emerging on the degraded agricultural lands as indicated by respondents.

Family	Scientific name	Local name	Growth form	No.	%
Asteraceae	*Sonchus cornutus*	Moliata	aH	22	53.7
Commelinaceae	*Commelina imberbis*	Bowed	aH	2	4.9
	Evolvulus alsinoides	Deria	aH	27	65.9
	Ipomoea cordofana	Taber	aH	1	2.4
Fabaceae	*Desmodium dichotomum*	Abu Arida	aH	22	53.7
Gramineae	*Sorghum arundinaceum*	Adar	aG	20	48.9
Lamiaceae	*Ocimum basilicum*	Rayhan	aH	12	29.3
	Denebra retraflexa	Um Mamilha	aG	6	14.6
	Ischaemum brachyatherum	Boos	pG	6	14.6
	Schizachyrium exile	Hemira	aH	10	24.4
Resedaceae	*Caylusea hexagyna*	Daniba	aH	1	2.4
Scrophulariaceae	*Veronica sp.*	Abu Morowa	aH	27	65.9
	Striga hermonthica	Boda	aH	31	75.6

* Abbreviations stand for: aH: annual herb, pH: perennial herb, aG: annual grass, pG: perennial grass.

3.5.2.12 Plant Species Composition on Abandoned Agricultural Land

Trees/Shrubs

Acacia seyal var. *seyal*, *Ziziphus spina-christi*, *Acacia senegal*, *Balanites aegyptiaca* and *Dichrostachys cinerea* are the common trees/shrubs naturally regenerated on abandoned mechanized agricultural land as indicated by farmers (Table 3.13). Five of the trees/shrubs were belonging to family *Mimosaceae* and they can perform a nitrogen fixation process. It is clear that this reflect the high capability for these species to regenerate and survive under conditions of poor soil nutrients, grazing, repeated fire and cutting. However, *Acacia seyal* var. *seyal*, *Acacia senegal* and *Balanites aegyptiaca* are the tree/shrub species that farmers prefer to leave in their cultivated land as mentioned previously. While these species receive some degree of protection, other species like *Ziziphus spina-christi* shows very high natural regeneration potential on abandoned land. During the filed survey it was observed that most of the natural regeneration of *Ziziphus spina-christi* is by sprouts. This observation agrees with El Nour *et al*. (1995). They mentioned that natural regeneration of *Ziziphus spina-christi* in northern Gezira, central Sudan is mostly by sprouts, followed by natural seeding and few coppices. It was also documented that *Dichrostachys cinerea* show good recovery following fire and weeding disturbances (Obiri *et al*., 2004). Gijsbers *et al.* (1994) mentioned that man observed throughout Burkina Faso scattered well-grown trees, in a regular pattern, on cultivated or recently fallowed fields. These trees are not specifically planted, but are left on fields after fallow or tended because of their economic value.

Table 3.13: Trees and shrubs naturally regenerated on abandoned agricultural land as indicated by farmers.

Family	Scientific name	Vernacular name	No.	%
Balanitaceae	*Balanites aegyptiaca*	Hegleg	12	29.3
Combretaceae	*Combretum glutinosum*	Habeel	4	9.8
	Combretum hartmannianum	Sobag	1	2.4
Mimosaceae	*Dichrostachys cinerea*	Hargem	8	19.5
	Acacia polyacantha	Kakmot	4	9.8
	Acacia senegal	Hashab	27	65.9
	Acacia seyal var. fistula	Sofar	4	9.8
	Acacia seyal var. *seyal*	Taleh	35	85.4
Rhamnaceae	*Ziziphus maritiana*	Nabeg Elfeel	1	2.4
	Ziziphus spina-christi	Sidir	34	82.9

3.5.2.13 Factors Influencing Plant Species Composition and Succession during Abandonment

Respondents mentioned a comprehensive group of factors influencing plant species composition and succession during abandonment (Table 3.14). It is clear that most farmers (34 respondents – 93 %) believe that grazing is the most important factor determining plant species composition and succession on abandoned agricultural land. Other important factors are duration of abandonment (68 %), duration of cultivation (51 %), rainfall (42 %), fires (39 %) and weed composition (20 %).

In fact the rate and paths of natural succession vary widely on abandoned land formerly under continuous agricultural production. The principal commonality is the nonlinear relation between the intensity and duration of land-use and the time required for recovery after abandonment. Factors influencing succession on old fields are extremely complex, and many contradictory results could be seen from a first glance in the literature written in this topic (Daily, 1995; Fernandes and Sanford, 1995; Wezel and Boecker, 1998; Colin *et al.*, 2000). Daily (1995) mentioned that severity of erosion, initial floristic composition, and character of the *ex situ* seed source are paramount. Furthermore, Fernandes and Sanford (1995) highlighted that different land uses and even different cultivated species can have significant long-term effects on site quality, species diversity, and time required for re-establishment of previous forest. Wezel and Boecker (1998) speak about other factors and they mentioned that plant communities developed in relation to intensity and history of cultivation, time and site characteristics, while fallow age have no importance for the differentiation of the plant communities.

However, it could be concluded that such factors were more or less site related factors depending on the prevailing local environmental (e.g. edaphic and climatic) conditions and the land uses practices. In this respect the novelty of the following farmers' perception is indispensable and is the key to understand and analyse factors influencing plant species composition and succession during abandonment.

Table 3.14: Factors influencing plant species composition and succession during abandonment as indicated by farmers.

Factor	No	%
Duration of cultivation	21	51.2
Duration of abandonment	28	68.3
Types of previously cultivated crops	7	17.1
Rainfall	17	41.5
Soil condition	3	7.3
Grazing	34	82.9
Fires	16	39.0
Weed species	8	19.5
Others	1	2.4

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3.7 Appendices

Appendix 3.1: Questionnaire for Collecting Historical Information from Key Informants

1- When was the first time that farmers started to introduce mechanization and where?

……………………………………………………………………………………………..

2- When did the farmers begin to leave part of their land abandoned?

……………………………………………………………………………………………

3- Yield estimation and changes of weeding and ploughing time in the last five decades for the two main crops cultivated in the area.

Decade	Sorghum			Sesame		
	Yield (sacs* / hour**)	Times of weeding	Times of ploughing	Yield (ardeb*** / hour)	Times of weeding	Times of ploughing
1960s						
1970s						
1980s						
1990s						
2000s						

*1 Sac of sorghum = 91.50 kg

**1 hour = 5 feddan (1 Feddan = 1.038 acre = 0.42 ha) g

***1 Ardeb of sesame = 44. 93 k

4- What are in your opinion the possible causes of plant species disappearing and decreasing?

……

……

…………………………………………..…………………………………………………..………………

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5- What are in your opinion the changes in the plant species composition in Doka area?

Family name	Scientific name*	Vernacular name	Changes	Life form	Local uses

Appendix 3.2: Questionnaire for Collecting Agricultural, Social and Ethno-Botanical Information about Degradation and Abandonment of Mechanized Rain-Fed Agricultural Land from Large-Scale Framers

I. General

- Questionnaire No.: …….. - Date: ……/……/ 2006
- Site of interview: ……………………………… - Enumerator: ………………………

II. Personal Information

1. Name: ……………………………………………
2. Age: ………… yrs
3. Education: a. Illiterate ( ) b. *Khalwa* ( ) c. Primary ( ) d. Intermediate ( )
   e. Secondary ( ) f. Graduate ( )
4. Years of farming experience: ………. yrs

III. Agricultural land

5. Location of the farm: ………………………
6. Area of the farm: ………. *feddan*
7. How long have you been cultivating your present land? ……….. yrs
8. What are the main crops cultivated? a. Sorghum ( ) b. Sesame ( ) c. Others ( )

IV. Land degradation

9. How do classify the yield of your land? a. Good ( ) b. medium ( ) c. Poor ( )
10. Have you experienced any instances of degradation on your farm?
    a. Yes ( ) b. No ( )
11. If yes what are the major indicators? a. Decrease of yield ( ) b. Increased weed infestation ( ) c. Soil compaction ( ) d. Others (…………………..….) ( )
12. If yes, what are the reasons? a. Rainfall ( ) b. Continuous cultivation ( )
    c. Mono-cropping ( ) d. Using inferior seeds ( ) e. Others (……………) ( )
13. What are the measures you used to improve and/or mitigate your land?
    a. Fertilization ( ) b. Crop rotation ( ) c. Double ploughing ( )
    d. Prescriptive fire ( ) e. Abandonment ( ) f. Nothing ( )

V. Abandonment

14. Do you leave part of your land abandoned? a. Yes ( ) b. No ( )

15. If yes how many *feddans* or %? ………………….

16. For how long would you leave your land abandoned? …………yrs

17. What is in your opinion the sufficient period for the land to recover? ………. Yrs

28. After how many years of cultivation would you leave your land abandoned?…. yrs

19. Why do you leave your land abandoned? a. To restore soil fertility ( )

b. To control weeds ( ) c. Financial shortage ( ) d. Insufficient rainfall ( )

20. What are in your opinion the advantages of abandonment?

a. Restoring soil fertility ( ) b. Producing woody material ( )

c. Control weeds ( ) d. No advantages ( ) e. I do not know ( )

21. What are in your opinion the disadvantages of abandonment/fallow periods?

a. Reduction of cultivated area ( ) b. Weed harbouring ( ) c. Shrub invasion ( ) d. No disadvantages ( ) e. I do not know ( )

22. How do know you that your land has recovered?

a **.** Key species indicators (…………………, …………………, ……………..)( ) b**.** Soil indicators (……………………) ( ) c**.** Others (………………….) ( )

VI. Vegetation covers on cultivated and abandoned land

23. How do you treat the trees and shrubs species appearing on your cultivated land? a. Leave all ( ) b. Remove all ( ) c. Leave some ( )

24. If you leave some which species do you prefer to leave and why?

Species	Reason							
	Cultural value	Shade	Fire wood	Building material	Charcoal	Gum	Fruits	Others

25. What is (are) the method(s) you use to remove trees and shrubs from your land? a. Cutting the stem ( ) b. Uprooting ( ) c. Burning ( )

d. Others (……………….) ( )

26. What are the grasses and herbs emerging on your cultivated land and when did they emerge?

Group	Time of emergency		
	Beginning of the rain season	Mid rainy season	Late rainy season

27. What are the grasses and herbs that appeared on your farm when the land degraded?

……………………….. ……………………………… ………………………………..

……………………….. ……………………………… ………………………………..

28. What are the trees and shrubs which naturally regenerated on your abandoned land?

………………………… ………………………… ………………………..

………………………… ………………………… ………………………..

29. Do you practice any activities on your abandoned land?

a. Wood cutting ( ) b. Firewood collection ( ) c. Grazing ( ) d. Nothing ( )

30. Is there any difference in plant species composition on areas cultivated with Sorghum or Sesame? a. Yes ( ) b. No ( )

31. If yes, give a list of species:

Areas cultivated with Sorghum	Areas cultivated with Sesame

32. What are in your opinion the main factors influencing the plant species life cycle and composition during the abandonment period?

a. Length of cultivation period ( ) b. Length of abandonment period ( )

c. Type of cultivated crop ( ) d. Rainfall ( ) e. Soil condition ( )

f. Grazing ( ) g. Fires ( ) h. Weed species ( ) i. Others (………….) ( )

33. Any additional comments or observations?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Appendix 3.3: Results of Large-Scale Farmers' Questionnaire

Table 1: Age analysis as indicated by respondents.

Age	NO.	%
30 – 40	10	24.4
41 – 50	11	26.8
51 – 60	9	22.0
61 – 70	9	22.0
71 and above	2	4.9
Total	41	100.0

Table 2: Experience as indicated by respondents.

Experience (yrs)	No.	%
8 – 20	14	34.1
21 – 30	14	34.1
31 – 40	9	21.0
41 – 60	4	9.8
Total	41	100.0

Table 3: Agricultural land holdings as indicated by respondents.

Size of agricultural land (in feddans)	No.	%
500 – 999	17	41.5
1000 – 2000	17	41.5
2001 – 4000	5	12.2
4001 and above	2	4.9
Total	41	100

Table 4: Duration of cultivation as indicated by respondents.

Duration of cultivation (yrs)	No.	%
6 – 20	12	29.3
21 – 40	19	46.3
41 and above	10	24.4
Total	41	100.0

Table 5: Farmers' assessment of their land productivity.

Classification	No.	%
Good	8	19.51
Reasonable	9	21.95
Poor	24	58.54

Table 6: Occurrence of incidences of land degradation as indicated by respondents.

Instances of degradation	No.	%
Yes	35	85.37
No	6	14.63

Table 7: Percentage of abandoned/fallow land in the total agricultural land as indicated by farmers in the Doka Area.

Percentage of abandoned land from total land	No.	%
15 – 30	22	56.4
31 – 45	6	15.4
46 – 60	9	23.1
61 and above	2	5.1
Total	39	100.0

Table 8: Why farmers abandoned their lands.

Reasons for land abandoning	N0.	%
To restore soil fertility	29	
To control weeds	25	
Financial shortage	12	
Rainfall	10	
Others	3	

Table 9: Duration (in yrs) of abandonment/fallowed period as indicated by farmers in the Doka Area.

Duration of abandonment (yrs)	No.	%
1 – 6	32	82.1
7 and above	7	19.9
Total	39	100.0

Table 10: Optimum period (in yrs) of fallowing according to the farmers' perceptions.

Range (yrs)	No.	%
3 - 6	20	51.3
7 – 10	19	48.7
Total	39	100.0

Table 11: Duration of cultivation (in yrs) after abandonment.

Duration of cultivation (yrs)	No.	%
4 – 6	13	33.3
7 – 9	7	17.9
10 – 12	14	35.9
13 – 15	3	7.7
16 and above	2	5.1
Total	39	100.0

Table 12: Reasons for abandoning agricultural land as indicated by respondents.

Reasons for land abandoning	No.	%
To restore soil fertility	29	70.7
To control weeds	25	61.0
Financial shortage	12	29.3
Rainfall	10	24.4
Others	3	7.3

Table 13: Farmers perceptions for trees/shrubs regenerated naturally on cultivated agricultural land.

Trees and shrubs	No.	%
Leave all	0	00.0
Remove all	7	17.1
Leave some	34	82.9
Total	41	100.0

4 Mapping of Abandoned Agricultural Land

4.1 Abstract

The aim of this study is to evaluate the capability of TERRA ASTER imagery and its indices and feature components to map abandoned agricultural land in the southern Gadarif Region, Sudan. Abandoned agricultural land represent about 17 % (31790.59 ha) of the study area. The optimum bands combination of raw ASTER VNIR and its driven indices successfully map the land-use/land-cover (LULC) in the study area with reasonable overall accuracy. The maximum likelihood classification shows that about 46 % (84614.60 ha) of the area is under cultivation while 19 % (35871.21 ha) were classified as bare land. Due to spectral confusion some LULC classes were not fairly classified. There were difficulties to discriminate between some of the recently abandoned and under cultivation areas, because the regeneration process on some of the recently abandoned lands is so slow that they appeared like cultivated ones. Therefore, recently abandoned agricultural land is the least accurate class (66.32 %). The consequence of land abandonment has been the increase of vegetation. Land-use has determined the type of land-cover and the degree of land-cover change is the direct result of abandonment and recultivation of agricultural land. There is a need to monitor LULC changes in order to provide quantitative evidence of the relationship between land abandonment and the formation of new landscape patterns.

4.2 Introduction

4.2.1 General

Although the Gadarif Region underwent wide-spread deforestation due to mechanized rain-fed agriculture expansion for the last fifty years, recently a significant area of this land has been abandoned due to a drastic decrease in yield and an increase in weed infestation. Like many developing countries, Sudan is experiencing a rapid land-cover change, but its assessment is often restricted by financial resources, accessibility and the lack of up-to-date maps and data. Remote sensing represents a suitable and cost-efficient and some times – like in this case – indispensable means to provide such information. The present study is the first one tackling this topic in the Gadarif Region where the abandoned agricultural fields represent about 15 to 20 percent of the total agricultural land (SKAP, 1992; Sulieman and Buchroithner, 2006). This is a remarkable portion for a region which produces 30 to 40 percent of Africa's largest country (approx. one million square miles) total production of sorghum, the primary staple food in the country. Moreover, there is an urgent need to assess and evaluate the natural vegetation cover on abandoned agricultural land that supports richer assemblages of biological species in order to preserve the habitats and protect many plants and animal species. Abandoned agricultural land in the Gadarif Region is characterized by a high spatial and temporal heterogeneity of vegetation patterns (Figure 4.1). This heterogeneity cannot be regarded as a simple mixing of LULC over large areas but, rather as the formation of patchy patterns with complex mixtures resulting from disturbance (e.g. recultivation, grazing, fires) and recovery cycles.

4.2.2 Potential of Remote Sensing for Mapping Abandoned Agricultural Land with Emphasis on Secondary Vegetation Succession

Remote sensing is an attractive source of thematic maps such as those depicting LULC as it provides a map-like representation of the Earth's surface that is spatially continuous and highly consistent as well as available at a range of spatial and temporal scales (Buchroithner, 1989; Foody, 2002). Thematic mapping using remotely sensed data is typically based on an image classification. This may be achieved by either visual or computer-aided analysis. LULC change is a fundamental variable that impacts many parts of the human and physical environments and was regarded as the most important variable of global change affecting ecological systems (Vitousek, 1994).

Land-use activities, along with natural disturbances, are the primary driving forces behind the successional changes in plant ecology in the abandoned agricultural land in the Gadarif Region. Like any biological resource, abandoned agricultural lands are renewable as long as they are managed on a sustainable basis. Destruction caused by human activity is the greatest threat to plant communities and biodiversity in the area. Although the process is easily to observe, it is difficult to quantify (Blatt *et al*., 2005). In spite of its both ecological and socio-economic importance, not many studies related to the mapping of vegetation succession in Sudan have been conducted concerning abandoned agricultural land. The author did not find any previous study tacking this topic in the Gadarif Region. For understanding the response of vegetation to disturbance and to design strategies for ecosystem management and restoration, sufficient knowledge of the mechanisms, in addition to the rates and pathways of secondary succession, is crucial (Sarmiento *et al*., 2003; Çakir *et al*., 2007). However, up-to-date and accurate information about the present situation regarding the distribution of abandoned agricultural land and its successional stage is an essential prerequisite and base for any future activities for managing abandoned agricultural land in the Gadarif Region.

Figure 4.1: A typical pattern of abandoned agricultural vegetation from dry (A) and rainy seasons (B) in the form of patches with diverse species composition and stage of growth which reflect different disturbances of the habitat. Photographs by the author. March 2005 and July 2007.

LULC mapping is one of the most important and typical applications of remote sensing data. Although the methods of data acquisition clearly vary according to the purpose of and the scale of mapping, there have been significant shifts in the main data collection techniques for vegetation mapping within the last three decades. There has been an exponential growth of vegetation maps based on satellite data since the early 1980s, while studies which rely entirely on data collected in the field, though only representing a small proportion of the total of maps produced, have remained relatively constant over this period (Millington and Alexander, 2000). In many research fields the ecological consequences of land abandonment implying secondary successions, have been studied for several decades (Çakir *et al.*, 2007). The importance of understanding the secondary succession in abandoned systems is receiving more interest from scientists (Risch *et al*., 2004).

Optical remote sensing data have been used extensively to map the extent and rates of deforestation and, more recently, the extent and temporal dynamics of secondary growth. Results from NASA's Landsat Pathfinder Project revealed extensive areas of secondary growth throughout the tropics (Salas and Skole, 1998). Thematic Mapper (TM) spectral bands 3, 4, 5 and 7 were found to be suitable for differentiating between vegetation types as a result of their chlorophyll absorption and mesophyll reflections (Grignetti *et al*., 1997). Due to its advantages high-resolution satellite imaging, however, should be used for the mapping of the secondary vegetation succession. Çakir *et al*. (2007) stated that the spatial and spectral resolution of Landsat imagery provides means for mapping and monitoring land-cover at landscape level; nevertheless, it does not have the potential for mapping and monitoring of a minor vegetation communities or land-cover types at stand level because of its low resolution. Thus, high-resolution satellite imagery should be used either alone or with field survey data. The availability of high resolution satellite imaging, such as IKONOS and Quickbird, provides an opportunity to recognize ground features that were previously not observable.

A particular strength and advantage of remote sensing is its ability to provide an overview over the LULC classes that would be difficult to be achieved by ground survey alone. Moreover, classifying vegetation by remote sensing is valuable because it can determine vegetation distribution and occurrence over very large areas in a short time for a reasonable price. Advances in technology led to developments in methods of vegetation classification, creating new and more sophisticated components, indices and powerful data transformations. Domaç *et al*. (2004) mentioned that classifying original Landsat TM bands and/or image components may cause unsatisfying results in spectrally confused fields. In such cases the demand for accurate LULC information may require more explanatory components. Those components should represent specific information for land-covers and not contain redundant knowledge. The results of Domaç *et al*. study suggest that using spectrally altered bands and indices improves the accuracy of the classification 10 – 15 percent.

Challenges and Limitations

The widespread use of satellite data for mapping vegetation suggests that the spectral channels provided by the existing sensors are adequate for differentiating between life-forms (Shoshany, 2000). Unfortunately, the quantitative detection of sparse vegetation in remote sensing imagery, and hence in many arid and semiarid areas worldwide, remains problematic.

Ustin (2004) summarizes some significant challenges for retrieving vegetation parameters from remote sensing in arid and semi-arid areas: 1) low vegetation cover over on bright soils means the vegetation signal can be swamped out of the pixel-averaged signal, 2) exposed, variable soil surfaces can contribute significantly to the within-scene variability, 3) open canopies and bright soils can contribute to significant multiple scattering and nonlinear mixing and 4) rapid phenological changes are accompanied by spectral changes in arid and semi-arid vegetation which can lead to temporally and spatial significant spectral intra-variability.

Cingolani e*t al*. (2004) cited three major problems of mapping natural vegetation with mid-resolution satellite images (e.g. Landsat TM) using supervised classification techniques: 1) defining the adequate hierarchical level for mapping, 2) defining discrete land-cover units discernible by the satellite and 3) selecting representative training sites. In order to solve these problems, they developed an approach based on the: 1) definition of ecologically meaningful units as mosaics or repetitive combinations of structural types, 2) utilization of spectral information to define the units and 3) exploration of two alternative methods to classify the units once they are defined: the traditional maximum likelihood method which was enhanced by analysing objective ways of selecting the best training sites, and an alternative method using discriminant functions directly obtained from the statistical analysis of signatures.

Despite these challenges and limitations it is possible to remotely retrieve quantitative information about vegetation. Shoshany (2000) showed improvements in the classification accuracy of woodland vegetation by applying segmentation techniques using ancillary data. The added value provided by using band ratios and vegetation indices allow him to identify different physiognomic-structural typologies in northern Sardinia.

4.2.3 Vegetation Indices and Feature Components

Vegetation index (VI) is a dimensionless, radiometric measure usually involving a ratio and/or linear combination of the red and near-infrared (NIR) portions of the spectrum. They serve as indicators of relative growth and/or vigour of green vegetation, and are diagnostic of various biophysical vegetation parameters.

Nowadays, the use of VIs to detect and map vegetation is widely accepted in remote sensing applications. Such indices focus on the use of red and near infrared wavebands where differential reflectance by photosynthetically active vegetation gives a low red and a high near infrared response. Indices range from a simple red/near infrared ratio to more complicated indices that include background soil conditions and atmospheric effects.

Feature extraction involves simplifying the amount of resources required to describe a large set of data accurately. When performing an analysis of complex data, one of the major problems stems from the number of variables involved. Analysis with a large number of variables generally requires a large amount of memory and computational power or a classification algorithm which fits the training samples and generalizes poorly to new samples. Feature extraction is a general term for methods of constructing combinations of the variables to get around these problems while still describing the data with sufficient accuracy. Although a reduction in dimensionality is desirable, the error increment due to the reduction in dimension has to be without sacrificing the discriminative power of the classifiers. Feature extraction methods can be both unsupervised and supervised, and also linear and nonlinear. (Benediktsson *et al*., 2003).

4.2.3.1 Chlorophyll-Based Indices

Simple Ratio Index

The Ratio Vegetation Index (SRI) is simply the ratio of red (R) to near-infrared (NIR) brightness values and capitalizes on the increase in brightness as one move from the red to the infrared data space (Equation 1).

$$\text{SRI} = \frac{NIR}{R} \qquad [4.1]$$

Normalized Difference Vegetation Index

The Normalised Difference Vegetation Index (NDVI) is the most widely used vegetation index (Equation 4.2). The NDVI is a more complex version of SRI, and has been used in numerous vegetation assessment studies. Many of them have shown that NDVI is responsive to rapidly growing highly reflective plant communities. Kennedy (1989) used the NDVI calculated from Advanced Very High Resolution Radiometer (AVHRR) data to study vegetation in Tunisia, whilst Ringrose and Matheson (1987) considered its application to rangeland in Botswana. The NDVI has been widely used in describing relationships between vegetation characteristics such as above-ground biomass, green biomass and chlorophyll content (Tucker, 1985). Purevdorj *et al*. (1998) estimated the percentage of the vegetation cover from vegetation indices using simulated AVHRR data derived from *in situ* spectral reflectance data. They found that the transformed soil-adjusted vegetation index and NDVI gave the best estimates of the vegetation cover for a wide range of grass densities. However, NDVI is sensitive to optical properties of the soil background (Baret and Guyot, 1991). The soil background effect is particularly important when the vegetation cover is sparse. In order to reduce the soil background effect some new indices which are less influenced by soil brightness were developed.

$$\text{NDVI} = \frac{(NIR - R)}{(NIR + R)} \qquad [4.2]$$

The use of VIs to characterize the vegetation cover can be limited by various physical effects that affect the signal at the sensor. Bannari *et al*. (2002) cited a number of factors that influenced red and near-infrared spectral bands: drift of the sensor’s radiometric calibration, atmospheric effects, relief effects, effects of the optical properties of the bare soil subjacent to the vegetation cover, spatial and spectral characteristics of the sensors.

Transformed Difference Vegetation Index

Bannari *et al*. (2002) developed the Transformed Difference Vegetation Index (TDVI) (Equation 4.3) to overcome the problems of NDVI which are weaknesses that result from the design and the analytical formulation of the vegetation indices. The potential of this index is evaluated by comparing it to the Soil Adjusted Vegetation Index (SAVI) and to the NDVI, with respect to linearity and saturation problems. And they conclude that the TDVI performs better than NDVI and SAVI. It does not saturate like NDVI or SAVI and it shows an excellent linearity as a function of the rate of vegetation cover, and shows the same sensitivity as the SAVI to the optical proprieties of bare soil subjacent to vegetation cover.

$$TDVI = 1.5 * \left[(NIR - R) / \sqrt{NIR^2 + R + 0.5} \right] \quad [4.3]$$

Tasselled Cap Transformation

The Tasselled Cap Transformation (TCT) was originally developed for agricultural investigations (Kauth and Thomas, 1976). It is a VI commonly used as an indicator of vegetation health and assessing vegetation and land-cover change. The TCT incorporates more information into vegetation indices by using all image bands. The resulting brightness (TCTB), greenness (TCTG), and wetness (BGW) indices, so named for the features in the data that they emphasize, improve vegetation classifications because they are sensitive to phenological changes. Yarbrough *et al*. (2005) cited that the goals in applying the TCT are: the multi-spectral data are rotated in eigenspace and aligned with physical characteristics of the scene and the variance of the data is compressed into a smaller spectral space. This compressed space has been defined by the coordinate axes: Brightness, Greenness, and Wetness. Yarbrough *et al*. (2005) used ASTER at-sensor radiance and reflectance data to generate transformation coefficients.

$$TCTB^{¤} = -0.274\,NVIR_1 + 0.676*VNIR_2 + 0.303*VNIR_{3n} \quad [4.4]$$

$$TCTG^{¤} = -0.006*NVIR_1 - 0.648*VNIR_2 + 0.564*VNIR_{3n} \quad [4.5]$$

¤At-sensor reflectance coefficients (Yarbrough *et al*., 2005)

4.2.3.2 Soil Line-Based Indices

Soil-Adjusted Vegetation Index

The Soil-Adjusted Vegetation Index (SAVI; Equation 4.6), a modified version of the NDVI, was proposed by Huete (1988). It normalises differences in soil substrate, thus allowing a more accurate estimate of the vegetation cover. In SAVI, the soil adjustment factor was used to account for soil background variations. SAVI incorporates an adjustment factor, based on the amount of vegetation, from zero for high vegetation to one for low vegetation. In the absence of extrinsic knowledge, an intermediate adjustment factor of 0.5 has been suggested and generally applied. Purevdorj *et al.* (1998) mentioned that the adjustment factor of 0.5 was found to reduce soil effect for vegetation with intermediate density. One of the drawbacks for SAVI is that it supposes an adjusted soil factor range between zero and one and that the exact determination of this factor is not possible.

$$SAVI = \frac{(NIR - R)}{(NIR + R + L)}(1 + L) \qquad [4.6]$$

where L = Soil adjusted factor

Modified Soil Adjusted Vegetation Index

Attempting to account for differences in soil background, Qi *et al.* (1994) proposed the modified SAVI (MSAVI). In MSAVI the constant L was replaced by a dynamic soil-adjusting factor. The difference, however, is that SAVI uses a manual adjustment L, while the MSAVI uses a self-adjustment. Baret *et al.* (1989) proposed the Transformed SAVI (TSAVI) by taking into account the soil line *slope* and *intercept* rather than using a universal adjustment factor. This index is a measure of the angle between the soil line and the line which joins the vegetation point and a point belonging to the soil line. The MSAVI is a modified version of the SAVI. Qi *et al*. (1994) demonstrated that the MSAVI better accounted for soil variability than the SAVI applied to a cover measure of cotton.

Optimum Soil Adjusted Vegetation Index

A minor but potentially important variation to SAVI has been proposed by Rondeaux *et al*. (1996). This approach to optimize the adjustment factor for general applications resulted in a recommended adjustment factor of 0.16, rather than 0.5. The optimized SAVI (OSAVI) is similar to SAVI, only with an adjustment factor of 0.16 under conditions of high substrate and vegetation heterogeneity.

Soil-Line Identification

The soil-line, a linear relationship between bare soil reflectance observed in two different wavebands originally discovered by Richardson and Wiegand (1977):

$$NIR = \beta_1 R + \beta_0 \qquad [4.7]$$

where: β_1 is the soil line slope and β_0 is the intercept.

The soil-line is widely used for interpretation of remotely sensed data. Soil-line parameters are extensively used to derive estimates of vegetation growth through vegetation indices. The theoretical basis of the soil line was laid on using a radiative transfer model in which reflectance was split into its single and multiple scattering components. The slope of the soil-line corresponds to the ratio of the single scattering albedos affiliated to the two wavebands in which the soil-line was defined. The intercept originated from the difference in multiple scattering observed in each of the two wavelength bands used. The soil-line concept is very robust over the whole optical domain as long as soil types are separated and the effects of the surface roughness are considered. In the middle infrared spectral domain, the soil-line concept failed when soil moisture was a factor of variation (Baret *et al*., 1993). Vegetation indices are based on the principle that significant differences exist in the reflections of healthy vegetation and dry bare soil as a function of wavelength (Richards and Jia, 1999).

4.2.3.3 Principal Component Analysis

Principal component analysis (PCA) is a multivariate statistical technique for the simplification of a data set by reducing its dimension. The technique was first developed by Hotelling (1933) for his work in educational psychology. Research efforts developed in two parallel directions. In statistical literature the main interest was in the area of sampling theory, whereas in pattern recognition the main concern has been with feature extraction methods such as information compressibility (Singh and Harrison, 1985). Technically speaking, PCA is an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component; PC), the second greatest variance on the second coordinate, and so on.

For remotely sensed imagery the PCA is often used to determine the underlying statistical dimensionality of the image data set, to enhance image, to apply change detection and to characterise seasonal changes in land-cover (Singh and Harrison, 1985). Genç and Smith (2005) compare the PCs for five different satellite images in the same study area. Among all the PCs (for all the datasets) the first three PCs contain most of the variance of the original datasets and all the other PC bands contain noise. This applies to both moderate and high-resolution imagery. They suggested that instead of original images the first three PCs could be used for classifications in agricultural and wetland areas.

4.2.3.4 Supervised Classification

Classification of land-cover from remotely sensed data has always been one of the main applications of remote sensing. It is an important and not always easy task, since the images are high-dimensional and complex in nature. As the number of categories and the amount of data involved increases, the complexity of the classification problem becomes more difficult e.g. to determine the characteristics of the categories and allocate a pixel to one of the categories (Cetin *et al.*, 2004).

There are several classification strategies and techniques attempting to satisfy certain remote sensing product conditions and end-use requirements. These can generally be categorized into two categories: deterministic and fuzzy classifications. Deterministic classification entails the isolation of certain pixel information into few defined classes. A pixel will fall into one and only one category if it devotes 100% of its information to the class it is assigned. On the other hand, the fuzzy classification system tries to retain the multiple facets of a single pixel (Klawonn and Kruse, 1993). In fuzzy classification methods, a pixel may fall into several classes with a certain degree of contribution.

Technically speaking, classification of remotely sensed data is used to assign corresponding levels with respect to groups with homogeneous characteristics, with the aim of discriminating multiple objects from each other. The level is called class. A classification will be executed on the basis of spectrally defined features, like density, texture etc. in the feature space. It can be said that classification divides the feature space into several classes based on a decision rule.

Supervised classification can be defined as the process of using samples of known identity (i.e. training pixels) to classify pixels of unknown identity (i.e. to assign unclassified pixels to one of the land cover classes; Campbell, 2002). A procedure most often used for quantitative analysis of remote sensing imagery. It rests upon using suitable algorithms to label the pixels in an image as representing particular ground-cover types or classes. For this, a variety of algorithms are available ranging from those based upon probability distribution models to those in which the multi-spectral space is partitioned into class-specific regions (Richards and Jia, 1999).

One advantage of supervised classification is that it allows the analyst to have control over the selection of informational categories tailored to a specific purpose and geographical region. Also, supervised classification is tied to specific areas of known identity and determined by the selection of training areas. Moreover, it is possible to detect errors in classification by examining training data and to check if they have been correctly classified (Campbell, 2002). The main problem with supervised methods is that the learning process heavily depends on the quality and number of the samples of the classes of interest e.g. training data set (Gomez-Chova *et al*., 2003). Moreover, a supervised classification is not able to recognize and represent special or unique categories not represented in the training data (Campbell, 2002).

4.2.4 Objectives

The aim objective of this study is to evaluate the capability of TERRA ASTER image data and its indices and feature components to map abandoned agricultural land. To do so it was also intended to identify the optimum original bands, indices and feature components of ASTER imagery combinations for the discrimination of different classes of abandoned agricultural land.

4.3 Data

4.3.1 ASTER Imagery

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument on board NASA’s TERRA satellite launched in December 1999. ASTER acquires 14 spectral bands and can be used to obtain detailed maps of land surface temperature, emissivity, reflectance and elevation. The specifications of the 14 ASTER spectral bands are mentioned in Table 4.1. With its high spatial resolution and multi-spectral bands ASTER is capable of analyzing vegetation covers and soil using the visible and near infra-red wavelength (VNIR), classifying minerals by short-wave infrared (SWIR) and identifying rocks and water bodies by thermal infra-red (TIR). Bands 3B and 3N which are stereo-images could be used to generate a Digital Elevation Model. Despite its relatively young age, ASTER attracted the scientific community, and now a bulk of literature is available (http://asterweb.jpl.nasa.gov/bibliography.asp). Imagery used for this study was acquired 07 February 2005. Only the VNIR bands were included in the analysis.

4.3.2 Field Data

Field reconnaissance survey was carried out in the initial stage, while intensive field work was conducted two times during dry and rainy seasons (2005 and 2006). Ground-control points were collected using a hand-held Geographical Positing System (GPS) instrument with approximately 15 m real-time accuracy. Interviews with farmers were also conducted to assist image interpretation. A digital camera was used to collect photographs from different LULC types and local features. The data used also included topographic map sheets (1:100 000) from 1983.

Table 4.1: ASTER spectral bands characteristics

Sub-System	Band No.	Spectral Range (μm)	Spatial Resolution (m)
VNIR	1	0.520 – 0.60	15
	2	0.630 – 0.69	15
	3N	0.78 – 0.86	15
	3B	0.78 – 0.86	15
SWIR	4	1.60 – 1.70	30
	5	2.145 – 2.185	30
	6	2.185 – 2.225	30
	7	2.235 – 2.285	30
	8	2.295 – 2.365	30
	9	2.360 – 2.430	30
TIR	10	8.125 – 8.475	90
	11	8.475 – 8.825	90
	12	8.925 – 9.275	90
	13	10.25 – 10.95	90
	14	10.95 – 11.65	90

4.4 Methodology

4.4.1 Image Pre-Processing

To correct for both solar and atmospheric effects Chavez's (1996) COST Model was used. Image rectification is achieved by using 1:100 000 topographic map from 1983.

4.4.2 Development of Classification Key

Six LULC classes were defined during the field survey, namely: natural forest, cultivated agricultural land, secondary natural forest on abandoned agricultural land, old abandoned agricultural land, recently abandoned agricultural land and bare land. Phenology, composition and structure of the natural vegetation existing in the abandoned agricultural land are highly variable and present particularly difficult problems for remote sensing studies of vegetation distribution and classification. The major components include mixtures of herbs, grasses, shrubs and trees at different growth stages, crop debris, and bare soil. Moreover, the patchy distribution of the abandoned fields among the cultivated land represents an additional source of spectral confusion, especially for the recently abandoned agricultural land. The main drivers for temporal change are climate (mainly rainfall), recultivation and various types of disturbance, like fire, grazing and firewood cutting. During the field survey ground data were acquired after tours guided by farmers and local forest officers. Parts of this data were used to determine the reference signatures for the classification process, while the other part was used as an independent reference to evaluate the classification accuracy.

4.4.3 Image Processing and Analysis

4.4.3.1 Vegetation Indices and Feature Components

The indices and feature components used for the analysis beside the original ASTER VNIR bands are first three PCs, SRI, NDVI, TDVI, TCTG, TCTB, SAVI, MSAVI, TSAVI and OSAVI. In order to be convenient for the study, the indices values was extended to the gray range of 0 to 255. The Spatial Modeller in ERDAS Imagine (Version 8.7) was used for generating the indices. For TCT indices the coefficients developed by Yarbrough *et al*. (2005) was used (Table 2). Concerning the soil-line base indices, Richardson and Wiegand (1977) equation (Equation 4.7) was used to calculate the *slope* and *interception* (Figure 4.3).

Table 4.2: Tasselled Cap Transformation coefficients for ASTER at-sensor reflectance (Yarbrough *et al*., 2005).

Axis	Band 1	Band 2	Band3N
Brightness	- 0.274	0.676	0.303
Greenness	- 0.006	- 0.648	0.564
Wetness	0.166	- 0.087	- 0.703

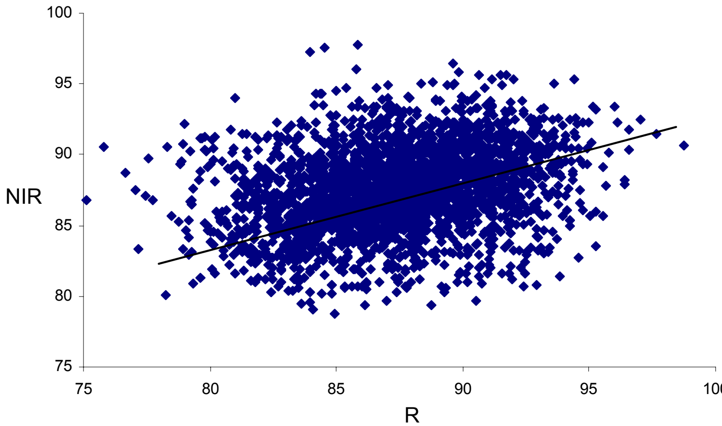

Figure 4.3: Soil-line derived from R and NIR bands of ASTER February 2005.

4.5 Results and Discussion

4.5.1 Supervised Classification

4.5.1.1 Selection of Optimal Band Combination

Before starting with the image classification visual and statistical comparisons were performed as a basis for the selection of the optimum band combination. Band selection for remotely sensed image is an effective means to mitigate the dimensionality of the data. Due to different characteristics of LULC classes the use of too many variables in a classification procedure may decrease classification accuracy (Price *et al*., 2002). Lu and Weng (2007) stated that it is important to select only the variables that are most useful for separating land-cover or vegetation classes, especially when hyper-spectral or multi-source data are employed. Price *et al*. (2002) evaluate the use of raw Landsat (TM) band combinations and several derived vegetation indices (TCTB, TCTB, TCTW, NDVI, Greenness Vegetation Index (GVI), Mid-infrared, PC1,2,3) to determine optimal vegetation indices and band combinations for discriminating six grassland management practices in eastern Kansas, USA. Their results showed that among the transformed datasets, the GVI was found to be the best for the discrimination of grassland management types.

Figure 4.4 shows spectral response curves of the LULC classes using raw and transformed ASTER data. Spectral signature curves are graphical representations of the spectral response of a certain type of LULC as a function of wavelength. Each LULC class has its own unique spectral reflectance curve. These curves are defined by the varying percentage of reflectance. Plotting the spectral reflectance curves in graphic form allow to determine which bands are most useful for discriminating certain surface categories. Theoretically, the higher the contrast (gaps) between the signature curves of any two types of LULC, the easier it should be to distinguish them and, hence, the greater the potential is for fast and accurate LULC mapping.

After performing correlation analysis it was decided that VNIR2, VNIR3, PC1, SRI, TCTB and SAVI should be used for further interpretation of the LULC classes and thus, for the supervised classification. VNIR2 and 3 were the two ASTER bands used for generating vegetation indices. Apan *et al*. (2002) found that the same band produced the best average separability. Surprisingly, TCTG in this study did not show any discrimination of LULC classes. The reason for this could be that the study was conducted during the dry season so that the reflection of the stressed vegetation is dominated by the background signal of the soil. When a plant is under stress and chlorophyll production is decreased, the vegetation shows much lower reflectance. This is very evident in arid environments that are characterized by sparse and heterogeneous vegetation. Heterogeneity in arid environments is a major problem in remotely determining the vegetation cover. Understanding of the local conditions and its associated land-cover attributes remain an important aspect in accurately determining the vegetation greenness using remotely sensed data (Nyokabi and Laneve, 2004).

The SAVI showed a better discrimination than the other indices, even than its transformed version (TSAVI) which was calculated by using the soil-line method (Figure 4.4). However, this was expected due to the weak correlation of the R and NIR, because of the small area of the bright object (The area used was small out-crop surrounded by forest). Lawrence and Ripple (1998) mentioned that among the soil-adjusted indices which they use a computed soil-line performed best. On the other hand among the ratio-based vegetation indices they used, the unadjusted indices (SRI and NDVI) performed best because the soil-line was not substantially different from that assumed by these indices. As a result, for the soil-adjusted indices, TSAVI, which used a site specific soil-line, explained more variability in vegetation cover than other soil-adjusted indices.

Lawrence and Ripple (1998) stated that all vegetation indices they used (SRI, NDVI, SAVI, TSAI, MSAI, OSAVI) were found to be highly correlated to green vegetation cover. From the ratio-based vegetation indices, the unadjusted indices (SRI and NDVI) performed best because their soil-line was not substantially different from the one assumed by these indices. For the soil-adjusted indices, TSAVI which used a site-specific soil-line, explained more variability in the vegetation cover than other soil-adjusted indices.

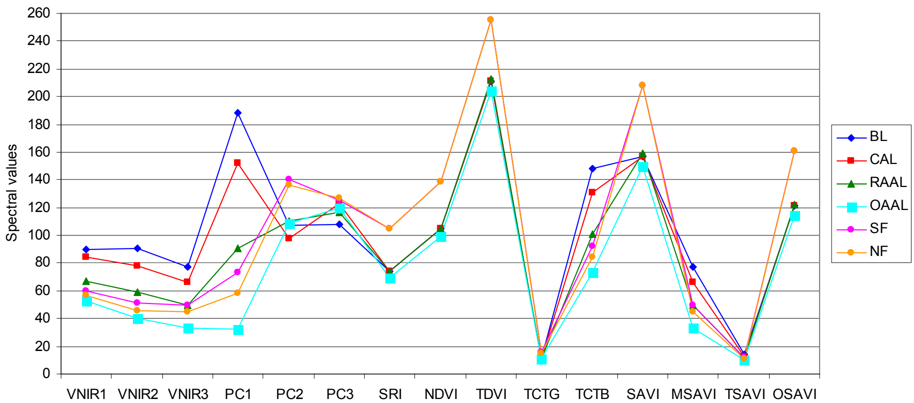

Figure 4.4: Spectral response curves of LULC using original and transformed ASTER VNIR bands.

4.5.1.2 Signature and Training Data Evaluation

Sufficient and accurate training data must be acquired to classify areas of interest using a supervised classification method. However, the relatively small patches of abandoned agricultural land and an their uneven distribution within the cultivated land (Figure 4.1) means that collecting training areas sufficiently large to represent the features of interest is not an easy task.

Apan *et al*. (2000) performed a signature evaluation using ellipses and dendrograms to examine the spectral properties of individual training sample classes and their separability against others. Statistical analyses of spectral responses from training samples as well as ellipse and dendrogram plots show that the confusions can be inferred between a few patches of bare soil and residential areas. In contrast, most vegetation and non-vegetation areas (bare soil, water) are spectrally distinct. The results of the first run of the maximum likelihood classification confirm the above findings of the statistical evaluation of the training sample. Following the patterns of confusions training data, many areas were misclassified. The statistics contained in the signatures aid in determining whether the classes are good in terms of their separability in the multi-dimensional feature space (Apan, 1997). It is, however, evident that even with high-resolution imagery still some contaminations occur in the training signature. Plantier *et al*. (2006) assessed the spectral separability for forest cover using scatter plots and the Battacharrya Distance. They conclude that the very high spatial resolution of IKONOS data is not sufficient for the discrimination of some forest classes due to spectral confusion.

Table 4.3: Contingency error matrix of training data for the maximum likelihood classification.

Classified	Reference data (%)						Total
data	1	2	3	4	5	6	pixel
1	**99.66**	0.00	0.00	0.00	0.00	0.00	5932
2	0.00	**99.98**	0.00	0.00	0.06	0.00	4705
3	0.00	0.00	**99.74**	0.57	0.18	0.00	8756
4	0.34	0.00	0.07	**98.86**	0.12	0.00	4550
5	0.00	0.02	0.08	0.57	**99.64**	0.00	1713
6	0.00	0.00	0.00	0.00	0.00	**100.00***	
	5952	4695	8750	4574	1685		

*Masked class (natural forests)

4.5.2 Accuracy Assessment

LULC maps derived from remote sensing always contain errors due to several factors which range from the classification approach to the method of satellite data capture. In order to wisely use the LULC maps which are derived from remote sensing and the accompanying land resource statistics, the errors must be quantitatively explained in terms of classification accuracy (Muzein, 2006). An evaluation of the classification results was performed using validation sites, obtained independently of the training areas. The percentage of correctly classified sites for each LULCC was presented in Table 4.4.

The producer's accuracy represents the probability that a reference sample will be correctly mapped and measures the errors of omission. In contrast, the user's accuracy indicates the probability that a sample from a land cover map actually matches the reference data and measures the error of commission. The two measures together are extremely useful as they give the commission and omission errors.

The overall Producer’s accuracy was 85.85 % and ranged between 99.00 % for bare land to 70.61 % for recently abandoned agricultural land. For the user’s accuracy also the most accurately classified was bare land and again 99.00 %. Recently abandoned agricultural land is the least accurate class but this time reached only 66.32 %. Natural forest was not included in the assessment because it was already masked. In study conducted by Muzein (2006) in an agricultural landscape of the Ethiopian rift valley the overall accuracy of the whole classification amounts to 83 %. He argued that this degree of accuracy is comparatively not bad, since the differentiating between vegetation types is always difficult in such dry environment the with Landsat ETM+ resolution. Using Landsat MSS and ETM imageries an overall accuracy of 78.13 % was recorded for mapping desertified areas in central Sudan (Mohamed, 2006).

Table 4.4: Maximum likelihood classification accuracy assessment of LULC classes.

Class	Producer’s accuracy (%)	User’s accuracy (%)
Bare lands	99.00	99.00
Cultivated agricultural land	81.12	80.88
Recently abandoned agricultural land	70.61	66.32
Old abandoned agricultural land	90.00	85.12
Secondary forests on abandoned agricultural land	88.52	90.90
Overall	85.85	84.44

4.5.3 Visibility of Abandoned Agricultural Land in ASTER Imagery and its Transformations

The results of supervised classification using the maximum likelihood algorithm show that about 46 % (84614.6 ha) of the area is under cultivation (Table 4.5), while 19 % (35871.21 ha) were classified as bare agricultural land. Abandoned agricultural land (recent and old) represents about 17 % of the total area. Secondary forest on agricultural land gains 4.46 %. Natural forests, however, cover only 13.39 % of the study area.

Due to spectral confusion some LULC classes were not fairly classified. Clear examples for this are roads. Although they are easily visible in the classified image (Figure 4.5), it was not possible to classify them as a separate class. The road Gadarif-Metemma is the only paved road in the area (not covered with Asphalt until the image acquisition date). Other roads represent only small paths of 3 to 4 m wide along boundaries between fields.

One of the main concerns of this work was to classify different types of abandoned agricultural land. However, there were difficulties in discriminating between some of the recently abandoned and cultivated agricultural land, because the regeneration process on some of the recently abandoned lands was so slow that they appeared like cultivated ones. Duncan and Chapman (1999) mentioned that unassisted forest succession on degraded croplands in East Africa proceeds slowly. This is probably also linked with a difficulty to separate the spectral signal of the two classes. Such problems of spectral confusion and classification errors are also expectable, when not very high resolution imagery is used to classify sparse heterogeneous LULC classes. To reduce confusion during the classification process, a mask for natural forests was applied. This ensured that only vegetation covers on abandoned agricultural land were included in the classification process. The secondary forests on abandoned agricultural land were found to be a different soil type which is locally called *Azaza*[1]. Almost the whole area with this type of soil, which was formerly cultivated for a short period, is now covered by secondary forests in its climax phase. This long abandonment period is due to the characteristics of the soil. During the first years of cultivation *Azaza* soils have very high productivity but quickly degrade. Most farmers leave their holding of this type of soil for woody material and charcoal production. As expected, the separability between bare land and all other LULC classes was excellent. This is mostly due to the distinct spectral reflection of pure soil.

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1) *Azaza:* is sandy clayey soil characterized as Luvisols, having loamy sand surface horizon overlaid by reddish brown sandy clay loam.

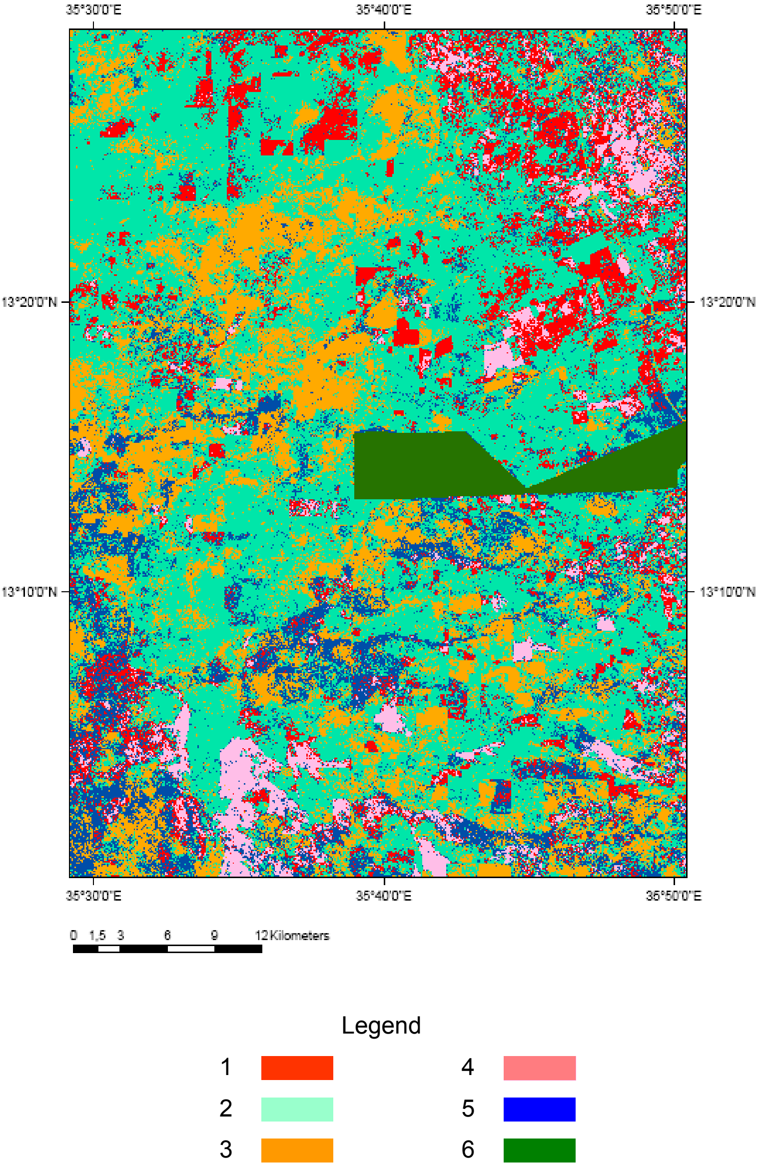

Figure 4.5: Maximum likelihood classification showing LULC classes.

Table 4.5: Area and percentage of LULCC using maximum likelihood classification of raw VNIR ASTER image and some of its transformations (cf. text).

Class	Area (ha)	%
Bare lands (1)	35871.21	19.35
Cultivated agricultural land (2)	84614.60	45.65
Recently abandoned agricultural land (3)	20974.97	11.32
Old abandoned agricultural land (4)	10815.62	5.83
Secondary forests on abandoned agricultural land (5)	8260.74	4.46
Natural forests (6)	24826.37	13.39
Total	185363.5	100.00

In study conducted by Petit *et al.* (2001) in Zambia it was found that recent fallows could not be discriminated in a separate class. They appear to be belonged to three different classes. If fallows are covered by little or no vegetation and are dominated by bright soils, they belong to the sandy soils or harvested agricultural land classes. In the case of a low vegetation cover and dark soils, they are included in the settlement or harvested agricultural land classes. When they have a more dense vegetation cover, they look spectrally like cultivated lands with crops or herbaceous savannahs. However, a multi-temporal analysis of images acquired in dry and wet seasons could help to discriminate between uncultivated land and recent fallows.

Relating this discussion to the objectives and motivations of this work, it can be stated that land abandonment is an important cause of changes in landscape patterns. There is a need to monitor LULC changes in order to provide quantitative evidence of the relationship between land abandonment and the formation of new landscape patterns. Appropriate management policies to encourage sustainable development can then be developed (Bielsa *et al*., 2005).

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5 Vegetation Composition and Structure of Abandoned Agricultural Land: Effects of Previous Land-Use and Age of Fallow

5.1 Abstract

Abandonment of agricultural land to restore soil fertility is a common practice among farmers in the Gadarif Region, Sudan. The present study seeks to provide a new contribution to the understanding of vegetation regrowth on abandoned agricultural land by investigating the impacts of the previous cultivation period and age of fallow on vegetation composition, structure and species diversity. The results of the study show that both factors have significant effects on the subsequent regeneration of plant species and thus the vegetation development. The oldest abandoned farmlands were recolonized by tree/shrub species, whereas recently abandoned ones are at the herbaceous vegetation stage. There is a general tendency regarding the number of species to decreasing with increase period of cultivation. Most of the calculated vegetation structure variables showed significant differences (e.g. woody species height and diameter). The plant-species diversity-pattern of on the abandoned agricultural land shows domination of herbaceous species with some scattered woody species. Vegetation changes due to land abandonment may have implication for the conservation of plant-genetic resources in the area, overall plant species diversity and composition of different fauna harboured in this habitat. The current regeneration capacity in the abandoned land may not be sufficient to reach full restoration of the climax vegetation except for some pockets which received more regenerative resources. Nevertheless, to ensure sustainable development of the successional vegetation long term operational research plans should be followed.

5.2 Introduction

5.2.1 General

Botanical studies of secondary vegetation on abandoned agricultural land as an indicator of the natural restoration process is a well established approach and increasingly receiving more attention from the scientific community (Chapman and Chapman, 1999; Duncan and

Chapman, 1999; Rivera *et al*., 2000; Asefa *et al.*, 2003; Lemenih, 2004; Benjamin *et al*., 2005). Although this topic have been tackled in many Sahelian regions of Africa (Wezel and Boecker 1998; Wezel and Haigis 2000; Asefa *et al*., 2003; Wezel; Schlecht, 2004), the present study, however, is the first one investigating this topic in the Gadarif Region where the abandoned agricultural fields represent about 15 to 20 per cent of the total agricultural land (SKAP, 1992; Sulieman and Buchroithner, 2006).

Abandoned agricultural areas provide a significant contribution to afforestation projects and serve as refuges for plant species previously dominating the area. Although these were not the farmers' objectives beyond the abandonment of agricultural land in the Gadarif Region, there exists a motivation for farmers to produce woody materials on their abandoned land. The study also raises some of the most challenging questions like to what extent the natural regeneration in fallow land can fulfil the objectives of restoration or at least rehabilitation. At the same time natural regeneration plays an important role that shows a clear demonstration of the success and benefits of fallowing agricultural land on one hand and on the other hand offers a comparative judgment between natural and artificial regeneration from both the silvicultural and financial point of view. This showed a clear picture concerning the potentiality of this approach for both farmers and agricultural policy makers through specific management recommendations that enhanced plant species conservation in agricultural land, the so-called Conservation Agriculture[1].

The Forest National Corporation (FNC) Investment Act of 1990 and the Ministerial Order 345/95 obliged old land proprietors to conform to the allocation of 10 and 5 % of their rain-fed and irrigated farmland, respectively, for forestry; and to allow 20 % of the holdings for forestry (Abdelnour, 1999; Ibrahim, 2000). In fact these recommendations were ignored by most farmers. So it is normal to see the mechanized scheme farms devoid of any tree cover (Elnagheeb and Bromley, 1992; Glover, 2005). Tscharntke *et al.* (2005) mentioned that the maintenance of biodiversity and ecosystem functioning requires closer collaboration with farmers and foresters. In these human-dominated landscapes, conservation strategies are a matter of public debate, discoursing over which type of ecosystem or landscape is wanted and should have priority for conservation.

1) Conservation Agriculture aims to achieve sustainable and profitable agriculture and subsequently improves livelihoods of farmers through the application of the three principles: minimal soil disturbance, permanent soil cover and crop rotations (FAO, 2007).

At local and regional scales, land-use changes are among the most immediate drivers of species diversity. Intensification of land-use, especially the conversion of natural ecosystems into agro-ecosystems, is supposed to both change the composition and reduce the diversity of biological communities. Therefore, one of the possible ways of counteracting the current loss of biodiversity may be to reduce the intensity of land-use or to abandon cultivated land (Van der Putten *et al.*, 2000). In this way agriculture can contribute to the conservation of high-diversity systems which may provide important ecosystem services. Agricultural land use and biodiversity conservation which have been traditionally viewed as incompatible can contribute to the conservation of high-diversity system, which may provide important ecosystem services such as pollination and biological control. Only recently, however, there has been an increasing recognition that such a conservation focus is of limited value and that the importance of population exchanges among areas of different disturbance regimes and among early and late successional habitats needs to be acknowledged (Tscharntke *et al*., 2005). According to Asefa *et al.* (2003) land abandonment is the common conservation strategy to promote restoration of biodiversity in degraded agricultural and grazing lands worldwide. Secondary forests have many valuable ecological characteristics, and their wise management could mitigate socio-economic factors leading to the destruction of mature forests and can be important sources for local domestic uses and habitat for many native plant and animal species (Finegan, 1992; Rivera *et al*., 2000).

Land-use history may be particularly important in areas such as the Gadarif Region that have been dominated by mechanized agriculture in the last five decades. Identifying the role of previous human activity is often difficult because land-use is poorly documented (Eberhardt *et al*., 2003) which is a typical situation for the study area. The importance of taking into account the land-use history in the analysis of vegetation community composition on abandoned land is increasingly recognized (Wezel and Boecker, 1998; Motzkin *et al*., 1999; Asefa *et al.*, 2003; Eberhardt *et al*., 2003; Benjamin *et al.,* 2005). However, attention to land-use/land-cover (LULC) is necessary to understand successional dynamics (Morana *et al*., 2000). Particular attention must be given to the effects of past land-use in the efforts to protect and restore successional communities. If past land-use has played a central role in the development of desired vegetation patterns, then land-use practices rather than natural disturbances might represent the best guide for active management intended to maintain these communities through time (Eberhardt *et al*., 2003).

Benjamin *et al*. (2005) stated that understanding the transformation of an agricultural landscape is essential for the understanding of the origins and evolution of abandoned agricultural land.

5.2.2 Passive Restoration

Passive restoration means allowing natural processes to return to a stream by stopping activities that cause degradation or prevent recovery (Kauffman *et al*., 1997). The natural restoration processes should be used wherever possible. Bradshaw (1996) gave three interesting arguments for that. Firstly, they cost nothing, which is an important point for country like Sudan where exists almost no real financial support for restoration programs. Because it is simply beyond the priorities of local or regional governmental institutions. Second, they are likely to be self-sustaining because they originate from nature. And third, they can be used on large scales. Furthermore, the natural restoration process is very important to enhance the biological diversity of the landscape (Yirdaw, 2002). Also it allows nature to show its potential under specific site and prevailing environmental conditions, while active restoration is always based on few selected species. Afforestation programmes in the Gadarif Region carried by FNC are mainly based on few Acacia species namely, *Acacia senegal*, *A*. *seyal* var. *seyal*, *A*. *seyal* var. *fistula* and *A*. *mellifera*.

5.2.3 Constraints of Passive Restoration and Possible Enhancement Methods

In fact, the natural process can finally achieve full restoration, some time it may take a long time and need to de assisted (Bradshaw, 1996; Yirdaw, 2002) because human disturbance of these degraded areas often depletes resources needed for natural regeneration (e.g. seed banks, soil nutrients) and forest succession may depend on the arrival of dispersed seeds (e.g. by wind or animals). Duncan and Chapman (1999) stated that unassisted forest succession on degraded croplands in Uganda proceed slowly. Plant recruitment in degraded areas may include few trees and will probably be limited to areas below isolated midsized and tall trees. Several factors can delay or stop regeneration in degraded areas, and the importance of these factors may vary geographically. Chapman and Chapman (1999) cited a comprehensive list of factors that hamper to reach a full restoration of the abandoned agricultural land: topsoil erosion, nutrient exhaustion, or limited stump sprouting as well as seed bank depletion, i.e. source plants that produced new seeds may be too distant or scarce and seed dispersers agents (e.g. animals and birds) may not be attracted to degraded areas.

5.2.4 Active Restoration

Unsuccessfulness of afforestation projects in Sudan is common, although land degradation has been detected earlier than in other African countries (Stebbing, 1953). Ibrahim (1993) stated that reasons range from corruption to lack of grass-root participation of local communities. Officially, climatic desiccation is to be blamed for the failure of the projects. However, for the Gadarif Region there exist successful examples, but at small scales. Lemenih (2004) showed that restoration of soil attributes and native forest flora on degraded sites in Ethiopia can be fostered with the help of fast-growing tree plantations. He also observed that considerable differences exist between the plantation tree species involved both in fostering the regeneration of native woody species and restoring soil attributes. He concluded that one of the most important silvicultural precautions in using plantation forestry for ecological restoration is the decision which species to use. The choice of species needs careful consideration and should be based on knowledge of the species' effects on soil attributes and local biodiversity. Hussein and Sulieman (1999) proved that direct seeding show better growth performance (height and diameter) than the nursery stock and it was recommended for the establishment of large-scale afforestation projects in the Gadarif Region.

5.2.5 Motivation of Study

Mechanized rain-fed agriculture represents the main land-use practice in the study area, so its contribution is critical for successful conservation and restoration now and in the future. The impacts of previous land-use and the age of fallows on species composition and plant community structure have been well documented in many parts of the world. The negative environmental effects associated with the clearance of natural vegetation due to the rapid expansion of mechanized rain-fed agriculture in the Gadarif Region are significant and include, beside others, loss of biodiversity, lack of grazing areas and social instability.

The present study seeks to provide a new contribution to the understanding of vegetation regrowth in abandoned agricultural land for the purpose of providing a support for restoring currently abandoned/degraded agricultural land and possible future management plans for an ecologically and economically important region. Moreover, this investigation highlights the importance of such habitats for the conservation of native plant species which has been threatened due the expansion of the mechanized rain-fed agriculture.

5.2.6 Objectives

The objectives of this study were to assess the natural vegetation composition on the abandoned mechanized rain-fed agricultural land and to analyze the impact of the previous cultivation period and age of fallow on vegetation composition, structure and species diversity.

5.3 Methodology

5.3.1 General

Prior to the field work a supervised classification for 2003 Landsat ETM data was carried out to determine the spatial configuration and distribution of LULC classes in the study area. This first step is very important to determine a suitable sampling frame which has to be designed for this work. A set of historical and ecological variables to be measured were selected. However, it is not possible neither the objectives of this study to test all factors influencing plant species composition and succession during abandonment of degraded agricultural land as has been elaborated by farmers (Chapter 3). The field surveys were conducted in two phases: The first phase was during the dry season in March and April 2005 for sampling trees and shrubs and the second phase was during the rainy season in June and July 2006, the purpose was mainly to sample the herbaceous plant species. The optimum way is to collect the two data sets at one time, but due to the need of the data set for further investigations concerning the combination of field data with remote sensing imagery (Chapter 6) it was decided to follow this approach so as to avoid the effect of clouds on satellite imagery. On the other side the herbaceous cover survey was delayed until the rainy season of 2006, the time of its emergence in the study area.

5.3.2 Sampling Procedure

Selection of Sampling Sites

Restoration of biodiversity through land abandonment reflected both the spatial and temporal variations of previous land-use (mechanized rain-fed agriculture). The selection of sample sites on the abandoned agricultural land has been based upon pre-specified conditions:

- Duration of cultivation: two periods were chosen 10 to 19 year and more than 19 years;
- Time since abandonment 3 to 6 and more than 6 years;
- Land-use history with satisfactory accuracy;

- Agricultural land that has not been subject to severe disturbance events (e.g. cuttings, repeated fires, intensive grazing) and
- First of all, farmers were willing to carry out the sampling (non-destructed samplings have been used).

According to the above mentioned conditions stratified random sampling was conducted in the following four groups of abandoned agricultural land (hereafter called Communities):

1. Cultivated for 10 to 19 years and abandoned for 3 to 6 years (COMM1)
2. Cultivated for 10 to 19 years and abandoned for more than 6 years (COMM2)
3. Cultivated for more than 19 years and abandoned for 3 to 6 years (COMM3)
4. Cultivated for more than 19 years and abandoned for more than 6 years COMM4).

The above mentioned pre-requisites have, however, their influence on survey execution and duration and the total number of sample plots taken. Nevertheless, the novelty of this approach could be that it would be sound to collect accurate data instead of scattering the effort for large uncertain samples. The selection of areas with certain pervious cultivation periods and abandonment durations was based on interview results (Chapter 3). Moreover, commences, observations and arguments mentioned by farmers during transect walks and pre-sampling field visits were taken into account. Farmers' descriptions of land-use history were cross-checked by comparison of Landsat MSS and ETM multi-temporal imagery (Chapter 2). It is very important that sufficient reference information about the sampling sites is collected so that any changes in the vegetation between sites can be explained. In any restoration situation it is very essential to become fully aware of the natural processes already occurring (e.g. primary vegetation) prior the disturbance, as existing species which colonized the area may tell very little (Brandshaw, 1996).

Sample Plot Size

Assessing plant diversity is very sensitive to plot size. To avoid common problems certain consideration has been followed. The sample plot size was selected according to apparent homogeneity or heterogeneity of vegetation and also the further step of joining field data with remote sensing imagery (ASTER with 15 m resolution) and GPS shift error were considered. Furthermore, the abandoned area from each agricultural land was not of equal size. Accordingly, a nested sample plot of 20 x 20 m^2, 1 x 1 m^2 was used to sample plants of different sizes and other variables of interest. The size of 20 x 20 m^2 plots has been used by many studies in regions with comparable conditions and objectives (Yirdaw, 2002; Gole, 2003; Lemenih, 2004).

Sample Size

A total of 118 randomly located sample plots were collected. 78 samplings were conducted in the first phase, while only 40 were re-sample in the second phase because some abandoned lands were re-cultivated or did not fulfil the pre-specified conditions for sampling. However, estimating total plant diversity with plots has remained elusive because only a small portion of landscape can be sampled due to constraints like cost and time (Stohlgren *et al.,* 1997) and at the same time using species-area relations were untested for accuracy at large spatial scales. A primary consideration for the patterns of mapping plant diversity is to use minimum mapping units small enough to accurately capture the abundance of rare but important plant species.

5.3.3 Parameters Measured

In the major of plot of 20 x 20 m^2 numbers of all trees, shrubs, their saplings and seedlings and the respective species were recorded. From each identified species heights and diameters of five randomly selected individual trees/shrubs were measured. The 1x1 m^2 quadrate was three times randomly allocated to sample the abundance and composition of the herbaceous species. Again, the 1 x 1 m^2 quadrate was positioned randomly inside the major 20 x 20 m^2 plot, this time to assess the herbaceous biomass. The herbaceous biomass in side the quadrate was harvested and weighted. Visual estimations of the cover by the survey crew were recorded. The survey crew consisted of 3 persons with good plant identification knowledge and well acquainted with the study area.

5.3.4 Statistical Analyses

Abundances and frequencies of all tree and shrub (hereafter called woody species) as well as herb and grass species (hereafter called herbaceous species) were compiled on plot basis. Abundance is the number of individuals of particular species per plot. The absolute frequency of a species is the number of plots in which the species was recorded. Relative frequency of a species is the ratio of absolute frequency of the species to the total number of study plots. Several diversity indices were used to measure the diversity of herbaceous species. Shannon Diversity and Evenness Indices were used to separately calculate the species evenness, since Shannon Diversity Index is a single number and does not indicate the proportion of contributions of its components (richness and evenness) to diversity. In this context Shannon Evenness Index was calculated as the ratio of the Shannon Diversity Index to the maximum diversity. The value is represented by the natural logarithm of the number of species. However, the Shannon Index assumes that individuals are randomly sampled from an infinite large population (Magurran, 1988). The Simpson Index is considered a dominance index because it weights towards the abundance of the most common species. The index gives the probability of any two individuals drawn at random from an infinitely large community belonging to different species. Cluster analysis was used to classify herbaceous species based on abundance data. Cluster analysis is a technique for classifying numerical data using multiple attributes. It is an exploratory technique whose goal is to help to better understand what patterns exist in a given data set and to propose explanations for those patterns (van Tongeren, 1987).

A pre-test for the data sets shows that the frequencies of the samples were not normally distributed. The Mann-Whitney and Kruskal-Wallis non-parametric tests were used to compare woody species growth parameters (namely, height and diameter), herbaceous biomass accumulation and percentage cover. The Mann-Whitney Test is one of the most powerful non-parametric tests for comparing two populations. It is used here to test the null hypothesis between the two main communities (e.g. cultivation periods). The Kruskal-Wallis Test is applied to test the null hypothesis that all four sub-communities have identical distribution functions against the alternative hypothesis that at least two of the communities differ significantly. A further test was performed to separate between communities (Sachs, 1991). The Statistical Product and Service Solutions (SPSS) Software was used as analysis tool.

5.4 Results

5.4.1 General

The results will be presented according to the four communities surveyed. Of course not all abandoned land was covered during the survey but the four communities quite well represent the general situation of abandoned land in the study area.

5.4.2 Floristic Composition

A total of 52 flowering plant species representing 27 families were recorded in the abandoned agricultural land during the two survey phases in 2005 and 2006 (Appendix 5.1). Out of these, 27 were herb, 10 grass, 11 shrub and 4 tree species (Figure 5.1). There is one unidentified shrub. All recoded species were native. Herb species dominated the total number of species recoded (51.92 %). Out of all the herbaceous species there were only 5 perennials (2 herbs + 3 grasses). The rest were annuals. Among the woody plants, shrubs were the dominant (species 11), while trees represent only 7.69 %. At family level, *Gramineae* and *Mimosaceae* were the most abundant with 7 and 5 species for each. However, 16 families (30.80 %) were represented by only one species.

The abandoned agricultural land was dominated by herbaceous species with scattered woody species. This however, reflects the natural structure of savannah vegetation which is the natural cover on those areas before the introduction of mechanized agriculture (Figure 5.2).

The four communities of abandoned agricultural land show distinct species compositions (Figure 5.3) which nevertheless, reflect the effect of previous land-use and the time since abandonment. The highest richness in species (30 species) was recorded for COMM2, while the lowest species richness was gained by COMM4. Herb species were dominant in all communities, and tree species had the lowest frequency. They were only recorded in two communities.

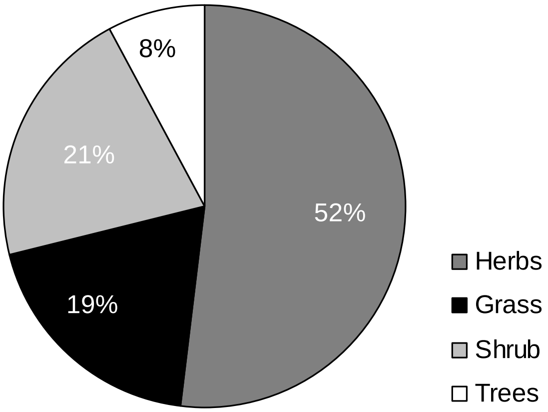


Figure 5.1: Percentage of plants recorded on abandoned agricultural land in the Doka Area during the field surveys in 2005 and 2006.

Figure 5.2: Vegetation composition and structure of different abandoned agricultural lands. A, B: Old abandoned land during the dry and rainy seasons dominated by *Acacia seyal* var. *seyal,* one of the main species characterizing the natural vegetation in the area. C: Recently abandoned land during the first few weeks of the rainy season dominated by a dense herbaceous cover. Photographs by the author. March 2005 and July 2007.

5.4.3 Herbaceous Species

5.4.3.1 Abundance and Frequency

A total of 37 herbaceous species were observed during the second field survey. It was not possible to resurvey COMM4 during the second field survey because the abandoned areas of this community were recultivated. The structure and composition of herbaceous species among different communities differed significantly. Table 5.1 shows the list of recorded herb and grass species on abandoned land, their abundances, rank orders and frequencies. Figure 5.4 shows the herbaceous species ranking based on relative abundance. Species abundance was also expressed as percentages to provide direct comparison between communities. The highest average abundance among all communities was recorded by *Digera muricata* in COMM2 (22.98 % relative abundance and 25 % relative frequency). This species however, is totally absent in the other two communities. *Ischaemum afrum* is the most frequent species in the three communities (100 %) with a relatively high to low abundance (between 12.07 – 4.30 %). Figure 5.5 shows abundances of the ten most common herbaceous species recorded. The five most abundant species were *Commelina imberbis, Digera muricata, Achryanthes aspera, Schizachyrium exile* and *Echinochloa colona.* Only ten species, namely *Achryanthes* *aspera, Ischaemum afrum, Evolvulus alsinoides, Desmodium dichotomum, Epaltes alata, Ophiuros papillosus, Abelmoschus esculentus, Ipomoea cordofana, Phyllanthus maderaspatensis* and *Veronica sp.,* show up in all communities, but with different portions of abundance and frequency. Figure 5.4 shows comparative representations of their relative abundance. Each community distinguished itself by some groups of species. In COMM2 recoded 11 unique species and in COMM1 and COM3 4 and 2 species were recorded respectively. In all communities about 50 % of the abundance is awarded by the first three ranked species. On the other extreme, 12 species were recorded in only one plot. In COMM1 the first three species, namely *Commelina imberbis, Schizachyrium exile* and *Achryanthes aspera,* gained the full frequency, and nearly 95 % of the total abundance accounted to half of the total number of species observed in this community. Abundance is not all positively related with the frequency in the three communities. However, the less frequent species at the end of each group are, however, associated with less abundance.

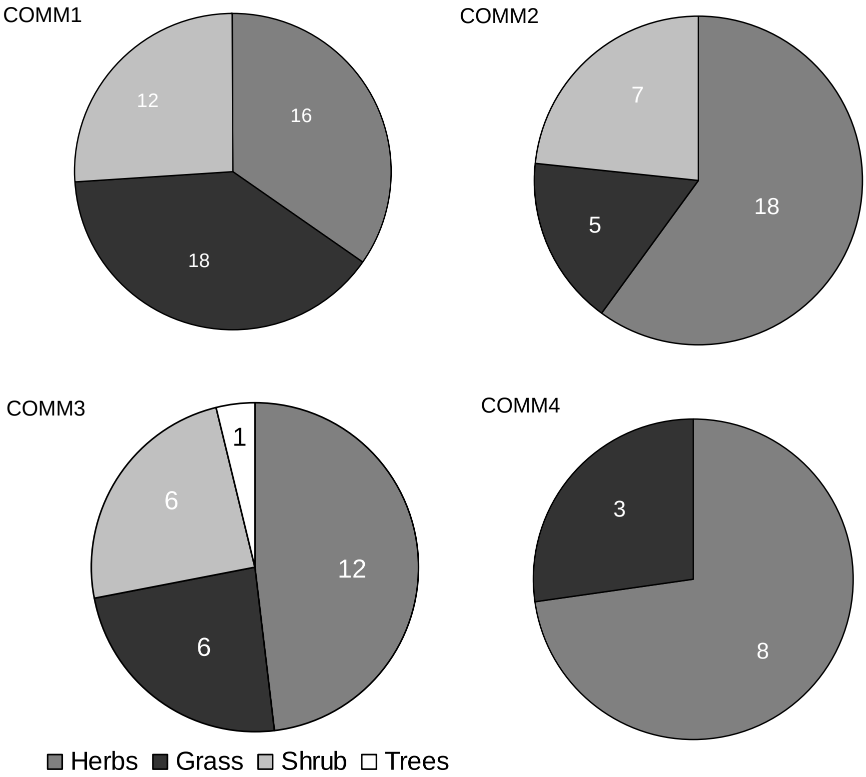


Figure 5.3: Plants recorded on the abandoned agricultural land in the Doka Area during the field surveys in 2005 and 2006.

Table 5.1: Rank order of average abundances (descending) and frequencies of herbaceous species recorded on abandoned agricultural land in the Doka Area during the field survey in 2006.

Comm unity	Rank order	Species	Abund ance	Relative abundance	Absolute frequency	%Relative frequency
COMM1	1	*Commelina imberbis*	10600	27,16	6	100
	2	*Schizachyrium exile*	5578	14,29	6	100
	3	*Achyranthes aspera*	5533	14,18	6	100
	4	*Ischaemum afrum*	4711	12,07	6	100
	5	*Evolvulus alsinoides*	4356	11,16	6	100
	6	*Desmodium dichotomum*	1978	5,07	6	100
	7	*Epaltes alata*	1267	3,25	5	83,33
	8	*Leucas urticifolia*	1222	3,13	3	50
	9	*Cyperus rotundus*	77	1,99	2	33,33
	10	*Hybanthus enneaspermus*	689	1,77	6	100
	11	*Echinochloa colona*	556	1,42	5	83,33
	12	*Ophiuros papillosus*	422	1,08	4	66,67
	13	*Abelmoschus esculentus*	356	0,91	6	100
	14	*Ipomoea cordofana*	267	0,68	5	83,33
	15	*Euphorbia aegyptiaca*	267	0,68	3	50
	16	*Phyllanthus maderaspatensis*	156	0,40	5	83,33
	17	*Amaranthus graecizans*	89	0,23	2	33,33
	18	*Ocimum basilicum*	67	0,17	1	16,67
	19	*Solanum dubium*	44	0,11	1	16,67
	20	*Veronica sp.*	44	0,11	1	16,67
	21	*Ipomoea sinensis*	22	0,06	1	16,67
	22	*Sonchus cornutus*	22	0,057	1	16,67
COMM2	1	*Digera muricata*	16222	22,98	3	25
	2	*Achyranthes aspera*	14444	20,46	8	66,67
	3	*Evolvulus alsinoides*	7889	11,18	11	91,67
	4	*Ceratophyllum demersum*	7067	10,01	4	33,33
	5	*Aristida adscensionis*	6700	9,49	5	41,67
	6	*Ophiuros papillosus*	4311	6,11	8	66,67
	7	*Brachiaria obtusifolia*	4278	6,06	4	33,33
	8	*Ischaemum afrum*	2833	4,01	12	100
	9	*Epaltes alata*	2056	2,91	9	75
	10	*Desmodium dichotomum*	1456	2,06	4	33,33
	11	*Ipomoea cordofana*	889	1,26	2	16,67

Table 5.1 Cont.

	12	*Commelina imberbis*	878	1,24	4	33,33
	13	*Cucumis dispaceus*	622	0,88	6	50
	14	*Ipomoea sinensis*	256	0,36	4	33,33
	15	*Thunbergia annua*	156	0,22	3	25
	16	*Pancratium trianthemum*	100	0,14	1	8,33
	17	*Blephairs linarifolia*	78	0,11	2	16,67
	18	*Corchorus spp*	67	0,09	1	8,33
	19	*Tephrosia uniflora*	67	0,09	1	8,33
	20	*Veronica ssp*	56	0,08	3	25
	21	Unidentified	56	0,08	2	16,67
	22	*Abelmoschus esculentus*	44	0,07	1	8,33
	23	*Phyllanthus maderaspatensis*	33	0,05	1	8,33
	24	*Cucumis melo*	22	0,04	1	8,33
	25	*Teramnus labialis*	11	0,02	1	8,33
COMM3	1	*Schizachyrium exile*	9095	18,65	14	100
	2	*Echinochloa colona*	8914	18,28	14	100
	3	*Achyranthes aspera*	7648	15,68	14	100
	4	*Evolvulus alsinoides*	5486	11,25	14	100
	5	*Ischaemum afrum*	4533	9,30	14	100
	6	*Desmodium dichotomum*	4400	9,02	12	85,71
	7	*Ceratophyllum demersum*	2743	5,63	12	85,71
	8	*Ophiuros papillosus*	1895	3,89	10	71,43
	9	*Amaranthus graecizans*	1457	2,99	6	42,86
	10	*Veronica sp.*	657	1,35	14	100
	11	*Sorghum purpureosericeum*	457	0,94	3	21,43
	12	*Hybanthus enneaspermus*	419	0,86	6	42,86
	13	*Epaltes alata*	400	0,82	12	85,71
	14	*Sorghum arundinaceum*	190	0,39	2	14,29
	15	*Phyllanthus maderaspatensis*	143	0,29	9	64,29
	16	*Ipomoea cordofana*	105	0,21	3	21,43
	17	*Abelmoschus esculentus*	76	0,16	5	35,71
	18	*Leucas urticifolia*	76	0,16	4	28,57
	19	*Euphorbia aegyptiaca*	48	0,10	3	21,43
	20	Unidentified	19	0,04	2	14,29

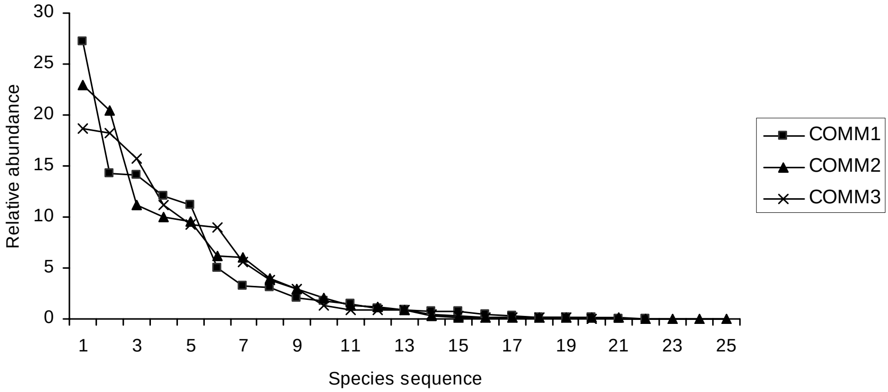


Figure 5.4: Ranking of herbaceous species based on relative abundance.

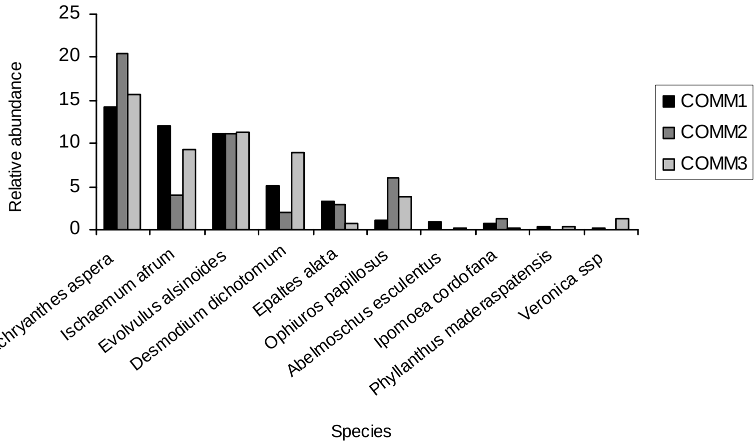


Figure 5.5: Abundances of the ten most common herbaceous species recorded on the abandoned agricultural land in the Doka Area during the field survey in 2006.

5.4.3.2 Diversity Indices

A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simple species richness (i.e., the number of species present); they also take into account the relative abundances of different species. The diversity of a community depends on the number of species and the evenness with which the individual species are distributed within it. However, the description of a community's diversity merely in terms of its diversity index is to confound these two factors.

To detect the diversity situation among herbaceous plant species in different communities in the study area several indices were used (Table 5.2). The value of the Shannon Diversity Index is usually falling between 1.5 and 3.5, while the value of Shannon Evenness Index ranges between 0 and 1. The greater their values, the greater the sample diversity. In this case, the index represents the probability that two individuals randomly selected from a sample belong to different species (Magurran, 1988). The Simpson Dominance Index is another type of diversity measurement where species individuals are weighted according to their abundance of the most common species rather than providing a measure of species richness. The higher the dominance, the lower is the diversity in the community.

Because of the limited number of communities (degree of freedom = 2) further statistical comparisons were not performed. It is clear that COMM2 which represents the agricultural land that has been cultivated for 10 to 19 years and that is now abandoned for more that 6 years is the richest in species (25 species). COMM3 is the least in species richness. A detailed look reveals the effect of the number of species on abundance (Table 5.1). Shannon Diversity Index shows that COMM3 gains the highest value (2.26), followed by COMM2 (2.25). On the other hand, it can be seen that the Shannon Evenness Index is almost the same for all communities (from 0.71 to 0.75). In general, there was not much variation in the degree of dominance between the communities. This degree of dominance shows to what extent the communities are diverse.

Table 5.2: Species number, Shannon Diversity and Evenness Indices as well as Simpson Dominance Index for herbaceous species on the abandoned agricultural land in the Doka Area during the field survey in 2006.

Community	Species number	Shannon Diversity Index	Shannon Evenness Index	Simpson Dominance Index
COMM1	22	2,21	0,74	0,15
COMM2	25	2,25	0,71	0,14
COMM3	20	2,26	0,75	0,13
Overall	37	2,66	0,74	0,099

5.4.3.3 Cluster Analysis

Cluster analysis (CA) is a multivariate procedure for detecting natural groupings in data. The clustering is based upon the placing of objects into more or less homogeneous groups, in a manner such that the relationship between groups is revealed. Nentwig *et al*. (2003)

stated that CA may be the only method which allows the ordination and grouping of a large set of species and habitats as discrete groups. Its finality is the measurement of similarity between samples from communities.

The aim for CA in this study is to give information on the internal data structure of each community, in other words to detect similarity and dissimilarity in species coexistence based on species abundance data. Euclidean Distance and Ward's Method of hierarchical grouping was performed to identify similarities and dissimilarities based on species abundance. The advantage of Ward's Method is that it minimizes the total mean sum of squares or residual sum of squares (van Tongeren, 1987).

In the following dendrograms cases with a short distance/high similarity are closely related. Cases showing a short distance are close indicating that they are agglomerated into one cluster with high coefficient of alikeness. Looking at the dendrogram in Figure 5.6 it can be seen that in COMM1 *Veronica sp*., *Ipomoea sinensis*, *Sonchus cornutus*, *Amaranthus graecizans*, *Solanum dubium*, *Phyllanthus maderaspatensis* and *Ocimum asilicum* has been classified in the first cluster. A careful look into the abundance data (Table 5.1) for those species supports this result. However, *Commelina imberbis*, which is the most abundant species in this group, distinguishes itself from all other recorded species in this community. In COMM2 (Figure 5.7) almost half of the species show similarities and where clustered into the first group. This time the most unsimilar species to their group were *Achryanthes aspera* and *Digera muricata*. COMM3 shows a more or less heterogeneous way of clustering (Figure 5.8). Nevertheless, the last nine species show a gradually increasing way of clustering.

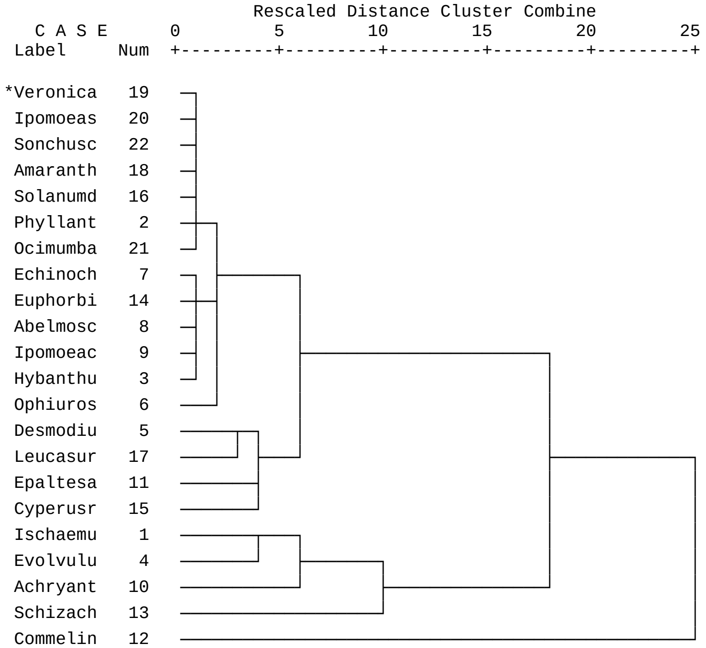


Figure 5.6: Dendrogram using Ward's Method for COMM1 performed by Euclidean Distance.

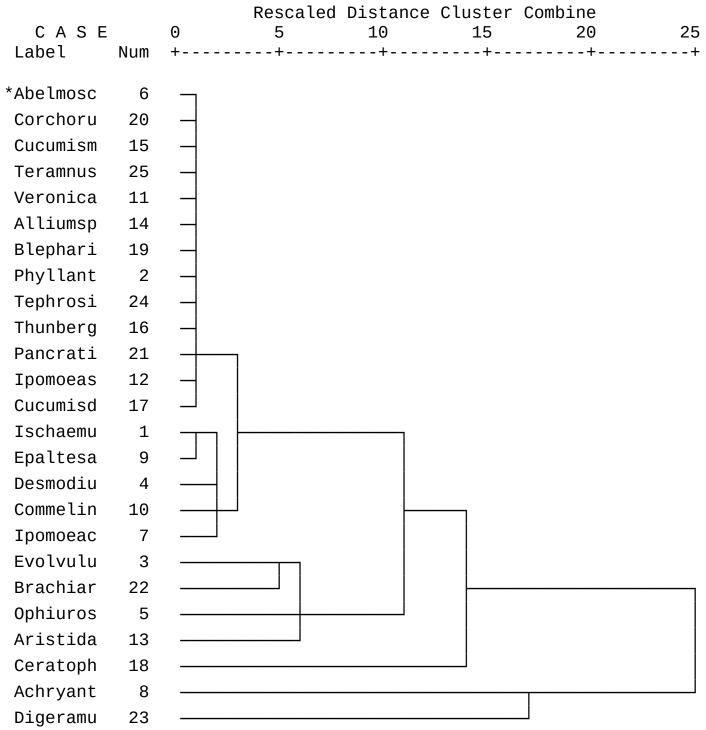
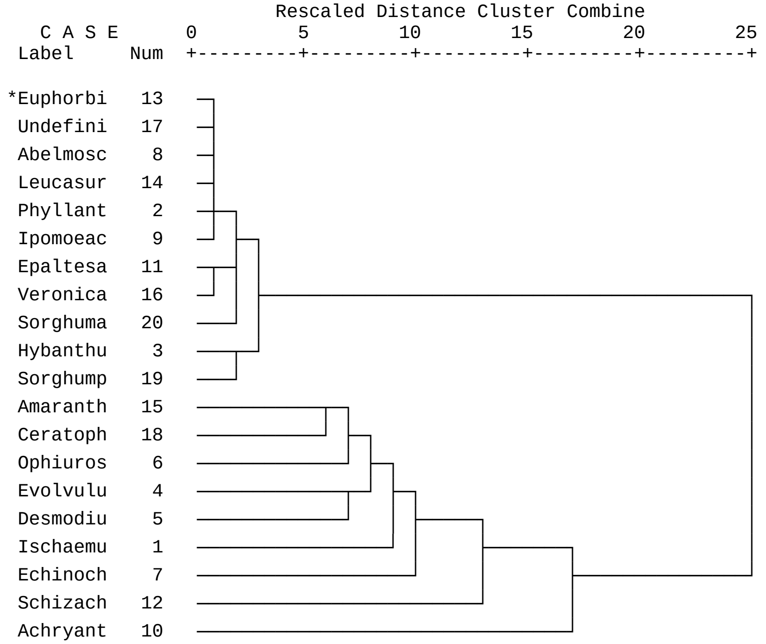


Figure 5.7: Dendrogram using Ward's Method for COMM2 performed by Euclidean Distance.



* For abbreviated species names in Figures 5.6, 5.7 and 5.8 see Appendix 5.1.

Figure 5.8: Dendrogram using Ward's Method for COMM3 performed by Euclidean Distance.

5.4.4 Woody Species

5.4.4.1 Abundance and Frequency

Vegetation cover on abandoned agricultural land reflects the typical savannah cover which is mostly comprised of grasses and few scattered shrubs and trees (Figure 5.2). Although the natural vegetation of the area initially consisted of *Acacia seyal* and *Balanites aegyptiaca* Savannah (Harrison and Jackson, 1958), the vegetation on abandoned agricultural land reflects a different picture. Both *Acacia seyal* and *Balanites aegyptiaca* were not the dominating woody species. Instead, *Ziziphus spina-christi* shows the best performance with the highest average abundance in COMM1 (22.62) and COMM3 (37) (Table 5.3). However, *A. seyal* var. *Seyal* ranks third in COMM1 and second in COMM2 and COMM3. *A. seyal* var. *seyal*, *Ziziphus spina-christi* and *Acacia polyacantha* exist in all four communities. It is clear that COMM3 shows an acute drop in the species order, while the other communities show a relatively steady behaviour (Figure 5.9).

Table 5.3: Rank order of average abundances (descending) and frequencies of woody species recorded on abandoned agricultural land in the Doka Area during the field survey in 2005.

Community	Rank order	Species	Abundance	Relative abundance	Absolute Frequency	Relative frequency
C1	1	*Ziziphus spina-christi*	22,62	36,36	5	38,46
	2	*Calotropis procera*	18,58	29,87	4	30,77
	3	*A. seyal* var. *seyal*	8,88	14,29	8	61,54
	4	*A. seyal var. fistula*	5,65	9,09	6	46,15
	5	*A. senegal*	4,85	7,79	2	15,38
	6	*Acacia polyacantha*	1,615	2,6	2	15,38
C2	1	*Acacia polyacantha*	85,4	57	5	33,33
	2	*A. seyal var. seyal*	32,9	21,96	13	86,67
	3	*Ziziphus maritiana*	10,5	7,01	3	20
	4	*Dichrostachys cinerea*	8,4	5,61	4	26,67
	5	*Undefined*	6,3	4,21	3	20
	6	*Ziziphus spina-christi*	4,2	2,80	2	13,33
	7	*Calotropis procera*	2,1	1,40	1	6,67
C3	1	*Ziziphus spina-christi*	37	70,48	12	57,14
	2	*A. seyal var. seyal*	5	9,52	6	28,57
	3	*A. senegal*	4,5	8,57	9	42,86
	4	*Dichrostachys cinerea*	2,5	4,76	1	4,76
	5	*A. seyal var. fistula*	1,5	2,86	2	9,52
	6	*Acacia polyacantha*	1	1,90	2	9,52
	7	*Balanites aegyptiaca*	0,5	0,95	1	4,76
	8	*Combretum aculeatum*	0,5	0,95	1	4,76
C4	1	*A. senegal*	36,57	44,49	17	58,62
	2	*Ziziphus spina-christi*	19,19	23,35	11	37,93
	3	*A. seyal var. seyal*	15,57	18,94	15	51,72
	4	*Dichrostachys cinerea*	5,79	7,05	3	10,34
	5	*Balanites aegyptiaca*	2,53	3,08	2	6,90
	6	*Combretum glutinosum*	1,09	1,32	1	3,45
	7	*A. seyal var. fistula*	0,72	0,88	2	6,90
	8	*Acacia polyacantha*	0,36	0,44	1	3,45
	9	*Acacia mellifera*	0,36	0,44	1	3,45

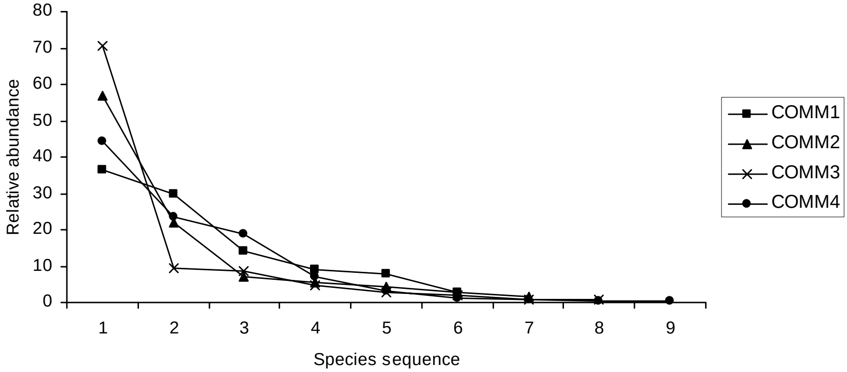


Figure 5.9: Woody species ranking based on relative abundance.

5.4.4.2 Stocking Density

The average number of woody species per unit was 152 stems per ha. The Kruskal-Wallis Test shows an overall high significance different in all four communities (*F = 0.019*). The mean number of woody species was highest in COMM2 (251.7 stems/ha) and lowest in COMM1 (100 stems/ha), which represents the recently abandoned land (3 – 6 years). A further test (Sachs, 1991) was performed to separate between the communities and the results show that COMM2 is significantly different from the other three communities.

5.4.4.3 Growth Parameters

The mean height and at root-collar diameter of the recorded woody species is shown in Figure 5.10. It is clearly that irrespective to the community *Acacia senegal* gained the best height (424 cm) and diameter (99 mm). This is not surprising because this species received persistence by the farmers for its commercial production of gum Arabic. Both of the two dominant woody species of the natural vegetation showed medium to weak development. *A. seyal* var. *seyal* shows medium growth for the measured parameters (height: 246 cm; diameter: 54 mm, both in COMM2), while *Balanites aegyptiaca* reached 102 cm in height and 20 mm in diameter in COMM4. Due to the problem of the presence/absence of some species on statistical analysis was performed.

5.4.5 Herbaceous Biomass

There exists a noticeable difference among the communities regarding the herbaceous ground cover. The Kruskal-Wallis Test shows a very high overall significance difference. Figure 5.11, however, shows a considerable difference in the non-woody ground cover.

The mean biomass of herbaceous vegetation ranged from 62.5 to 0.0 kg per ha. The highest mean of non-woody biomass accumulation was recorded in COMM1 (38.27 kg/ha) followed by COMM3 (23.99 kg/ha).

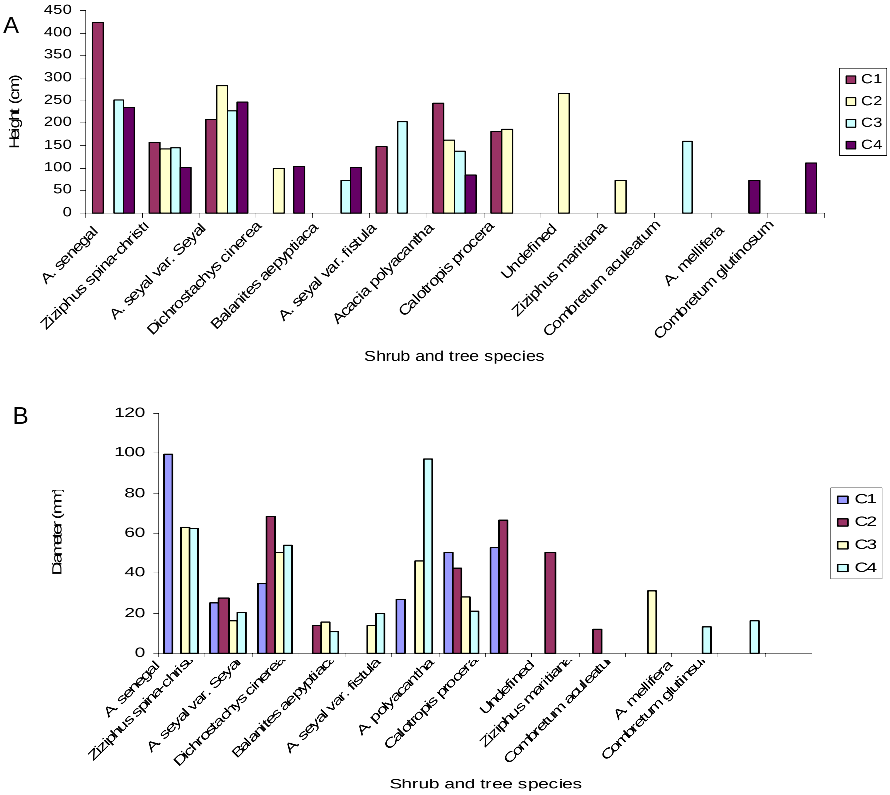


Figure 5-10: The mean height (A) and root-collar diameters (B) of woody species in the abandoned agricultural land in the Doka Area.

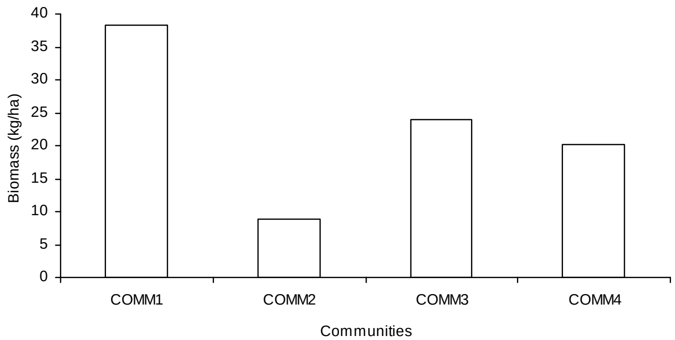


Figure 5.11: Mean herbaceous biomass on abandoned land in the Doka Area.

5.4.6 Percentage Cover

The assessment of the percentage of the herbaceous cover was based on visual estimation by the survey crew. In average the cover was 51 %, which is relatively high for a dry season coverage (Figure 5.12). The percentage ranged from 95 % to 0 %. The Kruskal-Wallis Test shows an overall very high significance difference. In COMM2 the average herbaceous cover was the lowest (21 %), in COMM1 it was as high as 74%.

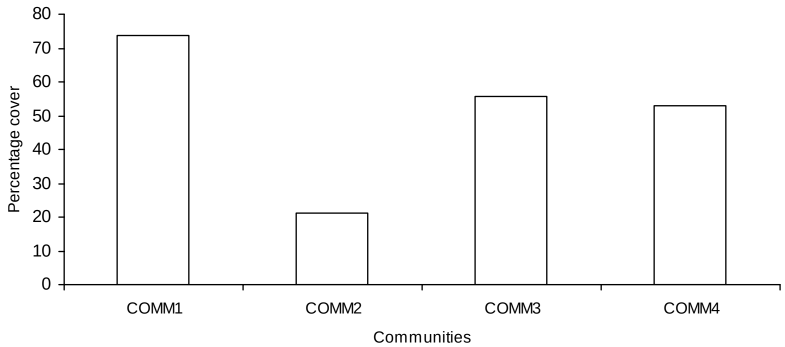


Figure 5.12: Mean percentage of herbaceous cover for four abandoned agricultural in the Doka Area.

5.5 Discussion

5.5.1 Effects of Previous Land-Use and Age of Fallow

The results of the study show that both factors, the previous cultivation period and the age of the fallow, have significant effects on the subsequent regeneration of plant species and thus the vegetation development. Several authors have investigated the effects of these two factors beside others (Stover and Marks,1998; de Blois *et al*., 2001; Asefa *et al*. , 2003; Benjamin *et al*., 2005;). de Blois *et al*. (2001) stated that among the sets of factors considered to explain variations in species composition, the historical factors explained the highest amount of variation in tree vegetation. Benjamin *et al*. (2005) mentioned that past use has influenced the vegetation of abandoned farmlands by promoting the establishment of spiny shrubs, thus creating a very distinct type of abandoned farmland. The time since the abandonment of agricultural activities influences the vegetation. The oldest abandoned farmlands are mostly shrub-dominated, whereas recently abandoned ones are at the herbaceous vegetation stage. In addition to the historical and ecological factors, it is also important to look at spatial factors to explain part of the abandoned agricultural land dynamics. This link between current vegetation and previous land-use has also been detected by Eberhardt *et al*. (2003) who have shown that analyses of the overall vegetation variation reveal a strong relationship between species composition, species abundance and past land-use. To further explore the influences of past land-use on the individual species distribution, presence/absence data for the species were analyzed. This showed that ten of the 20 common but not ubiquitous species occur disproportionately in relation to the land-use history.

Vegetation pattern, composition, and structure are strongly related to past land-use at the landscape and stand level. The effect of land-use history in the development of secondary vegetation on sites previously used for agriculture principally reflects differences in the intensity of past land-use (Benjamin *et al*., 2005). Therefore the newly developed vegetation patterns represent a combination of natural and human disturbance processes initiating persistent compositional and structural differences. At four degraded grazing sites in northern Ethiopia Asefa *et al*. (2003) showed that the age of land abandonment had a significant effect on the diversity of the herbaceous and tree species. The shrubs did not respond positively to differences in the age of abandonment, while herbs showed a quadratic polynomial response in terms of species abundance and richness. Maximum restoration for the diversity of herbs was achieved after 3 years of rest followed by a decline, most likely reflecting changes in management as well as replacements of the weedy species by perennial grasses. This suggests that extended periods of grazing exclusion not always promote biodiversity of herbaceous plant species in comparison to short periods of rest followed by grazing.

5.5.2 Floristic Composition and Vegetation Structure

A comparison of the species diversity with the results of previous studies in the area was not possible. The author could not find any previous work mentioning plant species occurring in the study area. Due to many differences a comparison with forest is not feasible and is also not the objective of this work. However, in this respect the comprehensive species-list given by farmers and key informants (Chapter 3) offers a unique qualified chance. 67 % of species recorded during the survey were mentioned by the farmers. However, it was observed that farmers tend to mention the plant species which affect their crops (e.g. weed species). Nevertheless, this degree of compatibility shows to some extent the reputation of the approach (e.g. combining local knowledge and field survey) not only for the data collection, but also for the design of the sampling frame for this work. The survey was conducted during five weeks in June and July 2006. It is necessary to mention that due to intra-seasonal emergence of plant species, it had to be expected that the late emerging species will be missed from the lists. For example, the inter-annual variation of species composition of fallow vegetation in the semi-arid Niger shows that most species occur with different abundance from year to year, but certain species that are present in the first year may even be absent in the following year (Wezel and Schlecht, 2004). If vegetation studies cannot be conducted every year, this irregular species occurrence makes it difficult to select species that might function as character species for plant communities or as indicator species for a certain site and certain soil characteristics. Wezel and Schlecht (2004) stated that, although inter-annual species variation is reported for different regions throughout semi-arid West Africa, most studies concentrated on few species or focused on species germination rates, while studies concerning the broad spectrum of different herbaceous plant communities are still rare for the West African Sahel. However, this also could be implies for the southern Gadarif Region (East Africa Sahel).

There is a general tendency regarding the number of species to decrease with the increase of the period of cultivation. There is a clear difference in the structure between communities. Most of the calculated vegetation structure variables showed significant differences. The overall species richness of a community gives a general impression of its diversity. In this respect, the results of the study show a plant-species diversity-pattern of degraded land where it is dominated by herbaceous species with some scattered woody species. Wezel and Schlecht (2004) found that in the semi-arid Niger the herbaceous vegetation of rangeland and fallow is dominated by annual species. Wilsey and Potvin (2000) stated that changes in land-use, habitat fragmentation, nutrient enrichment, and environmental stress often lead to reduced plant diversity. However, the analysis of historical and land-use changes and vegetation succession on abandoned farmland has provided a general pattern of succession following farming abandonment, where land is re-colonized by spontaneous vegetation, and passes from a herbaceous phase to a shrub-dominated phase, and eventually to a forested phase (Benjamin *et al*., 2005). All recorded species were native to area and there are no exotic species recorded. Agricultural activity, however, led to the development of vegetation patterns that are rather unique compared to prior conditions.

5.5.3 Implication for Conservation

Vegetation changes due to land abandonment may have a implication for the conservation of plant-genetic resources in the area, overall plant species diversity and composition and diversity of different fauna harboured in this habitat. The current regeneration capacity in the abandoned land may not be sufficient to reach full restoration of the climax vegetation except for some pockets which received more regenerative resources. Nevertheless, to ensure sustainable development of the successional vegetation in the long term operational research plans should be followed.

The biggest plant family – species and abundance wise – recorded in the area was *Gramineae*. Although the domination of herbaceous plants is considered a disadvantage by local farmers, such species can serve as a gene source for any breeding programme for their domesticated relatives. The study area is the part of the origin habitat of Sorghum[2] which is a very important crop in Sudan serving as a primary source of food and beverage for a total of millions of people in the country.

The possibility that wild relatives of cereals may provide a genetic basis for resistance or tolerance to infection may be of enormous values for the development of resistant crops which is of high interest. For example a wild relative of cultivated sorghum, *Sorghum arundinaceum*, demonstrated tolerance to infection by *Striga asiatica*, with little impact of *Striga asiatica* on host growth or grain production compared to the detrimental impact of the parasite on cultivated sorghum (Gurney *et al*., 2002). Cultivation of sorghum with weedy and wild-related species represents a great benefit for gene diffusion from wild and weedy forms onto related cultivated crops. Further analysis of genetic diversity on sorghums of the Sudan, including wild, weedy, inter- mediate, and cultivated types, would permit better understanding of gene flow and evolutionary relationships among related gene pools. It may thus, result in an improved use and conservation of sorghum genetic resources (Grenier *et al*., 2004).

2) Over 3,000 years ago sorghum originated in the Northeast quadrant of Africa and slowly dispersed into other parts of Africa. Sudan is widely recognized as a major centre of its diversity. The diversity of sorghum appears to be highly correlated with the duration of the domestication and the type of farming practiced (Grenier *et al*., 2004).

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5.7 Appendix

Table 5.1: Plant species recorded during the field surveys 2005 – 2007.

Family	Species	Abbreviation	growth form
Acanthaceae	*Blepharis linarifolia*	Blephari	aH
	Thunbergia annua	Thunberg	aG
Amaranthaceae	*Achyranthes aspera*	Achryant	aH
	Amaranthus graecizans	Amaranth	aH
	Digera muricata	Digeramu	aH
Amaryllidaceae	*Pancratium trianthemum*	Pancrati	aH
Asclepiadaceae	*Calotropis procera*	Calotrop	Sh
Asteraceae	*Sonchus cornutus*	Sonchusc	aH
Balanitaceae	*Balanites aegyptiaca*	Balanite	Tr
Capparidaceae	*Maerua angolensis*	Maeruaan	Tr
Ceratophyllaceae	*Ceratophyllum demersum*	Ceratoph	aG
Combretaceae	*Combretum aculeatum*	*Combreta*	Tr
	Combretum glutinosum	*Combretg*	Tr
Commelinaceae	*Commelina imberbis*	Commelin	aH
	Evolvulus alsinoides	Evolvulu	aH
Compositae	*Epaltes alata*	Epaltesa	aH
Convolvulaceae	*Ipomoea cordofana*	Ipomoeac	aH
	Ipomoea sinensis	Ipomoeas	aH
Cucurbitaceae	*Cucumis dispaceus*	Cucumisd	aH
	Cucumis melo	Cucumism	aH
Cyperaceae	*Cyperus rotundus*	Cyperusr	aG
Euphorbiaceae	*Cephalocroton cordofanus*	Cephaloc	Sh
	Euphorbia aegyptiaca	Euphorbi	aH
	Phyllanthus maderaspatensis	Phyllant	aH
Fabaceae	*Desmodium dichotomum*	Desmodiu	aH
	Dichrostachys cinerea	Dichrost	Sh
	Teramnus labialis	Teramnus	aH
	Tephrosia uniflora	Tephrosi	aH
Gramineae	*Aristida adscensionis*	Aristida	pG
	Brachiaria obtusifolia	Brachiar	aG

	Echinochloa colona	Echinoch	aG
	Ischaemum afrum	Ischaemu	pG
	Ophiuros papillosus	Ophiuros	aG
	Sorghum arundinaceum	Sorghuma	pG
	Sorghum purpureosericeum	Sorghumap	aG
Lamiaceae	*Leucas urticifolia*	*Leucas ur*	aH
	Ocimum basilicum	*Ocimum ba*	aH
Liliaceae	*Allium sp*	*Allium sp*	pH
Malvaceae	*Abelmoschus esculentus*	*Abelmosc*	aH
Mimosaceae	*Acacia mellifera*	Acaciame	Sh
	Acacia polyacantha	Acaciapo	Sh
	A. Senegal	Acaciase	Sh
	A Seyal var. *fistula*	Acaciasf	Sh
	A. Seyal var. *seyal*	Acaciass	Sh
Rahmnaceae	*Ziziphus maritiana*	Ziziphum	Sh
	Ziziphus spina-christi	Ziziphus	Sh
Scropulariaceae	*Veronica sp.*	Veronica	aH
Solanaceae	*Solanum dubium*	Solanumd	pH
Tiliaceae	*Corchorus spp.*	Corchoru	aH
Violaceae	*Hybanthus enneaspermus*	Hybanthu	aH
----------	*Schizachyrium exile*	Schizach	aH
Unidentified 1	Unidentified	Unidetif	Sh

Table 5.2: Species composition in accordance with their number and percentage in the abandoned agricultural land in the Doka Area.

Life form	Number of species	Percentage
Herb	27	51.92
Grass	10	19.23
Shrub	11	21.15
Tree	4	07.69
Total	52	100

Table 5.3: Species occurrence composition in accordance with their number and percentage in the three survey communities of abandoned agricultural land in the Doka Area during field surveys in 2005 and 2006.

Community	Herb	Grass	Shrub	Tree	Total
COMM1	16	4	6	0	26
COMM2	18	5	7	0	30
COMM3	12	6	6	1	25
COMM4	NS	NS	8	3	11

Note: NS: not sampled

6 Modelling the Restoration Potential of Some Abandoned Agricultural Land

6.1 Abstract

The ability to model and predict patterns of some biotic variables on the basis of physical landscape attributes could mitigate the damage and facilitate the preservation of biodiversity. It is necessary to develop spatial modelling methodologies for rapid and cost-effective mapping of degraded areas to assess their biological value for nature conservation. Understanding community assemblage patterns at habitat level using field data in conjunction with remotely sensed and topographic data has the potential to explain restoration and rehabilitation pattern of degraded lands. Abandoned agricultural land (AAL) in the Gadarif Region represents about 15 to 20 percent of the total agricultural land. Abandonment of degraded land becomes increasingly important for the restoration of soil fertility and natural vegetation.

The study investigates the potential of some remotely sensed and topographic variables as predictors for restoration/rehabilitation patterns of some AAL using nonparametric multiplicative regression. Both response and prediction matrices were based on 46 plots. Field data was collected by using 20 x 20 m^2 sample plots, while the remote sensing and topographic variables were an average of 3 x 3 windows (resolution 15 x 15 m^2). The model used was based on Local Mean-Gaussian function. From the group of variables used to assess the restoration potential of some abandoned agricultural land, VNIR2, PC2, PC3, SRI, NDVI, SAVI, age of fallow and altitude succeeded to estimate some of the predefined restoration variables.

6.2 Introduction

6.2.1 General

The Gadarif region has undergone profound land-use changes during the past half century. Natural vegetation had been progressively cleared due to the expansion of mechanized rain-fed agriculture and subsequently part of cultivated lands had been abandoned by farmers due to severe yield reduction and weed infestation. As direct and indirect consequences of land-use changes, abandonment of degraded agricultural land is a widespread phenomenon in the Gadarif Region, where it represents about 15 to 20 percent of the total agricultural land (SKAP, 1992; Sulieman and Buchroithner, 2006). Abandoned land becomes increasingly important as temporary reservoirs of genetic diversity, stocks of carbon and nutrients, and moderators of soil fauna as well as for the restoration of soil fertility. Furthermore, poor agricultural practices following natural vegetation clearing exacerbated processes of land degradation. Land degradation refers to a reduction in the capacity of land to supply benefits to humanity. It results from a complex social, economic, cultural, political, and biophysical forces operating across a broad spectrum of time and spatial scales (Chisholm and Dumsday, 1987).

6.2.2 Restoration of Degraded and Abandoned Agricultural Land

The Society for Ecological Restoration (SER, 2004) defines ecological restoration as an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. However, the restored ecosystem will not necessarily recover its former state, since contemporary constraints and conditions may cause it to develop along an altered trajectory. Vegetation structure is a primary concern in all restoration efforts and must play an important role in judging restoration success.

Restoration and rehabilitation of the degraded lands is important for many reasons. First, increasing crop yields is crucial to meet the needs of the growing human population. Second, anthropogenic changes in land productivity have adverse impacts on major biogeochemical cycles that regulate greenhouse gas fluxes. Third, biodiversity preservation depends, in part, on increasing yields on human-dominated land to alleviate pressure to convert remaining natural habitat. And fourth, land is frequently a limiting factor of economic output, and its degradation threatens to undermine economic development and social stability (Daily, 1995).

Understanding of recovery mechanisms are needed to prevent further degradation and to retain the multiple values of productive land. Knowledge about the ecological processes occurring in abandoned farmland is found gradually in several studies. The analysis of historical and land-use changes and vegetation succession on abandoned farmland has provided a general pattern of succession following farming abandonment, where land is recolonized by spontaneous vegetation, and passes from a herbaceous phase to a shrub-dominated phase, and eventually to a forested phase (Benjamin *et al*., 2005).

Restoration pathway is a complex phenomenon which reveals previous land-use and the prevailing environmental condition. For example, in the semiarid Bashang area, northern China, after fields were abandoned, vegetation restoration and plant species composition moved toward natural grassland community with time. Soil nutrients levels gradually improved with increasing years of land abandonment, with a faster restoration rate in the early vegetation recovery stage and a slower rate in the late succession stage. The results suggested that soil degradation may occurred drastically by inappropriate land-use and management with a short time, while soil restoration for a degraded ecosystem may take long period of time (Zhao, 2005).

Land abandonment implies a process of ecological succession, in which vegetation reoccupies former farm land. Restoration of biodiversity through land abandonment reflected the spatial and temporal variations of previous land-use prevailing in the mechanized agricultural land. It is essential to fully understand the environmental condition undergoing agricultural land abandonment to measure the relative importance of ecological, spatial and historical factors determining vegetation dynamics.

6.2.3 Linking Land-Use and Spatial Modelling of Plant Community

Disturbance in from of land-use is one of the key factors that shape the vegetation development and any future succession after abandonment. To achieve a better assessment of plant community responses, reliable data on the attributes of large number of species along gradients of disturbance are required. However, the complementary nature of remote sensing data and its appropriateness to be combined with field data provide an optimum chance for linking land-use and spatial modelling of plant community. Fischer (1990) identified land-use as the factor with the highest predictive power when modelling community distribution in a human-disturbed landscape. But situations with strong disturbance, human influence, or successional dynamics can thus only be modelled with difficulty (Brzeziecki *et al*., 1993; Lees and Ritman, 1991).

Satellite remote sensing is providing an increasing variety of spatial data layers that are potentially usable as model input or for validation of model output (Turner *et al*., 2004). Cohen and Goward (2004) stated that remote sensing, geographic information systems, and modelling have combined to produce a virtual explosion of growth in ecological investigations and applications that are explicitly spatial and temporal. Modern terrestrial ecology relies on remote sensing for modelling biogeochemical cycles and for characterizing land-cover, vegetation biophysical attributes, forest structure, and fragmentation in relation to biodiversity.

Although spatial variation within a cover type can also be important, the relative consistency of these functional adaptations within cover types has proved to be enormously useful when combined with spatial data for land-cover characteristics. In this way, land-cover parameters required by models (e.g. biomass, species composition) can be estimated spatially and allowed to interact with information on climate, soils, or other environmental factors (Ollinger *et al*., 1998; Turner *et al*., 2004). The rapidly proliferating volume of spatial data generated by remote sensing has created a significant challenge in terms of designing algorithms that optimally assimilate, integrate, and refine these data into useful information (Turner *et al*., 2004). A major benefit to spatial models is that they can estimate many measurable variables; the model algorithms thus represent hypotheses that can be assessed and potentially revised. Specifying the type of land-cover is an important first step in the implementation of spatial models, because cover types differ widely in their characteristics. These differences in attributes are the result of adaptations to specific environments (Reich *et al.,* 1997).

Statistical modelling is often used to relate sparse biological survey data to remotely derived environmental predictors, thereby providing a basis for predictively mapping biodiversity across an entire region of interest. The most popular strategy for such modelling has been to model distributions of individual species one at a time. Spatial modelling of biodiversity at the community level may, however, confer significant benefits for applications involving very large numbers of species, particularly if many of these species are recorded infrequently. Commonly used predictors include terrain indices, long-term average climate surfaces, edaphic variables, land-cover variables and spectral bands or indices from remote sensing imagery (Ferrier and Guisan, 2006). Nevertheless, the satellite observation of Earth began almost 30 years ago, however, the relationship between vegetation indices and physical parameters of vegetation has not been completely clarified, which is urgently required not only for analysis of vegetation in an arid area but also for estimation of biomass on Earth by remote sensing technology (Ishiyama *et al.,* 2001).

For example in order to partition the variation of the vegetation between ecological, historical and spatial variables, Benjamin *et al*. (2005) used a redundancy analysis. By analyzing separately the historical variables, the spatial variables and then the environmental variables, it was possible to identify the statistically significant variables. Price *et al*. (2002) overlaid 73 study plots onto the 18 spectral bands using a GIS overlay operation to determine whether spectrally significant differences existed among the six grassland types they studied. At each location, the reflectance values of the nine closest pixels (3×3 pixel area) were used to estimate the spectral mean and variance associated with each plot. A Stepwise Discriminant Analysis was used to determine the most important spectral variables (raw Landsat TM and vegetation indices) for predicting grassland types in eastern Kansas. They found that among the raw Landsat TM bands, TM4 was the best for discriminating the six grassland types and among the vegetation indices evaluated, the Tasselled Cap Greenness was the best discriminator of the evaluated grasslands. The experimental results of Ishiyama *et al.* (2001) indicate that the vegetation index is highly correlated with physical parameters of vegetation; in particular, dry biomass and leaf area index, but the correlation coefficient between vegetation index and vegetation coverage is slightly low. To study the potential of landscape and habitat variables derived from remote sensing and topographic, Luoto *et al*. (2002) used Landsat TM images and a digital elevation model to built multiple regression models for the total number of plant species and the number of rarities. Nevertheless, modelling of biological diversity based on satellite images and GIS can provide useful information needed in land-use planning. However, due to the potential pitfalls in processing satellite imagery and model-building procedures, the results of predictive models should be carefully interpreted.

6.2.4 Motivation of Study

Natural recovery of the abandoned agricultural land has the potential to enhance biodiversity, improve ecological functioning, and improve human livelihoods. A fundamental interest in studying abandoned agricultural restoration/ rehabilitation is to understand the main drivers of its succession pathway. In previous parts of this work, it has been shown that, how various social and ecological aspect has been affecting the development of mechanized rain-fed agriculture in the Gadarif Region and how is the situation currently, especially for the abandoned filed. In this part of the study it was intended to explore how different spatial, ecological and historical factors and their different representation forms interact with remotely sensed variables drown from ASTER imagery.

6.2.5 Objectives

The objectives of the study are to investigate the potential of some remotely sensed data and topographic data as predictors for restoration patterns of some abandoned agricultural land and to examine which of the habitat variables correlate most strongly with the restoration patterns.

6.3 Site Description

Within the study area some abandoned agricultural lands which show a rapid vegetation recovery were identified (Figure 6.1). The identification of the potential restoration sites was based on both mapping of abandoned agricultural land (Chapter 4) and detailed field surveys during 2005 and 2006 (Chapter 5).

Figure 6.1: Examples of some abandoned agricultural land (after 6 to 8 years of fallow) in the southern part of the study area which shows high natural regeneration potential. Photographs by the author. July 2006.

6.4 Data Input

Detailed information concerning the field data was presented in Chapter 5. Field based variables include: herbaceous biomass and percentage cover. Remotely sensed data was driven form from ASTER VNIR and the Digital elevation Model (DEM) was driven from ASTER 3B and 3N bands. Land-use history information was recorded from farmers. Table 6.1 shows spatial data layers used for the assessment of the restoration potential of some abandoned agricultural land and their sources.

Table 6.1: Data layers used for the assessment of the restoration potential of some abandoned agricultural land and their sources.

Source	Variable	Description
ASTER VNIR	VNIR1,2,3	
	PC1,2,3	
	SRI*	
	NDVI	
	TDVI	
	TCTG	
	TCTB	
	SAVI	
	MSAVI	
	OSAVI	
DEM generated from ASTER 3B and 3N	Altitude	Elevation above sea level (meters)
	Slope	Inclination from horizon (degree)
Land-use history	CP	Cultivation period (years)
	Age	Time since abandonment (years)

* Detailed description and mathematical computation of these indices was presented in Chapter 3

6.5 Methodology

6.5.1 Modelling Strategy and Basic Approach

One of the main challenges for community-level modelling is deciding which of the many possible strategies is most appropriate for a given situation (Figure 6.2). Community-level modelling offers a far richer set of analytical strategies than does species-level modelling. Nevertheless, the choice of which community-modelling strategy to employ in any given situation need to be informed by an awareness of the full range of alternatives (Ferrier *et al*., 2002b).

To determine the pattern of secondly succession on abandoned agricultural land, the field data were used as restoration response variables while remotely sensed variables were considered to be the predictive variables (Table 6.1). Statistical modelling of biological survey data in relation to remotely mapped environmental variables is a powerful technique for making more effective use of sparse data in regional conservation planning. The method is often based on using abiotic environmental predictors that describe various attributes of terrain, climate and substrate. This approach is predicated on an assumption that these variables are sufficient to explain observed biological distributions. In other words, such modelling assumes a direct deterministic relationship between field variables and mapped abiotic environmental variables. In reality, however, this relationship may be far from perfect if environmental variables are not mapped at a sufficient level of spatial resolution and accuracy, or if key variables are not considered in the modelling (Ferrier *et al*., 2002a). Variables describing the current abiotic environment of the area can therefore explain only a proportion of the pattern in of the restoration potential of the abandoned agricultural land. Therefore, historical information such as the duration of cultivation and time since abandoned were considered in the modelling process.

6.5.2 Nonparametric Multiplicative Regression

Regression relates a response variable to a single (simple regression) or a combination (multiple regressions) of environmental predictors (explanatory variables). The predictors can be the environmental variables themselves or, components derived from the environmental variables through multivariate analysis. Regression analysis has been a popular empirical method of linking relate sparse biological survey data to remotely derived environmental predictors to provide continuous estimates for variables such as biomass, percent woody canopy cover, and leaf area index (Cohen *et al*., 2003).

Nonparametric regression, like linear regression, seeks relationships between a response variable and one or more predictors. Nonparametric regression does not, however, seek coefficients in a mathematical equation of fixed overall form. Instead, it seeks to optimize fit to the data without reference to a specific global model. In nonparametric regression the predictor does not take a predetermined form but is constructed according to information derived from the data. One of the disadvantages of the nonparametric regression requires larger sample sizes than regression based on parametric models because the data must supply the model structure as well as the model estimates.

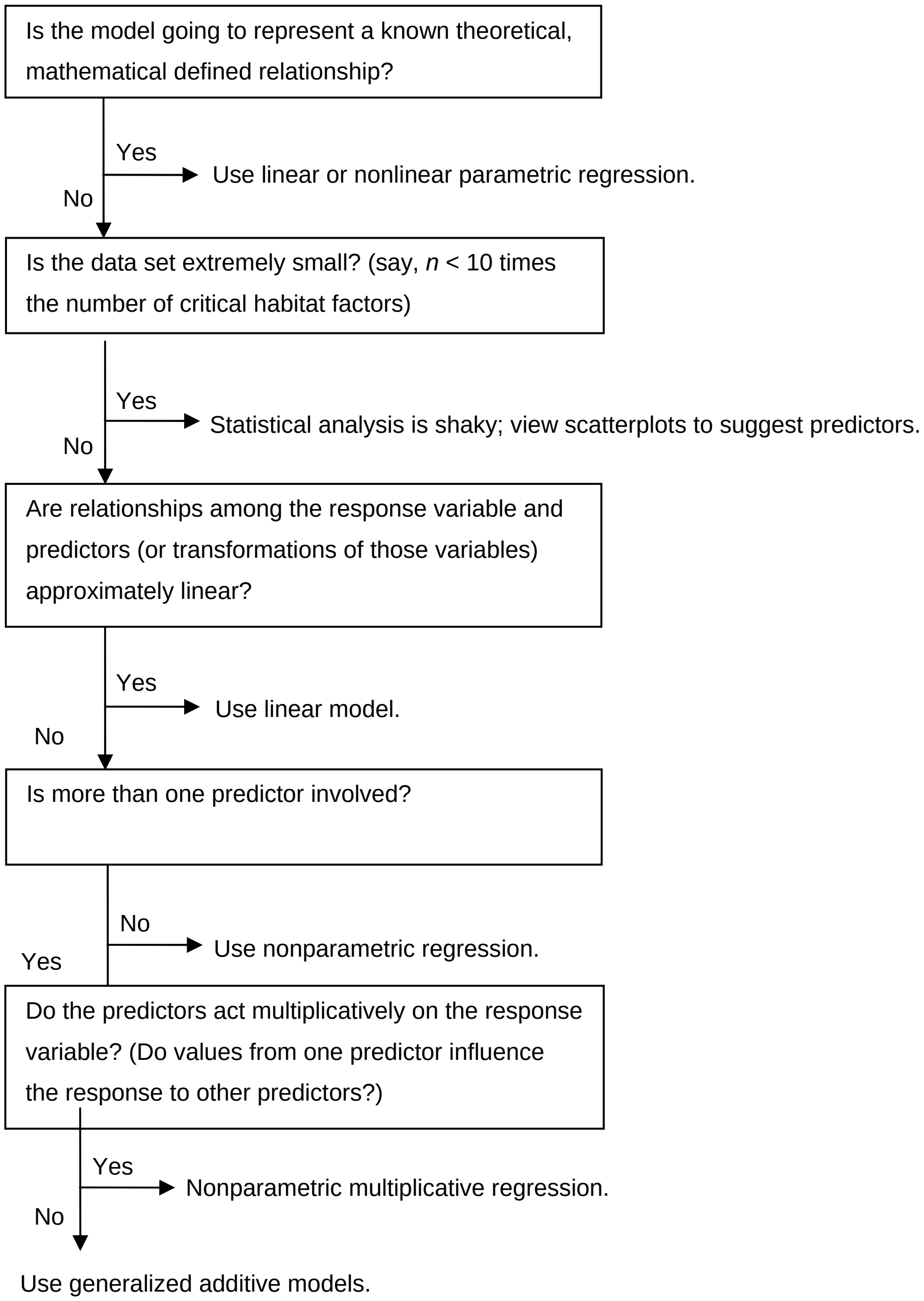

Figure 6.2: Decision tree for some general classes of habitat models (McCune, 2006a).

Nonparametric multiplicative regression (NPMR) is a form of nonparametric regression based on multiplicative kernel estimation. This is a smoothing technique that can be cross-validated and applied in a predictive way. Many other smoothing techniques are well known, for example smoothing splines and wavelets. Optimum choice of a smoothing method depends on the specific application. NPMR is useful for habitat modelling, because it models the complex interactions among predictors in the same way that organisms integrate the numerous factors affecting their performance (McCune, 2006b). Optimizing the selection of predictors and their smoothing parameters in a multiplicative model is computationally intensive. NPMR can be applied to either presence-absence or quantitative response data, with either categorical or quantitative predictors.

6.5.3 Analysis Tool

The software package HyperNiche (McCune and Mefford, 2004) applies the concepts of NPMR to predictive habitat modelling and species response functions. However, a nonparametric regression model can be applied in many ways, essentially the same ways that one can apply traditional regression model. In this respect the software was used to model the restoration potential of some abandoned agricultural land. So far NPMR has been applied only to problems with a single response variable. HyperNiche seeks the best NPMR model by selecting the set of predictor variables and choosing the tolerance for each of those variables. In brief, multiplicative kernel smoothers allow the effect of each predictor to depend on the value of other predictors without needing to specify those interactions. This approach also rely on the normal response of organises to a particular habitat, where the response is to a combinations of interacting factors.

Two types of inputs were used for modelling: field data as response variables and remote sensing and DEM variables as prediction matrix (Table 6.1) in a form of non-parametric multiple regression in which the response is estimated from a multiplicative combination of all predictors. This new modelling approach was introduced by McCune in his pioneer work which was published recently (McCune, 2006b). This kind of model provides two important advantages over other approaches: it automatically represents predictor interactions by combining predictors multiplicatively, such that the effect of one predictor can vary in a complex way with other predictors, and it requires no assumptions about the overall shape of the response surface. The chief disadvantages of multiplicative kernel smoothers are that the response surface must be fitted with a computationally intensive trial-and error method and the results do not include an equation relating the response to the predictors.

Instead, interpretation must rely on graphical visualization, measures of fit, and sensitivity analysis for individual predictors.

Having explored the response surface in a multidimensional space, one can then sensibly choose an appropriate functional form and proceed with non-linear regression or a generalized linear model. In this respect a further analysis was carried out using non-linear multiple regression (NLMR) in SPSS version 11.5. Using this multi-approach analysis the study will benefit from the powerful capability of the smoothing kernel in HyperNiche and its 3D response surfaces which are visually represented.

Both response and prediction matrices were based on 46 plots. Field data was collected by using 20 x 20 m^2 sample plots, while the remote sensing variables were an average of 3 x 3 windows (resolution 15 x 15 m^2) for 15 predictors. The model used was based on Local Mean-Gaussian function (hump-shaped). The local model specifies the shape of the function that is used to fit a value for a specific point in the space defined by the independent variables. In HyperNiche, the kernel function is optimized by using a cross-validation procedure to select a weighting parameter. The relationship between weight given to an observation and distance from the target point can be defined in many different ways. A simple, flexible solution is to use a Gaussian (hump-shaped) function centred on the target point (Figure 6.3). An observation with exactly the same environment as the target point would receive full weight (1.0), smoothly diminishing to near zero weight with increasing distance from the target point. When the response variable is declared as quantitative, model quality is evaluated in terms of the size of the cross-validated residual sum of squares in relationship to the total sum of squares which was implemented as "cross R^2" in HyperNiche, because the calculation incorporates a cross-validation procedure (Antoine and McCune 2004).

Model Fitting and Evaluation

Fitting an NPMR model requires simultaneous selection of predictors and their tolerances from a pool of available predictors. This demands an iterative search through a potentially enormous number of possible models, which is accomplished with the software HyperNiche (McCune and Mefford, 2004). Variables are added in forward stepwise fashion, at each step making a grid search of variables and their tolerances. Variables already in the model are simultaneously evaluated for removal or change in tolerances with the addition of a new variable (McCune, 2006a).

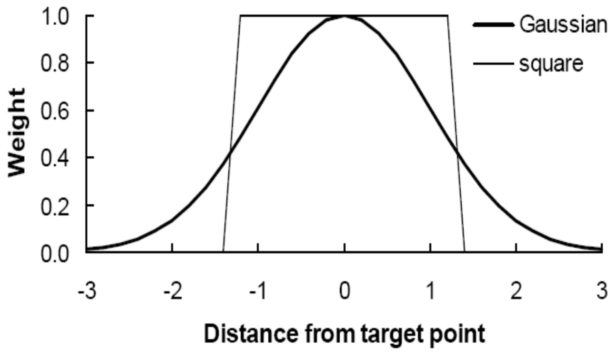

Figure 6.3. Uniform (square) weighting functions versus Gaussian (hump-shaped) function. In this example, the full range of the environmental variable spans 6 unspecified units and the target point is in the centre of that span (McCune, a2006).

6.6 Results

6.6.1 Patterns of Response Variables in the Abandoned Land

Herbaceous Biomass

NPMR uses a local multiplicative smoothing functions with leave-one-out cross validation to estimate the response variable. A Gaussian weighting function with a local mean estimator was used in a forward stepwise regression of biomass against the predictors.

The xR^2 differs from the traditional R^2 because each data point is excluded from the basis for the estimate of the response at that point. Consequently, with a weak model, the residual sum of squares can exceed the total sum of squares and thus xR^2 becomes negative. Rather than fitting coefficients in a fixed equation, NPMR fits ‘tolerances’, the standard deviations used in the Gaussian smoothers.

Herbaceous biomass predictions show five best models that means five variables from the predictors. The best xR^2 value is 0.16. Figure 6.4 and 6.5 show some of the herbaceous biomass predictors. Herbaceous biomass shows strong response to NDVI. The fitted response surface for SRI and NDVI values are averages of the dependent variable for a given value of the herbaceous biomass. NDVI was the strongest environmental gradient describing patterns in biomass on abandoned agricultural land communities in the study area. Biomass on abandoned agricultural land increased slightly with SIR (Figure 6.4) and dropped before it increases steadily. The calculate correlations of herbaceous biomass with NDVI is strong (R^2 = 0.65). Figure 6.5 show 3-dimentioanl graphs of different herbaceous biomass prediction variables.

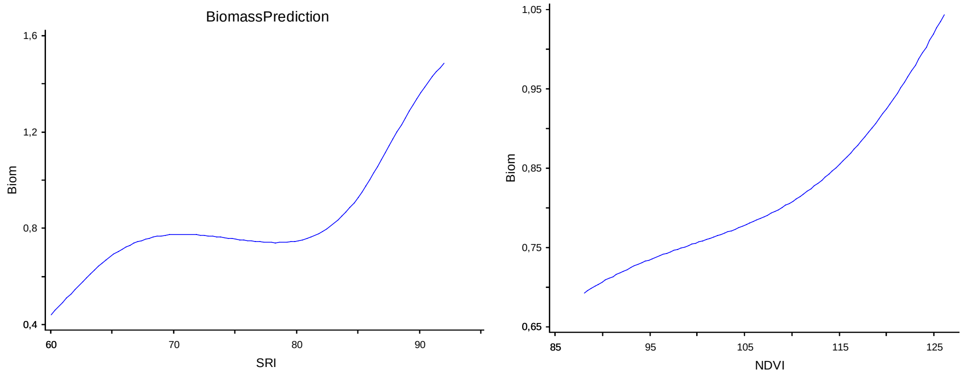

Figure 6.4: The relationship between herbaceous biomass and SRI and NDVI in 2D graphs.

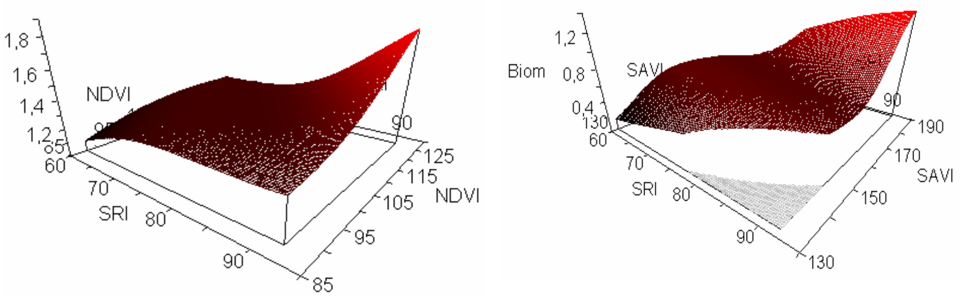

Figure 6.5: SRI, SAVI and NDVI against herbaceous biomass depicted 3D graphs for both predictors. The small dropout from the surface in B had insufficient local data to fit the model.

Percentage Cover

SRI was the best single variable describing patterns of percentage cover on the abandoned agricultural land (xR^2 = 0.12). When coverage was over 50 % shows more strong relation (Figure 6.6). This time beside the SRI, VNIR2, PC2 and PC3 are the predictor of percentage cover (Table 6.3).

Table 6.2: Summary table showing the best model for a series of increasing number of predictors to estimate the percentage of the herbaceous cover.

```
*****************************************************************
Best single variable and tolerance for each response variable
Response Predictor Type    Tolerance       xR2            N*
PerCover  SRI         Q     4.800         0.1094          20.49
*****************************************************************
```

DEPENDENCE OF FINAL MODEL ON NUMBER OF PREDICTORS FOR RESPONSE VARIABLE PerCover

Response	NumVars	xR2	xR2 change	N*	Tol-Variable	Tol-Variable	
PerCover	1	0.109	0.109	20.5	4.80-SRI		
PerCover	2	0.169	0.060	6.2	4.10-VNIR2	6.40-SRI	
PerCover	3	0.232	0.063	4.0	4.10-VNIR2	7.25-PC2	6.40-SRI
PerCover	4	0.267	0.035	1.5	2.05-VNIR2	7.25-PC2	9.15-PC3
6.40-SRI							
The following models did not meet the data:predictor ratio of10.0							
PerCover	5	0.343	0.077	1.1	2.05-VNIR2	7.25-PC2	9.15-PC3
8.00-SRI	3.05-TCTb						

NumVars: number of predictor variables.

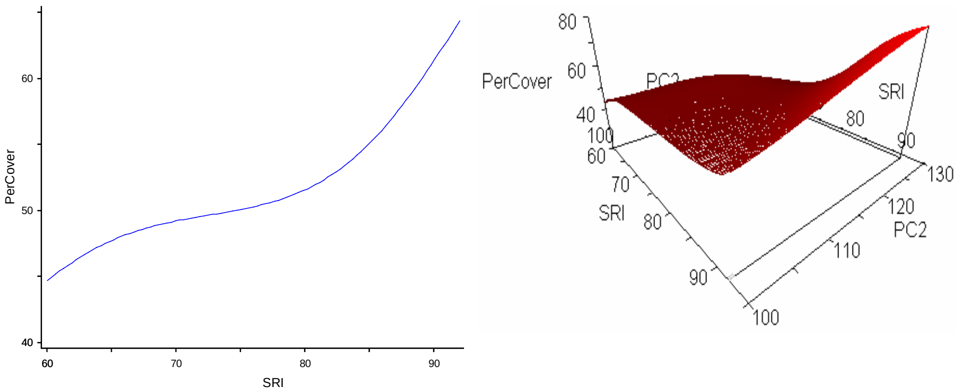

Figure 6.6: The relationship between percentage cover and SRI (A). B depicted local mean NPMR model fit to response surface from two predictor (SRI and PC2) NPMR model.

Land-Use History

Differences in pervious cultivation period were not related to any of the spectral indices or topographic parameters. Concerning the age of fallow prediction variables with the greatest explanatory power were: VNIR and SIR (Figure 6.7) and xR^2 is 0.23.

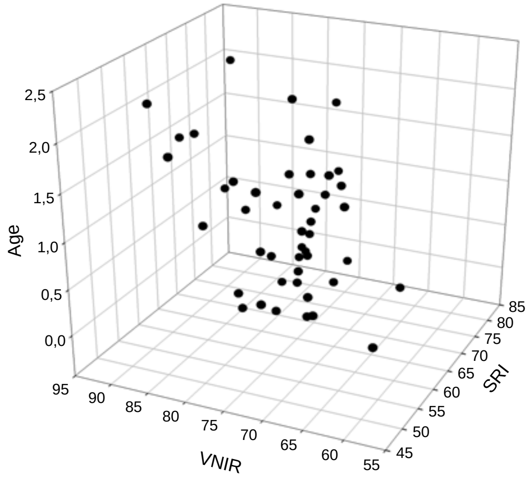

Figure 6.7: Relationship between age of fallow and VNIR and SIR spectral values.

Topographic Variables

There is no any of the topographic variables show up in the best model fits group using the NPMR. When using non-linear stepwise regression it was the same. However, altitude was found to have slight power to estimate herbaceous biomass (R^2 = 0.21). This may be due to the absence of obvious topographic variations within the area or the limited numbers of samples were not sufficient to capture the topographic features of the study area.

6.7 Discussion

As highlighted by several authors, it is necessary to develop spatial modelling methodologies for rapid and cost-effective mapping of degraded areas to assess their biological value for nature conservation (Nagendra and Gadgil, 1999; Luoto *et al*., 2002, Price *et al*., 2002).

From the group of variables used to assess the restoration potential of some abandoned agricultural land (Table 6.1), VNIR2, PC2,3, SRI, NDVI, SAVI, age of fallow and elevation successed to estimate some of the predefined restoration variables. In particular the SRI and the NDVI have dominated the related literature. Modifications to these indices have been proposed to account for background effects associated with incomplete canopy cover (i.e. SAVI). Modelling the relationship between spectral vegetation indices and vegetation variables and reflectance data are well established (Cohen *et al*., 2003). Heiskanen (2006) demonstrates the potential of ASTER data, to map biomass and LAI in the mountain birch forests in Utsjoki, northernmost Finland, using field data. There is a significant relationship between biomass and LAI. VNIR2 has the strongest correlation against biomass (r = -0.831) and LAI (r = -0.847). He mentioned that the good spatial resolution of the VNIR bands and the availability of the higher order data products make ASTER an interesting data source for vegetation mapping and modelling.

The possibility of classifying extensive areas of land rapidly from digital satellite imagery provides increasing opportunities to develop quantitative ecological models of land-cover and biological diversity relationships (Griffiths *et al.*, 1993). With remote sensing data it is possible to extrapolate information from site-based ecological studies to wider areas (Vande Castle, 1998). During the past decade, ecologists have begun to use satellite multi-spectral imagery as an aid in understanding community assemblage patterns. Landscape level habitat analysis using remotely sensed data, particularly in conjunction with topographic and other kinds of geographic data, has the potential to explain species level biodiversity patterns (Luoto *et al*., 2002).

Depending on the spatial resolution and the techniques used to generate these maps, topographic variables can be used to evaluate the correspondence between digital and field observed attributes for any location. Selecting a subset of plots that meet criteria of high correspondence between digital and real topography can significantly improve the model parameterization (Zimmermann and Kienast, 1999; Guisan and Zimmermann, 2000). Davis and Goetz (1990) found that vegetation pattern was significantly associated with slope, exposure and monthly solar radiation. The also results indicate the potential for analyzing plant species distributions in relation to dynamic patterns of solar radiation.

Monitoring vegetation activity at a regional scale should necessarily be carried out with of remote sensing techniques. This is particularly true for the Sahelian zone where direct measurements are difficult due to both the high diversity and heterogeneity of vegetation formations and logistic problems associated with field measurements (Mougin *et al*., 1995). Mougin *et al*. NDVI is commonly used to monitor the sahelian vegetation development during the growing season as it is known to be highly correlated to vegetation parameters like the leaf area index. In addition, the NDVI integrated over a growing season can be used to estimate the aboveground biomass through a simple linear relationship.

Seen *et al*. (1995) assessed the potential of vegetation indices for inferring vegetation parameters. NDVI, SAVI, GEMI (Global Environmental Monitoring Index), SRI show that a good tracking of the evolution of LAI. NDVI integrated over the growing season is compared to net primary productivity for different sites, regions, and growing seasons. A near-linear relationship is found. On the whole, the results suggest that vegetation indices contain information which is useful for the ecosystem model, despite the fact that perturbating factors make the retrieval of this information difficult.

Topographic variables were poor predictors of abandoned agricultural land restoration in the study area. This could be due to data insufficiency or the modelling technique followed was not appropriate. Additionally the study area is almost flat and the undulation topography is not that acute. The influence of topography on landscape properties obviously varies in different climatic, geomorphic and geological conditions and hence the results of these investigations, as a rule, reflect regional characteristics. DEMs are used in a wide range of landscape investigations. Furthermore, the combined use of remotely sensed data and DEMs has become an important trend in geomatics (Florinsky, 1998).

Vegetation patterns are significantly influenced by the landscape topography. Because topography influences the migration and accumulation of substances moved by gravity along the land surface and in the soil. Correlation and regression analyses of DEMs and remotely sensed data are mainly used together with a simple visual comparative analysis of scenes and topographic variable maps (Campbell, 1983; Wu, 1987). These procedures basically provide a better understanding of natural processes and the results can be used to determine the data-transformation rules in image classification (Florinsky, 1998). Keith and Bedward (1999) successfully modelled the spatial distribution of the 79 floristic groups using a set of spatial data layers. The derived variables represented topographic position, relief, shelter and soil moisture at varying spatial scales. However, appropriate data set to parameterize the model is needed.

Two general classes of approaches have been applied to infer biophysical properties of land cover: 1) Empirical approaches that rely primarily on curve-fitting to correlate various measures of surface reflectance, including vegetation indices, to the biophysical characteristics of interest and 2) Physical modelling approaches that attempt to forward model the relationship between stand-level biophysical characteristics and reflected and emitted radiation. These models are referred to generally as canopy reflectance models. Once developed and tested, the understanding gained from the models can then be used to either develop algorithms to relate biophysical characteristics to reflectance or the reflectance models can be used directly in the so-called inverse model that is, solved for the biophysical parameters given an input of reflectance (Hall *et al*., 1995).

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7 Conclusions and Recommendations

Land-use/land-cover (LULC) change is perhaps the most prominent form of global environmental change since it occurs at spatial and temporal scales immediately relevant to the human beings' daily existence. Those transforms, when coupled with climate change and variability in fragile ecosystem like the Sahel are likely to affect natural resources and habitats in a complex manner and sometimes in an irreversible way. Independent of long-term regional cumulative adverse dimensions, changes in LULC will have strong local social and environmental implications, such as alterations in social-stability, conflicts on natural resources, impacts on rates and types of land degradation, and reduced biodiversity. It is therefore widely recognized that an understanding of changes in LULC is central to the debate of sustainability.

Agriculture is one of the most common forms of human disturbance and occurs in many forms with a variety of environmental effects and consequences. Human disturbance, primarily in the form of mechanized rain-fed agriculture, has had major effects on the natural vegetation and other natural resources of the Gadarif Region. Being able to gain a better understanding of such profound changes is a priority concern of the research community. Fundamental elements of such research should, however, incorporate beside the basic human forces that motivate or drive theses changes their impact on biophysical processes.

The aim of the present study is to reveal the influences of the introduction of mechanized rain-fed agriculture and its rapid expansion on the natural vegetation in the southern Gadarif Region from different prospective. The main objectives of the study are to conduct multi-temporal analyses of natural vegetation clearing, to identify the human and social factors influencing LULC changes by exploring the farmers' attitudes and perceptions towards vegetation changes and land degradation processes, to assess the current situation of agricultural land with emphasis on abandoned agricultural land and to examine the impact of land-use history on floristic and structural attributes of fallow vegetation and its possible restoration and rehabilitation. To achieve these objectives the study utilized a series of techniques to map and model the vegetation changes within the last four decades. Beside the intensive use of remote sensing imagery, interviews with key informants and farmers and detailed filed surveys were conducted.

Main Findings

- Large scale mechanised rain-fed agriculture is the driving force for LULC change in the study area. It expanded from 500 ha in the 1940s to about 2.3 million ha in 2006.
- The average natural vegetation clearing rate was around 0.8 % per year, and the most rapid clearing occurred during the seventies when conversion rates increased to more about 4.5 % per year.
- Farmers are aware that soil degradation, in various forms, is taking place on their cultivated agricultural land. This is based on their perception and interpretation of indicators such as weed infestation, reduced soil fertility and soil compaction. Continuous cropping, mono-cropping, rainfall shortage and the use of inferior seeds were the main reasons of land degradation indicated by farmers.
- Abandonment of agricultural land to restore soil fertility is a common practice among farmers in the Gadarif Region. Abandoned agricultural land represent about 17 % (31790.59 ha) from the total area, while area under cultivation is 46 % (84614.60 ha).
- Subsequent natural regeneration of plant species and vegetation development on abandoned agricultural land are subject of previous cultivation period and age of fallow.
- The current regeneration capacity in the abandoned land may not be sufficient to reach full restoration of the vegetation which previously dominated the area, except for some pockets that received more regenerative resources.
- The results of field surveys in conjunction with remotely sensed and topographic data have the potential to explain restoration and rehabilitation pattern of degraded/abandoned agricultural land.
- From the group of variables used to assess the restoration potential of abandoned agricultural land, VNIR2, PC2,3, SRI, NDVI, SAVI, age of fallow and altitude succeed to estimate some of the predefined restoration variables.

Recommendations

The findings of the study seem to be representative not only for the whole Gadarif Region or other areas in Sudan, but also for other regions in the Sahel Zone with similar problems and similar environmental and social conditions. Thus the study concludes with the following recommendations:

- One of the most practical conservation approaches is to let farmers to play a role in managing their abandoned land. Such management aims to allow a certain level of uses and benefits while maintaining the natural vegetation development in order to achieve maximal restoration.
- Understanding the impact of agriculture on biodiversity is critical for effective conservation management.
- Due to high spatial and temporal changes of abandoned agricultural land, their mapping with only annual scenes is not sufficient. Therefore, the use of cheap multi-temporal imagery of adequate spatial resolution, e.g. MODIS, is highly recommended.
- Further research is needed to quantitatively evaluate the mechanisms enhancing vegetation recovery on abandoned agricultural land.
- Understanding the conversion of agricultural activities is beyond any doubt essential for the understanding of the origin and evolution of abandoned farmland.
- For a complete survey of plant species in the area it is necessary to conduct a long-term experiment (during early, mid and late rainy season and for more than one year).
- Although the study investigated the vegetation development in abandoned mechanized rain-fed agricultural land in the southern Gadarif Region, a full understanding of the path-way needs surveys that includes more types of abandoned lands and to investigation of the effects of other local environmental conditions (e.g. fire, grazing, distance from forests etc.) for more than one season.

Summary

The study was conducted at the vicinity of the rural town of Doka in an area of about 55 x 40 km2. The aim of the study was to map and model the influences of the introduction of mechanized rain-fed agriculture and its rapid expansion on the natural vegetation in the southern Gadarif Region. To achieve these objectives the study utilized a series of techniques. Beside the intensive use of remote sensing imagery, interviews with key informants and farmers as well as detailed field surveys were carried out. Multi-temporal analyses of remote sensing imagery showed that during the seventies the average natural vegetation clearing rate increased most rapidly and then began to slow down. Farmers are aware that land degradation, in various forms, is taking place on their cultivated agricultural land. This is based on their perception and the interpretation of indicators such as weed infestation, reduced soil fertility and soil compaction. Continuous cropping, mono-cropping, rainfall shortage and the use of inferior seeds were the main reasons of land degradation indicated by the farmers. Abandonment of agricultural land to restore soil fertility is a common practice among farmers in the Gadarif Region. The study proved that the subsequent natural regeneration of plant species and the vegetation development on abandoned agricultural land are subject to the previous cultivation period and the duration of the fallow. The current regeneration capacity of the abandoned land may not be sufficient to reach full restoration of the previous vegetation climax except for some pockets which received more regenerative resources. Field surveys in conjunction with remotely sensed and topographic data have the potential to explain the restoration and rehabilitation patterns of degraded/abandoned agricultural land to a good extent. The findings of the study seem to be representative not only for the whole Gadarif Region or other areas in Sudan, but also for other regions in the Sahel Zone with similar problems and environmental and social conditions. One of the most practical conservation approaches is to let farmers play an active role in managing their abandoned land. Such management aims to allow for a certain level of use and benefits while maintaining the natural vegetation development on theses area in order to achieve maximal restoration. Although the study investigated the vegetation development in abandoned mechanized rainfed agricultural land, a full understanding of the path-way needs surveys that include more types of abandoned land and investigation of the effects of other local environmental factors (e.g. fire, grazing, distance from forests etc.) for more than one season.

Kartierung und Modellierung von Vegetationsveränderungen in der Region Süd-Gadarif, Sudan, unter Nutzung von Fernerkundung: Einflüsse der Landnutzung auf biophysikalische Prozesse

Zusammenfassung

Die Studie wurde südlich des Landstädtchens Doka in einem Gebiet von etwas mehr als 55 x 40 km² durchgeführt. Ziel der Arbeit war die Kartierung und Modellierung der Einflüsse der Einführung der mechanisierten niederschlagsabhängigen Landwirtschaft und ihrer schnellen Expansion auf die natürliche Vegetation in der Region Süd-Gadarif. Zum Erreichen dieser Ziele nutzt die Studie eine Reihe von Techniken. Neben der umfangreichen Nutzung von Fernerkundungsdaten fanden Interviews mit Schlüssel-informanten und Bauern sowie detaillierte Geländeaufnahmen statt.

Die multitemporale Auswertung der Fernerkundungsdaten zeigt, dass die Verdrängungsrate der natürlichen Vegetation in den 1970er Jahren sehr stark anstieg, um danach langsam abzunehmen. Die Bauern sind sich bewusst, dass Devastierung in verschiedenen Formen auf ihrem bewirtschafteten Ackerland stattfindet. Dies gründet sich auf deren Wahrnehmung und Interpretation von Indikatoren wie Unkrautausbreitung, geringerer Bodenertrag und Bodenverdichtung. Ununterbrochene Bewirtschaftung, Monokulturen, geringere Niederschläge und die Nutzung von minderwertigem Saatgut sind die von den Bauern angegebenen Hauptgründe für die Devastierung.

Flächenstilllegungen von Ackerland zur Steigerung der Bodenerträge sind gängige Praxis bei den Bauern der Region Gadarif. Die Studie konnte nachweisen, dass die natürliche Regeneration von Pflanzenarten und die Vegetationsentwicklung auf Brachland von der vorherigen Bewirtschaftungsperiode und der Dauer der Brache abhängig sind. Die gegenwärtige Regenerationsfähigkeit des Brachlandes ist mit Ausnahme von einigen kleinen Gebieten nicht ausreichend, um die vollständige Wiederherstellung der früheren natürlichen Maximalvegetation zu ermöglichen. Geländeaufnahmen in Verbindung mit topographischen und Fernerkundungsdaten haben das Potential, die Restaurations- und Rehabilitationsmuster auf devastiertem oder brachliegendem Ackerland zu einem Gutteil zu erklären.

Das Ergebnis der Studie ist nicht nur für die gesamte Region Gadarif oder andere Gebiete im Sudan repräsentativ, sondern auch auf andere Regionen der Sahelzone mit ähnlichen Problemen und Umwelt- und sozialen Bedingungen übertragbar. Einer der praktikabelsten Schutzansätze ist, den Bauern eine aktive Rolle bei der Bewirtschaftung des Brachlandes einzuräumen. Diese Bewirtschaftungsziele erlauben ein bestimmtes Niveau der Nutzung und der Erträge, während man die natürliche Vegetationsentwicklung zur maximalen Wiederherstellung erhält. Obwohl die Studie die Vegetationsentwicklung auf einigen brachliegenden mechanisiert bewirtschafteten niederschlagsbewässerten Ackerflächen in der Region Süd-Gadarif untersucht, sind für ein volles Verständnis der Zusammenhänge umfassendere Aufnahmen von mehr Brachlandtypen und die Untersuchung der Effekte anderer lokaler Umweltbedingungen (bspw. Feuer, Beweidung, Abstand zu Waldflächen) erforderlich.