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The Impact of Land-Use Change on the Livelihoods of Rural Communities: A case-Study in Edd Al-Furssan Locality, South Darfur State, Sudan

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Explanation of the doctoral candidate

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Declaration

I hereby declare that this thesis entitled ***"The Impact of Land-use change on the Livelihoods of Rural Communities: A case-study in Edd Al-Fursan Locality, South Darfur State, Sudan"*** submitted to the Faculty of Environmental Sciences is my original work and any work taken from other authors is duly acknowledged within the text and references chapter. It is my own responsibility to declare that it has not been previously submitted or accepted for the award of any degree of the university or institutions.

Masarra Ahmed Adam Bashir

Dresden, Germany

November, 2012

Dedicated

To my parents…….. Ahmed and Fatima for their love, endless support and encouragement.

Husband Aziz and

Daughter Saba

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List of abbreviations

ASTER	Advanced Spaceborne-Thermal Emission and Reflection Radiation
CBS	Central Bureau for Statistics
CFSAM	Crop and Food Supply Assessment Mission
CIC	Colour Infrared Composite
CVA	Change Vector Analysis
DFID	Department For International Development
D-JAM	Darfur-Joint Assessment Mission
DLC	Darfur Land Commission
DOS	Dark Object Subtraction
ENVI	Environmental for Visualizing Images
ERDAS	Earth Resource Data Analysis System
ERTS	Earth Resources Technology Satellite
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
FAO	United Nations Food and Agriculture Organization
GPS	Global Positioning System
HAC	Humanitarian Aid Commission
IFAD	International Fund for Agricultural Development
IDPs	Internally Displaced Persons
IOM	International Organization for Migration
IR-MAD	Iteratively Reweighted Multivariate Alteration Detection
Km^2	Square Kilometer
LULC	Land Use/Land Cover
MAF	Maximum Autocorrelation Factor
MDTFs	Sudan Multi-Donor Trust Funds
MSS	Multispectral Scanners
NAPA	National Adaptation Program of Action
NASA	National Aeronautics and Space Administration
NGOs	Non Governmental Organizations
NIR	Near-Infrared
NRC	Natural Resources Canada
PCs	Principle Components

PCC	Post Classification Comparison
PIPs	Policies Institutions and Processes
RBV	Return Beam Vidicon
RGB	Red Green Blue
SDS	South Darfur State
SAMI	State Ministry of Agriculture and Irrigation
SPSS	Statistical Package for Social Science
TCT	Tasseled Cap Transformation
TM	Thematic Mapper
UN	United Nations
UNCCD	United Nations Convention to Compact Desertification
UNDP	United Nations Development Program
UNEP	United Nations of Environmental Program
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
WB	World Bank
WFP	World Food Program
WMO	World Meteorological Organization
WSDC	Western Savannah Development Corporation

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CHAPTR ONE

General Introduction

1.1 Background

The world's drylands cover about 5.2 billion hectares (one-third of the land area of the globe, UNEP, 1992). Roughly one-fifth of the world population lives in these areas, and about 40 percent inhabits degraded lands (UN & IFAD, 2000). Drylands are areas characterized by land degradation and are directly linked to both climate variation and unsustainable human activities, such as overgrazing, deforestation, and poor agricultural management practices (Murray, et al, 1999). However, pastoralism, with widespread and highly mobile, subsistence food production primarily from smallholding rainfed systems for subsistence or local consumption and markets and natural woodlands for fuelwood, are predominant land uses in dry lands (FAO, 2004).

With regard to land-use practices in Sub-Saharan African drylands, rainfed agriculture dominates the region and supports various rural livelihoods (FAO, 2004). It is characterized by low crop yields, which results from scarce and unreliable rainfall amounts that combine with extensive agriculture and results in the overexploitation of forests, woodlands and rangelands (FAO, 2004). As such, poverty and hunger are predominant, as more than 50 percent of Africa's poorest people are concentrated on "low potential" lands that are prone to degradation (Holtz, 2008).

Sudan, as a Sahelian country, was subjected to severe episodes of drought in recent decades, particularly during the 1970s and 1980s, and this resulted in the deterioration of natural resources due to intensive cultivation and overgrazing (Ali et al., 2008). Accordingly, people faced famines and large numbers of animals were lost as a result of shortage of fodder and water. On the other hand, the continuous aridity in the region, which combined with water shortage and low vegetation cover, intensified the process of desertification (Leroy, 2009).

The process was further exacerbated by human activities; farmers responded to the changing environment with the continual expansion of cultivation into marginal and fragile areas as a means to adapt to declining yields and resorted to the generation of income from the sale of tree crops to overcome their shortage of income (Teklu, Braun & Zaki, 1991).

The Darfur region is a territory in Western Sudan that lies in the Sahel region, and is characterized by vulnerability in livelihood, suffers from environmental degradation, population growth, conflicts, climate change, dependence on natural resources and lacks opportunities for diversification. Due to these challenges, as the population increases the frequency of droughts are also growing (Bromwich, 2008). Agriculture and livestock, which comprise the main productive sectors in the Dafur region, are frequently affected by drought. Repeated droughts have contributed to the depletion of natural resources and the impoverishment of people in this region (Young et al., 2005). Furthermore, the erosion of soils and the depletion of productive land in Darfur, as the result of desertification over the past several decades, led to mass population movement southward in search of better conditions for pasture and farming. The ability of local people to adapt to the new situations and the subsequent questions of land use and resource sharing continue to threaten peaceful coexistence in the area and the social cohesion of the entire community (King & Osman, 2004).

Young et al. (2005) reveal that rainfall also plays a major role in the degradation of natural resources. Rainfall statistics show that (overall) rainfall in the region has declined, which results in a shorter and unreliable rainy season. Since 1986, farmers and herders have both recognized that ecological deterioration was emerging as a result of declining rainfall, which forced them to apply land-use practices that were not sustainable. These included cutting down trees and over-cultivating fragile lands, leading to deforestation and desertification, when stable Goz degenerates are transported by windblown sand and induce declining yields. Over-grazing has also contributed to the degradation of the pasture.

The primary human activities practiced in South Darfur State are traditional rainfed-shifting system of cultivation and livestock rearing. Livestock play an important role in Southern

Darfur by providing capital, food production, status, animal traction, and manure (Tahir & Siddig, 2009). However, over the course of the last decades, increased numbers of both human and animal populations migrated into this area. This may have resulted from environmental factors, or may also be the result of conflicts and war in the Greater Darfur Region (Abusuwar & Yahia, 2009). The mass movement of herders with their animals has affected the rangelands in Southern Darfur. Therefore, as the result of population growth, unsustainable land practices have emerged, which resulted in the major loss of forests, and is considered to be the main cause of deforestation in the region (UNEP, 2008).

Abdella (2004) illustrates that a quick regeneration of the natural ecosystem following persistent human impact is difficult. Dynamic processes involved in the removal of topsoil, which is caused by overcultivation and overgrazing, reactivated the consolidated sand dunes and resulted in a decreased crop production. Accordingly, poverty and food insecurity have increased.

1.2 Description of the Study Area

1.2.1 Sudan

Sudan is located in Northeast Africa. It covers an area of approximately 1.882.000 km², between latitudes 8.45˚ and 23.8˚ North and longitudes 38.34 and 21.49 East. The country is bordered by Egypt in the north, the Red Sea in the northeast, Eritrea and Ethiopia in the east, South Sudan in the south, the Central Africa Republic in the southwest, Chad in the west and Libya in the northwest. Its most dominant geographic feature is the River Nile, as the Nile basin constitutes 67.4percent of the country's total area.

Sudan's latest census (2008) estimates the population of Sudan to be 33,419,625 persons. The average annual population growth rate is 2.8percent; however, the rate varies significantly among the different regions, as well as between urban and rural areas (Haub, 2011).

The climate of Sudan ranges from desert, semi-desert and dry in the utmost north (Northern

State, North Kordofan and North Darfur). The central and southern regions are characterized by semi-desert to rainy climates, whereas a Mediterranean climate prevails. However, the most significant climatic variables are rainfall and the length of the dry season. Variations in the length of the dry season depend on which of two air flows predominates dry northeasterly winds from the Arabian Peninsula or moist southwesterly winds from the Congo River basin.

The most extreme temperatures are found in the far northern part of the country, where summer temperatures can often exceed 43° C and sandstorms blow across the Sahara from April to September. These regions typically experience virtually no rainfall. In the central area around and just south of Khartoum, average annual temperatures are around 27° C, with rainfall averaging about 200 mm/year and rarely exceeding 700 mm/year.

1.2.1.1 Distribution of dryland in Sudan

The FAO defines drylands on the basis of the length of the growing season, as zones which fall between 1-74 and 75-199 growing days represent arid and semi-arid drylands, respectively (FAO, 1978). These regions are also characterized by low, erratic and highly inconsistent rainfall levels, receiving between 100 to 600 mm rainfalls annually. The main feature of “dryness” is the negative water balance between the annual rainfall (supply) and the evaporative demand.

According to Ayoub (1998), 31percent of Sudan’s territory is hyper-arid, 63percent are drylands susceptible to desertification. This is noteworthy, as 82 percent of the population lives in the regions.

According to Youb (1998), aridity zones in North Sudan can be classified into three categories:

Hyper-arid zones are true desert regions, which have extremely low rainfall — varying from 0- 25 — that is unequally distributed over both time and space. The vegetation is extremely scarce, and is generally found in a state of depression or almost permanently dry watercourses, which carry some runoff during rare rainstorms.

The arid zone receives annual precipitation totals between 100-300mm, with inter-annual rainfall variability in the range of 50-100 percent. The carrying capacity of this zone is very low. In this zone, strong winds associated with summer thunderstorms result in dust storms.
The semi-arid zone is characterized by precipitation totals between 400 and 800 mm per annum. Grasslands and shrub vegetation dominate these regions, providing some good-quality grazing during the wet season. Rainfed agriculture is maintained in this region, but yields show marked variation from year to year as inter- annual variability is between 25-50 percent. Despite successful years of grazing and crop production, these activities are susceptible to seasonal and inter-annual moisture deficiencies.

1.2.2 Edd Al-Fursan Locality

Edd Al-Fursan, originally Edd Al-Ghanam until the presidential order in 1992 that renamed the locality Ed Al-Fursan, is located in southwest South Darfur State, 90 kilometers from the center of the state. It covers an area between longitude 24˚ 00´ to 24˚ 30´ E and latitude 11 ˚ 30´ to 12˚ 00´ N, and is approximately 11,000 km² in size. According to the 1993 census, the area is inhabited by a population of 375,000. However, the current population levels are believed to be much higher, nearly 600,000, as a result of the recent war situation and the great number of displaced people that rushed to the area.

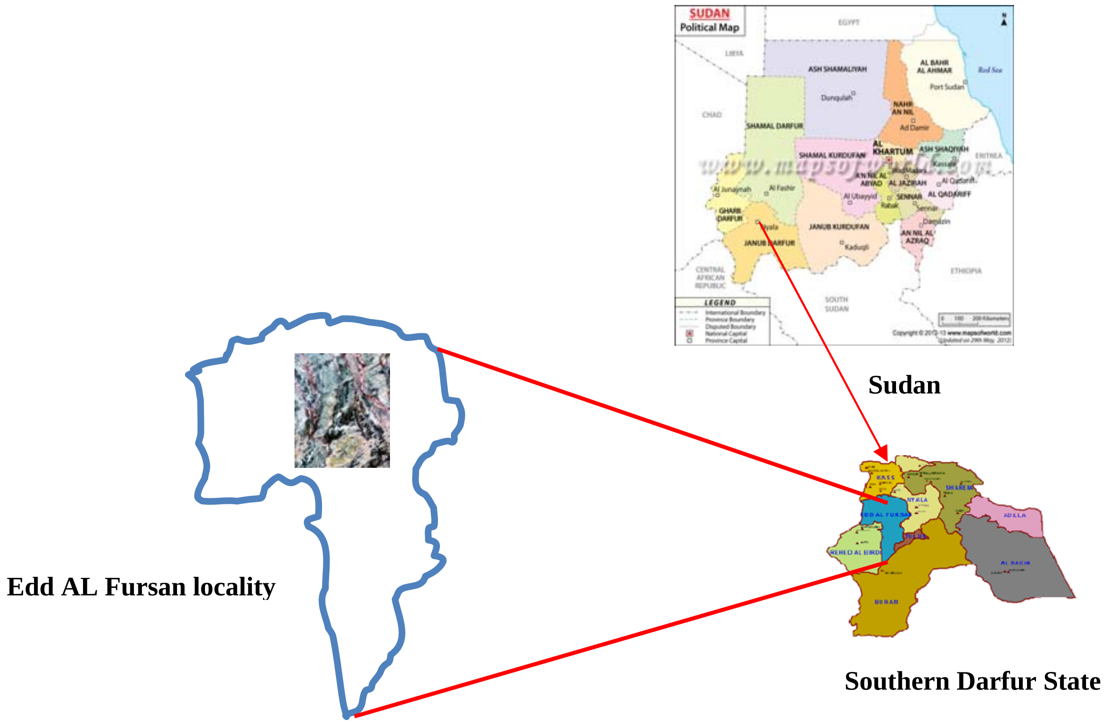

Figure 1.1 Location of the study area: composite RGB (1, 2, 3) ASTER imagery 2008

1.2.2.1 Physical features of the area

The Edd Al-Fursan area is part of what is referred to as the Bagarra Repeating Pattern, consisting of sandy ridges alternating with basins of clay and silty soils. In general, the region is characterized by large areas of sandy to loamy soils with vast areas of alluvial plains traversed by many wadis and seasonal streams draining the southern slope of Jabal Marra.

Figure 1.2 Some physical features of the area, Photo by the author, 2010

The superficial deposit of the area may be subdivided into three types:

Alluvial deposits

The alluvial deposits are located along the valleys of the presently flowing *wadis*[1]. Alluvial sediments are generally coarse and ill-sorted in the upstream slope, whereas the wadi flows along a well-defined course; in the middle slope, the wadi flows in a broad sandy channel and is flanked by silty terraces. Here, the alluvial deposit contains thick beds of coarse sands and clays. In the downstream slope, the wadis flow over their own flood plains; the sediments are fine-grained and in many places, the thickness of the deposits may reach 30 m.

Goz sands

Goz[2] sands cover large areas of this locality. They comprise stabilized sand, with a maximum recorded thickness in South Darfur of 18 m.

Basement pediment deposits

The basement complex is primarily comprised of a cover of superficial deposits composed of a mixture of residual soil, sheet wash and very thin sheets of alluvium. These deposits are fine-grained silts and clays with some gravel and quartzite fragments.

1.2.2.2 Climate and Rainfall

Edd Al-Fursan's climate consists of a rainy season lasting approximately from June to September, and a dry season covering the rest of the year. Records show that 90 percent of the annual rainfall occurs between June and September, while 10 percent falls in May and October. Temperatures are very high in April and May and are the lowest during December and January (winter season).

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[1] seasonal water course
[2] Stabilized sandy soils

The average rainfall recorded between 1943 and 1974 was 615 mm, while between 1993 and 1999, it was 454 mm and 499 mm for the years between 2000 and 2006 (SMAI, 2006).

During the dry season, northerly winds prevail, whereas southerly winds prevail during the rainy season.

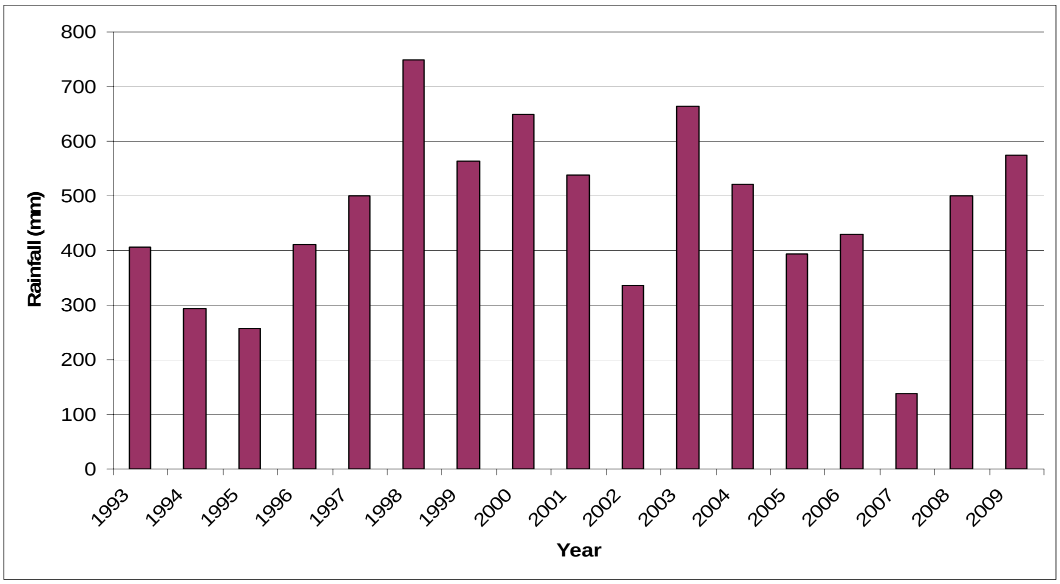

Figure 1.3.Distribution of annual rainfall in the area
Source: State Ministry of Agriculture Annual Report (1993-2009)

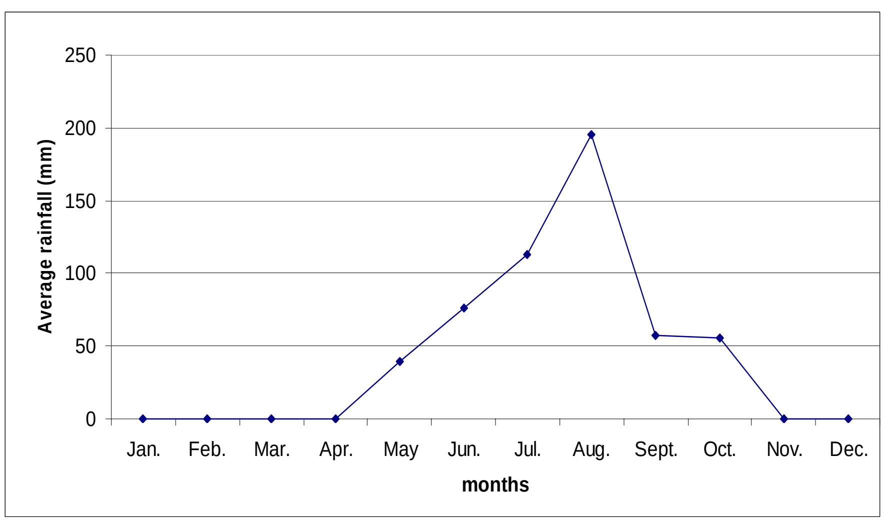

Figure 1.4 Mean monthly rainfall distribution pattern in Edd Al-Fursan locality (2004-2009).
Source: State Ministry of Agriculture Annual Report (2004-2009)

1.2.2.3 Geology

There are two distinguishable geological units in the Edd Al-Fursan locality: Basements Complex and Nubian Sandstone.
The term basement complex covers a wide range of metamorphic rocks. It includes the larger parts of this area and is often overplayed with a weathered layer that is rarely more than 5 m thick. This geological formation has far-reaching consequences and water sources. However, suitable prospects for ground water are only found in smaller areas such as fractures or fault lines.

Nubian sandstone formations are found in a few outcrops in this area. The formation is known to possess good potential for ground water.

1.2.2.4 Vegetation

The area's dominant rainfall and soil types influence the vegetation cover. Thus, the prevailing type of vegetation comprises open thorny savanna, including important species such as *Acacia senegal* (Hashab), *Acacia milifera* (Kitir), *Acacia Oerfota* (Loat), *Faidherbia albida* (Haraz). Dense tree cover and other grass-like species occupy wadis and depressions.

1.2.2.5 Drainage system

Numerous small streams drain the southern slope of the Jebel Marra into this area, the largest of which is the Wadi Ibra with a catchment of about 30,000 km². It has eight tributaries that flow in to the Edd Al Fursan area, of which *Wadi Gendi*, *Wadi Kaya, Wadi Sinde and Wadi Bulbul* are the most notable.

These *wadies* with seasonal depressions provide large amounts of surface water during the rainy season; their total potential is high considering the size of the catchment area and average precipitation. However, most precipitation leaves the area as surface run-off and only

small parts are stored in natural depressions, or *hafirs*[1]. In the localities southern area, surface water is plentiful in natural depressions, including *rahads*, *butas*, *ragabas*, as the name used to describe these depressions depends on its size and shape.
Limited data are available about the chemical quality of surface water. In most areas the chemical water quality can be considered suitable for human consumption. The bacteriological quality may be considered poor due to the pattern of use by both humans and animals. In general, surface water is quite suitable for domestic purposes as well as for livestock.

1.2.2.6 Land-use types in the area

Edd Al-Fursan locality's population has access to various livelihood options, including a mixture of sedentary, semi-sedentary and nomadic groups. Nomads represent a little over one-quarter of the population. Many village clusters also include displaced persons and/or immigrants, primarily from North Darfur, having moved due to previous droughts experienced in their home region. However, currently inhabitants also include people from South Darfur who emigrated to Edd Al-Fursan following tribal conflicts and drought, while other residents originate from other parts of Africa.

Agriculture is the principal source of income. More than two-thirds of family income comes from livestock sales and processed products (milk, ghee, cooking oil). Additionally, more than a quarter of the population are involved in the sale of vegetables, groundnuts and cereals. Almost all households own donkeys and sheep or goats, while almost two-thirds of households also own cattle.

The sedentary population practices agriculture and livestock farming practices, consisting mainly of cattle and small ruminants (Figure 1.5). Cereals (mainly pearl millet) and groundnuts constitute the bulk of rainfed cultivation. In addition, vegetable production (under

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[1] A construction used to catch and store rain water

irrigation) is important, as a second crop accessible due to residual rainwater after the harvest of cereals.

The semi-nomadic ("transhumant") population is primarily involved in livestock herding (cattle). The nomadic population also herd cattle, but migrate much greater distances with their herds than the semi-nomadic populations.

Figure 1.5 Livestock grazing on farms as a land-use type in the study area. Photo by the author, 2010

As mentioned above, the Edd Al-Fursan locality has good-quality tree cover, and many of the trees have commercial value. Gum Arabic is harvested from the wild, but the local market demands have recently declined. As such, harvesting has been cut back at present. Fruit tree cultivation has been developing in recent years, including mango, guava, citrus fruit, papaya, and bananas have been introduced recently.

1. 3 Land degradation

Land degradation comprises the temporary or permanent decline in the productive capacity of land. Degradation adversely affects the productive, physiological, cultural and ecological functions of land resources, such as soil, water, plants and animals. (UNEP, 1992).

Scherr et al. (1996) reveal that by 2020 land degradation may pose a serious threat to food production and rural livelihood, particularly in poor and densely populated areas of the developing countries. Land degradation occurs in a number of forms, including depletion of soil nutrients, salinization, agrochemical pollution, soil erosion, vegetative degradation as a result of over grazing, and deforestation to increase farmland. All these types of degradation cause a decline in the productive capacity of the land, and thus reduce potential yields.
The UNCCD (1994) identifies that numerous factors can be attributed to the root cause of the loss of arable land, many or most of which are related to human development. The primary causes are deforestation, overexploitation for fuelwood, overgrazing, agricultural activities and industrialization. On a global basis, soil degradation is caused primarily by overgrazing (35 percent), agricultural activities (24 percent), deforestation (30 percent), the overexploitation of land to produce fuelwood (7 percent), and industrialization (4 percent)

In the Sudan, as in most other parts of Africa, human and animals lives rely on the delicate balance of soil, climate, water and flora. During the last three decades, this equilibrium has been disturbed, particularly in the vast arid and semi-arid areas of North Sudan. In addition to persistent drought, unsustainable methods of land use, such as large scale deforestation for mechanized rainfed farming and fuelwood, overgrazing in marginal lands and range fires, are destroying the Sudano-Sahelian ecozone in which about 70 percent of the Sudanese population live. As such, millions of people have been forced to abandon their home regions and have become internally displaced (Suliman, 1998).

1.4 Conflicts about natural resource use

Caas (2007) reports that political instability, natural disasters, unsustainable agricultural policies, and natural resources mismanagement are among the central causes of conflicts among the Sudanese people, where pastoral and farming communities are scattered throughout the country. The rapid expansion of mechanized agriculture from central Sudan into its regions, especially from the 1960s onwards, disrupted traditional land tenure systems, reduced transhumance routes, increased tension and frictions between pastoralists and farmers and created a large group of landless people (UNDP, 2004). This expansion combined with fluctuating levels of rain and a doubling of the population over the course of less than 25 years, which has ultimately resulted in competition and conflict for scarce natural resources. Like other parts of Sudan, the population of Darfur has increased substantially over the last fifty years. Accordingly, the population density has increased tremendously (Fadul, 2004) (Table1.1).

Table 1.1 Population density changes in Darfur (1956- 2003)

Year	Population	Density (Persons / km²)
1956	1,080,000	3
1973	1,340,000	4
1983	3,500,000	10
1993	5,600,000	15
2003	6,480,000	18

(Source: Fadul, 2004)

The increased population's need for livelihood has placed greater pressure on the limited natural resources. This coupled with a decline in rainfall levels, and thus frequent droughts and the spread of desert conditions, have resulted in food deficiencies and poverty (Fadul, 2004).

Ahmed, (2009) argues that due to severe competition for natural resources that are becoming scarce, the traditional symbiosis between herders and farmers has eroded in recent decades as people's livelihood have converged, shifting the moral geography of herders and farmers and bringing them into conflict with one another. This encouraged local tensions and provoked a violent resource-based conflict. Ecological imbalance, scarcity of water, deforestation, mismanagement of natural resources, claimed inequality in the distribution of available resources and national projects, and the lack of cooperation have contributed significantly to the present conflicts (King and Osman, 2004)

1.5 Objectives of the Study:

This study seeks to:

- Determine dominant land-use practices in the area using multi-temporal satellite images;
- Assess land-use changes in Edd Al Fursan locality, South Darfur State between 1972 and 2008;
- Evaluate the impact of land-use changes on rural livelihoods in terms of the availability of natural resources by using a qualitative technique;
- Provide up-to-date information that could be useful for measuring the impact of land-use change upon rural livelihoods;
- Develop a method that could assess the relationship between human activities and land-use change and the impacts of land-use change upon rural livelihoods.

1.6 Hypotheses:

This study predicts that:

- ✓ Edd Al-Fursan locality's land-use practices have changed severely between 1972-2008;
- ✓ Remote sensing and GIS can be used as suitable tools for assessing land-use change and the impact of this change on the rural livelihoods of rural people;
- ✓ A major cause of land degradation is a change in land-use patterns due to human activities;
- ✓ The patterns of land-use change have severely impacted rural livelihoods.

1.7 Organization of chapters

The thesis consists of six major chapters, which can be read independently. Chapter 1 includes the general introduction as well as a description of the study area, while Chapter 2 identifies potential resources in South Darfur State and land-use system. In Chapter 3, the use of multi-temporal Satellite data for land-use/land-cover change analysis is described, while Chapter 4 presents a livelihood analysis of South Darfur State. Chapter 5 describes the impact of land-use change on the livelihoods of rural communities in Edd AL-Fursan locality, South Darfur State. Chapter 6 and 7 present the complementary use of remotely sensed and socio-economic Data and overall conclusions and recommendations, respectively.

CHAPTER TWO

Potential Resources and Land-use System in South Darfur State

2.1 Abstract

Land resources play an important role in shaping rural livelihoods. They are considered a source of wealth, tribe identity, and social peace, but can also act as a source of conflict. Human are arguably largely responsible for land and natural resources management because they have the capacity to engage in productive activities that require planning, technology and collective work. For this reason, land has always been an important aspect in defining and reshaping relations between humans whether individuals or groups.

This chapter reviews the natural resource situation as well as land use with reference to the land tenure system in South Darfur State. This review illustrates that South Darfur State (SDS) is a large region with relatively abundant natural resources and wide ecological diversity that can offer a firm foundation for prosperous and sustainable agricultural development if properly tapped. The area is divided into three climatic zones: the northern zone (semi-desert), the central zone (semi-arid), and the southern zone (sub-humid) (SMAI, 2009). Since the 1984 drought, migration from North to South Darfur has been a dominant feature of this region. This has led to a rapid increase in human population, averaging 4.15 percent per annum, which resulted in competition for natural resources and, accordingly, soil degradation.

Land tenure and ownership in the region are traditional and is primarily governed by customary laws, including the regulations that provide access to, ownership of, and transfer of property and land through the *hakura*[1] system. Legally, all land that was unregistered before 1977 is considered government property. Accordingly, this thesis identifies three types of

[1] Traditional tribal system for allocating and managing land. Hakura is also the term used for the tribal land it self

land-use systems, based on land tenure type, including: farmer's tenure system, pastoralists, and the *Hashab* (Gum Arabic) tenure system. The study reveals that *hakura* system has been complicated by droughts, unequal distribution of natural resources, over-cultivation and overgrazing.

2.2 Introduction

The South Darfur State (SDS) is situated in the South-Western Sudanese Savannah belt between longitude 22° 40' and 27° 50' East and latitude 8° 30' and 13° 30' North (see Chapter One, Figure 1.1.). The 1983 census estimated that its population was 1.2 million persons. In 1993, the census identified that 2.1 million persons were living in the region, whereas this number increased to 4.5 million persons for the 2008 census. Rural populations represent 73 % of SDS's total population, while urban and nomadic populations comprise 22 % and 5 %, respectively. Livestock population can be approximated to 14.5 Million heads, comprising 5.2 heads of cattle, 4.4 heads of sheep, 3.9 heads of goat, 0.14 heads of camels, 0.45 heads of horses and 0.42 million heads of donkeys (SDS, Ministry of Animal Resource,

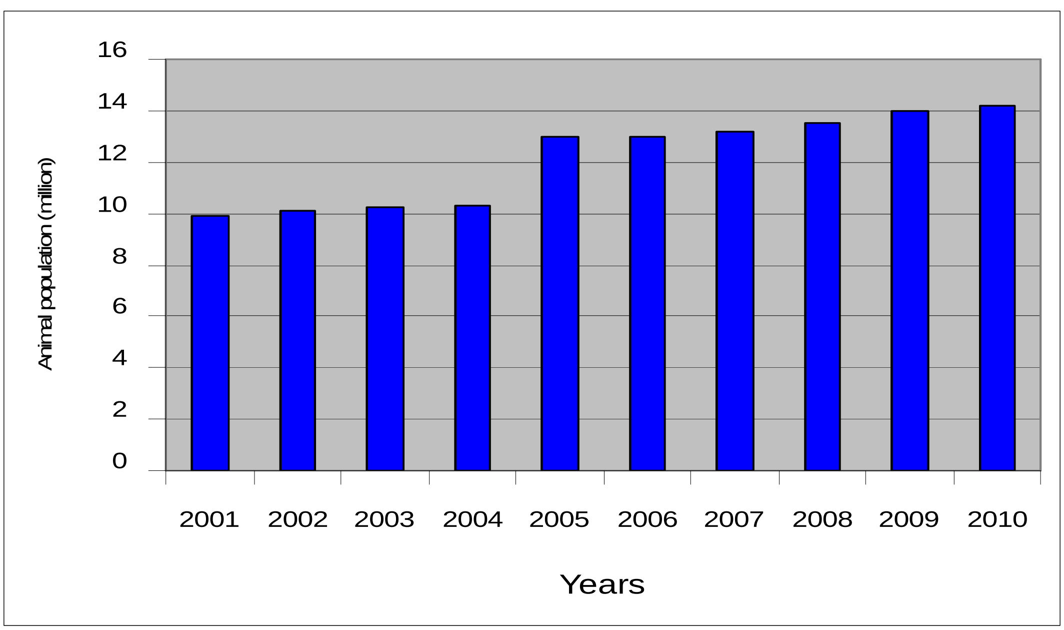

Figure 2.1 Animal population growths in SDS 2001-2010

Source: Ministry of Animal Resources, Annual Reports (2001-2010)

The surface area is estimated to be 138, 000 km², which is equivalent to 32 million feddans[1]. The suitable area for cultivation comprises 24 million feddan, 7 million of which is currently cultivated. The total area suitable for horticultural cultivation is 150, 000 feddans, 50, 000 of which is currently cultivated (SMAI, 2009). Traditional rain-fed agriculture is the predominant form of agriculture and provides a livelihood for 82 percent of the population. The two main staple crops are millet and sorghum, while groundnuts are the main cash crop. Figure 2.2 illustrate the production of these crops between 1987 and 2010.

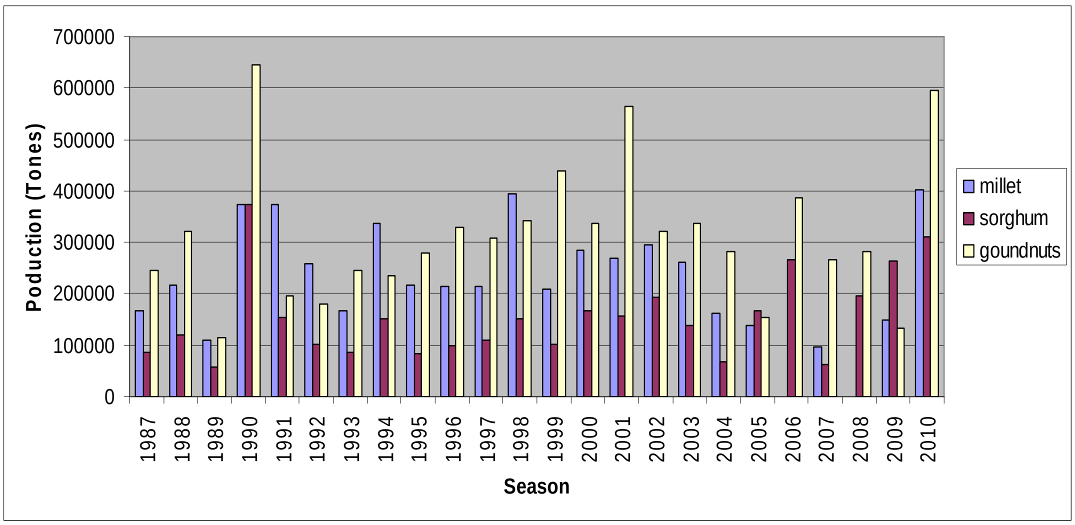

Figure 2.2 Crop Productions in SDS 1987-2010

Source: SMAI, Annual Reports (1987-2010)

2.3 Population

2.3.1 Status of Population

2.3.1.1 Size

Using the growth rates of 4.15 percent for 1993-1998, 3.48 percent for 1998-2003 and 3.41 percent for 2003-2008 years (CBS, 1993-2004), the population of SDS in 2008 was estimated to be 4.093 (UNICEF, 2010) million. This population increase can largely be

[1] A unit of area. it is used in Sudan and Egypt

attributed to natural growth as well as to immigration from the North Darfur State after the 1985 drought.

2.3.1.2 Population Distribution

Environmental degradation in North Darfur has led to a massive movement of population groups into the farming belt located in SDS (Banks, 2009). Accordingly, a large part of the regional rural population has moved in to central and southern SDS and will continue to do so in the future. Trade has always dominated Darfur's economy, while economic characteristics affect how different livelihood groups interact with each other (Smith & Fadul, 2008). The construction of the railway, highways and an airport led to rapid urban growth in SDS's larger towns. Migration to urban centers has transformed agricultural development in the state, as it currently faces a critical loss of productive labor in existing farming households and a breakdown of the family structure (Hamed, 2008). Furthermore, Hamed (2008) identifies that the development of water yards and permanent settlements during Western Savannah Development Corporation period between 1982 and 1997 (WSDC) resulted in the emergence of large villages and transformed seasonal grazing areas into intensively settled farm land especially in the state's eastern district.

The potential agricultural productivity of land has little influence on population distribution. In SDS, the least productive soils carry the largest populations; the low fertility sandy soil of the Goz land system is more populated than the fertile clay soil found on the alluvial land system. This is largely the result of a lack of available farming technology for clay soil, easy crop husbandry on the sandy soil and the availability of water in Goz land system.

Since 2003, civil war and the tribal conflicts comprise the main reasons for population distribution and redistribution in SDS. It has resulted in the massive displacements of 2 million people in Greater Darfur in general and over 95 thousand people in SDS in particular (HAC, 2006).

2.3.1.3 Socio-Economic Structure

According to the results of a CBS forecast for SDS in 2004, urban population totaled 22.02 percent. Population under 5 years of age represented 16.99 percent, while population of aged 6-24 years constituted 46.96 percent. Population between 25 and 59 years comprised 32.41 percent and population of 60 & over was 3.64 percent (Figure 2.3).

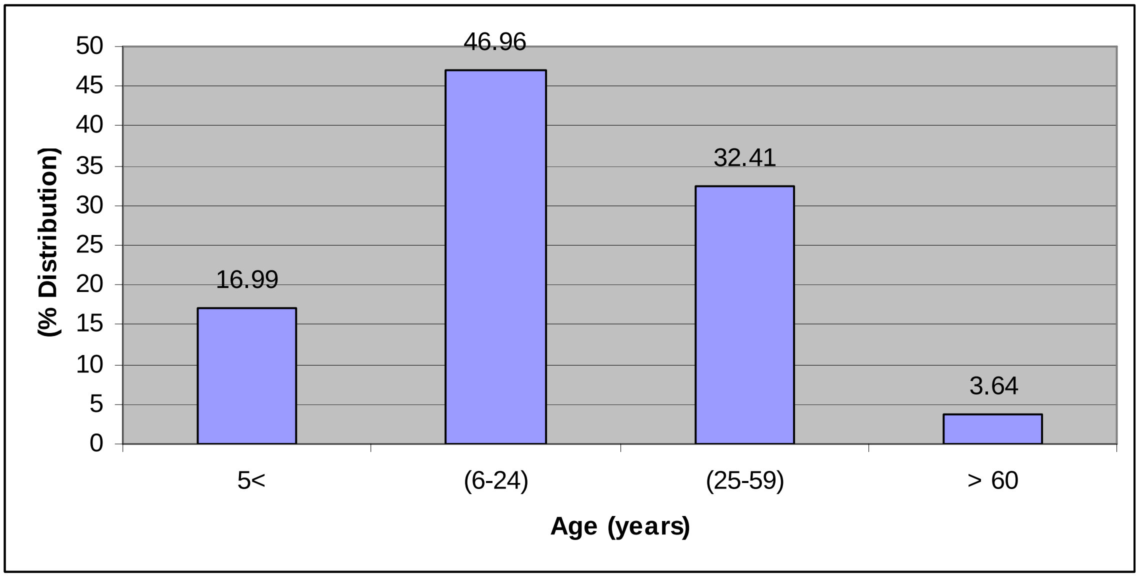

Figure 2.3 Population-age distributions in SDS

Source: Central Bureau of Statistics, Khartoum, 2006

Particular attention is required for the needs of 46.96 percent of the population who are currently between the ages of 6 and 24 years (school-aged), especially in rural areas. If the living standards of the farmers cannot be significantly improved over the next decades, the current trend for young men to migrate to cities such as Nyala will increase, leading to a considerable labor shortage on farms, and a greater dependence on female and child labor-associated agricultural production. This situation would have important implications for regional and national food security.

2.3.2 Trends

With regard to the population of SDS, three distinct trends are apparent.

1. Rapid Increase in Population Size

According to Omer (1993), the annual average population growth in Sudan is estimated at 2.9 percent, while SDS experiences an average growth of 4.15 percent per year. This is a result of immigration from North to South Darfur, as Fuller (1986) illustrates, hundreds of thousand of settled farmers from North Darfur have responded to the droughts experienced in the1980s by migrating to South Darfur, an area with greater amounts of rainfall. This led to overpopulation that resulted in natural resource degradation.

In 1983, the census recorded that the estimated population of SDS was 1.2 million persons. Using the growth rates of 4.15 percent for 1993-1998, 3.48 percent for 1998-2003 and 3.41 percent for 2003-2008 (CBS, 1993-2004), the population was estimated at 2.1 million persons in 1993. In 2007 and 2008, the population was estimated at approximately 3.7 million and 4.093 million people, respectively. The increase recorded in the alter years can primarily be attributed to conflicts and wars that have taken place in region since 2003, which push large numbers of Internally Displaced Person (IDPs) to concentrate around the capital of the state, Nyala, where camps and security areas are located.

2. Urbanization and Sedentarization

a. Urbanization

Urbanization is a dominant feature of Sudanese demography, and some of the highest rates of urbanization are recorded in the Darfur region (Abu Sin, 1983). That rate has been primarily sustained since the 1980s, as a result of draughts that forced migration to urban agglomerations, and has been facilitated by the accessibility of roads between Nyala, Zalingei and Al Fasher. In 1956, Nyala recorded a population of 12,000 persons; in 1964 and 1973, Nyala's population was 27,000 and 60,000 persons, respectively. The 1983 census identifies that the city boasted a population of 115,000 persons, while data from 1993 indicate that there were 227,183 persons, and 322,000 persons were recorded by the 2003 census. The forecasted population of SDS in 2008 was 4.5 million persons, of which Nyala town constituted 1.3 million persons (Figure 2.4).

In recent years, declining soil fertility, small farm sizes, growths in employment opportunities in non-agricultural urban activities and declining levels of security in rural areas have accelerated urbanization (UN, 2010).

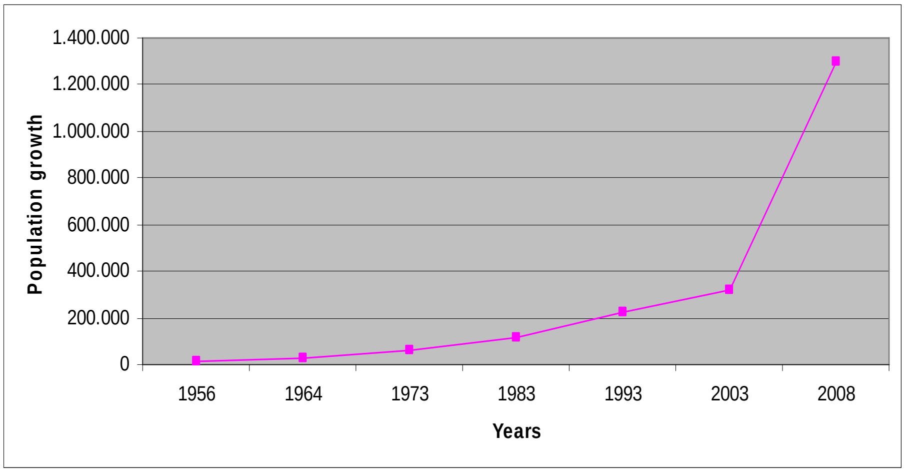

Figure 2.4 Population growths in Nyala town, capital of South Darfur State, 1956 -2008

Source: Central Bureau of Statistics, Khartoum, (1956-2008)

b**.** Settling Nomads

Khogali (1981) claims that the extensive settlement of nomads began after the Second World War, as a result of increased construction of water yards and *hafirs* (construction used to catch and store rainwater), improvements in transport facilities, particularly railway construction, growth in the number of settled markets and the introduction of social services (health and education) to rural areas.

The settlement of nomads was at initially seasonal, to enable the cultivation of staple food requirements. As cropping became a more “respectable” activity for nomads, some household members became engaged in the cultivation of cash crops such as groundnuts.
The increased labor required for harvesting and market cash crops promoted permanent settlement around water yards (Hamed, 2008).

No villages were recorded in the Eastern District in 1940. By 1956, half the population was classified as settled. In 1980, settlers comprised 60 percent of the population (El Khalifa et al., 1985). Moreover, since 1983, 90 percent of migrants had abandoned their semi-nomadic pattern of living and livestock husbandry and settled as millet farmers in the Goz areas (Ibrahim, 1984). Although the human population settled more often, livestock husbandry continued to be based on annual north-south migrations within SDS (El Khalifa et al., 1985).

3. Migration

HTSPE (2004) reveals that migration between North and South Darfur has been recorded since the twentieth century. The movement started as early as the 1904, before a decline in rainfall was recorded. Before the 1980s, migration was not a response to drought condition only, but was also due to rapid and powerful economic development in the region. Furthermore, farmers were also encouraged to move southward in Darfur, as South Darfur was characterized as a high rainfall zone and thus had more secure crop production (HTSPE, 2004). Since 2003, the continuous tribal conflicts and the civil war became the main factor attributed to migration from place of origin and settlements in northward.

2.4. Land Tenure and Ownership

2.4.1. Land Tenure Policy

Land tenure refers to the means by which interests in land are held or owned. Shivji et al. (1998) define land tenure as the sum of rules recognized by law as the primarily regulations for land ownership, allocation of land rights, the substantive content of those rights, their protection in law, their disposal and/or extinction as well as their regulation. According to IFAD (2008), land tenure refers to the rules, authorities, institutions, rights and norms that govern access to and control over land and related resources. It defines the rules and rights that govern the appropriation, cultivation and use of natural resources on a given space or piece of land. It also identifies who can use what resources, for how long and under what conditions.

Mitchell (2011) reveals that land tenure is related to a range of property rights vis-à-vis the land and its associated natural resources. These rights include movable rights, such as livestock, and immovable rights such as buildings and trees. Each of these rights may be considered as a stick in the "bundle of rights." Furthermore, land rights may be held by individuals or groups (e.g. private property) or by the state (ownership, trusteeship), etc). They may be based on national customary law or on combinations of both (Cotula, 2006).

The land tenure policy in Sudan is embodied in legislation that was founded in colonial land laws; this legislation identifies that customary land rights are generally not recognized by the government and statutory legislation has traditionally been used to bypass local customs by the state or for private interests in rural areas (Pantuliano, 2007).

2.4.2. Formal Legal Status of Lands

Land is the most important resource for rural livelihoods and all traditional farming in Sudan, particularly in its western region. The roots of conflicts in the Darfur region extend to the independence period but were accelerated since the 1970s due to the severe competition between farmers and herders over natural resources such as (water, pastures and farmlands), which had rapidly diminished at a time when both human and animal population were increasing (Zain Al Abden, 2009). This process was further complicated by changes in land tenure practices.

All lands in the Darfur are owned and distributed according to the customary law, which includes regulations of access to, holding and transfer of property and land through the *hakura* system, which was initially introduced in the seventeenth century (UN, 2009). Within the *hakura,* each member or group maintains primary access rights to use land for cultivation and grazing within the territory under the system of local administration, locally known as *Elidara Alahlia* (the system governs all matters regarding communal rights). This system is the only institution that is respected by both the state and members and has reliable information about all matters regarding the livelihood of the people (Eldadary, 2010).

According to the Act of 1970, all lands are the property of the government, but some cultivators, particularly migrants, refused to willingly cede their land to the state. The abolition of native administration strengthened this attitude and helped to disrupt the long established customary system. Disputes were taken to civil courts to solve the problem of how to establish individual rights of use — which does not amount to full ownership — and to reconcile traditional claims with the established government policy. The process became more complicated when charter-holders (wathiqa) issued by the Darfur Sultans emerged in the form of certain individuals laying claim to large areas as their property (Mohammed, 2004).

The process of land tenure was further complicated by droughts between 1973 and 1984, which combined with the inherently uneven distribution of natural resources and increased cultivation and pastoralism. This led to competition over resources and mass migration (Suliman and Elbushra, 2007). As migrants moved southwards in large numbers, they searched for agricultural land and pasture for their livestock. For many cultivators, they were able to obtain land to grow crops provided they respected the traditional customs of giving one tenth of the crop to the Sheik (village head). As their numbers increased, some started to look for more authority over land (Mohammed, 2004).

2.5. Land Users and Tenure Systems in South Darfur State

2.5.1. Crop Farming

Crop farming is the main economic activity for more than 80 percent of Darfur's population (Fadul, 2004). However, the Gos/Wadi farming, which is based on millet cultivation and animal raising, is also present in South Darfur. Moreover, due to reliable rain in this area, permits larger and more stable yields in addition to more varied crops (Manger, 2006).

Fuller (1986) describes the system of cultivation in Gos/Sandy soil of South Darfur, identifying that farmers cultivate farms following a rotational system that involves millet, groundnuts and fallow. The number of years of continuous cultivation typically varies roughly from three to eight years; the number of years fields are left to regenerate varies from three to ten years. During the period of continuous cultivation, farmers typically cultivate millet for a few years, and then cultivate groundnuts in the same field for others. Generally, about one-third of the cultivated area is planted with groundnut.

Household gardens (or *jabrake*) represent another form of crop cultivation, which is commonly practiced in South Darfur and is virtually exclusively the responsibility of women. In these gardens, women primarily plant cucumbers, maize, okra, tomatoes, and watermelons (Fuller, 1986).

Fadul (2004) identifies that by the end of the twentieth century the productivity of staple food crops had declined. Thus, because of declining production, farmers adopted a strategy to expand plots. In turn, farm sizes per household decreased due to population increase and the distribution of land through inheritance

2.5.1.1 Farmers Tenure System

Generally, land use is determined by different group's farming activities. In the past, traditional farming (Goz cultivation) was primarily used for subsistence. Land tenure was not an issue for traditional farmers because land was abundant, and there was no competition for land. However, with the emergence of desertification and the resultant shrinkage of cultivable land and a decrease in productivity, even traditional farmers started competing for land rights. The decline in productivity forced all farmers to increase their area, in order to increase output (Suliman, 2011).

2.5.2. Livestock Husbandry

Due to declining rainfall and crop yields, especially millet, livestock husbandry increased in importance in Darfur. However, livestock husbandry is less dependent on rainfall and is a marketable asset to families during a drought year (FAO, 2005).

In South Darfur, livestock husbandry includes goats, sheep, camel, horses and cattle, which is practiced by sedentary population or nomads. Cattle constitute is the dominant type of animal raised. About 1.6 million animal units are raised utilizing an area of 4.6 million hectares in which open grazing system is practiced including wet and dry grazing areas (Abousuwar & Yahia, 2010). Philip (2008) identifies that the grass cover of the pasture has been reduced in recent years due to shortage of rainfall; as such, the livelihoods of pastoralist communities have been threatened. Fodder is especially scarce during the extended dry period (October-May).

2.5.2.1. Pastoralists Tenure System

Young et al. (2005) identify that pastoralist tenure systems emerge when pasturelands and water sources are communally owned and utilized. The prolonged and severe drought of the 1980s undermined the symbiotic relationships between farmers and pastoralists. Pastoralists from the arid north were forced to move south searching for pasture and water, at a time when farming in the central rangelands was already expanding due to overpopulation. Moreover, the deepening processes of commercialization also resulted in changing patterns of land ownership and investment, as wealthy farmers and pastoralists shifted into mechanized farming (sorghum). Thus, enclosures expanded, particularly in the south, and large-scale traders started raising livestock for export on communal grazing land, leading to a change in herd composition (more sheep in the north and more cattle in the south and west). However, crop residues were sold rather than left for pastoralists. Furthermore, the expansion of farmland blocked migration routes.

2.5.3. Hashab (Gum Arabic)

Traditionally, gum production from *Hashab* tree constitutes an important source of cash for farmers in South Darfur State. The trees were managed as part of the farming system within the cereal-, fruit-, and vegetable-based systems, improving soil fertility, boosting yields, rejuvenating soil nutrients during fallowing and providing fodder for livestock (UN, 2009).

USAID & WB (2011) report that about 15 percent of Sudan's production of gum Arabic comes from Darfur, and is primarily produced in South Darfur. Tapping usually occurs in

October, while collection occurs approximately six weeks later. During drought phases, the trees are considered a regular and guaranteed farm income (UN, 2009).

2.5.3.1. Hashab Tenure System

Mohammed (2004) reports that Hashab ownership in Darfur constitutes the core of all other forms of land rights. This system has been historically supported by the hakura system, whereby individuals, clans and tribes were given land concessions by the Darfur Sultans in which hakuras were used and managed according to certain arrangements within the native administration in Darfur. Thus, the residents of Darfur provide firm tenure recognition in accordance with the hakura system. Accordingly, hashab areas can be transferred by inheritance, buying and selling and that is slightly different from other lands.

2. 6. Concluding Remarks

From the above analysis of natural resources and land-use systems in South Darfur the following conclusions can be drawn:

- SDS is a large region with (relatively abundant) natural resources and wide ecological diversity that can offer a firm foundation for a prosperous and sustainable agricultural development if properly used.

- Traditional rain-fed agriculture is the primary agricultural system and it provides livelihood for most of the population. Millet and sorghum are the main staple foods and crops and groundnut is the main cash crop.

- Most people in this region concentrate on sandy (Goz) soil land rather than the fertile clay soil of the alluvial land system due to availability of water in the Goz land system as well as the lack of available farming technology for clay soil and the easy crop husbandry associated with sandy soil.

- The expansion of agricultural lands as the result of an increased human population as well as declining productivity resulting from a shortage of rainfall negatively affected the range and pasture lands in the region.

- Land tenure and ownership in South Darfur is administered according to Darfur customary laws regulated by the *hakura* system.

- The system of land tenure has changed in recent years for various reasons, including population growth, droughts, natural resource degradation, and political instability, among others.

- Increased livestock population and the deterioration of the range and pasture have increased competition and friction between the animal owners and farmers.

- The communal grazing system is one of the most important factors that lead to conflict between nomads and farmers.

CHAPTER THREE

Use of Multi-temporal Satellite Data for Land-Use/Land-Cover Change Analysis

3.1 Abstract

This study aims to assess the rapid rate of land use/land cover (LULC) change in Edd Al-Fursan locality, South Darfur State, Sudan, using multi-temporal satellite imagery for 1972-2008. This change detection study will enable the quantification of change and the analysis of direction of change between different land use and land cover that has occurred over course of the study period (1972–2008). The change detection analysis was carried out using ERDAS IMAGINE 9.1, ENVI 4.5 and ArcMap 9.3 software. Four Landsat images as well as one Aster image were used from 1972, 1984, 1989, 1999 and 2008, respectively. The images were geometrically corrected to a common map projection, followed by image processing operations, namely atmospheric correction, supervised image classification and accuracy assessment. The major LULC classes present in the study area include grassland, forest land, fallow land, cultivated land and bare land. Three different methods for change detection were applied: Post-Classification Comparison (PCC), Change Vector Analysis (CVA) based on Tasseled Cap Transformation (TCT) and Multivariate Alteration Detection (IR-MAD) with. Maximum Autocorrelation Factor (MAF) method. The results of the change detection analysis show that the LULC in Edd Al-Fursan locality has changed since 1984 due to human and animal growth, drought incidence, environmental degradation as well as conflicts and war in recent years. Comparisons of LULC showed that the natural forest cover that was at 26 % in 1972 has decreased to 17 % in 2008. Therefore, the cultivated area has increased from 26 % to 30% while the bare land increased from 9 % to 14 %.

This study concludes that remote sensing can be used as an effective tool to detect land-use/ land cover change. However, information about patterns of LULC changes over time in the southern Darfur Region is not only important for this region's management and planning, it is also require for a better understanding of the human dimensions of environmental changes on a regional scale.

3.2 Introduction

Land is the fundamental factor of production that supports all living organisms, human existence and ensures survival.

Most human-associated sustenance activities, such as food production, shelter, infrastructure development and extraction of natural resources, depend on land. However, land resources are becoming increasingly scarce on a global scale, as a result of continued exploitation and mismanagement. Two concepts are closely related to land exploitation: land cover and land use. Lambin and Geist (2006) define land cover as the biophysical state of the earth's surface and immediate subsurface including biota, soil, topography, surface and ground water, and human modification such as roads and buildings. In contrast to land cover, land use can be defined as the purpose for which humans use and exploit the land cover. It involves both the manner in which biophysical attributes of the land are manipulated and the reason for that manipulation, for instance, why that land is being used (Lambin & Geist, 2006). Typical examples of land uses include agriculture, livestock herding, urban and infrastructure development. Furthermore, FAO (1995) defines land use as the number of operations performed on land, which are used by humans to generate benefits from natural resources. Changes in land cover caused by land use are largely the results of two factors: conversion and modification (Lambin & Geist, 2006). Land conversion comprises the replacement of one land-cover type with another and is measured by a shift from one land-cover type to an other, such as agricultural expansion and deforestation. In contrast, land cover modifications include more subtle changes that affect the character of the land cover without changing its overall classification (Turner & Ali, 1995; Lambin et al., 2003).

According to Turner and Meyer (1991) and Stern et al. (1992) land use/land cover change are affected by a variety of human-driven forces, namely demographic factors, technology, level of affluence, political structure, economic factors, and attitudes and values. These driving forces can change over time due to many reasons (for example economic cycles or population attitudes). Accordingly, the transition rate from one type of land use to another may also be influenced. However, change in land use and land cover can lead to major environmental consequences such as the loss of biodiversity, water pollution and soil degradation (Meyer & Turner, 1992). Moreover, land-use change also has a profound impact on food security and increased human vulnerability especially in Africa (Bottomley, 1998). In order to manage land and its natural resources effectively, it is necessary to consider the identification and qualitative description that influence land use/land cover change, in addition to the consequences and feedback of these changes (Baulies and Szejwach, 1998). Furthermore, LULC studies have been developed to improve understanding about the human and bio-physical factors that drive and shape land use/land cove changes (Baulies and Szejwach, 1998). However, relating human behavior and social structure with bio-physical attributes of the land is a fundamental aspect of LULC research. Recently, remotely sensed data have become a useful tool and an important scientific value for the study of human-environment interaction, particularly vis-à-vis land use/land cover changes (Dale et al., 1993 cited in Codjoe, 2007).

3.3 Definition of Remote Sensing

Remote sensing is defined as the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. The remotely collected data can take various forms, including variation in force distributions, acoustic wave distributions, or electromagnetic energy distributions (Lillisan et al., 2008). The multi-spectral and multi-temporal nature of satellite imagery facilitates the investigation of vegetation components, primarily based on their typical minimum/ maximum in the spectral reflectance bands in the red (600-700 nm) and near-infrared (NIR) (700-1100 nm) of the electromagnetic spectrum (Tucker, 1979; Sellers, 1985).

3.4 Change detection and its importance

Singh (1989) defines change detection as a process of identifying differences in the state of an object or phenomenon through observation at different times. Diallo et al. (2009) provide a different definition, arguing that change detection comprise processes that are used to determine the changes associated with land use/land cover characteristics based on geo-registered remote sensing data. According to Radke et al. (2005), change detection in images identifies the set of pixels that are significantly different between two consecutive images of the same scene. Moreover, Rimal (2005) reports that digital change detection technique is based on multi-temporal and multi-spectral remotely sensed data, which have great potential as tools for understanding landscape dynamics, including detection, identification, mapping and monitoring differences in land use/land cover change over time, irrespective of causal factors. However, change detection is useful in such diverse applications as land-use analysis, habitat fragmentation, urban sprawl, assessment of deforestation as well as other environmental changes (Ramachandra and Kumar, 2004).

3.5 Motivation of the Study

South Darfur lies in a region that suffers from the significant impact of environmental degradation. Overgrazing, deforestation and over-cropping have caused the poor soil in the area to deteriorate further, and consequently, yields have deteriorated. The absence of clear plans for land use can reduce the availability of local natural resources, limiting the options for rural livelihood that depend on natural resources for consumption or trade.

Due to land-use change, most rural inhabitants have become unable to cope with environmental hazards. This has led to competition and overexploitation of natural resources. Subsequently, conflicts and war have emerged and most rural inhabitants have abandoned their homelands and become internally displaced or refugees.

In South Dafur, many development strategies and programs for the use of natural resources lack the accurate spatial information that is required to support the vision of sustainability. The outcome of such a lack of information includes land degradation, desertification, internal displacement and conflicts over resources. Generally, natural resource information in South Darfur, in both the urban or rural sectors, is very limited (Azzain, 2004). Recently, remote sensing and GIS have become fundamental tools for understanding and monitoring LULC change, particularly in the tropics, the area with the most promising research opportunities (Westman et al., 1989).

3.6 Methodology

The following steps were employed within the scope of this study (Figure 3.1).

1. Acquiring satellite imagery based on phonological/seasonal aspects.

2. Gathering ground truth information.

3. Image processing (geometric corrections, radiometric correction, and image classification).

4. Accuracy assessment

5. Change detection

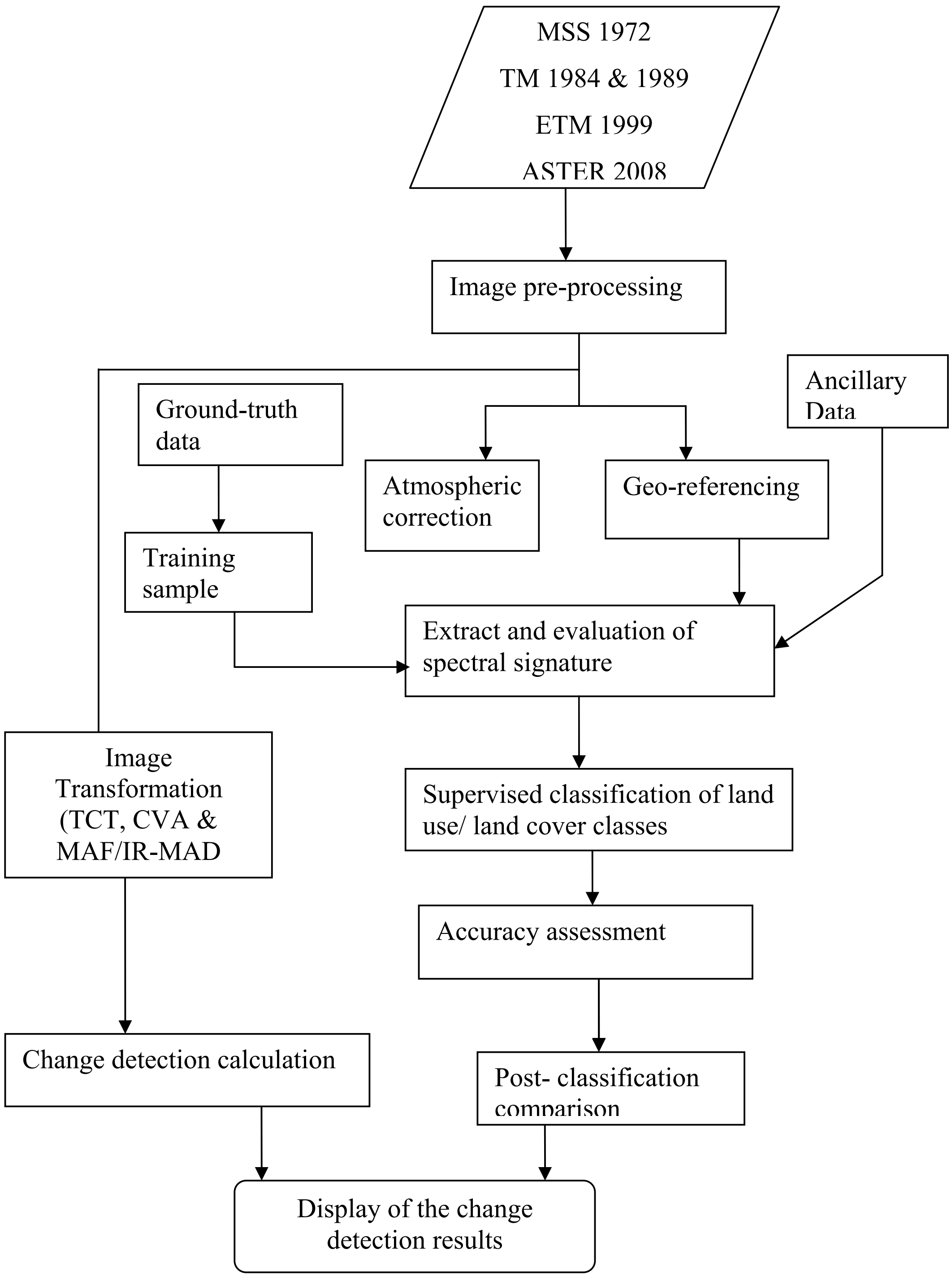

Figure 3.1 Methodological framework of the study

3.6.1 Data Acquisition

For the purpose of multi-temporal change detection, Cloud-free Landsat Multi-spectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM) and ASTER imagery were used (Table 3.1).

Table 3.1 Satellite imagery used for the multi-temporal change detection.

Satellite sensor	Path/row	Acquisition date	Spectral resolution	Ground resolution (m)
Landsat- 1 MSS	191/52	1972-12-18	1-4 bands	60*
Landsat -4TM	178/52	1984-11-21	1-7 bands	30
Landsat -5 TM	178/52	1989-11-07	1-7 bands	30
Landsat -7 ETM	178/52	1999-11-09	1-8 bands	30
ASTER	178/52	2008-02-01	1-3 bands	15*

*****Resampled resolution

3.6.1.1 LandSat

The Landsat program is the longest running enterprise for the acquisition of imagery of the earth from space. According to Lillesand et al., 2008 six Landsat satellites have been launched successfully, namely Landsat-1 to -5 and Landsat-7. Landsat-6 suffered a launch failure. The first Landsat satellite was launched in 1972; the most recent Landsat 7 was launched on April 15, 1999. However, five different types of sensors have been included in various combinations, including the *Return Beam Vidicon* (RBV), the *Multispectral Scanner* (MSS), the *Thematic Mapper* (TM), the E*nhanced Thematic Mapper* (ETM), and the *Enhanced Thematic Mapper Plus* (ETM+) (Lillesand et al., 2008).

3.6.1.1.1 LandSat Multispectral Scanners

The Multispectral Scanners (MSSs) were the first multispectral sensors to monitor earth resources from space. Developed by Santa Barbara Research Center for NASA's Goddard Space Flight Center, the first MSS was carried aboard the Earth Resources Technology

Satellite (ERTS 1), subsequently renamed Landsat 1. Five MSS sensors have been flown into space and the sensors on the Landsat 4 and 5 are currently operational.

3.6.1.1.2 LandSat Thematic Mapper

Landsat 4 and 5 carrying the Thematic Mapper (TM) sensor were launched in 1982 and 1984, respectively. The TM sensor is an upgrade of the MSS sub-system, and included efforts to incorporate improvements into a new instrument. The TM instrument is thus based on the same technical principle as the MSS but has a more complex design as it provides finer spatial resolution, improved geometric reliability, greater radiometric detail and more detailed spectral information. The MSS only has four broadly defined spectral bands, whereas the TM has seven spectral bands that have been customized to record radiation, which is of interest to specific scientific investigations (Campbell, 2002).

The Landsat Enhanced Thematic Mapper (ETM) sensor, launched in 1999, is a further development of the TM sensor. The Landsat 7 ETM sensor offers several enhancements when compared to the Landsat 4 and 5 Thematic Mapper sensors, including increased spectral information content, improved geodetic accuracy, reduced noise, reliable calibration, and the addition of a panchromatic band and improved spatial resolution of the thermal band (Masek et al., 2001).

3.6.1.2 ASTER

Advanced Spaceborne-Thermal Emission and Reflection Radiometer (ASTER) is one of the five state-of-the-art sensor systems on-board Terra, a satellite launched in December 1999. It was built by a consortium between the Japanese government, industry, and research groups. ASTER monitors cloud cover, glaciers, land temperature, land use, natural disasters, sea ice, snow cover and vegetation patterns at a spatial resolution of 90 to 15 meters. The multispectral images obtained from this sensor have 14 different spectral bands, which allow scientists to interpret spectral reflectance and emission in the visible near infrared, shortwave infrared and thermal infrared.

3.6.1.3 Color Infrared Composite (CIC)

Bands 2, 3 and 4 for the Landsat (TM and ETM) images, bands 1, 2 and 4 for the Landsat MSS and 1,2 and 3 for Aster image, which represent the green, red and Nearinfrared, respectively, were used to develop Colour Infrared Composite (CIC) for the image. The colors assigned to each of the bands are in the same order blue, green and red. This combination of colors gives various shades or tones of red for the healthy chlorophyll-rich vegetation in a CIC image. The richness of the red color is dependent upon the masonry and the structure of the leaves (ElMobark, 1991).

3.6.2 Gathering ground-truthing information

Ground–truthing was used to gather field data useful for the classification and verification of the satellite imagery. The field survey was carried out in February 2010 and historical land-use information was collected from farmers and herders who were knowledgeable about land-use change patterns during the respective period (1972-2008). (166) GPS points were recorded in the field to be used for training for the 2008 imagery and to determine the land use and land cover classes for the image classification process.

3.6.3 Image processing

Jensen (2005) states that when conducting process of change detection it is important to work with images from the same sensor as it ensures that data was acquired almost at the same time of the day (important to eliminate diurnal sun angle effects), in addition to the same spectral, spatial, look angle and radiometric resolution. Moreover, in order to obtain improved results from a change detection analysis, the sensor and environmental variables should be minimized as much as possible (Munyati, 2000). For greater accuracy, results largely depend on the geo-referencing of the images to be used and the relationship between the spatial resolution and spatial size of the changes (Munyati, 2000).

.6.3.1 Image Geo-referencing

Most satellite images are received as “row” data without the application of any coordinate system. These images generally contain geometric distortions so significant that they cannot be used directly as a map base without subsequent processing. The source of these distortions range from variations in the latitude, altitude, velocity of the sensor platform to factors such as panoramic distortion, earth curvature, atmospheric refraction and relief displacement (Lillisand et al., 2008). The images obtained from Aster 2008 and the 4 LandSat data (1972, 1984, 1989, and 1999) were geo-referenced using ERDAS IMAGINE 9.1 based on a Polynomial model. The ground control points used were mainly stream bends and junctions. The 2008 image had been acquired from UTM projection and was used as the base image. Using the Nearest Neighbor method, the images were resampled to a pixel size of 30 m × 30 m.

3.6.3.2 Radiometric and atmospheric correction

Radiometric correction is a process used to remove statistical noise and atmospheric extinction affecting image brightness values. Lillesand et al. (2008) state that the process is important due to variations in scene illumination, atmospheric conditions, viewing geometry variations and instrument response characteristics. In this study, the atmospheric correction was carried out using ENVI 4.5 Software, Dark Object Subtraction (DOS) method.

3.6.3.3 Image Classification

Navalgund et al. (2007) and Lillesand and Kiefer (2004) define image classification as the process of automatically categorizing all pixels of an image based on their spectral properties into land cover classes. Furthermore, Palaniswami *et al*. (2006) define image classification as the process of creating thematic maps from satellite imagery. The two primary methods of image classification are supervised and unsupervised classification, which will be discussed below.

3.6.3.3.1 Unsupervised classification

Unsupervised classification involves algorithms that examine the spectral values of pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the distribution of image value. The basic premise is that values within a given cover type should be close together in the measurement space, whereas data in different classes should be comparatively well separated.

3.6.3.3.2 Supervised classification

A supervised classification depends on the a priori knowledge of the location and the ability to identify land cover types that are contained within the image. This can be achieved through fieldwork, studies of the aerial photograph or by using other sources of information. According to NRC (2005), the process of supervised classification depends on numerous aspects. The first involves developing an appropriate classification scheme. Second, the training areas must be selected for each of the classes and statistics calculated for them. Third, the appropriate classification algorithm has to be selected, and once each pixel in the image, including those used as training areas, are evaluated and assigned a land cover class, the accuracy of the classification has to be assessed. Algorithms are commonly used in supervised image classification, such as *parallelepiped* classification, *minimum distance* classification and *maximum likelihood* classification. The maximum likelihood approach is, however, the most widely used per-pixel algorithm. This research used the maximum likelihood classification, as it is a preferred algorithm especially in land cover and land-use monitoring approaches, because it assumes that (1) image data are normally distributed and (2) pixels are composed of a single land cover or land-use type. However, the advantage of this method is that the results of a classified image are more accurate, as it requires the application of the most exact algorithm, the probability distribution function, which includes variance and co-variance matrix. Validation is ensured by ground-truthing, as is the case for both mini-distance and hyperbox methods.

In this study five LULC classes were determined: grassland, forest land, fallow land, cultivated land and bare land (Figure 3.3).

Table 3.2 Definition of LULC classes

Classes	Description
Grass land	Grassland represents small shrub species and early stage colonizing species.
Forest land	Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agriculture.
Fallow land	Cultivated areas that are left to be recovered after long period of cultivation. Fallow age is usually 4-10 years.
Cultivated land	Areas currently under crop or land being prepared for raising crops. Physical boundaries are broadly defined to encompass the main areas of agricultural activity and not based on the exact field boundaries
Bare land	Non-vegetated areas such as bare rocks or areas with very little vegetation cover, where soil exposure is clearly apparent

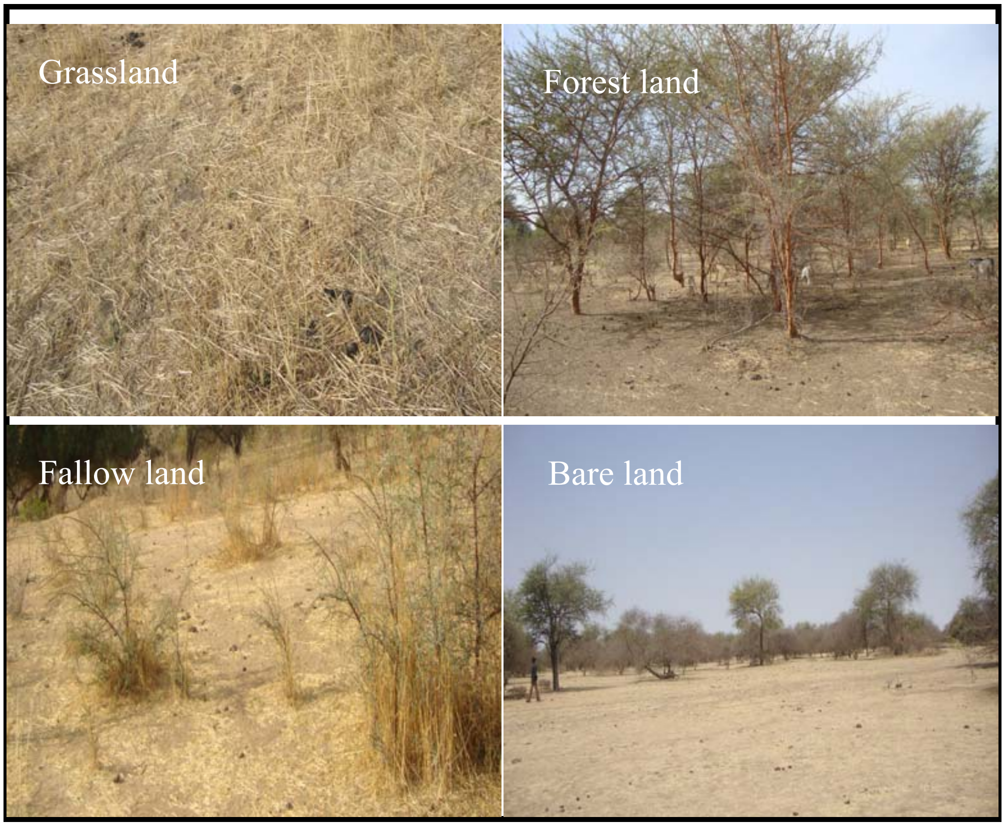

Figure 3.2 LULC classes in Edd Al-Fursan locality, photos by the author 2010

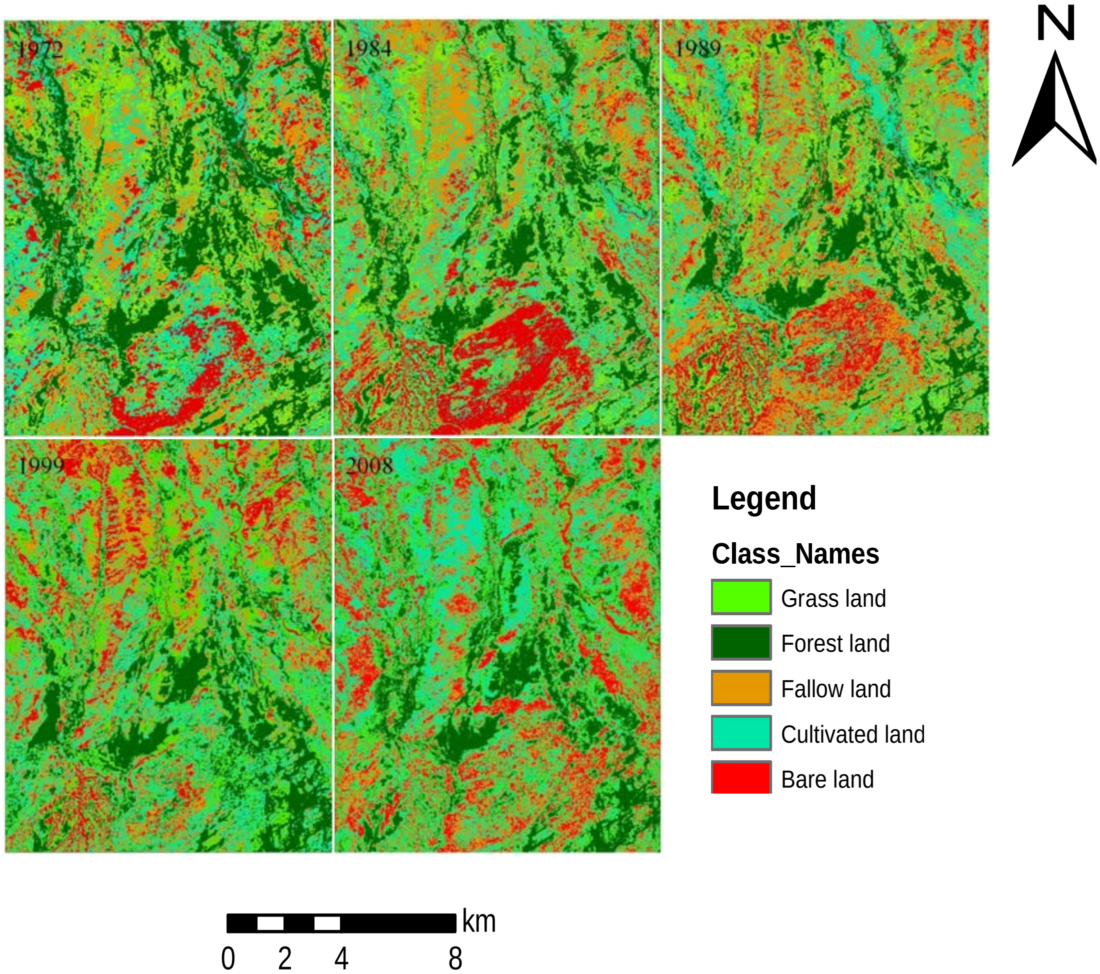

Figure 3.3 Maximum likelihood classification showing LULC for the period 1972-2008

Table 3.3 Area (ha) and percentage of LULC classes during the study period 1972 –2008

Classes	1972		1984		1989		1999		2008	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
1	21451.59	17.76	20913.84	17.32	19718.01	16.33	25212.15	20.88	22974.93	19.03
2	31464.72	26.06	21468.33	17.78	20229.93	16.75	22629.15	18.74	20408.49	16.9
3	24499.89	20.29	29406.6	24.35	36268.65	30.03	29561.94	24.48	24697.26	20.45
4	31939.2	26.45	32714.55	27.09	30700.44	25.43	30118.77	24.94	35683.2	29.55
5	11399.85	9.44	16251.93	13.46	13838.22	11.46	13233.24	10.96	16991.37	14.07
Total	120755.3	100	120755.3	100	120755.3	100	120755.3	100	120755.3	100

Where: 1 = grassland; 2 = forest land; 3 = fallow land; 4 = cultivated land; and 5 = bare land.

3.6.4 Accuracy Assessment

Accuracy assessment is an important process that must be completed to determine how correct the classified image is. Jensen (1996) pointed out that if through remote sensing, land use and land cover maps are produced and statistical results are to be useful, then it is important to conduct a quantitative assessment of the classification accuracy. This is important for post-classification change detection analysis. The accuracy of a classification is usually assessed by comparing the classification with some reference data that is believed to accurately reflect the true land cover classes. The overall accuracy is measured by counting how many pixels were classified consistently in the satellite image and on the ground and dividing this by the total number of sample pixels in each class.

To determine the accuracy of the image classification for the Landsat 1972, 1984, 1989 and 1999 images, for which no ground validation data or aerial photograph was available, the equalized random method was used to generate 60 reference points for the whole study area. These points were collected according to the different classes and overlaid on the unclassified image to check if the class given falls into the same spectra as was used to collect the training samples. A comparison of the Landsat classified images was made with the classified Aster image for which ground validation points were available. The results of the overall classification accuracy, producer's accuracy and user's accuracies, and Kappa values for each LULC, derived from the error matrix, were used to determine the degree of accuracy of the classification (Table 3.3)

Table 3.4 Summary of classification accuracies (%) for 1972, 1984, 1989, 1999, and 2008

Classes	1972		1984		1989		1999		2008	
	*Prod.	**Use.	Prod.	Use.	Prod.	Use.	Prod.	Use.	Prod.	Use.
Grassland	86	60	67	89	83	50	78	70	90	90
Forest land	82	90	100	75	90	90	100	80	90	90
Fallow land	64	90	80	86	71	100	69	90	82	90
Cultivated land	88	70	88	79	54	73	80	80	89	80
Bare land	90	90	86	100	100	90	100	100	100	100
Overall accuracy	83		83		85		87		92	
Kappa statistic	80		79		82		84		90	

Where: *Prod. = Producer's accuracy; and **Use. = User's accuracy

3.6.5 Change detection techniques

A variety of digital change detection techniques have been developed in the past three decades. Basically, different algorithms can be grouped into the following categories: algebra (differencing, rationing, and regression), change vector analysis, transformation (for example: principal component analysis, multivariate alteration detection, Chi-square transformation), classification (post-classification comparison, unsupervised change detection, expectation-maximization algorithm) and hybrid methods. Coppin et al. (2004), Lunetta and Elvidge

(1998), Lu et al. (2004), Maas (1999), Singh (1989), among others, provide reviews of the most commonly used techniques. Ernani and Gabriels (2006) mention that change detection analysis involves a broad range of techniques used to identify, describe and quantify differences between images of the same scene at different times or under different conditions. Lu et al. (2004) highlight the importance of selecting a suitable change detection technique to be used in a specific application area.

3.6.5.1 Post-classification comparison

The post-classification comparison (PCC) technique is the most straightforward method of change detection. It depends on the comparison of independently produced classified images by properly coding the classification results for time 1 and time 2 (Singh, 1989) and the output produces a change map that indicates a complete matrix of change (Figure 3.4).

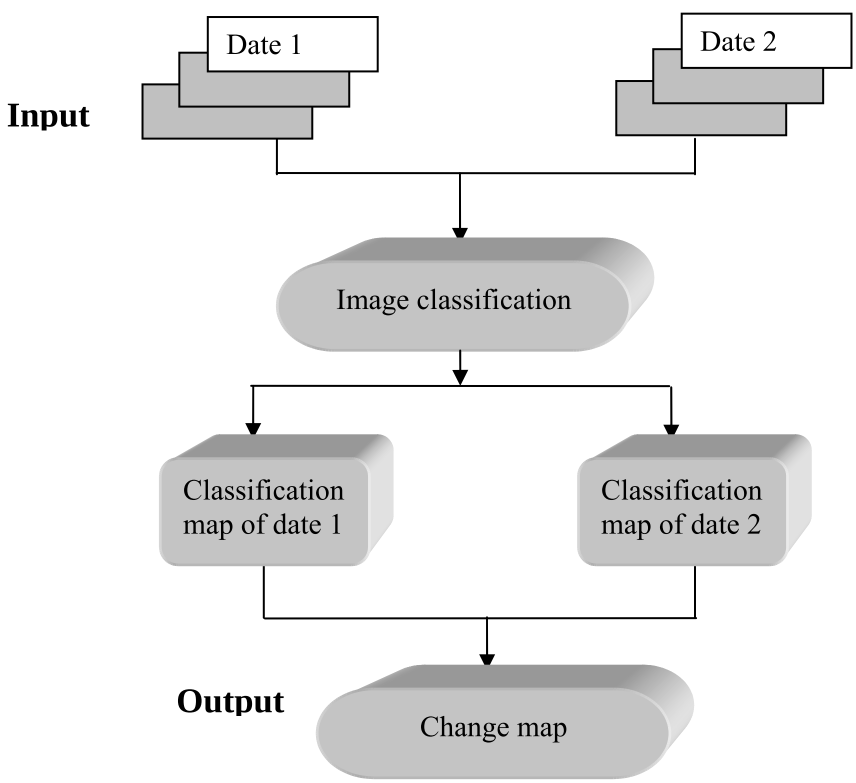

Figure 3.4 A flowchart of post-classification change detection technique

Asubonteng (2007) points out that PCC is a commonly-used quantitative technique for change detection, although challenges can arise when classifying historical image data.

Alphan et al. (2008) apply Post-classification comparison on supervised maximum likelihood decision rule for Landsat imagery from 1989, 2000, and Aster imagery from 2004, in an attempt to assess land cover changes in Kahamanmaras, Turkey. The study found that dramatic land cover conversions took place as a result of urbanization and agricultural expansion, resulting in vegetation degradation in the study area. Yang and Wen (2011) use post-classification comparison on a supervised maximum likelihood classification of Landsat ETM+ imagery from 2000 and 2002 to detect changes in Guangzhou in southern China. This study reveals that the largest change areas are exchanges of building and unused land with grassland. The advantages of post-classification comparisons include: (1) the technique avoids the need for strict radiometric calibration and minimizes the impact of atmospheric, sensor and environmental differences between multi-temporal images; and (2) the technique provides a complete matrix of change directions unlike image differencing. Macleod and Congalton (1998) highlight that post-classification comparison has significant limitations because it combines the errors from both classifications. Additionally, enough ancillary data must be presented to classify both data. Moreover, the change-map output of two classifications often display accuracies similar to the product of multiplying the accuracies of each individual classification (Stow et al., 1980 and Mas, 1999). Further limitations include the need for knowledge, expertise, and time to create classification products (Lu et al., 2004).

3.6.5.1.1 Land-Use/Land-Cover Change Rates

Post-classification comparison provides "from-to" information. Actual change can be obtained by a direct comparison between classified images from one date with that obtained on another date. Temporal changes that have occurred between the two dates can be measured by performing a change matrix (Appendix 1).

Between 1972 and 1984, agricultural land represented the highest percentage of coverage in Edd Al Fursan locality. This indicates that agricultural activities were the main source of income. The dynamic change of natural vegetation cover shows that forest land significantly decreased from 26 % in 1972 to 18 % in 1984, while grassland comprised the same percentage in the two respective years. This degradation in natural forest is a result of the drought periods in the late seventies and the beginning of the eighties that led people to exploit it as the main source of income. Moreover, the fallow and bare lands increased in 1984. The increase in fallow land resulted from people abandoning their farmlands while the increase in bare land can be attributed to the conversion of forest to bare land as a result of drought conditions as mentioned above.

In the period between 1984 and 1989, there was an extension period of drought in this area. There was no significant change in vegetation cover, but there was a high increase in fallow land as drought conditions push farmers to abandon their agricultural land and looking for other livelihood options. However, the increase in fallow land has led to a decrease in bare land area from 13.5 % in 1984 to 11.5 % in 1989.

The LULC changes for the period between 1989 and 1999, as it indicates an increase in the natural vegetation cover. Grasslands as well as natural forests increased from 16 %, 17 % to 21 % and 19 %, respectively. This is due to a good rainy season during this period as shown by the Ministry of Agriculture's annual rainfall report and expressed by farmers during interviews. This indicates that the environment had begun to recover from the drought conditions experienced previous to this period.

There was no obvious increase in agricultural land in this period, while there was a decrease in fallow from 30 % in 1989 to 24. % in 1999. This can be interpreted that some of the fallow land were converted to the natural vegetation. However, the bare land shows less decrease in 1999.

Between 1999 and 2008 there was a dramatic change in vegetation cover, as human and animal populations have increased in recent years due to conflict and environmental degradation resulting in high demand on food and fodder, which led to over-cultivation and overgrazing. However, grass and forest lands decreased from 21 %, 19 % in 1999 to 19 %, and 17 % in 2008, respectively. Moreover, agricultural land has increased from 25 % in 1999 to 30 % in 2008 resulting in a decrease in fallow from 24 % in 1999 to 20 % in 2008. On the other hand, bare land increased in 2008 in comparison to 1999 where constituted 14 % and 11%, respectively. This was the result of intensive agriculture and decrease in natural vegetation cover.

The LULC change rate for the 1972-2008 period indicates a high rate of deforestation, or 9.2 %. Therefore, cultivated land has increased from 26 % in 1972 to 30 % in 2008. This period shows an intensive pressure for land occupation due to land degradation as well as conflict that pushed a high number of IDPs to settle in this area, whereas most of them depend on forest products for their livelihood. Bare land levels have increased from 9 % in 1972 to 14 % in 2008, largely as the result of deforestation and intensive agriculture.

3.6.5.2 Tasseled Cap Transformation

The concept of tasseled cap transformation is a useful tool for compressing spectral data into a few bands associated with physical scene characteristics. It is a linear transformation of data that projects soil and vegetation information on a single plane in multispectral data space.

The TCT was applied to each of the four images using ERDAS 9.1. For the ASTER image, TCT was calculated using ArcMap Raster Calculator according to the following equations:

Wetness Layer

(0.166 * [subaster_2008.img - Layer_1]) + (-0.087 * [subaster_2008.img - Layer_2]) + (-0.703 * [subastr_2008.img - Layer_3])

Brightness Layer

(-0.274 * [subastr_2008.image - Layer_1]) + (0.676 * [subastr_2008.img - Layer_2]) + (0.303 * [subastr_2008.img - Layer_3])

Greenness Layer

(-0.006 * [subastr_2008.img - Layer_1]) + (-0.648 * [subastr_2008.img - Layer_2]) + (0.645 * [subastr_2008.img - Layer_3])

The results of the TCT produce an image file that consists of three bands that are attributed to soil brightness, vegetation greenness and soil or vegetation wetness. The TCT results were employed for the Change Vector Analysis calculation.

3.6.5.3 Change Vector Analysis

Since land undergoes changes or disturbances over a certain period of time, its spectral appearance normally changes. Change vector analysis (CVA) has been applied using various means and has advanced since Malila's (1980) application of the method to characterize change magnitude and direction in spectral space from a first to a second date.

Change direction is measured as the angle of the change vector from a pixel measurement at Time 1 to the corresponding pixel measurement at Time 2 (Figure 3.5). Angles that measure between 90° and 180° indicate an increase in greenness and a decrease in brightness. Lorena et al. (2002) designate this change direction to represent regeneration of vegetation. Angles that measure between 270° and 360° indicate a decrease in greenness and an increase in brightness. They indicate that this change of direction represents deforestation. Angles that measure between 0° and 90° and 180° and 270° indicate either increases or decreases in both bands of greenness and brightness. They identify that this change of persistence is representative of neither an increase nor decrease in vegetation found on the landscape.

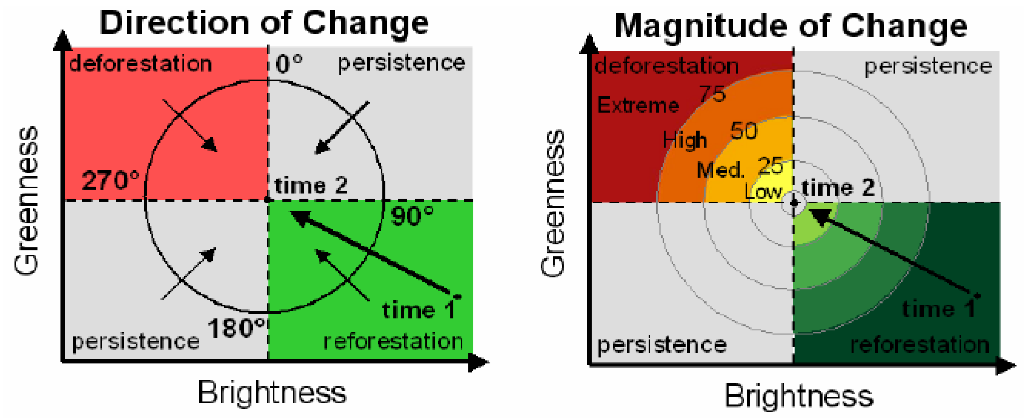

Figure 3.5 The process to detect the direction of change (left) and the magnitude of change (right) within a change vector analysis

Source: (Kuzera et al., 2005).

For this study the change vector analysis technique was performed using a designed tool imported to IDL ENVI.

The first step of the CVA method was to apply a tasseled cap transformation to the images in order to generate components of greenness and brightness and to define the new coordinate system on which the CVA is based (Figure 3.6). Thus, as a pixel undergoes change during a certain time-interval, its position in the defined coordinate system will change (Kauth & Thomas, 1976).

Using this method, two images were computed; the first image represented the vector intensity while the other identified the vector direction. The first image contains the information of change, while the second contains information on the type of change.

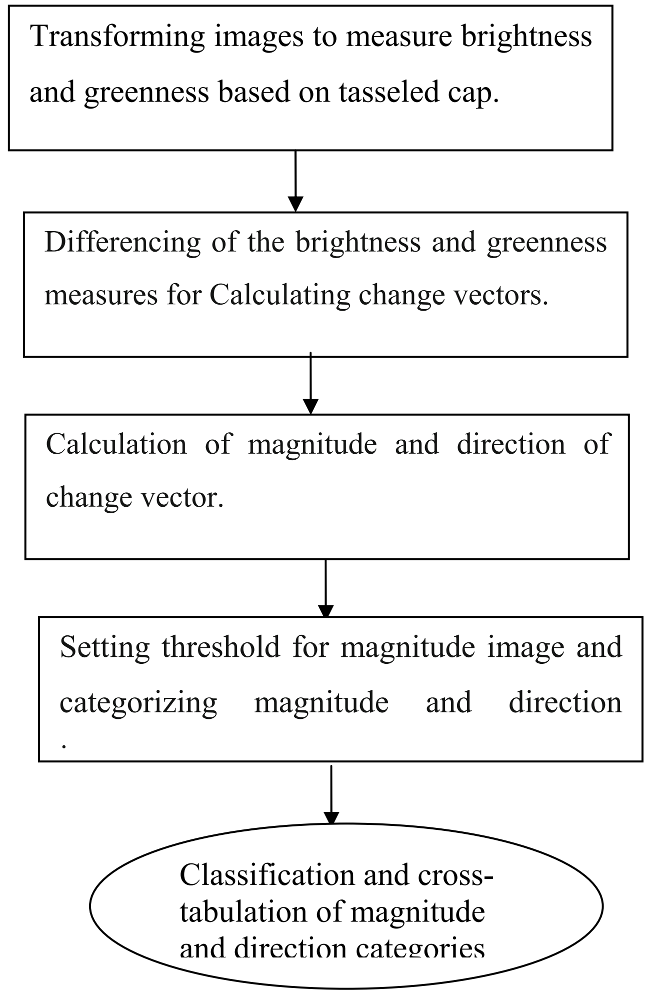

Figure 3.6 Change Vector Analysis procedure

Table 3.5 Possible change direction classes from brightness and greenness component and related types of change

Classes	Brightness	Greenness
Bare soil expansion	+	+
Deforestation	+	−
Persistence	+ −	+ −
Reforestation	−	+

Class 1 Changes (increase in brightness and greenness): represent areas of bare soil expansion.

Class 2 Changes (brightness increases while greenness decreases): indicate cleared vegetation areas.

Class 3 Changes (brightness increases or decreases and the greenness also increases or decreases): show areas of persistence

Class 4 Changes (decrease in brightness and increase in greenness): represent areas of forest reforestation.

According to the field survey, visual comparison of the original images and author's background knowledge, maximum likelihood classification has been carried out to show a quantitative analysis for the above mentioned classes (Figure 3.7) and (Table 3.6).

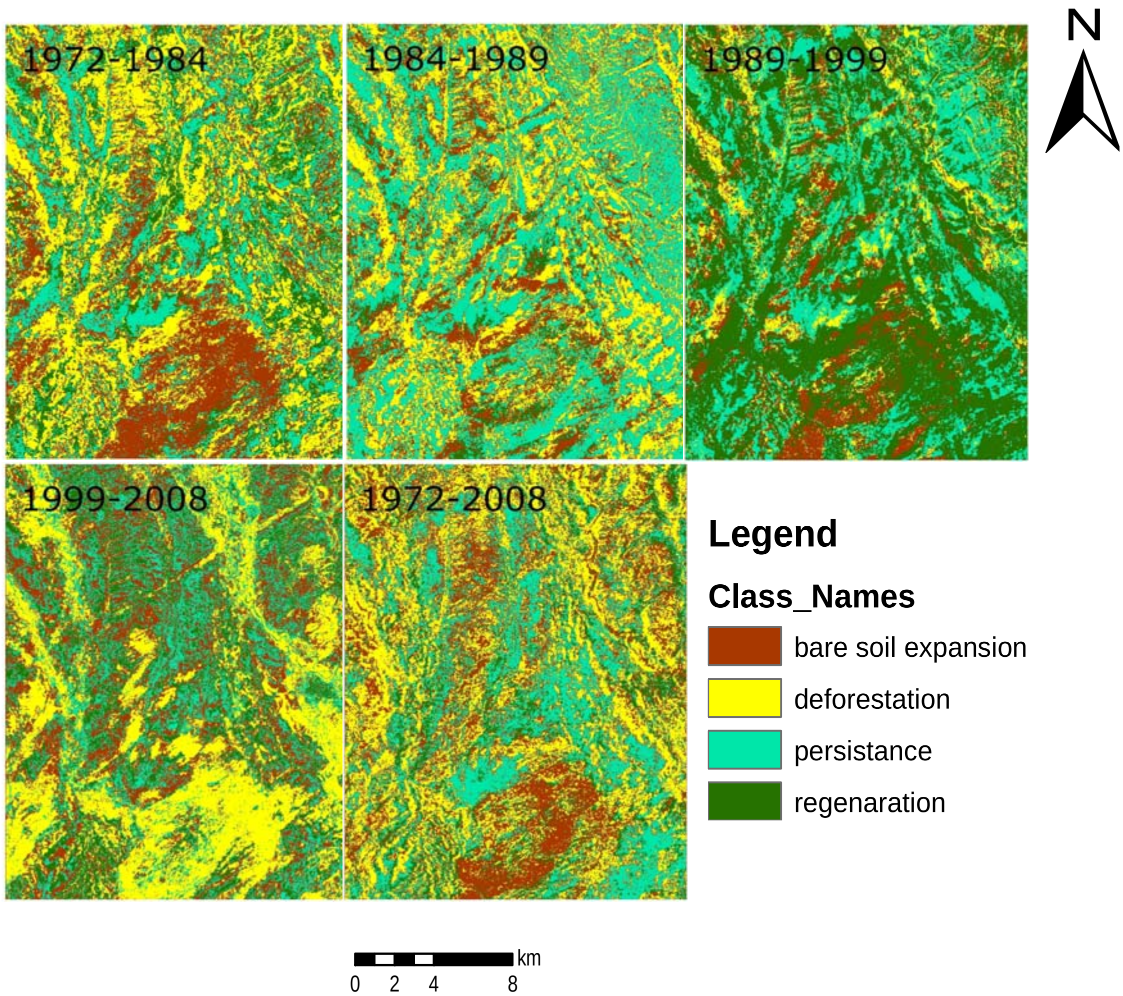

Figure 3.7 Maximum likelihood classification showing CVA classes 1972-2008

Table 3.6 Area (ha) and percentage of the CVA classes for the period 1972-2008

classes	1972-1984		1984-1989		1989-1999		1999-2008		1972-2008	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
1	38882.16	27.43	27986.67	23.18	16181.1	13.4	34506.99	28.57	38882.16	32.2
2	38171.34	31.76	35422.65	29.33	12704.76	10.52	38713.68	32.06	38171.34	31.61
3	30693.69	22.14	35422.65	40.38	34053.57	28.2	29194.74	24.18	30693.69	25.42
4	13008.06	18.67	8587.98	7.11	57815.82	47.88	18339.84	15.19	13008.06	10.77
Total	120755.3	100	120755.3	100	120755.3	100	120755.3	100	120755.3	100

Where: 1 = bare soil expansion; 2 = deforestation; 3 = persistence; and 4 = reforestation

3.6.5.3.1 Analysis of the change image 1972-1984

The change image for the years 1972 and 1984 (Figure 3.7) shows intensive dynamics related to deforestation and bare soil expansion, which constitute 32 % and 27 %, respectively, in a period characterized by drought conditions that led many farmers to clear area from its forest cover either for agricultural purpose or to sell the resources for profit. The harvested wood was sold at local market as firewood and/or building materials. Woody materials are still the prominent building materials in the area.

3.6.5.3.2 Analysis of the change image 1984-1989

This period experienced an extension of drought conditions in the area; the rate of deforestation remained high, representing 29 %, while the bare land decreased at a rate of 23 % when compared to the above period. This is because the persistence class remained high at about 40 percent.

3.6.5.3.3 Analysis of the change image 1989-1999

This period was characterized by a high rate of reforestation (48 %); this indicates that the area's environment had recovered from the drought. As reported by the State Ministry of Agriculture, together with respondents in the area, there was sufficient rainfall during this period. Therefore, local people started to cope with the drought conditions via different mechanisms.

3.6.5.3.4 Analysis of the change image 1999-2008

The change image referring to the years 1999 and 2008 shows a rapid increase in the deforestation rate (32 %) combined with bare soil expansion (39 %). This can be attributed to the rapid increase in human and animal population as the result of environmental crises and conflicts in recent years. However, most local people in this area depend more on the forest for their livelihood, either for fuelwood, brick making, or building materials. Therefore, the increase in animal populations led to overgrazing, which resulted in land degradation.

3.6.5.3.5 Analysis of the change image 1972-2008

Due to a rapid increase in both human and animal population in recent years, this period was characterized by an intensive change in land use that resulted in high clearance of forest by local people or overgrazing. As such, the rate of deforestation as well as the bare soil expansion constitutes the same percent (32 %). Therefore, this period is characterized by agricultural expansion, whereby most of the forest land was cleared and converted into agricultural land.

.6.5.4 Iteratively Re-weighted Multivariate Alteration Detection (IR-MAD)

The Multivariate Alteration Detection (MAD) method is based on a classical statistical transformation referred to as canonical correlation analysis, which was introduced by Nielsen et al. (1998) to enhance the change information in difference images (Figure 3.8). Essentially, this method identifies the difference between two linear combinations of spectral bands from the two acquisition time points. If the multispectral pixel intensities are measured at two different times by random vectors X and Y, it can be represented as follows:

$$X = \begin{bmatrix} X_1 & \cdots & X_k \end{bmatrix}^T$$

$$Y = \begin{bmatrix} Y_1 & \cdots & Y_k \end{bmatrix}^T$$

:

Where K is the number of spectral components. Linear combinations are then calculated:

$$a^T X = a_1 X_1 + \cdots + a_k X_k$$

$$b^T Y = b_1 Y_1 + \cdots + b_k Y_k$$

Such that the difference of the transformed vectors has maximum variance:

$$\max(\operatorname{var}\{a^T X - b^T Y\})$$

and is subjected to the constraints:

$$\operatorname{var}\{a^T X\} = 1$$

$$\operatorname{var}\{b^T Y\} = 1$$

Under these constraints:

$$\operatorname{var}\{a^T X - b^T Y\} = 2(1 - corr\{a^T X - b^T Y\})$$

Since this method is used for change detection, *aTX* and *bTY* are positively correlated. Therefore, determining the difference between linear combinations with maximum variance corresponds to determine linear combinations with minimum (non-negative) correlations,

$$\min(corr(\{a^T X, b^T Y\}))$$

This complies with canonical correlations analysis (Nielsen et al., 1998).

Iteratively Re-weighted is a modification of the Multivariate Alteration Detection (MAD) transformation (IR-MAD). Nielsen (2007) introduces this method to establish a better background of no change upon which to examine significant changes. Canty and Nielsen

(2008) explain that, the IR-MAD procedure is superior to the ordinary MAD transformation to identify significant change, particular for data sets in which the fraction of invariant pixels is relatively small.

Nori et al. (2008) apply Multivariate Alteration Detection to tropical forest (East Sudan, El Rawashda Forest Reserve), using satellite imagery from 2003 and 2006, in order to detect changes in vegetation cover. The study found that MAD transformation are good for unsupervised change detection methods for satellite images and it can be applied to any spatial and/or spectral subset of the full data set.

According to the IR-MAD method, two multi-channel imageries that cover the same geographic location and are acquired at different times are taken as two sets of random variables. The IR-MAD transformation is then performed on these random variable sets to produce a set of result varieties that are uncorrelated with each other. Accordingly, correlations between channels can theoretically be removed as much as possible, so that the actual change in all channels can be simultaneously detected in the resultant difference image (Zhang Lu, 2004).

In this study, a linear transformation was performed by applying iteratively re-weighted multivariate alteration detection (IR-MAD) by using a cross-matrix between two images for specific periods (1972-1984, 1984-1989, 1989-1999, 1999-2008, and 1972-2008).

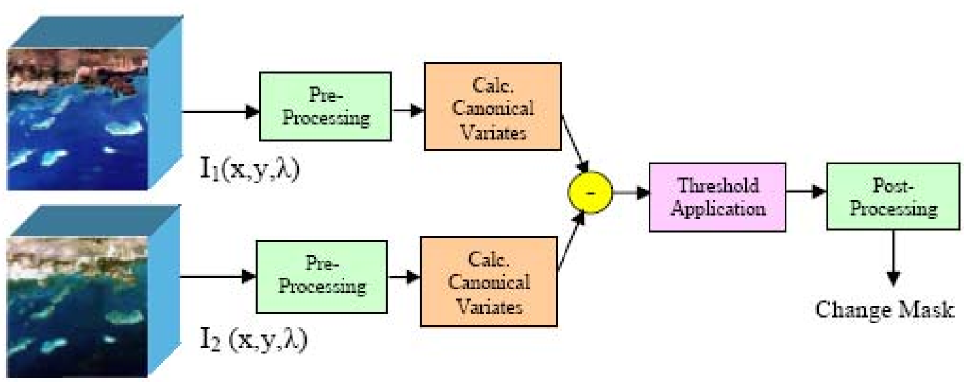

Figure 3.8 MAD Procedure
Source: Rivera (2005)

3.6.5.4.1 Interpretation of MAD Results

The interpretation of the resulting change images was based on the correlation between the transformed varieties and original data. Table 3.7., Table 3.8, Table 3.9, Table 3.10 and Table 3.11 show the correlation between the MAD and original spectral bands of the first period (1972-1984), second period (1984-1989), third period (1989-1999), fourth period (1999-2008) and fifth period (1972-2008) respectively. In all cases MAD 3 shows a high correlation in all bands which is an indicator of vegetation change. MAD 2 has a slightly low correlation with original bands in all periods except the third period (1989-1999) where the correlation is high. MAD 1 is uncorrelated with all original bands in all periods and shows image noise. If we consider MAD 3 and MAD 2 in all periods (Figure 3.9., Figure.3.10, Figure 3.11, Figure. 3.12 and Figure 3.13) we can identify positive change as indicated by white colour and negative changes as shown in black colour.

Table 3.7 Correlation matrix of the MAD components with the original MSS_1972 and TM_1984 bands

Original bands	**MAD 1**	**MAD 2**	**MAD 3**
MSS 1	-0.09	0.03	-0.49
MSS 2	0.00	-0.19	-0.49
MSS 4	-0.18	-0.24	-0.45
TM 2	0.17	0.01	0.48
TM 3	0.07	0.19	0.48
TM 4	0.15	0.23	0.46

Table 3.8 Correlation matrix of the MAD components with the original TM_1984 and TM_1989 bands

Original bands	**MAD 1**	**MAD 2**	**MAD 3**
TM 1984			
TM 2	-0.08	0.02	-0.57
TM 3	0.02	-0.17	-0.58
TM 4	-0.07	-0.20	-0.56
TM 1989			
TM 2	0.12	-0.08	0.58
TM 3	-0.01	0.20	0.54
TM 4	0.09	0.24	0.50

Table 3.9 Correlation matrix of the MAD components with the original TM_1989 and ETM_1999 bands

Original bands	MAD 1	MAD 2	MAD 3
TM 2	0.12	-0.61	-0.16
TM 3	0.06	-0.42	-0.43
TM 4	0.01	-0.38	-0.46
ETM 2	0.24	0.55	0.12
ETM 3	-0.03	0.29	0.50
ETM 4	0.06	0.27	0.51

Table 3.10 Correlation matrix of the MAD components with the original ETM_1999 and Aster_2008 bands

Original bands	MAD 1	MAD 2	MAD 3
ETM 2	-0.28	-0.29	-0.38
ETM 3	0.03	-0.01	-0.52
ETM 4	-0.04	0.03	-0.51
ASTER 1	0.00	0.21	0.46
ASTER 2	-0.13	0.02	0.55
ASTER 3	0.04	-0.06	0.56

Table 3.11 Correlation matrix of the MAD components with the original MSS_1972 and Aster_2008 bands

Original bands	MAD 1	MAD 2	MAD 3
MSS 1	-0.05	0.07	-0.53
MSS 2	0.09	-0.14	-0.58
MSS 4	-0.06	-0.25	-0.56
ASTER 1	0.11	-0.05	0.51
ASTER 2	-0.06	0.15	0.51
ASTER 3	0.12	0.22	0.48

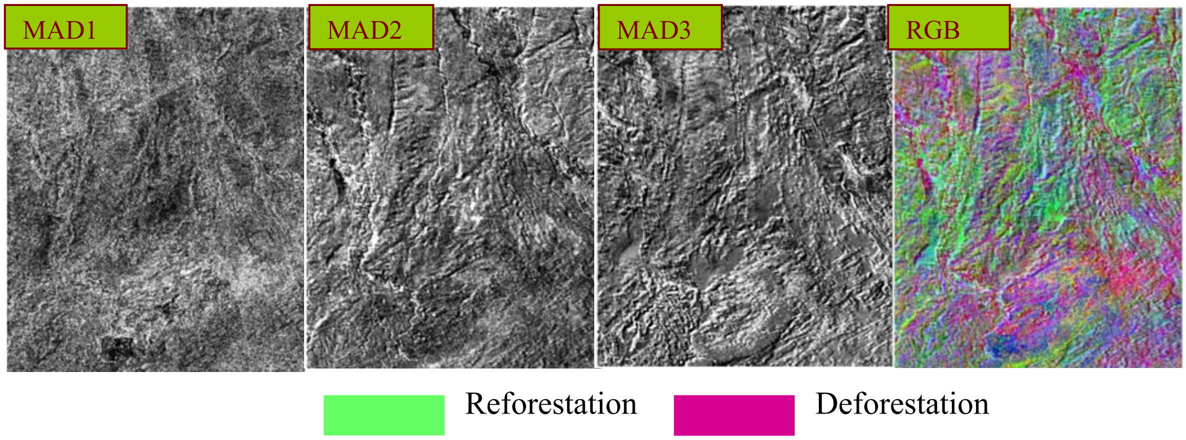

Figure 3.9 MAD components of MSS1972 and TM1984 and the three components as RGB

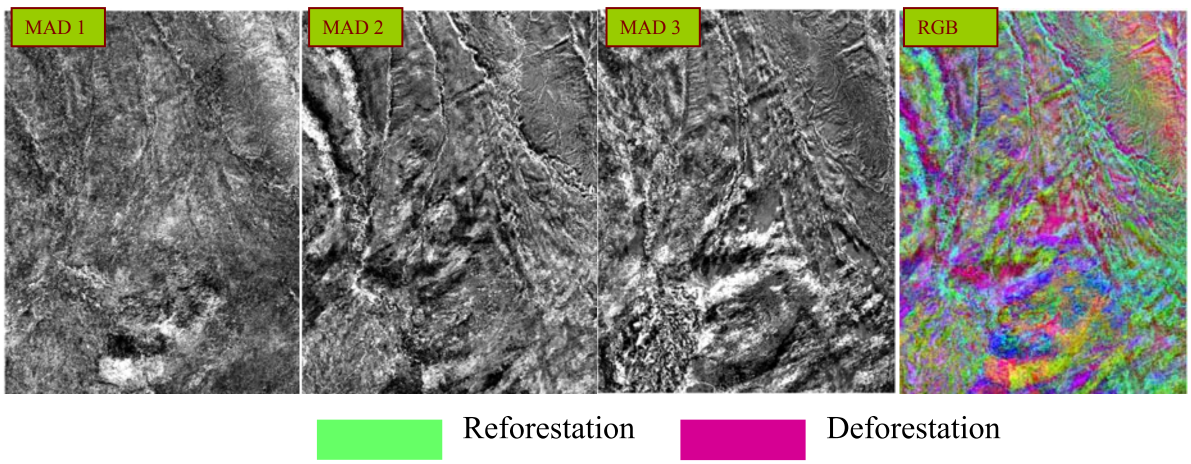

Figure 3.10 MAD components of TM1984 and TM1989 and the three components as RGB

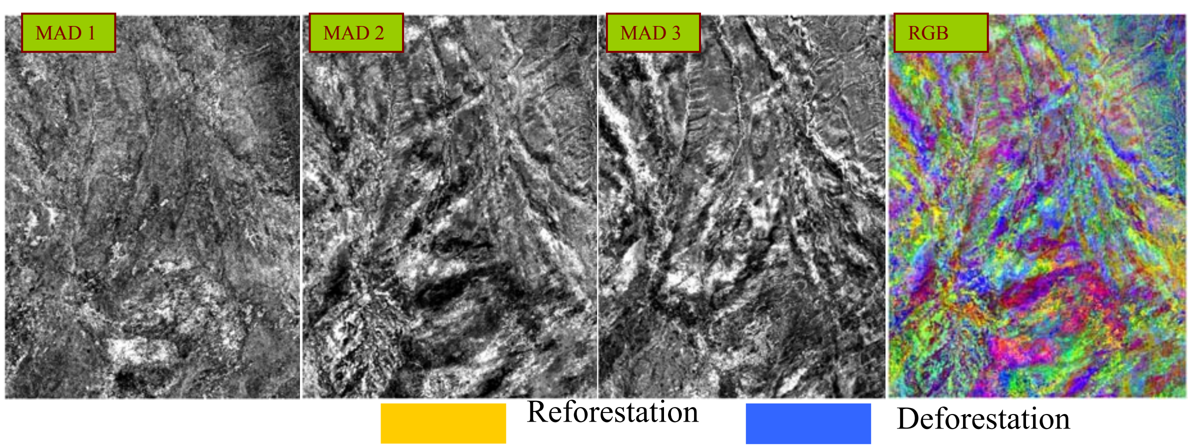

Figure 3.11 MAD components of TM1989 and ETM1999 and the three components as RGB

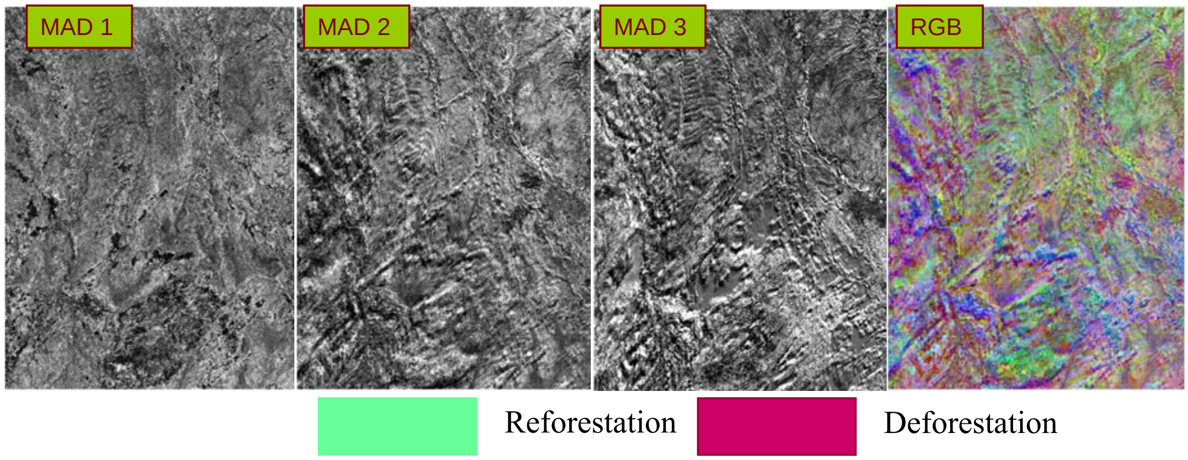

Figure 3.12 MAD components of ETM1999 and Aster2008 and the three components as RGB

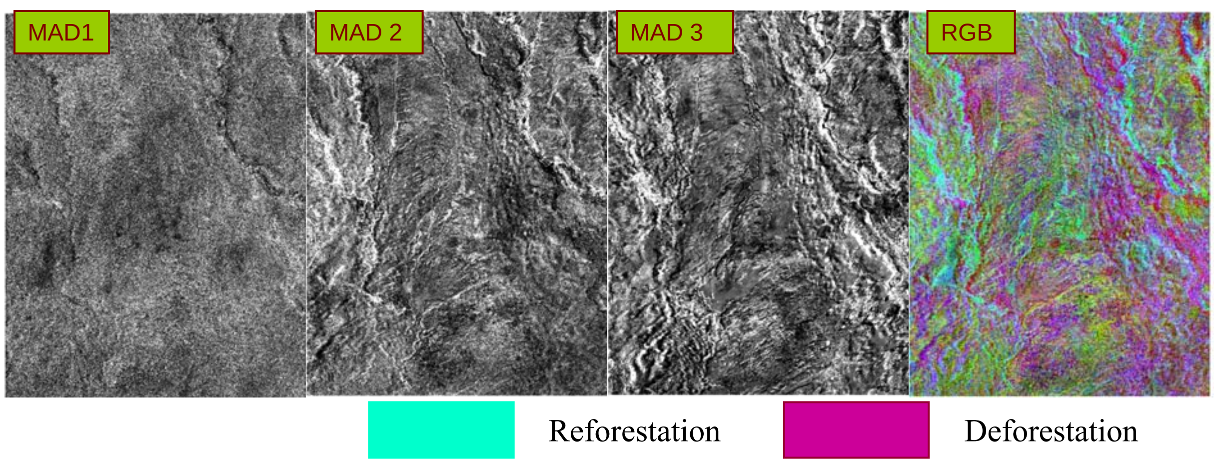

Figure 3.13 MAD components of MSS1972 and TM2008 and the three components as RGB

3.6.5.4.2 Maximum autocorrelation factor (MAF) analysis

To obtain maximum change areas with high spatial autocorrelation a Maximum Autocorrelation Factor (MAF) pre-processing of the IR-MAD varieties was conducted. The MAF transformation can be considered as a spatial extension of principal components (PC) analysis in which the new varieties maximize autocorrelation between neighboring pixels rather than variance (as with PCs).Figure 3.14, Figure 3.15., Figure 3.16, Figure 3.17and Figure 3.18 show the MAF/MADs of the first period images (1972-1984), second period (1984-1989), third period (1989-1999), fourth period (1999-2008) and fifth period (1972-2008) respectively. In all cases areas that are very bright or very dark are maximum change areas and with high spatial autocorrelation. In contrast to MAD components, the change information from all bands is concentrated in all MAF/MADs whereas the low order MADs are quite noisy. However, MAD/MAF RGB of the three components in all periods detects changes more clearly than MAD RGB components.

For discriminating change and no change pixels a procedure suggested by Bruzzone and Prieto (2000) was applied to MAD/MAF components to determine automatically the decision thresholds for change and no change areas.

3.6.5.4.2.1 MAF/MADs analysis for 1972-1984

If we consider MAF/MAD 1 for the first period (Figure 3.14) we detected negative change in western and eastern part of the area around the wadis, while in MAF/MAD 2 the negative change shown in different parts of the area in addition to positive change visible in the middle of the area. For MAF/MAD 3 the negative change shown in the south area (Goz soil). The decision threshold of these change areas are shown in Figure 3.15.

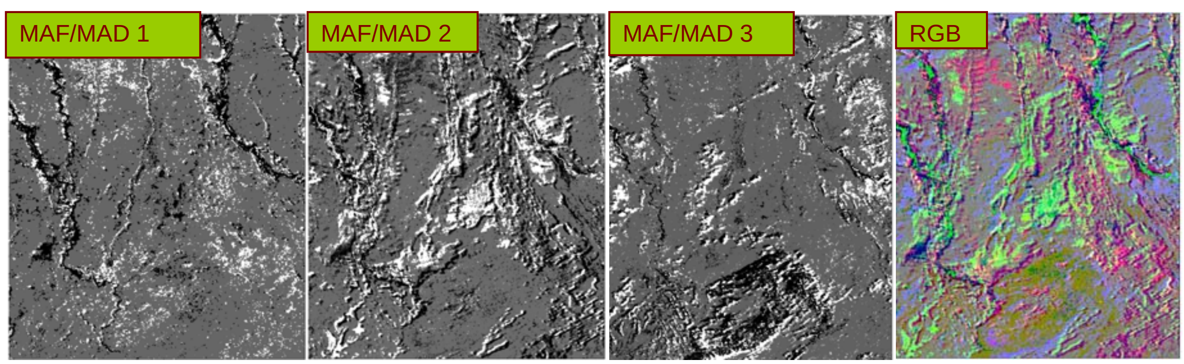

Figure 3.14 MAF/ MAD components of MSS1972 and TM1984 and the three components as RGB

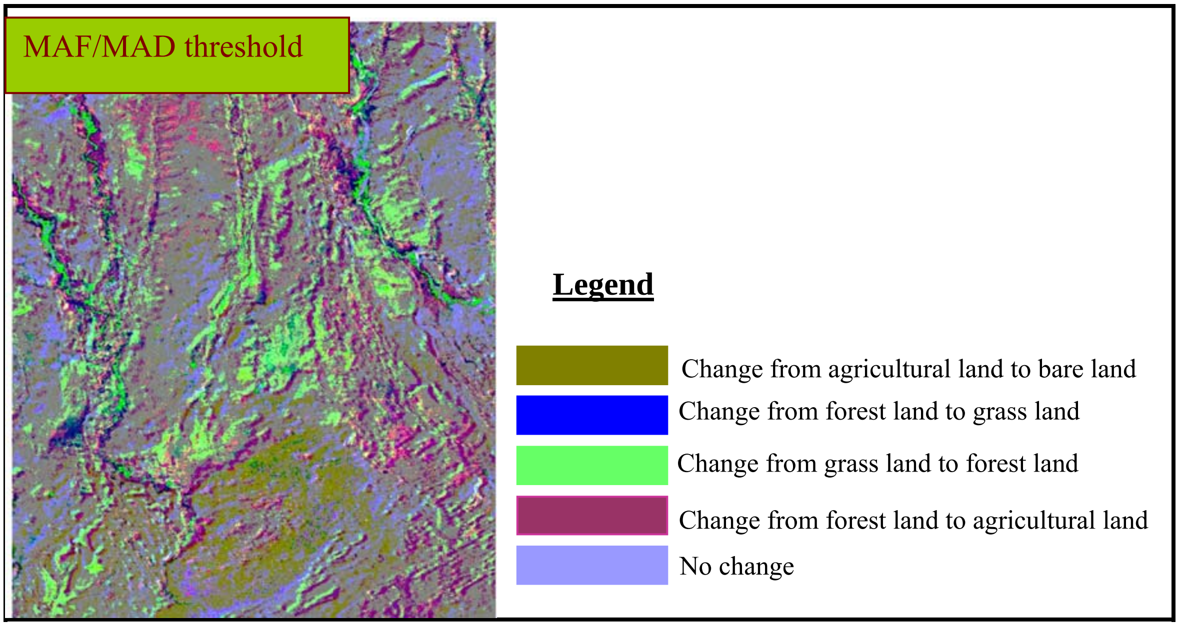

Figure 3.15 Changes given by the MAD/MAF of the three components from MSS_1972 and TM_1984 with automatic threshold

3.6.5.4.2.2 MAF/MADs analysis for 1984-1989

MAF/MAD 1 for the second period (Figure 3.16) showed that the positive change area is apparent in the southern area, while the negative changes are shown in small area in the middle and the southeast. For MAF/MAD 2 the change areas are apparent in different parts of the area. MAF/MAD 3 showed a positive change in the southeast, middle and west of the area, while the negative change is found in the south as well as in small area in the centre. Figure 3.17 shows the decision threshold of the change areas for the period 1984-1989.

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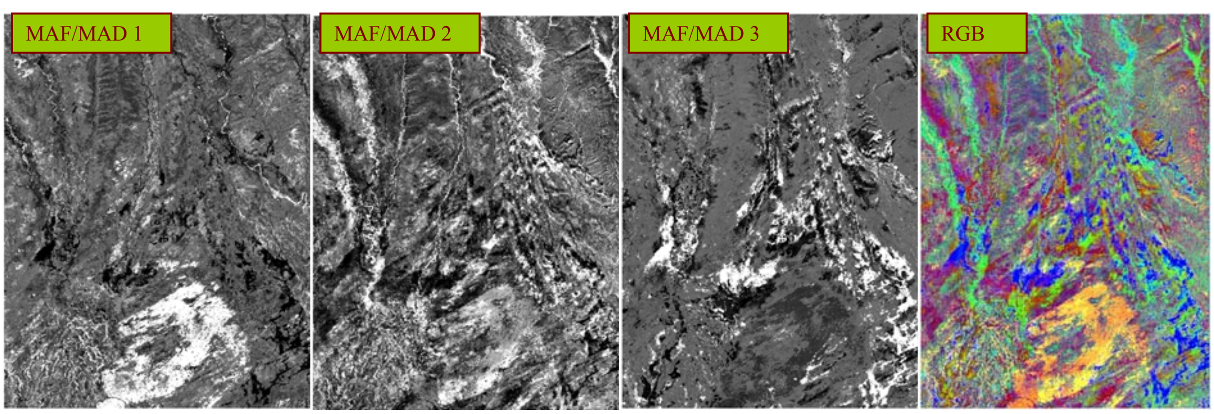

Figure 3.16 MAF/ MAD components of TM1984 and TM1989 and the three components as RGB

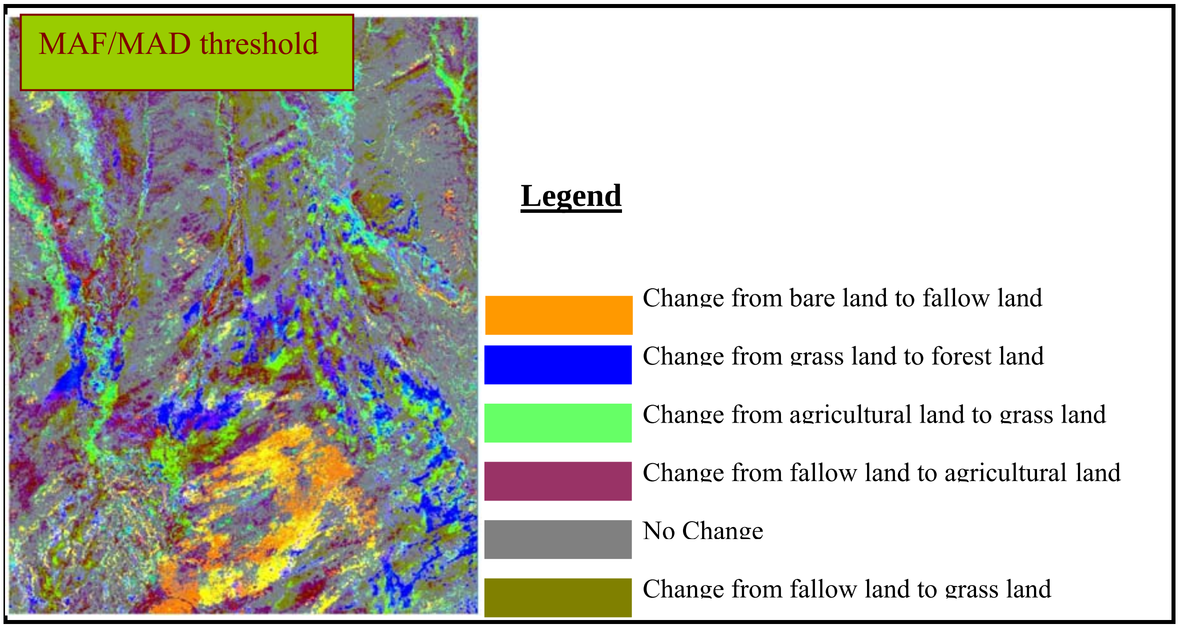

Figure 3.17 Changes given by the MAD/MAF of the three components from TM_1984 and TM_1989 with automatic threshold

3.6.5.4.2.3 MAF/MADs analysis for the period 1989-1999

As Figure 3.18 illustrates the positive change areas are located clearly in the middle and south of the area in MAF/MAD 1, MAF/MAD 2 show different changes (positive and negative) in different parts of the area. In MAF/MAD 3 the negative and positive changes are concentrated in the middle, southeast and southwest of the area. The decision threshold of theses change areas are shown in Figure 3.19.

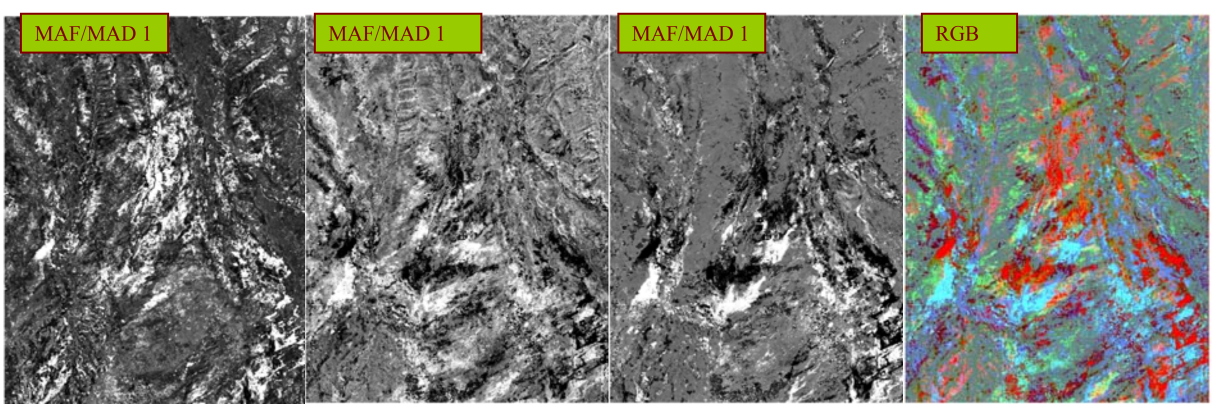

Figure 3.18 MAF/MAD components of TM1989 and ETM1999 and the three components as RGB

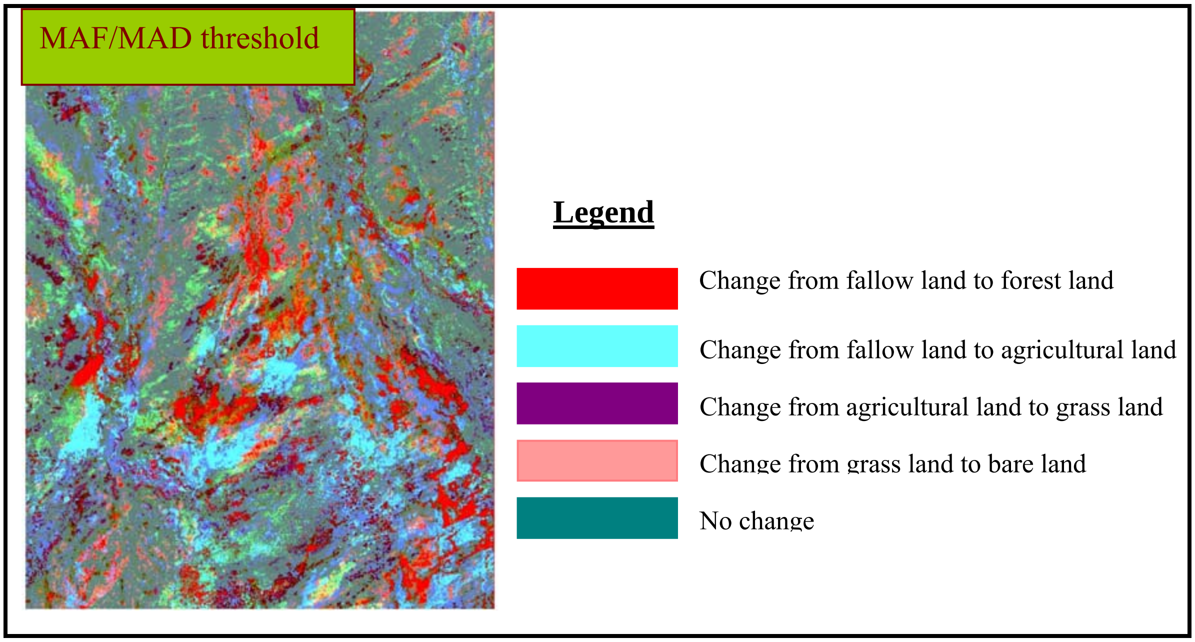

Figure 3.19 Changes given by the MAD/MAF of the three components from TM_1989 and ETM_1999 with automatic threshold

3.6.5.4.2.4 MAF/MADs analysis for the period 1999-2008

MAF/MAD analysis for this period (Figure 3.20) indicates that MAF/MAD 2 and MAF/MAD 3 identified the change areas more clearly than MAD/MAF 1. If we consider MAF/MAD 2 we note the positive changes in the center of the area in contrast to MAD/MAF 3 whereas the centre of the area shows negative change. Figure 3.21 show these change areas with an automatic threshold.

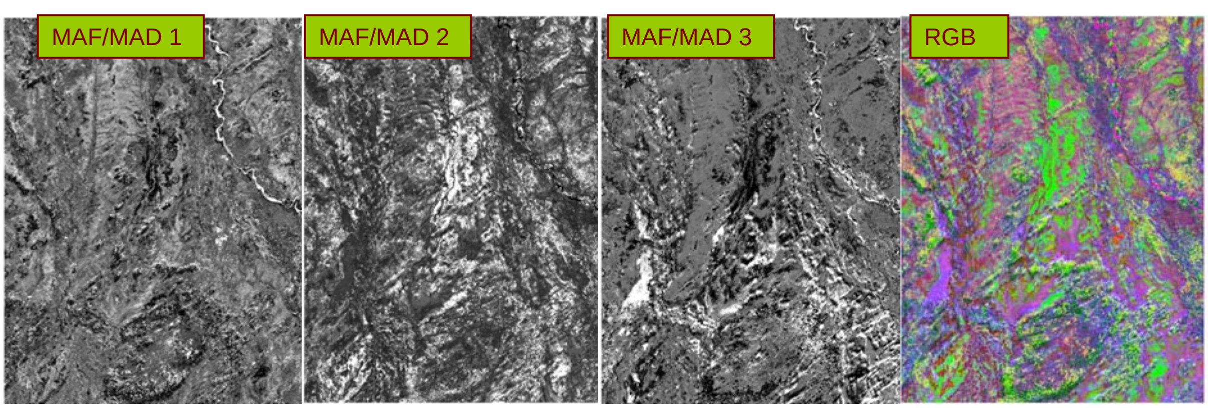

Figure 3.20 MAF/ MAD components of ETM1999 and Aster 2008 and the three components as RGB

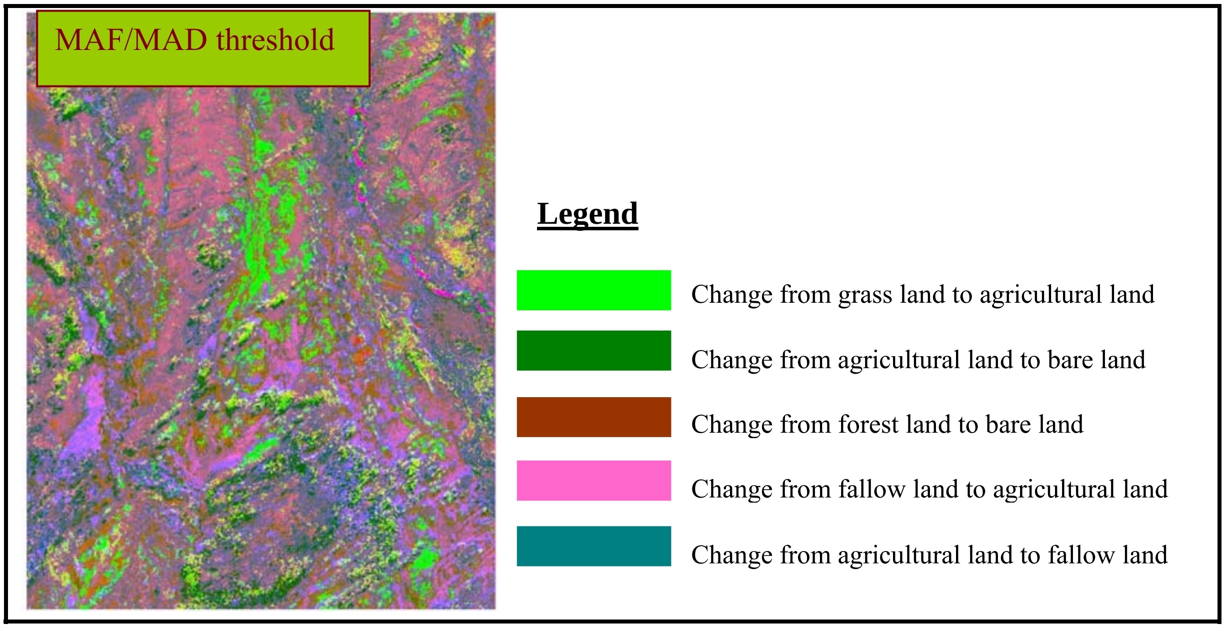

Figure 3.21 Changes given by the MAD/MAF of the three components from ETM_1999and Aster_2008 with automatic threshold

3.6.5.4.2.5 MAF/MADs analysis for the period 1972-2008

According to Figure 3.22 MAF/MAD 1 shows a small area of positive change in the eastern and western area. MAF/MAD 2 and MAF/MAD identified clear changes in different parts of the area. Figure 3.23 illustrates the decision threshold of the change areas for the period (1972-2008).

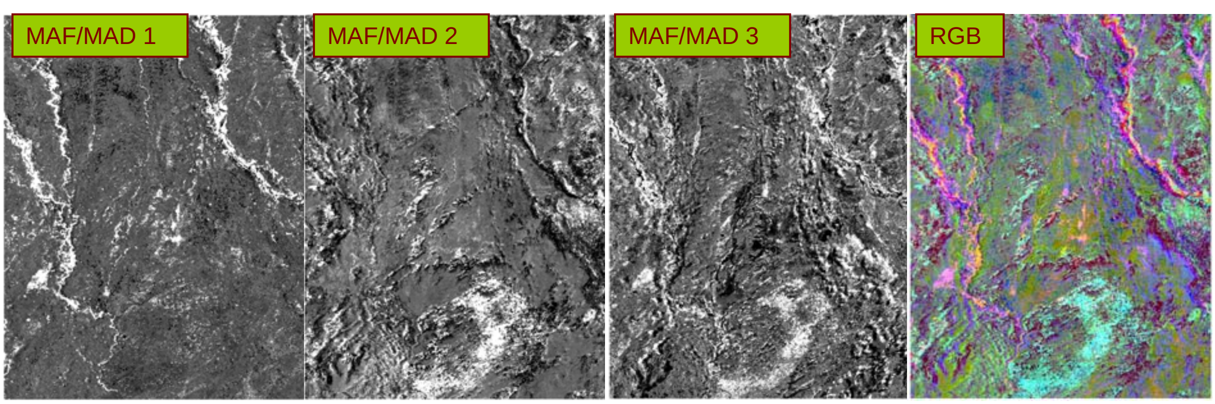

Figure 3.22 MAF/ MAD components of MSS1972 and Aster 2008 and the three components as RGB

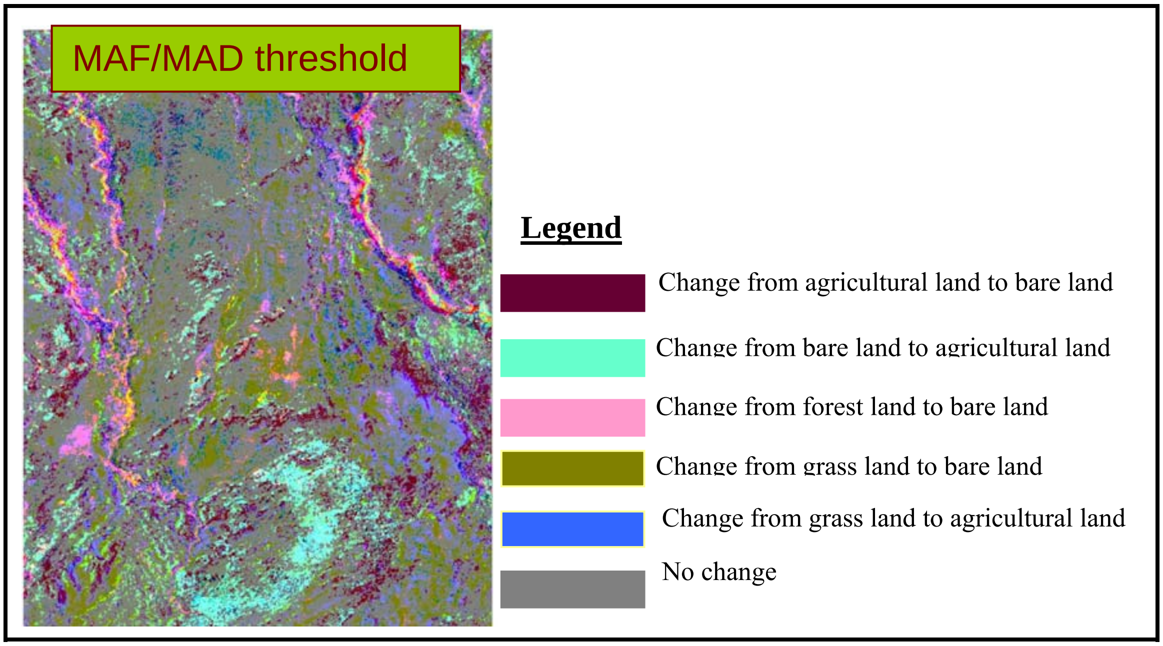

Figure 3.23 Changes given by the MAD/MAF of the three components from MSS_1972 and Aster 2008 with automatic threshold

3.7 Conclusions

The purpose of this chapter was to detect LULC change using supervised and unsupervised change detection approaches. The applicability of maximum likelihood classification, CVA based on TCT and the MAF/IR-MAD methods in multi-temporal satellite imagery change detection studies was demonstrated. The study proved that the maximum likelihood classification provided an accurate means to quantify, map, and analyze changes over time in LULC, that CVA based on TCT has an ability to detect vegetation cover in terms of deforestation and reforestation with measurable direction and magnitude. It has also been found that the automatic threshold determination procedure of MAF/IR-MAD provides a good unsupervised change detection method for satellite imagery in terms of visualizing the changes that have occurred over time.

This chapter concludes that remote sensing can be used to support some criteria and indicators for land use/ land cover monitoring. Specifically, the study successfully uses optical satellite remotely sensed images (i.e. Landsat- MSS, TM, ETM and Aster data) to detect change in LULC in Ed Al-Fursan area. Furthermore, the study was successfully able to detect LULC change and concluded that forest cover has decreased between 1972 and 2008 and has been replaced by agricultural land. As such, the levels of bare land have increased. This can be attributed to environmental degradation and an increase in human population as a result of conflict and war in recent years

CHAPTER FOUR

Livelihood in South Darfur State: An overview

4.1 Introduction

4.1.1 General Description of Major Environmental Factors in Darfur

The greater region of Darfur extends from the Sahelian zone in the south and to the desert zones in the north. Due to the fact that the region's natural resource base is fragile, especially in its northern areas, it is exposed to environmental and production hazards. There is a single rainy season (mostly July-September), with rainfall declining from up to 700mm per annum in the south to less than 200mm in the north. The region consists of upland and lowland areas. The altitude of Jebel Mara, at up to 3,000 meters, has a significant effect on the amount of rainfall in that area and its reliability. The lowlands include the northern desert, the stabilized Goz sand sheets in most of eastern Darfur and part of the south, important alluvial soils in the north and the west (including the wadi networks) and extensive drainage basins in the south (Swift and Gray, 1989). Population density varies according to these ecological and climatic zones; north of 16˚N, the population density is very sparse, while the South Darfur State is densely populated (IOM, 2010).

4.2 Livelihood Concepts and Definitions

The concept of livelihood is about individuals, households, or groups making a living, attempting to meet their various consumption and economic necessities, coping with uncertainties, and responding to new opportunities (De Haan and Zoomers, 2003).

Formally, a livelihood can be defined as "the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household" (Ellis, 2000).

Accordingly, the Department for International Development DFID's Sustainable Livelihoods Framework (DFID, 1999) (Figure 4.1) reveals that the inherent potential of people to achieve their goals (livelihood outcomes) through activities and choices (livelihood strategies) depends on their resources within their specific governance settings.

This Framework Divides Livelihood Resources (Capital) in to:

- Human capital − skills, knowledge, ability to work and good health;
- Social capital − networks and connectedness, trust, collaboration, attitudes, values and norms;
- Financial capital − savings, access to credit and loans, labor income, pensions, remittances, livestock, etc;
- Physical capital − infrastructure, tools and equipment; and
- Natural capital − natural resources and their goods and services, for example land, water, forests, and air quality.

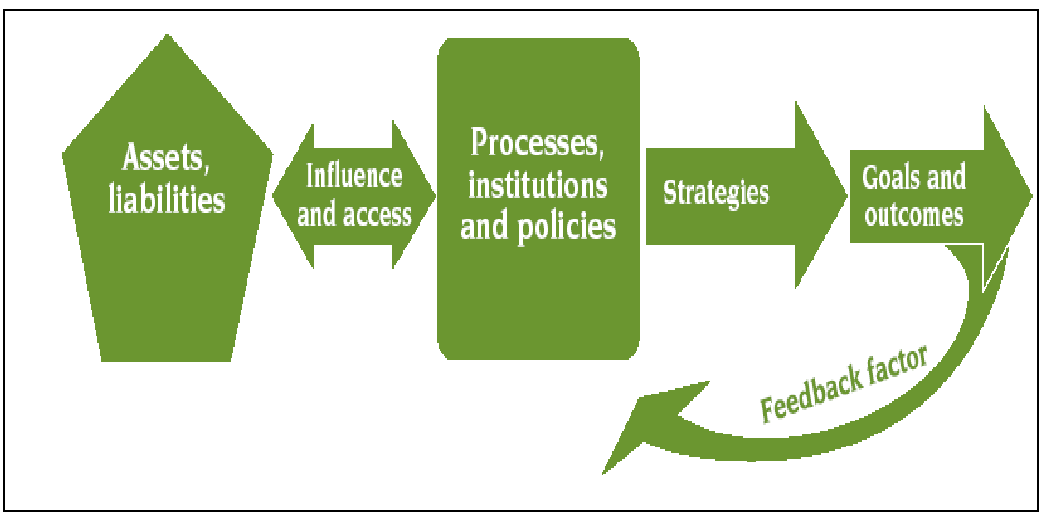

Figure 4.1 DFID's Sustainable Livelihoods Framework

Source: Young et al. (2005)

Policies and institutions include those systems (at both the macro and micro-level) that determine people's protection and welfare, or in their absence and their vulnerability. Institutions include judicial systems and rule of law, systems of leadership (both formal and informal), systems of conflict resolution, public services and markets.

Livelihood strategies are determined by livelihoods assets and policies, institutions and processes (PIPs). Assets and PIPs determine the livelihood options available to people and the feasibility of different livelihood strategies. In Dafur, household strategies include agricultural and livestock production, trade, seasonal migration for work, migration for work outside of Darfur, collection of wild foods, and firewood and grass collection.

Livelihood goals include the priorities and aims of the affected people themselves, for example, acquiring a sense of control over their life, as well as food and income security (Young et al., 2005).

4.2.1 Description of Livelihoods in Darfur

Much of the southern two-thirds of Darfur are suitable for pastoralism. Semi-nomadic pastoralists grow crops and raise livestock. Semi-nomadic pastoralist households have regular access to rural and village markets where they can sell milk during a good rainy season (Hamid et al., 2005).

Most of the nomadic pastoralists depend on their camel herds and keep less cattle, sheep and goats. Leroy (2009) identifies that nomadic pastoralist used to take their herds, between dry and wet season, to different grazing areas, and that has been a part of their adaptive strategies in response to changing weather conditions in the past. However, political instability and armed conflicts have affected the migration patterns of pastoralists. Furthermore, FAO (2005) illustrates that since 2003, herds in Darfur have reportedly been migrating southwards in search of safety, even during the rainy season. The conflict has further limited grazing ranges and, due to security reasons, surviving livestock are being controlled in concentrated areas, especially in the south, throughout the year.

For both pastoralist groups, famine sets in during the last months of the dry season between March and June when few animals provide milk and food consumption is limited to market purchases and wild foods (Hamid et al, 2005).

Sedentary agro-pastoralists practice rainfed agriculture; millet, sesame, and groundnut are planted on the sandy soils (providing the greatest portion of family subsistence) (Elasha, 2009). Sesame and groundnuts double as cash crops, although agro-pastoralists also sell their surplus sorghum to buy millet.

The harvest of the main staples occurs between October and December. Yields are relatively low, reflecting unreliable rainfall and poor soils as well as traditional labor-intensive, low-input, low-output technology using few purchased inputs. Even though yields reach about 650 kg/ha for sorghum, but only 300 kg/ha or less for millet (CFSAM, 2004/05 cited in WFP, 2005), agro-pastoralists plant several times more land in millet than sorghum. As a result, Darfur normally produces considerably more millet than sorghum.

Winter season vegetables are continuously planted and harvested between November and March, occasionally using small-scale pump irrigation. These horticultural crops represent a significant source of seasonal income for those who can deliver their produce to the bigger market towns. Winter season crops also offer employment opportunities for women and landless people (Hamid et al., 2005).

4.2.1.1 Livelihood Zones in South Darfur

The cultivated area in South Darfur has been gradually expanding over the course of the last few decades, as population growth in this state has been highest. The population in South Darfur is almost double the population of North and West Darfur. In addition to natural population growth, there has been significant migration into the state, especially from the drier and less productive North Darfur. Of the three states, South Darfur state has the most favorable conditions for rural livelihoods (Young et al., 2005).

According to UNICEF (2006), the livelihood zones for South Darfur state have been divided into four zones, which are illustrated in Table 4.1.

Table 4.1 Livelihood zones in South Darfur State

Source: UNICEF, 2006

Livelihood zone	***Location***	***Ecology***	***Livelihood strategies***
1) Low rainfall agro-pastoral	Areas bordering North Darfur: Shearia, Mershing	• Goz soils	• Millet & sorghum production • Groundnuts as cash crop • Livestock holdings: cattle
2a) Agro-pastoral: cash crop, groundnuts, dominant	Ed Daein, Buram, Tullus, Rehed El Berdi	• Goz soils	• Millet & sorghum production as staples and as cash crops • Production of groundnuts, sesame, karkadeh • Large Dinka labour force, working as sharecroppers, agricultural labourers and renting land • Gum Arabic • Livestock: cattle
2b) Agro-pastoral: livestock, cattle dominant	Ditto	• Goz soils	• Cattle pastoralism, migrating between Bahr el Arab and Nyala, or just into North Darfur • Millet & sorghum production as staples and as cash crops • Groundnut production
4) South Jebel Marra lowland	Kass, Shertai	• Fertile land • Rainfall: up to 700mm	• Rainy season: millet, sorghum, groundnuts, sesame, karkadeh, etc. • Irrigated during winter: cash crops, vegetables, onions, wheat, etc. (less than W Jebel Marra lowlands) • Fruit gardens as cash crops • Trade • Large numbers of cattle and shoats

4.2.1.2 Natural Resource-Based Livelihood Activities in South Darfur

4.2.1.2.1 Livestock-Related Activities

Livestock rearing, production, herding, trading and the use and trade of by-products (milk, meat, leather) is an important component of South Darfur State’s local economy and these activities constitute a traditional foundation for many key livelihood activities the region (FAO, 2010). The UNDP (2007) reports that livestock husbandry was originally a nomadic task in Darfur. However, recently sedentary farmers have started to participate in the activity to make use of their crop residues and to make use of communal lands to reduce agricultural risks as well. Seasonal migration is necessary as Lebon (1965) illustrates, as nomads are unable to remain in one place where there is a lack of water or grazing (or both) for an entire year. However, wadis and their tributaries constitute critical areas for dry-season grazing in South Darfur. In these areas, pastoralists feed their livestock using crop residues and *Acacia albida* until the rainy season starts and they start to move northward (Young et al., 2009).

The traditional livestock migration system was in many ways beneficial for both farmers and pastoralists. Based on high levels of cooperation and traditional rules, herds were allowed to transit through agricultural fields to feed on harvest residuals and access water sources. In exchange, livestock manure would fertilize agricultural land (IOM, 2010). However, agricultural expansion and severe prolonged drought periods in the 1980s undermined these symbiotic relationships, as both groups started to concentrate on the clay soils. Pastoralists from the arid north were forced to move south, where farming in the central rangelands was already expanding (El Hassan, 2008).

4.2.1.2.2 Agriculture

The predominant activity in the southern Darfur region is traditional agriculture, which is characterized by small-scale farming and the farmers constitute a group with limited or no access to technology and formal credit institutions.

Rainfed agriculture, based on smallholders' traditional methods, dominates the agrarian economy of South Darfur. This low input agriculture requires intensive labor. Until 1977, less than one per cent of the cropped area in South Darfur was irrigated, and mechanized agriculture was only practiced in 1.8 per cent of South Darfur's cropped area (Morton, 1985).

Morton (1985) describes that prior to the region, there has been a shift from traditional subsistence to cash agriculture (mainly grain and oil seeds) across the region. In the same report, he notes that cash cropping rapidly expanded, mainly in Darfur's south where cultivable soils are relatively extensive, although infertile. Pearl millet (*Pennisetum glaucum*) is the main staple food crops grown in the region, as it is highly preferred by the indigenous consumers, and sorghums (*Sorghum bicolor*) have also been recently introduced as a staple food (D-JAM, 2006). Several other cultivars and wild varieties are grown with major crops (for example, a mix of sorghum and groundnuts) in large plantations where they are locally important (for example watermelons) or widely cultivated in small amounts (for example okra).

According to WFP (2007), agricultural production and yields in Southern Darfur have historically been highly erratic due to unpredictable patterns of rainfall, pest infestations and the lack of appropriate agricultural inputs. Furthermore, as the population expands, demands on the land increase resulting in over-cultivation, and this degrades land quality over time, steadily depleting Darfur's ability to support rural livelihoods (UN, 2010).

4.2.1.2.3 Forestry-Related Livelihood Activities

4.2.1.2.3.1 Timber and fuelwood extraction

Extraction of building materials and fuelwood − firewood and charcoal − from forested areas has traditionally provided the basic supplies for Sudan's rural populations as well as much of its urban population (UNEP, 2007). However, significant deforestation was initially used in Southern Darfur in order to clear land for agricultural expansion, whereas more recently, agriculture and livestock production has fallen, and timber and firewood resources have increased in importance as livelihood sources, especially as demand has risen in urban markets (Buchanan-Smith *et al*. 2008). In addition, numerous local bakeries and brick-making industries have emerged, which demand large amounts of fuelwood, and this contributes further to deforestation (Buchanan-Smith et al., 2008). Scholars highlight the impact that deforestation has on land. Milani (2006) reports that the decline in tree and bush cover reduced soil productivity and promoted erosion, soil depletion and salinization in the region.

4.2.1.2.3.2 Gum Arabic

Sudan is the world's largest producer and exporter of gum Arabic, an exudate from the *Hashab* tree (*Acacia senegal*), which has few local uses but is highly demanded by food and pharmaceutical industries worldwide (Rahim et al., 2005). Within Sudan, 20 percent of the national gum Arabic extraction comes from Darfur (Sudan-MDTFs, 2007). In southern Darfur, medium-sized farms use a gum Arabic ecosystem to produce gum Arabic, annual crops, and livestock that can be a financially and environmentally sustainable enterprise as a family farm (USAID & WB, 2011). Gum Arabic not only provides farmers with additional income, its production also constitutes a coping strategy during crop failures. Planting *Hashab* trees also protects against soil and wind erosion (Sudan-MDTFs, 2007). *Acacia senegal* trees are grown according to a "bush fallow" system, whereby agricultural cropping and forest regeneration are practiced in sequence. With the completion of the forest rotation (the bush period), the land is cleared for crop farming. Yields are typically high due to fertilization by the nitrogen-fixing acacia; however, cultivation can continue for five to seven years before the land is forsaken for another bush rotation (UNEP, 2007).

The bush-fallow system supports local population's livelihoods because it is the major source of both cash and subsistence. However, the bush fallow system was disrupted and the traditional rotational fallow cultivation cycle has been dramatically shortened or completely abandoned (Awouda, 1973, cited in Mohamed, 2005). Although *Hashab* trees are resistant to periods of water stress, the combination of severe droughts, change in farming practices, clearing of Acacia Senegal stands for firewood and charcoal production as an unsustainable source of income, conflicts between farmers and herders, and the most recent crisis have negatively impacted the production of gum Arabic in the region (IOM, 2010).

4.2.1.2.4 Small-scale Natural Resource-based Livelihood Activities

Other activities that are directly related to natural resources in South Darfur that are of importance for the livelihoods of certain individuals or households but are of lower economic relevance on the South Darfur-wide scale include:

- Collection and trade of palm leaves and fodder;
- Fruit production and trade;
- Wild food collection, processing and trade;
- Collection and trade of salts for animal consumption; and
- Crafts and hut construction, particularly widespread in South Darfur, where the majority of homes and fences are constructed almost entirely of thatch and wooden poles that need to be replaced approximately every two years. Hut construction is based on a *Nafir* system of cooperation and implies the participation of a skilled architect, as the conical roof and the lower round base are separately constructed before the hut is assembled. Furthermore, some families base their entire income on the collection of grass for the thatching industry (Elsiddig, 2007 cited in IOM, 2010).

4.2.1.3 Livelihood Coping Mechanisms in South Darfur State

Many households in South Darfur State are able to cope, for the most part, with *expected* seasonal stresses. Nearly all households attempt to diversify their income by engaging in some sort of trading and marketing, long distance labor migration and remittance of income, and gathering and consuming wild foods and hunting (Hamid et al., 2005). For instance, in the case of climatic variability, diversification and staggered planting are among the common strategies that households use to reduce the effect of erratic rainfall (Damous and Khojali, 2004). Moreover, in the case of serious food shortage or famine, a household responds differently depending on its resource endowment, although the range of options remains to sell assets, starting with those accumulated for such purpose and ending with productive assets (Damous & Khojali, 2004). Migration of some or all family members to where they can find living options is a strategy that people from Darfur use to diversify their income sources and thereby increase their resilience to periods of hardship and food insecurity (Young, 2006). However, livelihood in southern Darfur has become increasingly difficult because of declining rainfall and the spread of desertification in recent decades that contributed to North-South migration in search of better conditions for pasture and farming, which, when combined with increasing population pressures, has created more direct competition for access to natural resources (Ahmed, 2009). Moreover, ecological imbalance, scarcity of water, deforestation, mismanagement of natural resources, unequal distribution of available resources have significantly contributed to conflict that threatens livelihood sustainability in the region (King & Osman, 2004).

CHAPTER FIVE

The Impact of Land-use change on the Livelihood of Rural Communities Based on Perception and Knowledge of Rural People

5.1 Abstract

This chapter seeks to identify and analyze rural people's attitudes, knowledge and perception of land-use change, and to examine the impact of land-use change on rural people's livelihood. The cross-sectional data were collected from 100 respondents using pre-structured questionnaires. The data were focused on respondents' socio-economic characteristics, drought and its affect on natural resources (for example agricultural land and crop production, land degradation, forest production and rate of deforestation). The narrative perception of the key informants was used to obtain a clear picture of different historical changes in land-use patterns from 1972 until 2008 in the Edd Al-Fursan area, South Darfur State. Additionally, they provide a beneficial description of the natural resources situation in the seventies and their degradation since the beginning of the droughts in the 1980s. The data were coded, entered in a computer and analyzed using the Statistical Package for Social Science (SPSS). Descriptive statistics and correlations were used to present the study results. The findings illustrate that the respondents are aware of changes in land-use patterns over the course of this period. The sampled population indicates that the driving forces of this change included environmental degradation, conflict and war, recurring droughts, human and animal population growth and human activities. This was based on their perception and interpretation of indicators such as the reduction of soil fertility due to over-cropping that led to lowered crop production, overgrazing that has resulted in the change in some grazing species and pasture degradation. The results of the study also indicate that deforestation caused by charcoal production, brick making and building materials ultimately led to land degradation and soil erosion. Moreover, the study illustrates that land-use issues in the study area were directly related to land tenure systems. However, the inability of land ownership and land management systems to cope with the demand for farms and pastures due to increased human

and animal population resulted in land degradation caused by overuse, which hinders the sustainability of rural livelihood in the area.

5.2 Theoretical Background

5.2.1 Introduction

Land and people are the most important natural resources that are mutually interrelated and interdependent for their sustainable development (Dhas, 2008). According to FAO (1999), land is an essential natural resource, both for the survival and prosperity of humanity, and for the maintenance of all the terrestrial ecosystems. Although it is a fixed, scarce, tangible and immovable resource, it is a degradable and transferable entity that is only sustainable when it is properly used by humans (Dhas, 2008).

The use of land is very wide and intense and the demand for land for its various uses has increased over time. In fact, there are competing uses such as forests, agriculture, industry, housing, infrastructure, services, and recreation. Land-use patterns are highly influenced by the various deliberate interventions by the people and have been undergoing significant changes (Lee et al., 1988; World Bank, 1984).

A vast majority of households, especially in third world countries, depend on land and other natural resources for satisfying their basic needs and achieving their long-term livelihood goals. Agriculture constitutes a major activity in most countries except for those in the industrialized world. Hence, crop production, use and commercialization of forest products, wild food gathering, and fishing as well as extensive grazing substantially contribute to the Gross National Product of these countries (De Wit, 2003). In traditional societies, the concept of land extends beyond the purpose of production. It also holds important social and spiritual values. Land is often the only available resources that rural families can rely on to build their lives (De Wit, 2003).

5.2.2 Consequences of Population Pressures on Land-use changes

Ramankutty et al. (2002) state that global land use has significantly changed in the past decades. Historically, the driving force for the majority of land-use changes is population growth, although there are several interaction factors involved. According to Deacon (1994), the growing population has increased demand for land, trees, and water, which, coupled with tenure insecurity or the absence of clear property rights, has resulted in the overexploitation of these natural resources, and this in turn has threatened the sustainable development of agriculture, forestry, and livestock sectors.

Gregersen, Oram, and Spears (1992) identify that increasing cultivation of marginal lands and their subsequent degradation under population pressure is a common phenomenon for densely populated countries around the globe. Moreover FAO (1995) reveals that the growing pressure on land pushes farmers to overexploit wood, water and other resources in order to meet household requirements. Such overexploitation may result in serious and irreversible environmental degradation, including deforestation, long-term erosion, decreased soil fertility, and desertification, which limits the development of agriculture in most areas. This is evident in sub-Saharan Africa. However, in the Sudanian zones, traditional production systems included techniques and enforceable rules for assuring sustainable use of the modest and fragile (low soil fertility, variable rainfall) resource base; those systems "have increasingly been disrupted, above all by rapid population growth" (Gorse and Steeds, 1987). In the Darfur region particularly, the increase in human population since the mid-1970s has intensified cropping and grazing patterns, resulting in shorter fallow periods for the fields and overgrazed range land leading to deterioration in yields and carrying capacities for the pasture (Bromwich, 2008). Furthermore, Morton (1996) reports that the population had grown rapidly, especially in South Darfur State, and this has placed land resources under pressure and accelerated the whole process of degradation.

5.2.3 Factors Affecting Land Use in Darfur Region

According to Abdul-Jalil (2006), there are six main factors that have reasonably influenced land use in Darfur. These factors are discussed below.

Drought

Darfur lies on the edge of a desert in an area that suffers from both an overall paucity of resources and a high degree of variability in the availability of resources (Bromwich, 2008). However, Darfur had suffered waves of severe droughts since the Sahelian drought of the late 1960s that reached its peak in the early 1980s and culminated in the worst famine disaster in Darfur during the twentieth Century (DLC, 2007). King and Osman (2004) depict that the recurring drought resulted in dramatic consequences. Some nomadic and agricultural activities, combined with the clearance of forests, acted as major contributory factors to soil nutrient depletion and reduced land productivity. Increased local demands for fuel, and growing pressures for higher levels of food production, led to shorter fallow periods and to the removal of the vegetation cover and the depletion of the topsoil layer on the Goz sands. The ultimate result of this process was the reactivation of the consolidated sand dunes and the advancement of moving sands, with all of their ecological and socio-economic consequences.

Increased human population

According to the 1973 census (Central Bureau of Statistics, 1973) and the 2003 estimates from the UNFPA (UNFPA/Central Bureau of Statistics, 2003), Darfur's population has expanded to nearly five times its population in 1973 (from 1 350 000 to 6 480 000). Due to this natural population increase, the farm plots had to be secured each year to satisfy the new family members. This has resulted in decreasing wasteland and a neglect of the fallow period, while even some nomadic migratory routes and resting places have been concerted to farmlands. Of the eleven recorded migratory routes in the 1950s, only three are currently operable today in addition to limited new routes (Abdul-Jalil, 2006).

Animal population growth

Despite recurrent droughts, the livestock population has increased in response to market demands (Young et al, 2005). Although pastoralists keep most of the livestock resources, the increase in livestock numbers is partly attributed to the non-pastoral population that is increasingly engaged in livestock husbandry as a secondary source of income or as investment when the farm income is not sufficient for household requirements (Young et al., 2005). This increase has ultimately resulted in pasture degradation.

Internal and external migration

According to Abdul-Jalil (2006), Darfur witnessed two types of migration trends that directly affected land-use patterns. A decade of mostly dry years (from the mid-1970s to the mid-1980s) triggered internal migration from northern Darfur. The displaced people sought refuge in the eastern Goz and the southern zone. These areas immediately began to show signs of saturation. In addition, pastoralists who came from Chad were tempted to cross the borders and look for permanent settlement in Darfur and this accelerated competition on land.

Increased Commercialized farming

Due to spread of education and urbanization in recent years, people in rural areas have begun to identify with new consumption patterns, for example the cultivation of some vegetables in small irrigated farming around the Wadis. As their need for cash increased, their agricultural strategies gradually became market-oriented (Abdul-Jalil, 2006). Oil seed’s production (peanuts, sesame and watermelon seeds) on the Goz soil has been greatly expanded to meet a growing export market. Vegetables and fruits cultivation are increasingly practiced when conditions permit. Small urban centers provide excellent marketing opportunities for such ventures.

Increase of market-oriented livestock breeding

Young et al (2005) report that sheep raising has become more favorable due to the expansion of the Sudanese livestock export market. Many nomadic pastoralists began to change the structure of their herds by concentrating more on sheep and less on camels. Moreover, export-led demands and the rise in the domestic consumption of red meat since the 1970s have influenced changes in herd composition in the livestock production system by encouraging a significant proportion of the cultivating population to become agro-pastoralists, thus creating a new class of wealthy groups investing in livestock production (Young et al., 2005).

5.3 Motivation of the Study

Land use/Land cover is a complex phenomenon affected by biophysical, demographic and socioeconomic factors. As such, it is important to investigate and understand the causes which play major roles in land degradation, particularly considering that a multitude of human and animal causes may contribute to land-use change trajectories and hence degradation. Their contributions are significant and vary over time and space according to specific human environmental conditions. This makes it difficult to create general explanatory models for land-use change. Meanwhile, comparative analyses of land-use dynamics will help to improve the understanding of the causes for land-use change and its impact (Lambin et al., 2003). Ibrahim (1982) identifies that land degradation and diminishing productivity are the major problems in the semi-arid areas of Sudan, while the actual causes of degradation are human activities. Therefore, it is important to study the social aspects of land use/land cover (LULC) changes and their environmental consequences in this region.

5.4 Methodology

5.4.1 Qualitative Data Collection Techniques

Qualitative information related to the socio-economic aspects of land-use changes and their impact on rural communities' livelihoods are an important tool for understanding the overall perception, attitudes and beliefs of the rural communities regarding their livelihoods in a degraded environment and its changing circumstances. This may help to understanding how people perceive land-use changes, how they explain it and react to the challenges encountered.

Qualitative research implies an emphasis on the qualities of entities and on processes and meaning that are not experimentally examined or measured in terms of quantity, amount, intensity, or frequency (Denzin & Lincoln, 2000). Quantitative studies, in contrast, emphasize the measurement and analysis of casual relationships between variables that are not processes. On the other hand, qualitative research seeks to discover the meaning that participants attach to their behavior and how they interpret situations (Woods, 2006). Patton (2002) reports that qualitative findings grow out of three kinds of data collection: (1) in-depth, open-ended interviews; (2) direct observations; and (3) written documents. Qualitative findings may be presented alone or in combination with quantitative data. At the simplest level, a questionnaire or interview that asks both fixed- choice (closed) questions and open-ended questions is an example of how quantitative measurement and qualitative inquiry are often combined (Patton, 2002) .

Merriam (2009) asserts that qualitative data focuses on understanding of how people interpret their experiences, how they construct their words, and the meaning that they attribute to their experiences. According to Patton (1990), qualitative records contain descriptions of "situations, events, people, interactions, and observed behaviors; direct quotations from people about their experiences, attitudes, and beliefs; and excerpts of passages from documents, correspondence, records and case histories." The resulting data may be coded for themes and interpreted qualitatively, or they may be coded and translated into quantitative data that is analyzed statistically (Boyatzis, 1998). This then leads to a detailed formulation or description of the current situation in the area.

5.4.2 Materials & Method

5.4.2.1 Survey Techniques

A field survey was conducted during the period from February to April 2010, including visits to 4 randomly selected villages within Edd Al-Fursan locality, namely: Ghanatir, Eraida, Dughgura and Elghaba (Figure.5.1). The qualitative data were collected using questionnaires, interviews, and group discussions to get a broad view about rural population's current perception about changes in land use and its impact on their life in the study area.

Figure 5.1 Sample photos of the selected villages, photo by the author, 2010

5.4.2.1.1 Questionnaire

Cross-sectional primary data were collected using a pre-constructed questionnaire designed to obtain information about the social characteristics of respondents, drought and its affects on the study area, the impact of land-use change on agricultural production, livestock production as well as pasture and forest production. The questionnaire was built on the author's background knowledge of the study area, group discussions with the key informants, and numerous questionnaires completed during previous research in the region. Moreover, a pre-test with five rural persons 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.

5.4.2.1.2 Key Informants Interview

To obtain information about historical changes in the study area, an interview was held with five elderly rural people from each village. The information focused on the changes in land use and land degradation, crop productivity, cultural practices and grazing species composition (for example disappeared, decreased, increased and invader plant species). However, in the local community, narration is the only means for documenting such information from generation to generation, and this knowledge may disappear with the death of the knowledgeable elderly persons, if other means of documentations were not used. This information can play important roles in restoring the degraded agricultural and pasture lands. 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 for restoration efforts, particularly for regions where degradation has occurred within the timeframe of local residents' memories.

5.4.2.1.3 Sample Size and Selection of Respondents

The sampling percentage amounts to 25 % from each village. 100 respondents were selected for this study. Gender dimensions were taken into account, and between five to eight women were selected in each village. The selected villages represent different geographical locations in the Edd Al-Fursan locality covering eastern, western, northern and southern regions. The random sampling method was used for to select the villages. The advantage of random sampling, as Hinton (1995) explains, is that each member of the sampled population can represent the entire population and has the same probability of being chosen. Hamid (2008) randomly selected 100 respondents to represent rural households in Edd Al-Fursan locality. Hinton (1995) argues that 25 respondents successfully represent the population in social studies.

For each village, a list of household owners was obtained from village leaders. The age group of 42-65 years was selected in order to use their indigenous knowledge acquired through experience as a reference. The aim was to assess and analyze the nature and magnitude of changes that interviewees perceived to have occurred on their lands over a 36-year period between 1972 and 2008.

5.4.2.1.4 Data Analysis

Data collected from interviews were coded, computerized and analyzed using the Statistical Package for Social Science (SPSS) version 18.00. Descriptive statistics and correlations analysis were used to explain the socio-economic characteristics of the respondents as well as the relationships between different factors, for example factors driving land-use change patterns, and to determine rural people's attitude and perception towards land-use change and its impact on their livelihoods.

5.5 Results and Discussions

5.5.1. Key Informant

The author is aware that the accuracy of this source of information is limited. However, after filling the questionnaire, all key informants were invited for discussion. The objective of this exercise was to verify the information provided by individuals. The age of key informants ranged from 62-78 years.

5.5. 1.1 Changes in Land-Use Patterns, 1972-2008

The key informants report that the dynamics of changes in land-use patterns were evident in Edd Al-Fursan locality during this period. They narrated that the natural resource situation during the 1970s was better than the latest decades despite drought conditions in the sixties and seventies. During these decades, the human population was lower, and agricultural land was properly used by local people. Consequently, there was a long fallow period ranging from 5-10 years and agricultural productivity was predominantly high. Therefore, the rate of deforestation was low and the conditions for palatable species in the pastures were favorable, the soil had a better fertility, and the rate of regeneration during the rainy season was high. The key informants also mentioned that during those decades there was an effective mechanism for conflict management between farmers and herders regarding issues of land use. Since the beginning of droughts in the early eighties, natural resources began to degrade, and human and animal populations increased due to human and animal migration from Northern to Southern Darfur. Furthermore, there was a natural increase in animal population. As a main source of income when agricultural productivity decreased, local people cleared forests and food deficiencies occurred. Consequently, food aid was introduced to the area by UN agencies, donor countries and some NGOs. The key informants also mentioned that the years 1983-1985 were considered the severe period of droughts as well as 1989, 1993, 1995, 2002 and 2007, which were less severe. As the result of recurring droughts, and conflict and war in the region, human and animal populations began to concentrate in areas with less conflict in the region, and this led to land resource degradation in recent decades. Respondents indicated that the degradation of land led to lower crop productivity, lack of palatable grazing species and a delayed regeneration period, and this resulted in decreased soil fertility. However, as a result of land degradation, land-use patterns changed in terms of over-cultivation without a fallow period, overgrazing and overcutting of trees for fuel wood, market purposes, agricultural expansion or building materials. Meanwhile, key informants identify that different grazing species, which were predominant in the region 30 years ago, are currently no longer present, or are available in limited amounts, including Difra *Echinochloa colonum*, Affan el khadeem *Chloris virgata,* Lessai*g, Zornia glochidiata* and Um malih *Sporobolus marginatus.* At the same time, the respondents mentioned some species which are not palatable for grazing, such as Hurab hawsa *Acanthospermum hisbidum* and Elnaiada, *Abutilon spp.*

5.5.2 Socio-Economic Characteristic of the Respondents

The respondents interviewed in this study were women (24 %) and men (76 %) with an age range of 42 to 65 years, as Table 5.1. illustrates.

Table 5.1 Age of the respondents

Age	(%) N^*=100
42-47	54
48-53	19
54-59	12
60-65	15
Total	100

N^*= sample size

Source: Field survey, 2010

The size of a rural family is normally large. The study results indicate that the majority of respondents (91 %) had a family size that ranged from four persons to more than eight persons. The large increase in the human population in recent years, especially in South Darfur State, has led to increased demands for food, which resulted in misuse of land and other natural resources.

5.5.2.1 Household Livelihoods

Figure 5.2 illustrate the main livelihood of respondents in the study area. Agricultural production constitutes the highest percent (44 %). Field crop cultivation represents the main farming activity, where all farmers are involved. The major field crops are millet, sorghum, and groundnuts. With respect to the type of crops, farmers in the region concentrate more on field rather than horticultural crops. This can be attributed to the fact that field crops are grown during the rainy season and horticultural crops require supplementary irrigation that is not accessible by most farmers. Moreover, inputs for horticultural crops are very costly and thus not affordable for farmers. Therefore, livestock production plays an important role in supporting rural families especially when the role of crops is decreasing as a result of drought and the negative impact of pests and diseases that cause frequent crop failure/damage. The results show that about 19 % and 8 % of the respondents were agro-pastoralist and pastoralist, respectively.

Casual labor has an important role in family income especially due to the fluctuation of farm income. As Figure 5.2 illustrates, 10 % of the respondents worked as casual laborers and 8 % were migratory labor who migrate to a nearby city for work in the markets, building construction, brick making, etc.

Wild food and forest products have always been important sources of food and were commonly used during the dry season, before the harvest, in the study area. About 7 % of the respondents reported that their main livelihood activity is the collection of wild food and forest products. The common species utilized by the household include Hijlej *Balanites aegyptiaca* Aradaib *Tamarindus indic*), and Gimbeel *Cordia abyssinica aethiopumand* Doom *Hyphaene thepaica*. Cutting firewood, charcoal production and materials for huts construction are important coping strategies that supplement household income, particularly for rural families who have no other means of income. Without exception, all village communities depend on forest products to supplement their livelihood. The trade activity represents the lowest percent; however, 4 % of respondents mentioned that they trade sugar, tomatoes, oil, tea, wild food and milk during the rainy season.

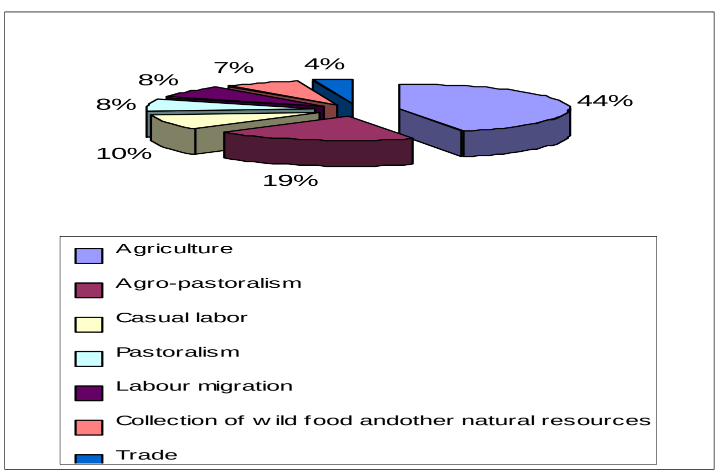

Figure 5.2 Main livelihoods of respondents in the study area
Source: Field survey, 2010

5.5.3 Drought and its Affects on Household Economic Activities

Frequent drought and environmental degradation are the major obstacles for livelihood security and food self-reliance especially in rural South Darfur State (Milani, 2006). According to the Central Bureau Statistic (2004), over 78 % of the state's population lives in rural areas, depending on agriculture, pastoralism and livestock rearing to secure a living.

Since the famous famine of 1984/85, the Southern Darfur region has been exposed to drought cycles during 1987, 1989, 1990, and 1993 (NAPA, 2007). Each drought caused crop failure, loss of livestock, reduction of forest areas and degradation of pasture lands (Morrod, 2003). This statement corresponds to the respondent's opinion that drought had become a common phenomenon in their area. However, 92 % reported that drought occurred in frequencies between 3 to 5 years, and could be attributed to the lack and variability of rainfall, and environmental degradation. Natural resources have been overexploited in the study area, largely as a result of recurring droughts as well as overpopulation (Table 5.2), which was reported by 90 % of the sampled respondents. Charcoal burning and cultivation of marginal lands constitute the highest percent 27.8 %, followed by cultivation of marginal lands and both overgrazing and cultivation of marginal lands, which represents 25.6 % and 20 % respectively. These figures indicate that the majority of rural people depend on agricultural land for their living. Moreover, overgrazing occurred as the result of pasture degradation, when the number of livestock exceeded the current capacity of the pasture. Therefore, charcoal production constitutes the main source of income during drought years when agricultural and livestock production decreases.

Table 5.2 Type of overexploitation of natural resources during drought years as reported by respondents.

Type of exploitation	Percent (%) N^*=100
Increased charcoal burning and cultivation of marginal lands	27.8
Cultivation of marginal lands	25.6
Overgrazing and cultivation of marginal lands	20
Increased overgrazing	12.2
Charcoal burning, overgrazing & cultivation of marginal lands	7.8
Charcoal burning and overgrazing	3.3
Charcoal burning	3.3
Total	100

.

N^*= sample size

Source: Field survey, 2010

5.5.4 Land-Use Changes and its Impact on Household Livelihoods

In recent years, patterns of land use have changed significantly in South Darfur State, largely as a result of frequent drought, land degradation and environmental crises. About 88 % of the respondents agreed that the pattern of land use has changed between 1972 and 2008. Table 5.3 describe these changes. A shift in livelihood strategies and cutting trees constitutes the highest percent (18 %), followed by a shift in livelihood strategies only (15 %), while over-cultivation of marginal lands and cutting of trees ranked third (14 %). In recent years, most rural households started to adapt new livelihood strategies to the extent that "sedentary agro-pastoralists are keeping more animals and pastoralists are growing more crops," which accelerates competition for land resources, and therefore over-cultivation and overgrazing. Accordingly, cutting trees either for building material, fuel wood or for market purpose has been practiced by the local people and this led to deforestation in the study area. Moreover, all respondents have mentioned several reasons for land-use change in the area, particularly the recurrence of drought, environmental degradation, conflict and war, and an increased human and animal population. The increased population density has intensified cropping and grazing, and this leads to shorter fallow periods for fields and overgrazed rangeland. These processes cause deterioration in yields and lower the carrying capacities of pasture. This situation corresponds with Abdella (2004) who reports that the presence of drought combined with population growth in the Darfur region increased demand for fuel and pressure for more food production, which led to a shortened fallow period and to the removal of vegetation cover and reactivation of sand dunes. Furthermore, decreased income has forced the local population to look for other available livelihood options, which in turn adds to the processes of degradation. In recent years, the intersection between environment and population pressures can result in increased violence, crop destruction, and stress on traditional dispute mechanisms.

Table 5.3 Description of land-use changes by the respondents

Description of change	**Percent (%)** N*=100
Shift in livelihood strategies and cutting trees	18.1
Shift in livelihood strategies	14.9
Over-cultivation of marginal lands and cutting trees	13.8
Shift in livelihood strategies and overgrazing	9.6
Shift in livelihood strategies, over-cultivation of marginal lands, overgrazing and cutting trees	7.4
Overgrazing	6.4
Over-cultivation of marginal lands	6.4
Shift in livelihood strategies, over-cultivation of marginal lands and cutting trees	5.3
Shift in livelihood strategies & over-cultivation of marginal lands	5.3
Over-cultivation of marginal lands and overgrazing	4.3
Overgrazing and cutting trees	3.2
Shift in livelihood strategies, overgrazing and cutting trees	3.2
Cutting trees	1.1
Shift in livelihood strategies, over-cultivation of marginal lands and overgrazing	1.1
Total	100

N* = sample size

Source: Field survey, 2010

The results show that the correlation coefficient between the type of natural resource exploitation during drought years and the patterns of land-use change is positive and significant, reported as 0.50 (Table.5.4). It is clear that droughts play a major role in natural resources degradation, which results in land-use change.

Table 5.4 Correlation between type of natural resource exploitation and land-use change patterns

		Type of exploitation	Description of land-use change
Type of natural resources exploitation	Pearson correlation	1	.496**
	Sig. (2-tailed)		000
	N	90	88
Description of land-use change	Pearson Correlation	.496**	1
	Sig. (2-tailed)	000	
	N	88	94

** Correlation is significant at 0.01 (2-tailed)

5.5.5 The Impact of Land-Use Change on Soil

There are two main types of soils in South Darfur State (Figure.5.3): the sandy soils and the dark clay soils. The sandy soils are mainly stabilized sand dunes known locally as Goz lands. The clay soils are vertisols with high clay content. Other than these two soils, there are the Pediplain soils, which are locally known as *gardud,* or *Naga'a*[1] soils, which are located in limited areas (D-JAM, 2006).

[1] Hard surface sandy loam soils

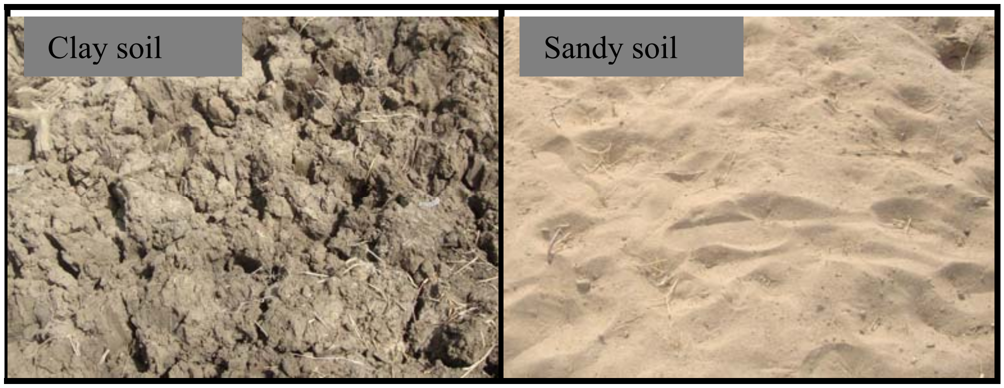

Figure 5.3 Soil types in the study area, photo by the author, 2010

Due to the overexploitation of natural resources and environmental degradation, soils in South Darfur State are degraded. The degradation of land means the loss of some or all of its productive capacity as the result of climatic factors and/or human activity (WMO, 2005). However, soil erosion occurs due to unwise human action, such as overgrazing, deforestation or over-cultivation, which leaves the land vulnerable during times of erosive rainfall or heavy winds.

The majority of the respondents (88 %) (Figure 5.4) identified that two types of soil erosion are common in the study area. 59.2 % of respondents mentioned that soil erosion was caused by water run-off during the rainy season, while 23.3 % reported that soil erosion was due to wind movement, and 17.5 % of respondents argued that soil erosion was caused by both factors. The most serious impact of erosion threatens the sustainability of agricultural productivity. Crops are particularly reliant on nutrients and water found on the upper horizons of soil, which are the most vulnerable to erosion by both water and wind.

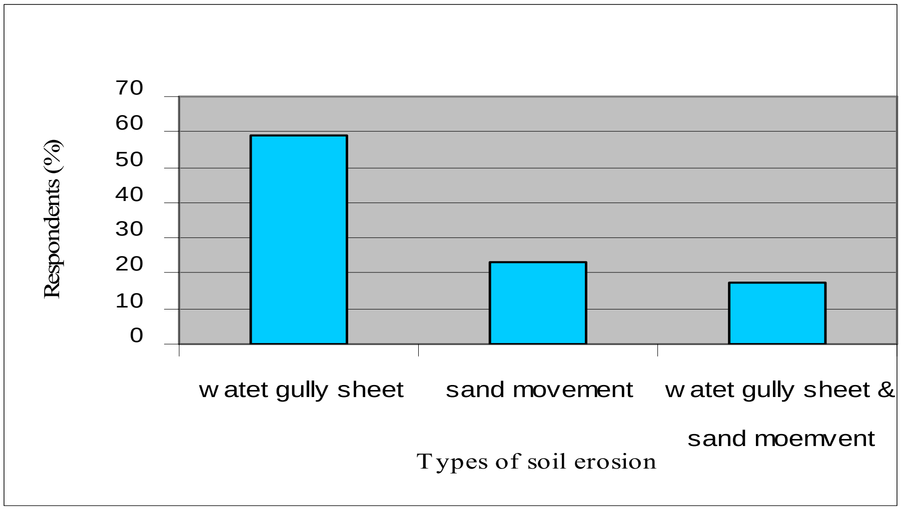

Figure 5.4 Dominant types of soil erosion in the study area
Source**:** Field survey, 2010

5.5.6. The Impact of Land-Use Change on Agricultural Production

Agriculture is broadly defined to include crop production, forestry, fruit and vegetable production. Philips (2008) argues that increased agricultural productivity would help meet the food and nutritional needs of Darfur's population, which has increased about seven-fold since the 1960s. Currently, Darfur's population is estimated to be 28 percent of Sudan's population.

Two types of traditional rainfed agricultural production are common in the study area. These include subsistence and commercial agriculture. The sampled respondents identified that subsistence agriculture constitutes the highest percent (75 %), while commercial agriculture comprises only 25 %. Moreover, the type of agricultural practice significantly depends on the land tenure system and on the size of holding that the individual owns. Figure 5.5 shows the different types of land ownership in the area. The land ownership ranges from landless (37 %) to inherited land (31 %), leased (20 %) to purchased (8 %) and donated land (4 %). Despite the fact that traditional agriculture, particularly Goz cultivation, is considered small-holders' subsistence form of land use, it faces increasing conflicts with other forms of land use. This is evident in the gradual increase in farm size and number of plots per household. This, in turn, has resulted in competition for land and a gradual shortage of land. Many factors have contributed, with varying magnitude, to this evident change in the traditional pattern. The prominent factors include desertification, increased livestock numbers and increased demands for food production. All these factors have ultimately resulted in tenurial and land-resource related conflicts in Darfur.

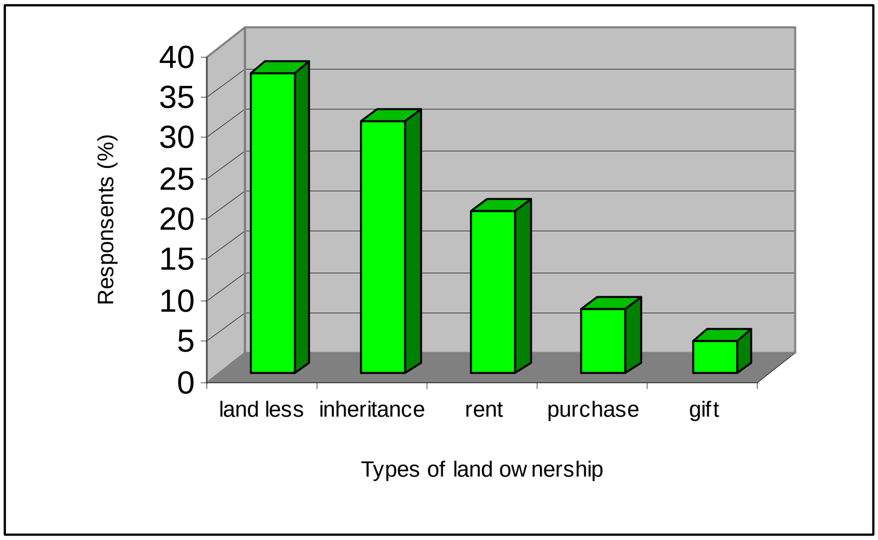

Figure 5.5 Types of land ownership
Source: Field survey, 2010.

The size of land holdings as indicated by the respondents are illustrated in Figure 5.6. The majority of respondents (56 %) own less than 5 feddans, 5-10 feddans are owned by 38 %, while only 6 % owned more than 10 feddans.

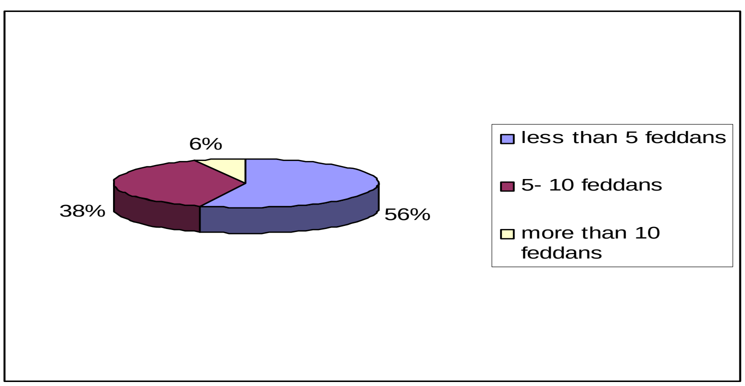

Figure 5.6 Size of land holding
Source: Field survey, 2010.

All respondents state that they grow different types of crops, including millet **(***Pennisetum typhodium),* sorghum (*Sorghum bicolor)*, groundnut (*Arachis hypogea),* and sesame (*Sesamum indicum),* which are the major crops in the study area. Millet and sorghum are the main staple food while the rest constitute cash crops.

In recent years, the productivity of farming crops in South Darfur State is hampered by low and declining rainfall, land and soil degradation, repeated grazing and cultivation without fallow or rest periods, poor traditional land tenure systems, and disfunctional user arrangements as well as isolation from extension services and markets (Phillips, 2008). About 81 percent of the respondents indicated that the fallow periods are shorter now (less than 4 years), due to the scarcity of agricultural lands and high food demands. Moreover, farming is also affected by the customary practice imposes that unused land reverts back to communal ownership and is subject to redistribution through established customary channels.

The majority of the respondents (79 %) mentioned that the farming harvest has been insufficient in the last 10 years, largely because of rainfall variability, land degradation and a lack of extension services. Moreover, more than half of them (62 %) agreed that the farming harvest was not enough for family consumption and marketing purposes.

Small-irrigated farming around the wadis is evident in the study area (Figure 5.7). One third of the respondents mentioned that they had previously owned a mixed farm, on which different types of vegetables (for example, tomatoes, sweet potatoes, onion, peppers, and okra) are grown. The vegetables are either sold in the villages or exported to nearby cities in the study area. The respondents indicate that this type of farming is economically viable, but lacks agricultural inputs (for example improved seeds and fertilizers). The farming land is irrigated by flood water of wadis or by diesel-powered pumps. The cost of the latter type of irrigation is relatively high.

Figure 5.7 Small irrigated farm (cultivating onions) in the wadis in the study area, photo by the author, 2010

As the result of land degradation and a decline in crop production, many people have abandoned their agricultural land. 60 %of respondents reported this phenomenon and most of them mentioned that people have left to work in the cities in building construction, brick making and water selling, as they presented better livelihood options. The current rate of outward migration to Libya, Egypt and others Arab Countries due to these reasons was high, as indicated by 75 % of respondents.

The coefficient of correlation between abandoning the farming system due to land degradation and the current rate of migration due to land degradation indicates a positive and significant correlation of 0.46 (Table 5.5).

Table 5.5 Correlation between abandoning farming due to land degradation and current rate of outward migration

		Abandoning farming due to land degradation	Current rate of migration
Abandoning farming due to land degradation	Pearson correlation	1	.460**
	Sig. (2-tailed)		000
	N	100	100
Current rate of migration	Pearson Correlation	.460**	1
	Sig. (2-tailed)	000	
	N	100	100

** Correlation is significant at 0.01 (2-tailed)

5.5.7 The Impact of Land-Use Change on Livestock Production and Pastures

Livestock is an important sector of the rural economy in South Darfur State. In this sector, rural people keep different types of animals, for example cattle, goats. sheep and donkeys. Respondents indicate that the latter is kept by all rural households for transportation and agricultural farm operations. The number of livestock kept by respondents ranged from 6-33 heads (per household).

All communities, including the nomads, pastoralists and sedentary communities in Southern Darfur, depend on vegetation and natural pasture for their livelihoods. In recent years, decreased levels of rainfall have led to a change of species composition. Tahir and Siddig (2007) depict that the total number of livestock in South Darfur State is estimated to be about 7.5 million animal units. This huge number of both transhumance and sedentary livestock has grazed a limited area of rangeland (about 26,000 km²) during the wet season for many years, since the land system is communal, whereby everyone has the right to graze on the lands, and this result in poor quality and low quantity forage in the area.

However, mobility in search of pastures and water in neighboring areas is an important livelihood strategy for the pastoralists and they have adjusted their seasonal movement in response to periodic drought conditions. The study results showed that about 92 % of the respondents identified that nomadic movements are evident in the study area. During the rainy season, a large number of nomads come from Central Republic of Africa and Chad and respondents believe that these nomads impact the pasture (Figure 5.8). More than half of the respondents (53 %) mentioned that the nomadic movements have severely degraded the pastures. Overgrazing has contributed to the change of some grazing species. Table 5.4 and 5.5 show the dominant species at the time of the study and species that were prominent 30 years ago, as reported by the respondents. Comparing Tables 5.6 and Table 5.7, it is possible to see that a number of palatable grazing species had disappeared, for example Nagila (*Cynodon dactylon),* Difra *(Echinochloa colonum),* Beghail (*Blepharis linariifolia),* Haskanit *(Cenchrus biflorus),* Elorz elghalo (*Orza barthii),* and Ashrut *(Tephrosia spp).* Similarly, new species have emerged, including Bano (*Echinochloa colonum),* Abogeghra (*Brachiaria spp),* Hurab hawsa (*Acanthospermum hisbidum),* Elnaiada, (*Abutilon spp),* and Umdofofo (*Pennisetum pedicellatum).* Other species are also present, such as Um malih (*Sporobolus marginatus)* and Abosabi (*Dactyloctenium aegyptium).* Moreover, some of the new species that have appeared in recent years are not palatable for grazing as indicated by the respondents, for instance Hurab hawsa (*Acanthospermum hisbidum)* and Elnaiada, (*Abutilon spp).*

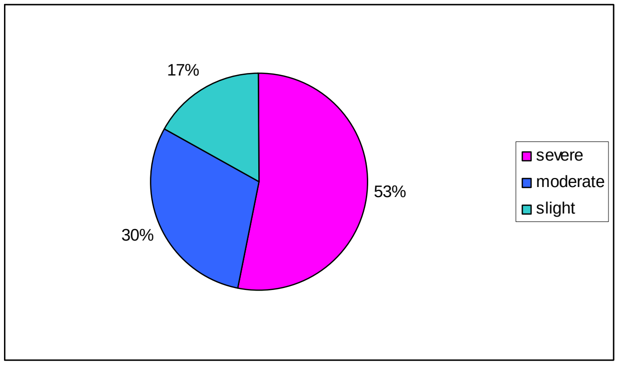

Figure 5.8 The impact of the nomadic movement on the severity of pasture degradation

Source: Field survey, 2010

Table 5.6 Dominant grazing species in the study area in the past 30 years

Species local name	**Species scientific name**	**Respondents (%)**
Beghail	*Blepharis linariifolia*	88 %
Um malih	Sporobolus marginatus	86 %
Difra	*Echinochloa colonum*	72 %
Abosabi	*Dactyloctenium aegyptium*	65 %
Haskanit	*Cenchrus biflorus*	43 %
Nagila	*Cynodon dactylon*	42 %
Elorz elghalo	*Orza barthii*	33 %
Ashrut	*Tephrosia spp*	16 %

Table 5.7 Dominant fodder species for grazing in the study area as reported by the respondents during the current survey

Species local name	**Species scientific name**	**Respondents (%)**
Umdofofo	*Pennisetum pedicellatum*	84 %
Hurab hawsa	*Acanthospermum hisbidum*	80 %
Elnaiada	*Abutilon spp*	78 %
Bano	*Eragrostis spp*	73 %
Abogeghra	*Brachiaria spp*	65 %
Um malih	*Sporobolus marginatus*	46 %
Abosabi	*Dactyloctenium aegyptium*	38 %

The study results indicate that the conditions of palatable species are negatively and significantly correlated with the impact of nomadic movement on the area at -0.43 (Table 5.3)

This indicates that the severity of the impact of overgrazing resulted in the reduction in the number of palatable species.

Table 5.8 Correlation between the conditions of palatable species and the impact of nomadic movement in the area

		Conditions of palatable species	Impact of nomadic movement in the area
Conditions of palatable species	Pearson correlation Sig. (2-tailed) N	1 63	-.433** 000 63
Impact of nomadic movement in the area	Pearson Correlation Sig. (2-tailed) N	-.433** 000 63	1 99

** Correlation is significant at 0.01 (2-tailed

The respondents indicated that all their animals graze outside and far away from their villages, in search of palatable fodder species as these species are not present around the villages during both the rainy and dry seasons (Figure 5.9). Accordingly, as the result of pasture degradation, the livestock suffers due to forage deficiency, which results in the prevalence of animal diseases that negatively impacts animal production in the study area.

Figure 5.9 Animal grazing outside the village in the study area photo by the author, 2010

5.5.8 The Impact of Land-Use Change on Forest Production

Firewood remains the main source of energy for most rural people in Southern Darfur. All respondents indicated that they own forest/wood lands in their area and that they use the products from trees for different purposes, for example building material, fuel wood, brick making, and charcoal production (Figure 5.10 & 5.11). Table 5.9 describes the favorable trees used for charcoal production, as indicated by the respondents. One-third of the respondents agreed that the favorable tree species for charcoal making were Sunut (*Acacia nilotica)* and Arad *(Albizia amara),* followed by 11 % who mentioned that sunut (*Acacia nilotica)*, hashab (*Acacia senegal)* and keter (*Acacia millefer*a) were the favorable tree species. All respondents stated that the rate of deforestation due to charcoal production, agricultural expansion and other activities is high to moderate. However, continued deforestation in the study area has contributed to soil erosion and land degradation.

Table 5.9 Favorable tree species for charcoal production

Local tree name	**Respondents (%)** N*=100
sunut & arad	29.6
sunut, hashab & keter	11.1
keter, sunut & hejlij	9.3
sunut, arad & keter	9.3
sunut, arad & hashab	9.3
sunut, arad & hejlij	7.4
arad & keter	3.7
sunut, keter, heljeij, & arad	3.7
hashab, keter & arad	3.7
sunut, arad, hejlij, keter & hashab	3.7
sunut & hashab	3.7
arad & keter	1.9
heljej & keter	1.9
arad & hejlij	1.9
Total	100

N*= sample size

Source: Field survey, 2010

Table 5.10 Scientific names of the tree species

Local name	**Scientific name**
Sunut	*Acacia nilotica*
Arad	*Albizia amara*
Hashab	*Acacia senegal*
Hejlij	*Balanites aegyptiaca*
Keter	*Acacia mellifera*

Figure 5.10 Firewood collections for brick production in the study area,
Photo by the author, 2010

Figure 5.11 Building materials and charcoal marketing in the study area,
Photo by the author, 2010

5.6 Conclusions

The issue of land use in the study area is directly related to land tenure systems and their changes are affected by different factors: demographic, biophysical and socio-economic factors. These include overpopulation, drought condition, migrations, increased commercialized farming as well as conflicts and war. The local people reveal that due to restriction of land ownership combined with unsustainable land management systems have limited their ability to cope with the demand for farms and pastures. As the number of people and animals increased, the land itself has become degraded through over-use and decreased rainfall.

The study results show that land-use changes between 1972 and 2008 have severely impacted the rural livelihood in terms of natural resources availability as indicated by low crop production, degradation of soil, forests and pasture. This has increased the suffering of rural people as they face food shortages and low incomes that threaten the sustainability of their livelihoods.

CHAPTER SIX

Complementary Use of Remotely Sensed and Socio-Economic Data

6.1 Abstract

This chapter attempts to establish links between socio-economic variables and satellite data. The study demonstrates that the LULC classes derived in the study by remote sensing are influenced by socio-economic variables. Furthermore, a demographic variable for example, population growth, is directly related to these classes. The causes of land-use change and their affects on natural resources, the environment, and livelihoods are modeled in this chapter. The model presents the following dominant land uses in the area: agricultural land, pasture land, fallow land, and forest land. At the same time, the model shows that the major causes of land-use change are: socio-economic factors (population and animal growth, conflicts and war) and bio-physical factors (drought condition). The study shows that some of the most profound changes have arisen from human activities concerning land miss-use, and the overexploitation of these have affected both the quality of natural resources, such as soils and forest, as well as the sustainability of food production. Moreover, it suggests that for predicting future land-use change methodologies are required that integrate and understand the processes affected by socio-economic and bio-physical drivers.

6.2 Introduction

Land is an essential asset and means to sustain rural livelihood. However, due to recent rapid growth in human population, the land-use land cover of the earth has been transformed especially in developing countries (Codjoe, 2007). At the same time, social organizations, attitudes and values have also experienced profound changes,

Lambin et al. (1999) argue that in order to understand environmental changes, it is important to consider the conditions and changes in land cover in combination with changes in land use, the rates of change in conversions, modifications and maintenance, processes of use, and the human forces and social conditions that influence the types and rate of processes. Meanwhile, land-use patterns are closely linked to cultural practices that shape local and regional resource management practices, subsistence practices, landscape perceptions, and land-use history (de Sherbinin et al., 2002). However, the integration of cultural and natural elements of land use can facilitate the holistic modeling of the past and present human settlement patterns.

Recently, social and physical scientists have begun to study the issue of integration of physical variables derived from remote sensing with collected socioeconomic and demographic data. Such integration leads to a better understanding of human impact and of human drivers of environmental and social changes.

Beginning in the 1970s, in the social science field, Reining (1979) and Conant (1978) conducted human ecology studies in Africa. Their studies were among the first initiatives that linked socio-economic data obtained from local populations and the study of their subsistence systems with remotely sensed Landsat data.

Other studies reflect the growing need for the social science community to use remotely sensed data in combination with demographic and socioeconomic data to study land-use change dynamics or to better understand the spatial distribution of population and socioeconomic phenomena. Several authors study the correlation between population data from the census, or collected from social survey at the village level, and land use/ land cover characteristics derived from satellite imagery (for example, Yuan et al., 1997; Radeloff et al., 2000). In addition, they also began to examine the correlation between biophysical and social variables. Lo and Faber (1997) conducted a case study that illustrates the correlation between environmental variables extracted from Landsat data and socioeconomic data from the census indicate that a combination of satellite data and census data determine livelihood assessment with an environmental perspective.

6.3 Link between socio-economic data and land use/land cover change classes in Edd Al-Fursan Locality

This section uses the results presented in Chapter 3 identifies the use of satellite imagery analysis to describe patterns of land use/land cover changes between 1972 and 2008 in the area. However, the patterns of LCLU change revealed by the imagery provide little information on the drivers of change. In contrast, the findings of the household survey (see Chapter 5) identify many of the fundamental driving forces behind land-use changes that occurred during that period. For example, the change of forest to agricultural land between 1972-2008 has been classified based on satellite imagery, while the causes and impact of this change have been reported by respondents.

Serra et al. (2008) mention that the dynamic change of LULC is mainly influenced by biophysical and human driving forces. However, as the result of population expansion in South Darfur State and Edd Al-Fursan area particularly as well as of climatic variability the demands on land have increased leading to intensive agriculture which is characterized by the over-cultivation of land, overgrazing by animals and deforestation (Figure 6.1).

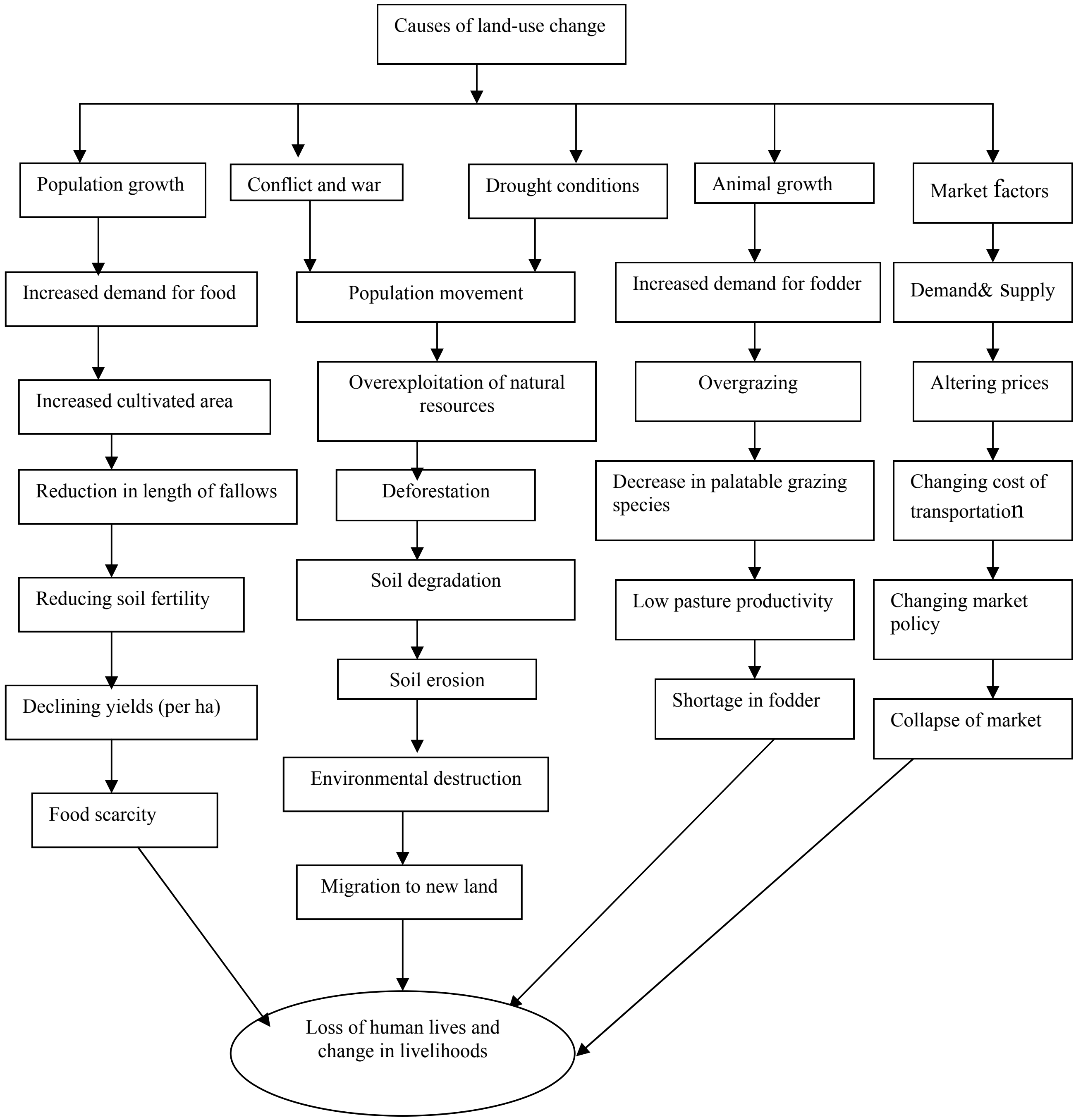

Figure 6.1 Factors driving land use change and their impacts on the livelihoods of the rural Communities

With reference to the time series satellite data and LULC change classes presented in Figure 6.2, links between population growth and LULC change classes can be established (Figure 6.3).

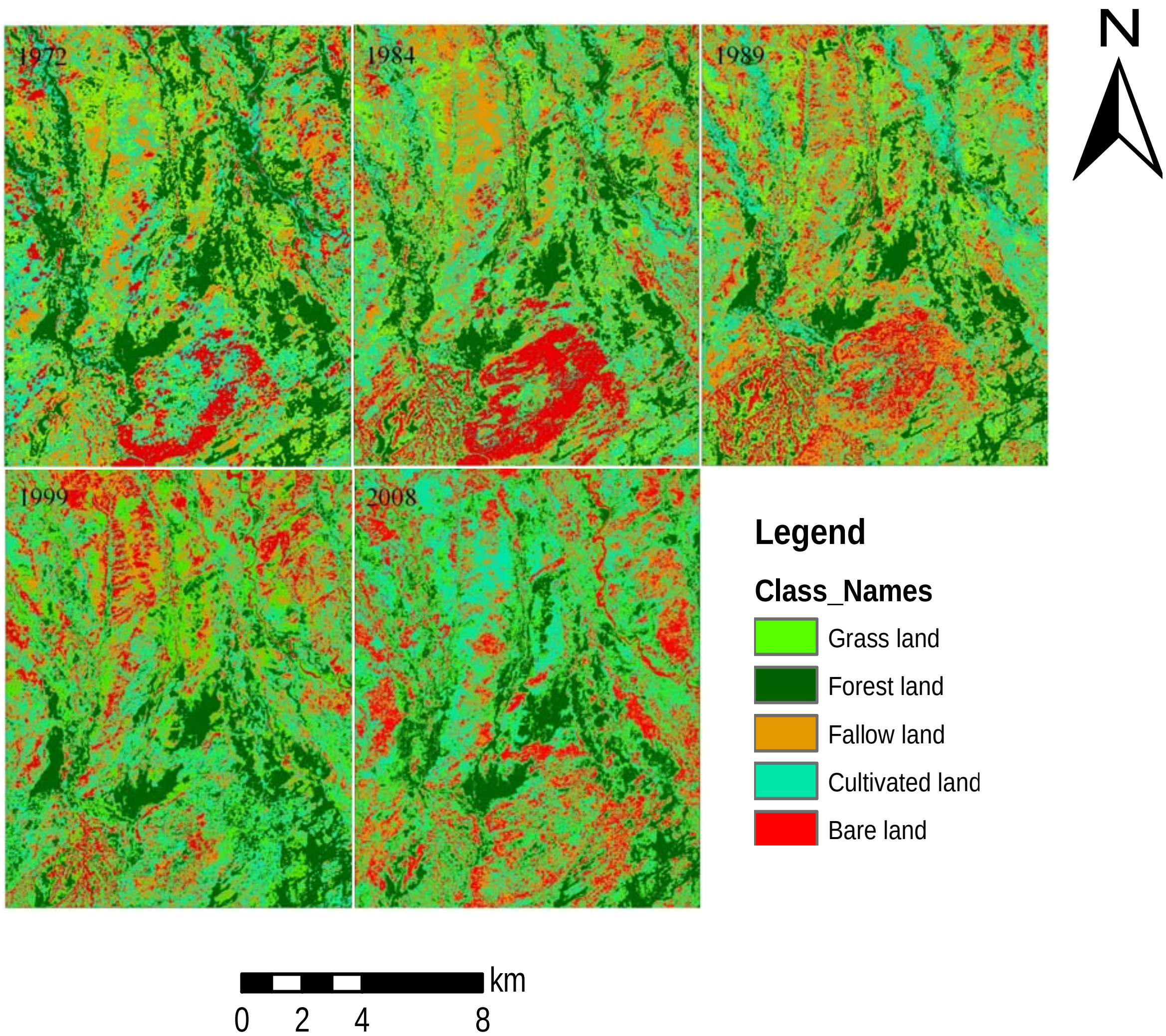

Figure 6.2 LULC in the study area for the period 1972-2008.

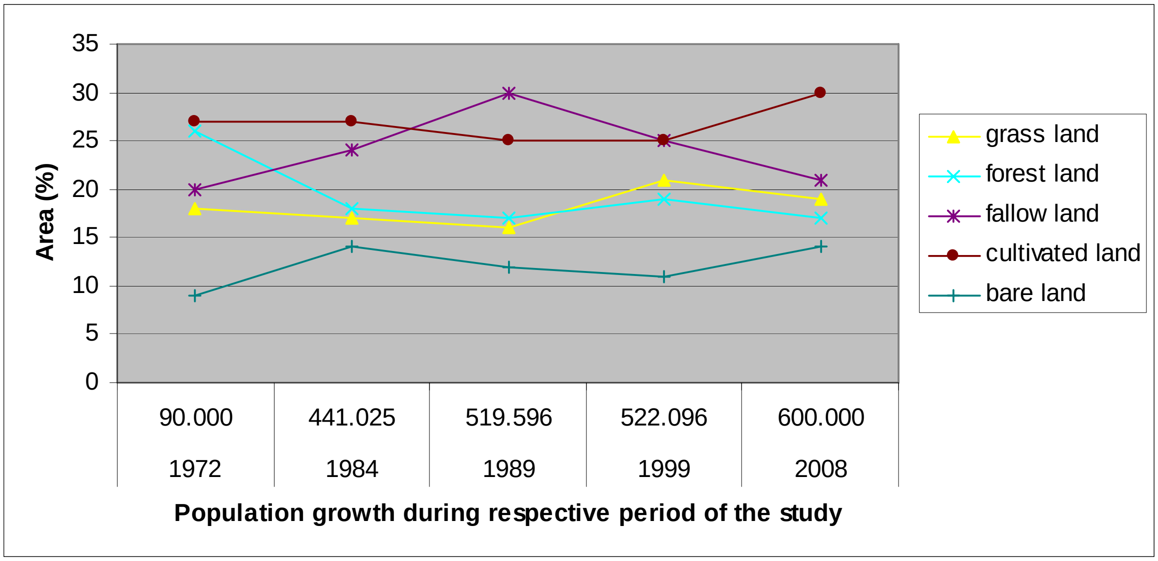

Figure 6.3 Link between population growth and LULC change classes during respective period of study

According to Figure 6.3., there is a direct relationship between human population and land-use change as indicated between 1972 and 2008. Between 1973 and 1984, the area's population increased five times as a result of periods of extreme droughts, which led to migration of people from Northern to Southern Darfur. This period is also characterized by the most significant decline in forest cover from 26 % to 18 %, as well as an increase in bare land. From 1984-1989, the drought was extended and thus, this period can be described by a significant increase in human population. During this 5 year period, there was a low decrease in forest, bare land and cultivated lands, while fallow land significantly increased as the drought forced most farmers to abandon their agricultural land which led to a decrease in bare area. During the 90s. Edd Al-Fursan locality's environment started to recover from drought conditions, despite an increased human population.

Due to conflict and war in Darfur at the beginning of the third millennium, the study area was considered the most secure place and thus it attracted displaced people (IDPs) to concentrate there, leading to an overexploitation of natural resources. Furthermore, forest land decreased from 19 % in 1999 to 17 % in 2008, while fallow land decreased from 25 % to 21 % due to an increased amount of cultivated land (from 25 % in 1999 to 30 % in 2008). Research findings from a number of case studies indicate that high population density may also lead to agricultural growth, as farming intensifies, but may also result in agricultural stagnation, involution and environmental degradation (Kates et al 1993). Here, the key factor is the pace at which the population grows.

Fig. 6.4 describes a model that can be used to explain how the socio-economic data can influence/derive land-use change, as well as how satellite data can be used to determine land-use change classes. Finally, the model interprets how land-use changes impact the livelihood assets of rural households as presented in Chapter 4.

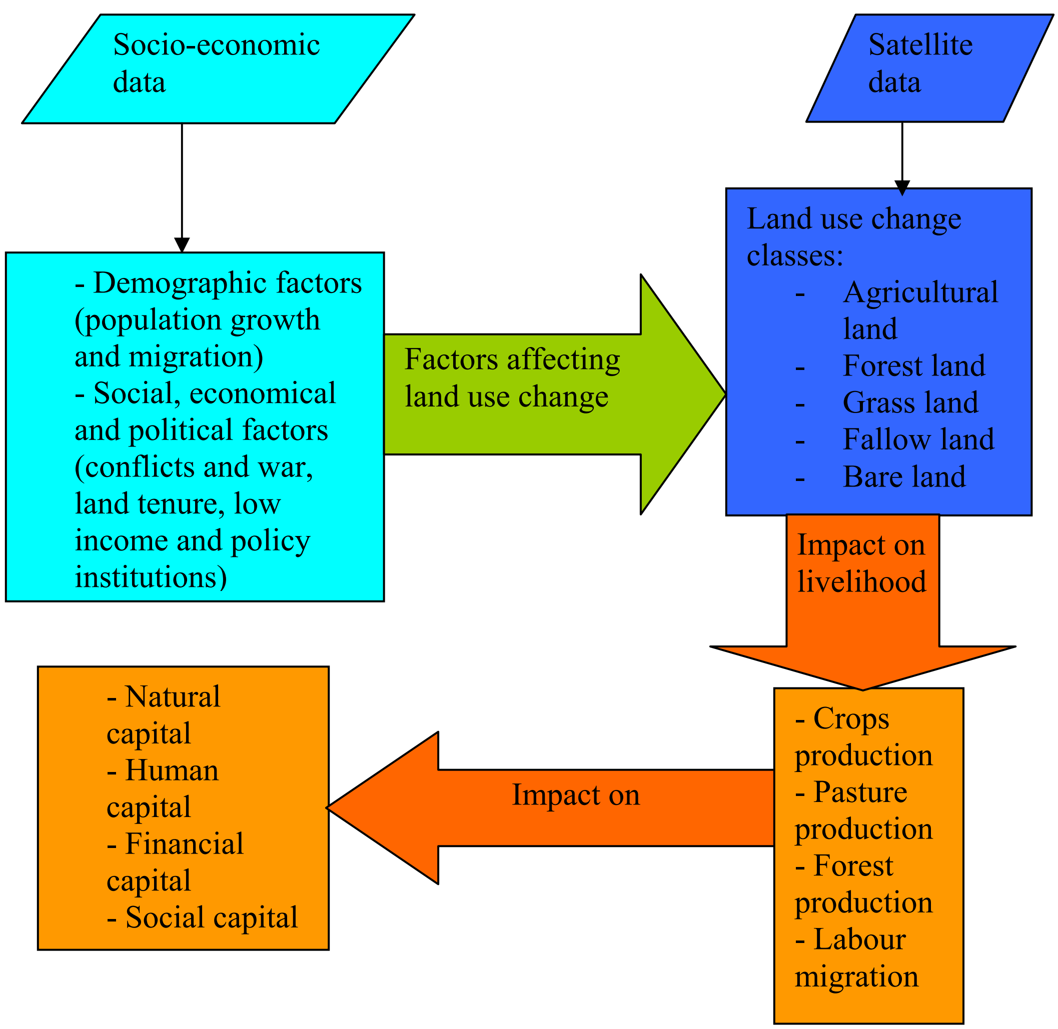

Figure 6.4 This model can be used to assess the relationship between land-use change and human activities and the impact of land-use change on the livelihood of rural communities.

6.4 Conclusions

Socio-economic and satellite data are strongly linked. Remote sensing and global positioning systems (GPS) have given rise to the advent of more precise geographically referenced data on land cover and land use irrespective of interest. Socio-economic data demonstrate factors that encourage land use/land cover changes. The study shows that some of the most profound changes have arisen from human activities concerning land misuse, and overexploitation of these have affected both the quality of natural resources, such as soils and forest, as well as the sustainability of food production. The study provides examples of methodological issues that are of increasing importance for researchers engaged in research about the driving forces of LULC, particularly as very-high resolution remotely-sensed imagery becomes available. Such imagery will provide greater detail about the land-use patterns on the land surface of a variety of biophysical attributes, thus facilitating the analysis of biophysical processes, land-cover patterns and their distributions, these factors' implications for ecological systems, and on the affected populations' livelihoods.

Chapter Seven

Conclusions and Recommendations

7.1 Conclusions

Land-use changes are complex processes that occur as the result of modifications in land cover to land conversion process. Land-use change is the outcome of interaction in space and time between biophysical and human dimensions, while moreover, it also has the potential to impact physical and social dimensions. Land use has been considered the most important factor that influences the livelihood of rural communities. Land-use associated issues play an important role in South Darfur State, as majority of its population depend on the land and its natural resources for their livelihood.

This study attempts to reveal the impact of land-use change on the livelihood of rural communities in Edd Al-Fursan locality, South Darfur State. The main objectives of the study include the following: (1) to use multi-temporal analyses to determine the major land use/land cover change classes; (2) to assess land-use changes between 1972 and 2008; (3) to assess the impact of land-use changes on rural livelihoods, in terms of natural resource availability, by using qualitative techniques and to develop a model that could be helpful for assessing the relationship between human activities and land-use change; and (4) to determine the impact that land-use change has upon rural livelihoods. To achieve these objectives a series technique was used to map and assess land use/land cover changes over the course of the last four decades. In addition to the use of remote sensing imagery, this study also used interviews with key informant and rural people to uncover the relationship between land use and livelihood.

The major land-use classes in the study area are forest land, grass land, fallow land, cultivated land, and bare land. At the same time, the main livelihood activities, as identified by the interviewees, include agriculture, agro-pastoralism, casual labors, pastoralism, labor migration, collection of wild food and other natural resources, and trade. This study identifies that land-use change in the study area is driven by both biophysical, for example drought and environmental degradation, and human factors, such as population growth, conflict and war. The results reveal that the major land-use changes occurred between 1972-1984, 1999-2008 and 1972-2008, as instances of droughts and immigration from north to south Darfur took place, as well as conflict and war in the latest period, which led to the overexploitation of natural resources. As the result of natural resource degradation, forests, which represented 26 percent of all land in 1972, has been cleared and converted into agricultural land, and amounted to 18 percent and 17 percent in 1984 and 2008, respectively. Moreover, the bare land area increased from 9 percent in 1972 to 13 percent and 14 percent in 1984 and 2008, respectively.

The rural people are aware that their natural resources are degrading and that patterns of land use changed during 1972-2008. This is based on their perception and interpretation of indicators such as deforestation, soil degradation, over-cultivation and overgrazing. As the result of land degradation and land-use changes, rural people are unable to cope with the present situation in order to secure their livelihood, as the majority depends on crops and livestock production for their income.

Finally, the study's findings indicate that remotely sensed and socio-economic data can be linked to show how human driven forces affects land use. With reference to time series, this study uncovers that increased human population between 1972 and 2008 in the study area directly affected land use. Moreover, in order to assess the relationship between land-use change and human activities and the impact of land-use change on rural livelihoods, the study proposes a model that illustrates how socio-economic data can be used to provide factors that affect land use. At the same time, remotely sensed data can be used to determine land-use classes and these can be linked to illustrate how land-use change impacts rural livelihoods.

7.2 Hypothesis test

- Given the first hypothesis "the study area's land-use patterns have changed severely between 1972 and 2008," the study illustrates that in general this statement is true, with the exception of 1989-1999.
- With regard to the second hypothesis "remote sensing is an adequate tool for studying and assessing the patterns of land-use change," the study identifies that satellite imagery is especially useful for assessing and mapping land-use change.

In general, all hypotheses were upheld and supported by the results presented in this study.

7.3 Limitations of the study

1. Low quality of MSS image
2. A limitation with remote sensing and satellite imagery in distinguishing between certain vegetation classes, due to the common heterogeneity of the cover type and spectral similarity which create some problems during the classification of the land use land cover.
3. Lack of periodical and historical records on climati, agricultural statistics, animal population census and other socio-economic.
4. Inaccessibility and security unrest in some locations of the study area during field surveys.

7.4 Recommendations

- Establishment of traditional laws by the local administration to ensure the proper management and use of land and natural resources.
- Training and increasing capacity building of researchers' vis-à-vis the application of remote sensing in natural resource management.
- Application of multi-temporal satellite imagery (with high resolution) for studying LULC change in the area.

- Improvement of agricultural activities via the introduction of intermediate technologies and modifying cropping patterns.
- Conducting environmental awareness programs to enable rural people to have a better understanding of and ability to manage their land and natural environment.
- Implementation of rangeland management by improving grazing land, grazing patterns, and by protecting shrubs and trees.
- Involvement of stakeholders, decision makers at the local, regional, and national level in natural resource management.
- Requirement for extensive research to develop a methodology that combines remotely sensed and socio-economic data to evaluate the impact of human-driven forces on land-use change and its impact on livelihood, which requires increasing the area to obtain representative cover over all climatic zones in the Southern Darfur region.

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Appendix1
LULC change matrix for 1972-2008

	Classes	Classification 2008					∑
		GL	FL	FAL	CL	BL	
Classification 1972	GL	5001.21	7585.38	3596.94	5453.19	1338.21	22974.93
	FL	4085.82	11000.88	1780.56	3126.6	414.63	20408.49
	FAL	3209.49	3532.95	6326.46	7961.04	3667.32	24697.26
	CL	7106.76	6795	8667.63	10123.65	2990.16	30700.44
	BL	2048.31	2550.51	4128.3	5274.72	2989.53	16991.37
	∑	21451.59	31464.72	24499.89	31939.2	11399.85	120755.3

	classes	Classification 1984					∑
		GL	FL	FAL	CL	BL	
Classification 1972	GL	5100.21	7258.14	3269.34	4491.36	794.79	20913.84
	FL	3805.47	12227.67	1754.91	3161.16	519.12	21468.33
	FAL	5252.49	3844.98	8629.83	8768.25	2911.05	29406.6
	CL	6086.52	6908.31	7083.72	10039.77	2596.23	32714.55
	BL	1206.9	1225.62	3762.09	5478.66	4578.66	16251.93
	∑	21451.59	31464.72	24499.89	31939.2	11399.85	120755.3

	Classes	Classification 1989					∑
		GL	FL	FAL	CL	BL	
Classification 1984	GL	4321.26	3886.47	4517.46	5287.68	1705.14	19718.01
	FL	4493.34	6794.82	3001.59	4553.46	1386.72	20229.93
	FAL	5100.57	4392.72	10566.18	10023.3	6185.88	36268.65
	CL	5228.28	4729.05	7827.03	9380.07	3536.01	30700.44
	BL	1770	1665.27	3494.34	3470.04	3438.18	13838.22
	∑	20913.84	21468.33	29406.6	32714.55	16251.93	120755.3

Classification 1989	Classes	Classification 1999					∑
		GL	FL	FAL	CL	BL	
	GL	4683.15	4654.08	6880.41	6210.36	2784.15	25212.15
	FL	3719.97	6074.01	5843.07	4707.45	2284.65	22629.15
	FAL	4664.07	3655.26	9735.21	8149.68	3357.72	29561.94
	CL	4698.63	4515.21	9211.14	8081.55	3612.24	30118.77
	BL	1952.19	1331.37	4598.82	3551.4	1799.46	13233.24
	∑	19718.01	20229.93	36268.65	30700.44	13838.22	120755.3

Classification 1999	classes	Classification 2008					∑
		GL	FL	FAL	CL	BL	
	GL	6271.74	4766.13	4719.6	5578.65	1638.81	22974.93
	FL	4939.47	9550.08	2159.37	3082.23	677.34	20408.49
	FAL	4167.9	2691	7066.53	7294.86	3476.97	24697.26
	CL	6877.89	3863.61	10987.2	8955	4999.5	35683.2
	BL	2955.15	1758.33	4629.24	5208.03	2440.62	16991.37
	∑	25212.15	22629.15	29561.94	30118.77	13233.24	120755.3

Where GL: grass land, FL: forest land, FAL: fallow land, CL: cultivated land, and BL: bare land

Appendix 2
Contingency matrix for the maximum likelihood classification

Year	Classified data	Reference data (%)					Row total
1972		GL	FL	FAL	CL	BL	
	GL	8	2	1	1	0	12
	FL	1	11	0	0	0	12
	FAL	0	0	11	0	1	12
	CL	0	0	3	9	0	12
	BL	0	0	1	0	11	12
	∑	9	13	16	10	12	50

Year	Classified data	Reference data (%)					Row total
1984		GL	FL	FAL	CL	BL	
	GL	8	0	0	1	0	9
	FL	3	9	0	0	0	12
	FAL	0	0	12	1	1	14
	CL	1	0	3	15	0	19
	BL	0	0	0	0	6	6
	∑	12	9	15	17	7	60

Year	Classified data	Reference data (%)					Row total
1989		GL	FL	FAL	CL	BL	
	GL	7	1	1	3	0	12
	FL	1	11	0	0	0	12
	FAL	0	0	12	0	0	12
	CL	1	0	2	9	0	12
	BL	0	0	1		11	12
	∑	9	12	16	12	11	60

	Classified data	Referenced data (%)					Row total
		GL	FL	FAL	CL	BL	
1999	GL	8	1	2	1	0	12
	FL	1	11	0	0	0	12
	FAL	0	0	11	1	0	12
	CL	0	0	2	10	0	12
	BL	0	0	0	0	12	12
	∑	9	12	15	13	11	60
	Classified data	Reference data (%)					Row total
		GL	FL	FAL	CL	BL	
2008	GL	11	1	0	0	0	12
	FL	1	11	0	0	0	12
	FAL	0	0	11	1	0	12
	CL	0	0	2	10	0	12
	BL	0	0		0	12	12
	∑	12	12	15	11	10	60

Where GL: grass land, FL: forest land, FAL: fallow land, CL: cultivated land, and BL: bare land

Appendix 3

Technical University of Dresden

Questionnaire about: The Impacts of Land Use Changes on the livelihood of Rural Communities Based on Perception and Knowledge of Rural People

A Case-study in Edd Al Fursan Locality, SouthDarfur State, Sudan

Date…………… Place………………… Coordinate………………

Nr……………… Name of observer……………………………………..

A/ Background

1) Sex

a) Female ( ) b) male ( )

2) Age ……………………………………….

3) What is your family size?

a) Less than 4 persons b) 4-8 persons c) more than 8 persons

4) are you from this village or migrant?

a) Yes ( ) b) No ( )

5) If no, since when you are in this village?.................................

6) What is your main livelihood activity?

Pastoralism ( ) b) Agriculture ( ) c) Agro-pastoralism ( ) d) other (specify)……………………………………………

7) Is drought a common phenomenon in the area?

a) Yes ( ) b) No ( )

8) If yes, how frequent does it occur?

a) 2-5 years ( ) b) 5-10 years ( ) c) once over 10 years ( )

B) Land use and natural resources exploitation

1) Are the natural resources overexploited during drought years?

a) Yes ( ) b) No ( )

2) If yes, what kind of exploitation?

a) Increase charcoal burning ( ) b) increase overgrazing ( ) c) increase cultivation of marginal lands ( )

3) Is there are changes in land use patterns in the area between the period 1979 and 2009?

Yes ( )   b) No ( )

4) If yes, describe

a) Shift in livelihood mechanism   b) over cultivation of marginal lands

c) overgrazing   d) cutting of trees   e) other (specify)………………………..

5) What is the type of land that you own?

a) Inheritance ( )   b) Purchased ( )   c) gifted ( )   d) rented ( )

6) Who is responsible for land ownership?

a) Government ( )   b) local administration ( )   c) other

(specify)………………..

7) Are there any signs of soil erosion in the area?

a) Yes ( )   b) No ( )

8) If yes, what is the dominant type of erosion?

a) Wind sand dunes ( )   b) water runoff ( )   c) both ( )

9) Is there nomadic movement in the area?

a) Yes ( )   b) No ( )

10) If yes, when they come?.................................

11) How is the impact on the area?

a) Slight ( )   b) moderate ( )   c) severe ( )

12) Is there any change in vegetation composition?

a) Yes ( )   b) No ( )

21) If yes, what are the dominant species now?

....

....

....

And 30 years ago

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

…………………

13) Are there forest/ wood lands in the area?

a) Yes ( )   b) No ( )

14) If yes, what is the rate of deforestation?

a) Fast ( )   b) moderate ( )   c) slight

15) Is making charcoal practiced in the area?

a) Yes ( ) b) No ( )

16) If yes, which are the best trees for charcoal?

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

17) Are these trees disappearing?

a) Yes ( ) b) No ( )

18) If so, at what rate?

a) Fast ( ) b) moderate ( ) c) slow ( )

19) What are the conditions of grazing palatable species?

a) Increased ( ) b) decreased ( ) c) disappeared ( )

20) What is the rate of vegetation regeneration when normal rains come?

a) Fast ( ) b) moderate ( ) c) slow ( ) d) no generation

C/ Agriculture production

1) What is the type of agriculture that you are practice?
   a) Subsistence agriculture ( ) b) commercial agriculture ( )

2) What is the size of your holding?

a) Less than 5 feddans ( ) b) 5-10 feddans ( ) c) more than 10 feddans ( )

3) What are the major crops grown?

....
....

4) Do you use any type of fertilizers?

a) Yes ( ) b) No ( )

5) What are the harvests now compared to harvest 10 years ago?

Very good ( ) b) good ( ) c) not good ( )

6) Do the harvests enough for family consumption and sell the remained one in the market?

a) Yes ( ) b) No ( )

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

8) If yes, after how many years of cultivation would you leave your land abandoned?…. years.

9) What is the age of fallow period now and 30 years ago? a) now………yrs b) 30 years ago……………..yrs.

7) Do you have small scale irrigation farms?

a) Yes ( ) b) No ( )

8) If yes, what are the crops grown?

…………………………………………………………….

9) Is irrigation economically viable?

a) Yes ( ) b) No ( )

10) What is the source of irrigation water?

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

11) Is irrigated farming increasing in the area?

Yes ( ) b) No ( )

12) Are you abandoning your farming due to land degradation?

a) Yes ( ) b) No ( )

13) If yes, what are your livelihood options?

…………………………………………………………………………………………………

14) What the current rate of outward migration due to land degradation?

a) High ( ) b) moderate ( ) c) low ( )

D/ Livestock production

1) What are the types and numbers of livestock that you own?

a) Cattle ( ) no ( ) b) Goat ( ) no ( ) c) Sheep ( ) no ( )

d) Camel ( ) no ( ) e) others ……………………………………………

2) Where do herders take their animals for grazing in rainy season?

a) Around the village ( ) b) outside the village ( ) c) far away from the village ( )

3) And in dry season?

a) Around the village ( ) b) outside the village ( ) c) far away from the village ( )

4) Is there any influx by outside herders to the area?

a) Yes ( ) b) No ( )

5) If yes, when they come and in what numbers..

a) Big numbers ( ) b) small numbers ( )

6) Does this influx affect water resources, pasture, agriculture …etc?

a) Yes ( ) b) No ( )

7) Do herders sell milk and milk products?

a) Yes ( ) b) No ( )

8) How are these products affected by drought and land use change?

a) Increased ( ) b) Decreased ( ) c) Not affected ( )