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Analysing environmental change in semi-arid areas in Kordofan, Sudan

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Abstract

Recent research has shown significant increasing trends in NOAA NDVI for the Sahel region during the period of 1982-1999. These observations could indicate that the amount of vegetation in the region is increasing. The changes could be interpreted as a recovery from the Sahelian droughts during the 1970´s and 1980´s. However, there are currently large uncertainties as to which processes that have influenced the changing vegetation pattern.

This study tries to explain the observed NDVI changes on a local and regional scale in semi-arid Kordofan, Sudan by studying different processes and comparing areas with a positive trend in NDVI with areas with a neutral trend in NDVI. A field work, including vegetation estimations and interviews, was done in 2004 and these data was complemented with high resolution Landsat data and precipitation data. Examined processes are vegetation changes, precipitation patterns, land use changes, population changes and changes in the amount of livestock.

In order to find out if the vegetation changes are different in positive and neutral areas a Landsat NDVI differencing analysis and a tasseled cap analysis from 1987 to 1999 was made. These analyses did not confirm the positive NOAA NDVI trend. Instead, they showed a decrease in vegetation. The interview result however, did confirm the observed NOAA NDVI trend. Regression analyses between precipitation and NDVI was made and it was found that the correlation between these variables is low, this could be interpreted as if rainfall is not the dominating factor in influencing NDVI. A land use classification was made from the Landsat data. The land use change analyses and the interview results show that increased cropping area may lead to increased NDVI. The population analysis shows that the population has increased both in areas that show a positive trend in NOAA NDVI and in areas that show a neutral trend in NDVI.

In order to locate the Landsat data in the vegetation cycle a method of image comparability was used. This method showed that the Landsat data from 1987 and 1999 do not entirely correspond to the same part of the growing season. This leads to the conclusion that the results from the Landsat NDVI trend analysis and the tasseled cap analysis are not completely reliable.

The conclusion is that it is difficult to explain the observed trend in NOAA NDVI between 1982 and 1999 on a local scale, based on the data that have been used in this study.

Sammanfattning

Forskning har visat på en trendökning i NOAA NDVI för Sahelområdet under perioden 1982-1999. Dessa observationer kan indikera att vegetationsmängden i området är ökande. Förändringen kan tolkas som en återhämtning från torkan som drabbade området under 1970- och 1980-talen. Vilka processer som påverkat det förändrade vegetationsmönstret är för tillfället till stor del okänt.

Denna studie försöker förklara de observerade NDVI förändringarna på en lokal och regional nivå i det semiarida Kordofan genom att studera olika processer och genom att jämföra områden med en positiv trend i NDVI med områden med en neutral trend i NDVI. Ett fältarbete som innefattar vegetationsuppskattning och intervjuer genomfördes 2004. Data som samlades in har kompletterats med Landsat- och nederbördsdata. De undersökta processerna är vegetationsförändringar, nederbördsmönster, markanvändningsförändringar, befolkningsförändringar och förändringar i boskapsantalet.

För att ta reda på om vegetationsförändringar skiljer sig åt i positiva och neutrala områden gjordes en Landsat differentiering analys och en tasseled cap analys mellan åren 1987 och 1999. Dessa analyser bekräftade inte den positiva trenden i NOAA NDVI. Tvärtom visade de på en vegetationsminskning. Intervjuresultaten bekräftade däremot den observerade NDVI trenden. Regressionsanalys mellan nederbörd och NDVI utfördes och det visade sig att korrelationen mellan dessa variabler är låg. Detta kan tyda på att nederbörd inte är den dominerande NDVI påverkande faktorn. En markanvändningsklassificering utfördes med Landsatdata. Denna analys visade tillsammans med intervjuerna att ökad åkerareal skulle kunna leda till en ökning av NDVI. Befolkningsanalysen uppvisade att befolkningen både har ökat i områden med en positiv trend i NOAA NDVI och i områden med en neutral trend i NDVI.

För att lokalisera Landsatdata i vegetationscykeln användes en bildkompabilitetsmetod. Denna metod visade att Landsatdata från 1987 och 1999 inte ligger i exakt samma period av växtsäsongen. Det leder till att resultaten från Landsat differentiering- och tasseled cap analyserna inte är helt pålitliga.

Slutsatsen är att det, baserat på materialet som använts i denna studie, är svårt att förklara den observerade NOAA NDVI trenden mellan 1982 och 1999 på lokal och regional nivå.

Table of contents

1 Introduction

1.1 Background

Africa is a large continent, covering over 30 million km^2 and including over 50 countries (Encyclopadia Britannica, 2004). Sahel is the name of the semi-arid transition zone south of the Sahara desert and north of the comparatively green savannah regions. It parallels the equator, stretching about 4000 km from the Atlantic Ocean in the west to the Red Sea in the east. The region extends between 10-20° N (Figure 1) with a mean annual rainfall ranging from about 150 mm in the north to about 600 mm in the south (Seaquist, 2001). In general, the region is dry, poor and over-exploited (Olsson, 1993). The large spatial and temporal variations in precipitation determine the distribution of agriculture and natural vegetation in this zone and the region is well known as an area of environmental degradation (Agnew & Chappel, 1999). The period from the 1960´s has been marked by recurrent droughts, leading to widespread famines and human disasters (Mattson & Rapp, 1991).

Satellites give unique possibilities to study variations in vegetation cover and growth. The Normalized Difference Vegetation Index (NDVI, a satellite based measure of vegetation activity and mass) computed from data of satellite sensors has been used for assessing green vegetation cover and the correlation between average NDVI and green biomass has been well established (Tucker et al., 1985; Eklundh, 1996).

Recent research has shown significant increasing trends in NDVI for the Sahel region during the period of 1982-1999 (Figure 1) (Eklundh & Olsson, 2003). These observations could indicate that the amount of vegetation in the region is increasing and they could be interpreted as a recovery from the Sahelian droughts during the 1970´s and 1980´s. However, there are currently large uncertainties as to which processes that have influenced the changing vegetation pattern. Proposed explanations include changes in precipitation, changes in land use such as altered grazing pressure and agricultural intensity and changes in population which can influence the land use. This study tries to investigate the observed NDVI changes on a local and regional scale in semi-arid Sudan. Vegetation studies are done in Kordofan, Sudan in the eastern part of Sahel (Figure 2).

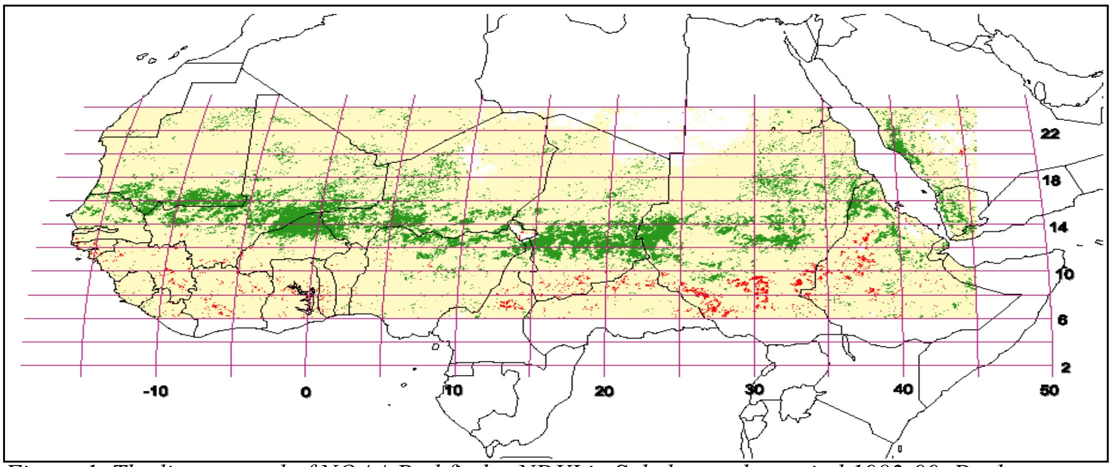

Figure 1. The linear trend of NOAA Pathfinder NDVI in Sahel over the period 1982-99. Dark green = strong positive trend, red = strong negative trend and yellow = no clear trend (Eklundh & Olsson, 2003).

1.2 Objective

This study include vegetation measurements/estimations and interviews in North Kordofan, Sudan and satellite and precipitation data analyses. It tries to answer if and why any changes in vegetation have occurred. Investigating the differences in terms of vegetation and land use for areas with a significant NDVI increase and for areas without a significant NDVI increase is the central part of the study. Specific objectives include testing of the following hypotheses:

$H_0$1. Are the vegetation changes in areas with a significant NDVI increase = vegetation changes in areas with no significant NDVI increase?

H_A1. Are the vegetation changes in areas with a significant NDVI increase ≠ vegetation changes in areas with no significant NDVI increase?

$H_0$2. Is the precipitation in areas with a significant NDVI increase = precipitation in areas with no significant NDVI increase?

H_A2. Is the precipitation in areas with a significant NDVI increase ≠ precipitation in areas with no significant NDVI increase?

$H_0$3. Is the land use change in areas with a significant NDVI increase = land use change in areas with no significant NDVI increase?

H_A3. Is land use change in areas with a significant NDVI increase ≠ land use change in areas with no significant NDVI increase?

$H_0$4. Are the population changes in areas with a significant NDVI increase = population changes in areas with no significant NDVI increase?

H_A4. Are the population changes in areas with a significant NDVI increase ≠ population changes in areas with no significant NDVI increase?

$H_0$5. Is the change in the amount of livestock in areas with a significant NDVI increase = the change in the amount of livestock in areas with no significant NDVI increase?

H_A5. Is the change in the amount of livestock in areas with a significant NDVI increase ≠ the change in the amount of livestock in areas with no significant NDVI increase?

2 The study area

2.1 Sudan

Sudan is the largest country in Africa and its capital is Khartoum. The country has a population of about 37 million people of which almost half is below 15 years old (Sweden: 18%). The country is one of the worlds poorest; GPD/capita is only $1360 (Sweden: $25,400). During 1984 and 1985 the country was stricken by a severe famine. Since 1983 a civil war in the southern part of the country has led to more than 2 million deaths and over 4 million people displaced (CIA, 2004). During 2003 peace talks started, but the same year another conflict started in the Darfur region in the western part of the country. Peace talks concerning that conflict have already started.

The country is rich in natural resourses such as oil, gold and chrome (Utrikespolitiska institutet, 2000), but agriculture is the most important sector and it employs nearly 80% of the workforce. Along the Nile, maize (*Zea mays)*, wheat (*Triticum aestivum*) and cotton (*Gossypium spp*) are grown on large irrigation schemes (Grove, 1998), but the arable land covers only a small part of the country and pastoralism and rainfed agriculture dominates the agriculture. Sudan is divided into 26 provinces. One of them is North Kordofan that is situated in the central part of Sudan (Figure 2).

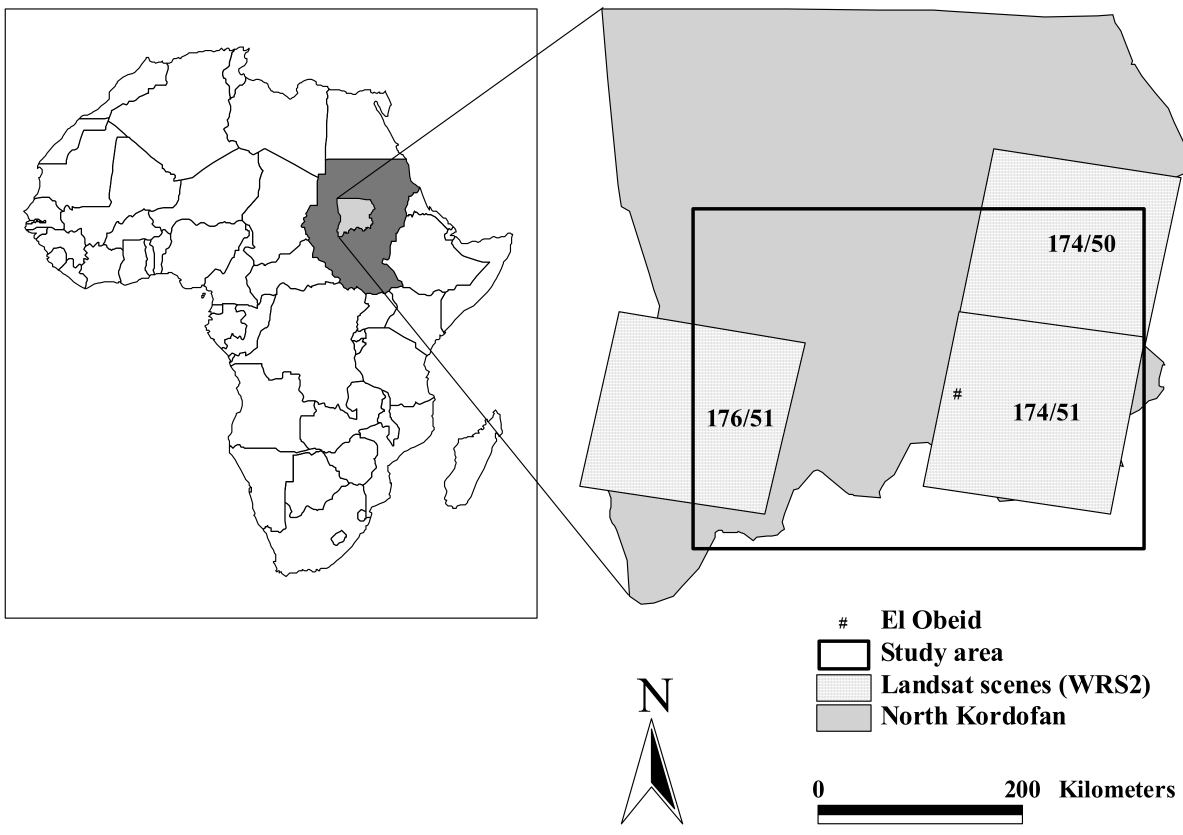

Figure 2. Africa, Sudan, North Kordofan, El Obeid and the Landsat scenes (path/row) in World Reference System 2 (WRS2) used in the analyses in this study.

2.2 North Kordofan

The study area is situated in the province of North Kordofan and it extends approximatly from latitude 12°40′ N to 14°20′ N and longitude 28°10′ E to 31°40′ E (Figure 2). The population of North Kordofan is about 1.5 million (2003) (UN, 2003) and the capital is El Obeid (Figure 2). The terrain is generally flat with some inselbergs in the north and in the south it rises to the Nuba mountains. Kordofan´s economy is mainly based on agriculture. Its export is for example gum arabic and sheep.

2.3 Soils

Between latitudes 13°00′ N and 12°30′ N, the soils mainly consist of sand sheets and dunes that are stabilized by vegetation. These Cambric Arenosols, locally named Qos, are coarse textured soils with aeolian origin. They are high in water permeability and have a low fertility. South of 12°30′ N the soils become more and more fine grained silty clay, mainly of alluvial origin. These Vertisols, locally named Gardud , are non-cracking clay soils, mixed with aeolian sand (FAO, 1997).

2.4 Climate

The climate is semi-arid with a mean annual rainfall ranging from less than 100 mm in the north to about 350 mm in the south. The precipitation is concentrated to the summer months (June to September) with August as the wettest month (Figure 3). The rain is often concentrated to a few occasions with high intensity and the rainfall show a great variability in both time and space (Hulme, 2001). The length of the rain season depends to a large degree on latitude, in south it is longer (Olsson, 1985). The mean annual temperature in the area is about 20°C, but during summer the temperature can reach as high as 45°C during day time.

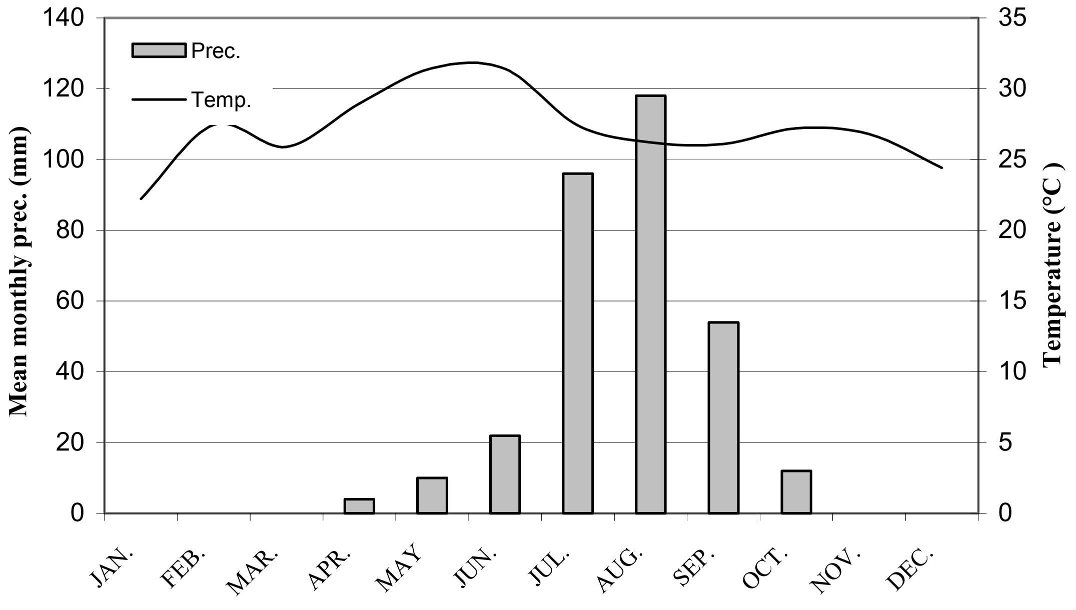

Figure 3. Mean monthly precipitation and temperature in El Obeid, which is situated approximately in the middle of the study area. Based on 30 years of data (1961-1990).

2.5 Vegetation

The area is sparsely vegetated as a result of the low amount of rainfall. The vegetation is exposed to extreme conditions and must survive drought, which can stretch over several years with little or no rain at all (Schmidt & Karnieli, 2000). In semi-arid ecosystems with a single rainy season there is usually a short growth period followed by a long dry season with a great reduction in the amount of green plant material.

In the northern part of the area the *Leptadaenia pyrotechniquea* is very common (Figure 4). It is a drought tolerant bush that indicates deep sandy soils (Mukhtar, personal communications). The under story consists mostly of the grass *Panicum turgidum*. The wadis in this area support trees such as *Acacia millifera*, *Acacia tortilis*, *Commiphora spp* and *Balanites aegyptiaca*.

Figure 4. The northern part of the study area is sparsely vegetated. The Leptadaenia pyrotechniquea bush is common. This picture is taken between Makawi and El Fylia.

To the south the vegetation is higher and denser. Common trees and shrubs are *Adansonia digitata*, *Acacia senegal*, *Acacia millifera*, *Calotropis procera*, *Indigofera pancifolia*, *Cadaba farinosa* and *Cordia rothii*. Trees and shrubs alternate with areas of open grassland (Figure 5).

Figure 5. The southern part of the study area is more densly vegetated. Acacia senegal is common and the ground is often covered by grass. This picture is taken east of El Obeid.

2.6 Land use and income

The land use is a mix of rainfed cultivation and pastoral grazing. The most common crops on the sandy soils in the north are millet (*Pennisetum typhoieum*), sesamé (*Sesamum indicum*), karkadé (*Hibiscus sabdariffa*), groundnuts (*Arachis hypogaea*) and watermelon (*Citrullus vulgaris*). On the clayey soils in the south, sorghum (*Sorghum vulgare*) replaces millet. Millet and sorghum are mostly grown for self consumption, the others are mainly cash crops.

In addition to cultivating crops, people also tap the indigenous *Acacia senegal* trees for gum arabic. This is a winter activity and it is an important source of income in some areas. Rotation farming is practiced in the area and the nitrogen fixing *Acacia senegal* trees are cut down when they are not productive any more. Then crops are grown on the fertile soils (Khogali, 1991).

The land use practices have changed markedly from a rotation system with long fallow periods (15–20 years) interspersed with short periods of cultivation (4–5 years) to more or less continuous cultivation over the last three to four decades. During the same period, crop yields have decreased. Crop yields have decreased mainly due to a marked decline of rainfall, but to some extent also due to the abandonment of fallow periods (Olsson & Ardö, 2002).

The most common livestock are sheep, goats, camels and cattle in some areas. These animals are seen not only as food but also as an investment and an insurance against possible crop failure. Before the drought in 1984, cattle were much more common in the region, but farmers in many areas have changed their livestock distribution since then towards the other animals because they regard cattle as less drought tolerant than for example sheep.

It is common that farmers go to urban areas or the farming areas in the Nile district as labour force during the dry season.The money that they earn is often sent back to the families and invested in livestock.

It is to the variability in rainfall supply that most environmental and social systems have traditionally adapted, for example, through pastoralism, diversification of income and mobility (Hulme, 2001).

3 Theoretical background

3.1 Remote sensing

Remote sensing means measuring at a distance without physical contact. When the sun´s electromagnetic energy reaches the earth´s surface, it will be reflected, absorbed or transmitted. The radiation that is used to identify objects with different remote sensing techniques are either the reflected or the emitted energy. The proportions accounted for by each process depend opon the nature of the surface, the wavelength of the energy and the angle of illumination (Campbell, 2002). Remote sensing uses the knowledge that the radiation intensity within different wavelengths often is typical for different objects. Different objects have different spectral signatures (Nämnden för skoglig fjärranalys, 1993). For example, at certain wavelengths, sand reflects more energy than green vegetation while at other wavelengths it absorbs more (reflects less) energy. Therefore, these spectral signatures can be used to distinguish one thing from another or to obtain information about shape, size and other physical and chemical properties (Figure 6) (Campbell, 2002). When the radiation passes through the atmosphere it will be affected aerosols and clouds that scattering it. This may lead to error in the data (Campbell, 2002).

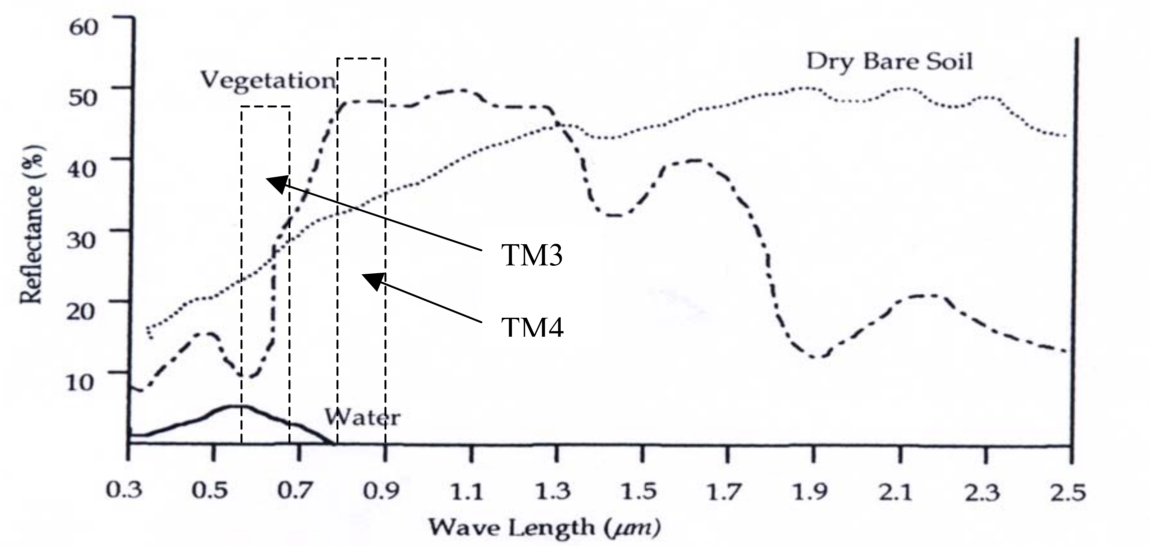

Figure 6. Spectral signatures for vegetation, dry bare soil and water and the position of Landsat TM bands 3 and 4, after Tso & Mather (2001).

3.2 The Normalized Difference Vegetation Index (NDVI)

Many natural surfaces are about equally as bright in the red and near-infrared part of the spectrum with the notable exception of green vegetation (Figure 6). Red light is strongly absorbed by photosynthetic pigments (such as chlorophyll) found in green leaves, while near-infrared light either passes through or is reflected by live leaf tissues (mesophyll structures and water content), regardless of their color. This means that areas of bare soil that have little or no green plant material will appear similar in both the red and near-infrared wavelengths, while areas with green vegetation will appear bright in the near infrared and very dark in the red part of the spectrum. By using these wavelengths different vegetation indices can be produced. The NDVI is the most widely used vegetation index and many studies have demonstrated its ability to describe vegetation phenology.

NDVI is calculated from atmospherically corrected reflectance from the visible and near infrared channels as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \text{(Equation 1)}$$

The resulting index value is sensitive to the presence of vegetation on the Earth´s land surface and can be used to address issues of vegetation type, amount, and condition. Equation 1 normalises the difference between the channels in order to produce values in the range of -1.0 to 1.0, where vegetated areas will have values greater than zero and negative values indicate non-vegetated surface features such as water, bare soil, or clouds.

NDVI is known to lag behind rainfall up to three months as the vegetation does not respond to precipitation immediately (Eklundh, 1996). The time lag differs between climatic zones. In dry regions it is shorter than in humid regions. The rapid response to rainfall in dry regions is interpreted to be due to the critical dryness for vegetation. In dry regions the dominant vegetation is annual/perennial grasses, which respond to rainfall rapidly (Tachiiri, 2003). The satellite observed peak of NDVI occurs at the same time as the peak of the delayed response of annuals and perennials to rainfall (Schmidt & Karnieli, 2000). NDVI is also known to be affected by the soil background signal in arid and semi-arid areas (Huete et al., 1994).

3.3 Land use classification

3.3.1 Land use change and classification

When land undergoes change or disturbance during a certain period of time, its spectral appearance normally changes. Different techiques have been developed to detect changes. This study uses both the maximum likelihood classification and a method based on tasseled cap (described in section 4.9).

3.3.2 Maximum likelihood classification

In nature the classes that we classify exhibit natural variation in their spectral patterns. One crop field does not look exactly like the other due to, for example, different crops and different stages in the vegetation cycle. As a result, remote sensing images seldom record spectrally pure classes. Instead, they display a range of brightness in each band and one can find that the different classes are overlapping each other (Figure 7) (Campbell, 2002).

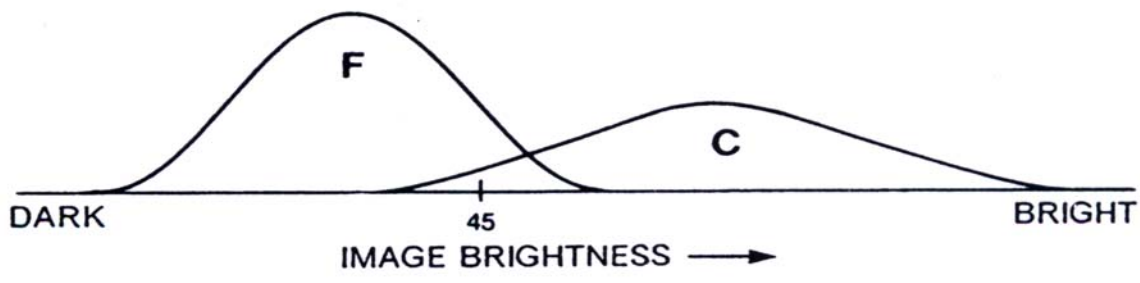

Figure 7. These frequency distributions represent pixels from two different training areas, fallow land (F) and crop land (C). The zone of overlap depicts pixel values common to both categories.The relations of the values within the overlap region to the overall frequency for each class form the basis for assigning pixels to the different classes, in Campbell (2002).

The maximum likelihood classification method takes this into consideration. When classifying a pixel in an overlapping region the method chooses the class that maximizes the probability of a correct classification. It uses the training data collected in field as a means of estimating means and variances of the classes. The means and variances are then used to estimate the probabilities. Thus, the method considers not only the mean values when assigning values during classification, but also the variability of brightness values in each class.

3.4 Satellite sensors used in this study

3.4.1 NOAA AVHRR

The use of the Advanced Very High Resolution Radiometer (AVHRR) provided by the National Oceanic and Atmospheric Administration (NOAA) polar satellite series present the opportunity to study land surface variables at a regional and global scale (Muchoney & Strahler, 1998). Although recent satellite sensors (MODIS etc.) may provide improved global land satellite data, the AVHRR record, which now extends over more than 20 years, is an invaluable source of historical land cover information. The AVHRR NDVI is created using data from channel 1 and channel 2 in the following way:

$$AVHRR\ NDVI = \frac{Channel\ 2 - Channel\ 1}{Channel\ 2 + Channel\ 1} \qquad \text{(Equation 2)}$$

The spectral and spatial resolution of the NOAA bands that are used in this study are shown in appendix I.

3.4.2 LANDSAT TM

Landsat 4, carrying the first Thematic Mapper (TM) sensor was launched in 1982. The TM sensor is an upgrade of the Multi Spectral Scanner (MSS) subsystem on which efforts where made to incorporate improvements into a new instrument**.** The TM instrument is thus based on the same technical principal as the MSS but with a more complex design as it provides finer spatial resolution, improved geometric reliability, greater radiometric detail and more detailed spectral information. The MSS has only four broadly defined spectral regions whereas the TM has seven spectral bands, customized to record radiation of interest to specific scientific investigations (Campbell, 1996). The spectral and spatial resolution of the Landsat TM bands that are used in this study are shown in appendix I.

3.4.3 LANDSAT ETM+

The Landsat Enhanced Thematic Mapper Plus (ETM+) sensor, launched in 1999, is a development of the TM sensor. The Landsat 7 ETM+ sensor offers several enhancements over the Landsat 4 and 5 Thematic Mapper sensors, including increased spectral information content, improved geodetic accuracy, reduced noise, reliable calibration, the addition of a panchromatic band and improved spatial resolution of the thermal band (Masek et al., 2001). The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) bands 3 and 4 provide red (R) and near infrared (NIR) measurements and can therefore be used to generate NDVI data sets in the following way:

$$Landsat\ NDVI = \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3} \quad \text{(Equation 3)}$$

The spectral and spatial resolution of the Landsat ETM+ bands that are used in this study are shown in appendix I.

3.4.4 Comparison of NOAA AVHRR and Landsat

One of the primary differences between the AVHRR and Landsat data products is the spatial resolution. The AVHRR sensors have a resolution that is much lower than the Landsat TM/ETM+ sensors. AVHRR data is transmitted at a maximum resolution of 1 km, and the NDVI product is generally produced at an even further reduced resolution (usually 8 km) in favour of providing global or large-scale coverage with daily acquisition (Murdiyarso & Warsin, 1995). The Landsat NDVI data are produced at a resolution of 30 m, which offers far greater detail, though it is able to provide less aerial extent. The acquisition occurs every 16 day, but it is often reduced by the presence of clouds and other atmospheric perturbations. Hence, there is a difficulty in acquiring good comparable data when making temporal studies. Thus, the AVHRR data are more appropriate for creating frequent global/regional NDVI products while the Landsat TM/ETM+ data are most useful for creating images with greater detail covering less area (Maselli et al., 1998).

3.5 NOAA Landsat fit

When using Landsat data from different years for comparison of NDVI it is important that the data are from the same part of the vegetation cycle. Using data from approximately the same dates in different years does not nessesary give a good result when comparing them. The reason is that the vegetation cycle does not show exactly the same pattern from year to year since the rain does not fall at the same time from year to year and the amount and intensity changes from year to year. When working with land use and land cover change this fact is important to have in mind (Runnström, 2003).

4 Materials and methods

4.1 Field work

The areas in which the field work and the interviews were conducted were chosen, to the largest extent as possible, to cover areas that have the same trend in both amplitude and integral NDVI. All positive areas in this study correspond to strong positive change as discussed by Eklundh & Olsson (2003). Thus, the change is statistical significant. No large homogeneous areas with a negative trend in NDVI were found in North Kordofan so the strong positive change is compared with areas that have a weak positive or a weak negative change. These areas are regarded as neutral since the change are not statistical significant. Single NOAA pixels are not used when choosing field work areas since they can be regarded as possible noise.

4.1.1 Vegetation measurement

The field data were collected during the dry season in February and March 2004. Table 1 and Figure 9 show in which areas the measurements have been done. The training areas were chosen in a way to give the broadest spectrum possible for the classes. Crop areas with different crops and fallow areas with different amount and type of vegetation were visited. The size of the training areas was chosen to be 50*50 meters since previous research has come to the conclusion that this is a suitable balance in size in semi-arid regions (Olsson, 1985; Wellens, 1997). Larger training areas could be preferred in order to minimize the influence of possible geometrically noise in satellite data and GPS data, but they can be too large in order to be examined thoroughly and the areas in which the field work was done are heterogeneous with many small fields (Figure 8).

Homogeneous areas that were smaller than approximately 100*100 m were excluded since they were regarded as too small since Landsat pixels are 30*30 meters and geometrically noise may occur both in the GPS data and in the Landsat data. The 50*50 m plot was taken in the centre of the homogeneous area. When the plot was a crop field the type of crop was observed and the GPS position was taken twice in the middle of the field in order to get a mean value and reduce possible noise. Since the field work was carried out in the dry season the crop fields often were bare. In such cases the local interpreter and villagers assisted in informing which crop that was grown during the previous growing season, 2003. If the plot was a fallow land the trees and bushes within the plot were counted and their crown diameters were measured. Furthermore, the amount of grass cover was estimated. The grass cover was divided into three classes, no grass, medium grass cover and dense grass cover and the position was taken in the same way as in the crop fields.
The sampling technique when collecting data for the accuracy assessment was based on sampling from car (Olsson & Stern, 1981). Before the field work was carried out a random selection of plots was performed. During the collection of plots for accuracy assessment the plots were divided into three classes:

- Crop land
- Fallow land without grass
- Fallow land with grass

The GPS points were taken in the middle of the plots and plots smaller than 100*100 meters were excluded.

Table 1. The villages, the coordinates and the NOAA NDVI trend 1982-1999 in the areas that field work and interviews have been carried out.

Village	N lat.	E long.	Change in NOAA NDVI 1982-1999
Abdel Hai	13° 21.018 N	30° 07.635 E	Neutral
Abu Kamdela	12° 48.631 N	31° 12.098 E	Neutral
Makawi	13° 55.976 N	30° 31.938 E	Neutral
Um Ganas	12° 59.360 N	31° 09.196 E	Neutral
El Bawabnes	12° 52.303 N	31° 36.625 E	Positive
El Fylia	14° 17.327 N	30° 23.035 E	Positive
Kalot	12° 39.106 N	28° 12.669 E	Positive

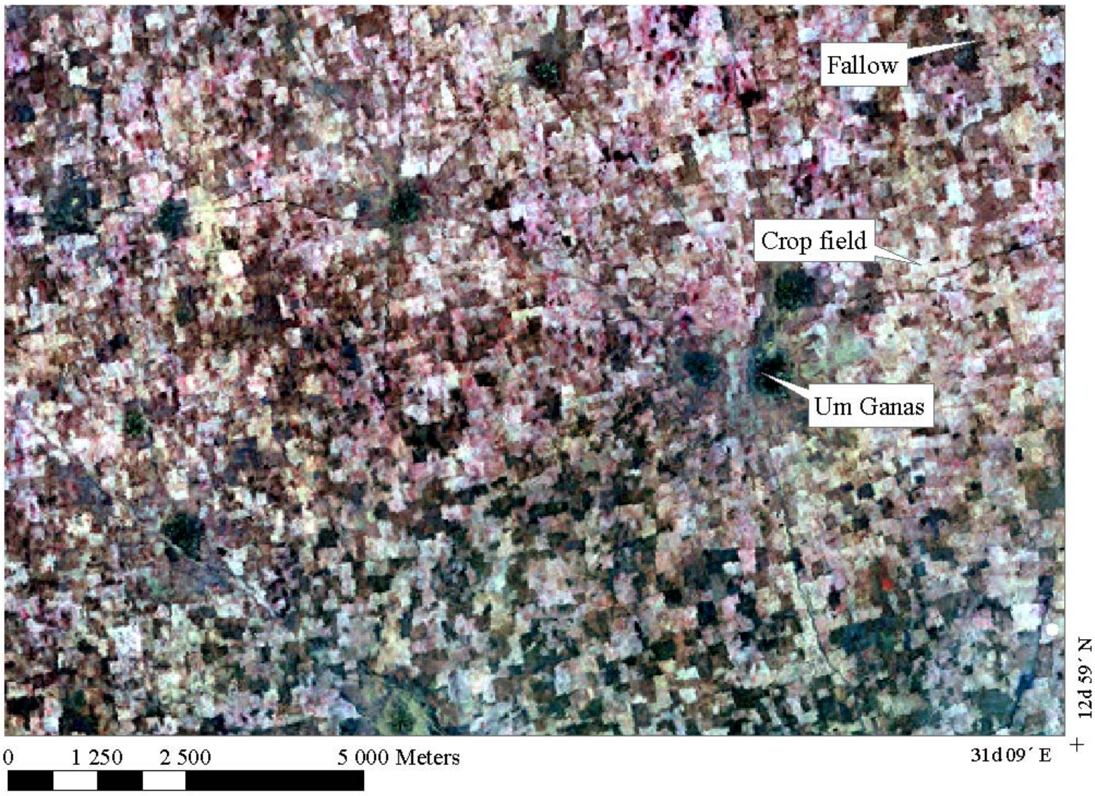

Figure 8. An example of the study area´s heterogeneity with many small fields. The bright fields are crop fields and the dark fields are fallow land. Villages are seen as dark circles with Um Ganas as an example.

4.1.2 Interviews

Interviewing local farmers is an important part in getting to know how the vegetation in the area has changed during the last two decades. The interviews were carried out with village leaders and farmers in seven villages (Table 1 and Figure 9). The main reason for interviewing the people in these villages was to establish a relationship between the satellite data and the qualitative vegetation history in the surroundings of the villages. The interviews covered the following areas:

- Vegetation
- Livestock
- Land use

- Fire wood
- Population

Depending on the type of survey different kinds of interview methods can be used. The interviewer determines how controlled the interview and the respondent´s answers will be. For the interviews in this study the semi-structured interview technique, based on a questionnaire, was used. This is a controlled and well prepared method since it is based on an interview guide. The interviewer knows what information is important, but still lets the respondents openly answer the questions (Berg, 1998). The interviews were performed as group interviews. This stimulates interaction between people and gives more ideas compared to individual interviews (Berg, 1998). It also requires less time than interviewing the same amount of people individually. A local interpreter with knowledge about the area and its different aspects assisted during the work. To minimize the problem of different interpretations the same interpreter was assisting during all the interviews. The questions that were used during the interviews are shown in appendix II.

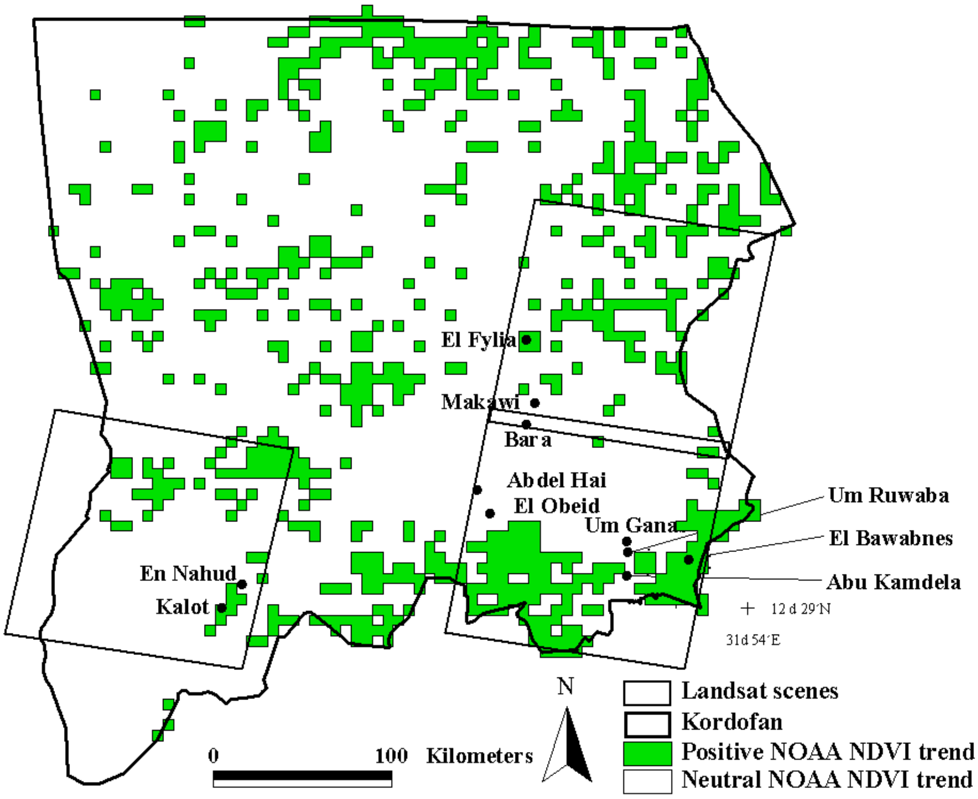

Figure 9. The villages and areas in which field work and interviews were done and the areas with a positive respective neutral trend in NOAA NDVI in Kordofan 1982-1999.

4.2 Remote sensing data

4.2.1 NOAA AVHRR

Eklundh & Olsson (2003) used the NOAA Pathfinder AVHRR Land (PAL) with a data window of 8*8 km covering the Sahel to compute the integrated and amplitude NDVI trend between 1982 and 1999. The integrated NDVI is the total area under the graph and amplitude NDVI is the difference between the base level and the graph maximum. The trends were calculated with TIMESAT (Jönsson & Eklundh, 2002). The data are 10-day maximum value composites (MVC) and it have been geometrically and radiometrically corrected. In spite of these corrections noise occur in the data, but it should be low over arid and semi-arid areas (Eklundh & Olsson, 2003). The trends were used in this study in order to locate areas with a positive respective neutral trend in NDVI in which field work could be done.

4.2.2 Landsat TM and Landsat ETM+

Geometrically corrected Landsat data were downloaded from the Global Land Cover Facility database (GLCF, 2004). Table 2 shows the path and row in WRS2 and acquisition dates for the data while Figure 2 shows the positions of the data.

Table 2. Acquisition dates and position in WRS2 for the Landsat data used in this study.

WRS2 P/R	TM Acquisition Date	ETM+ Acquisition Date
174/50	23.10.1987	25.08.2000
174/51	15.09.1987	27.11.1999
176/51	23.10.1987	27.12.1999

4.3 Precipitation data

Mean monthly precipitation data from 1982 to 1999 from the climate stations in Bara and El Obeid have been used. Table 3 shows the coordinates for the stations.

Table 3. The climate stations used in this study.

Climate station	N lat.	E long.
Bara	13° 42.308 N	30° 22.003 E
El Obeid	13° 10.469 N	30° 12.491 E

4.4 Image processing

4.4.1 Geometric correction of Landsat data

The Landsat data covering the same area from the two different dates were geometrically corrected to each other in order to cut out areas of interest and get the same size and exactly the same area. Every pixel in the Landsat TM data from 1987 was converted to the projection of the Landsat ETM+ data from 1999 and 2000. The reason that the TM´s were corrected to the ETM+´s is that the collected field data (training areas) correspond better to the ETM+´s that are newly taken. The nearest neighbour resampling was used in order to estimate the values of the pixels in the corrected pictures. This was done by using information in the uncorrected image. Each corrected pixel gets the value of the nearest uncorrected pixel. This method may introduce positional errors, but according to Kovalick (1983) in Campbell (2002) it is the most efficient method. Finally subsets of areas that surround the field work areas were cut out. These areas are about 600 km^2 each.

4.4.2 Conversion of Landsat 5 DN´s to Landsat 7 DN´s

In order to take advantage of the superior radiometric calibration of Landsat ETM+ the Landsat TM digital numbers (DN´s) were converted to ETM+ DN´s by the use of equation 4.

$$DN7 = DN5 \cdot slope + intercept \qquad \text{(Equation 4)}$$

where DN7 are the digital numbers of Landsat 7, DN 5 are the digital numbers of Landsat 5 and the slope and intercept values are as shown in Table 4 according to Vogelmann et al. (2001).

Table 4. The slope and intercept values used when converting Landsat 5 DN´s to Landsat 7 DN´s.

Band #	Slope	Intercept
1	0.9398	4.2934
2	1.7731	4.7289
3	1.5348	3.9796
4	1.4239	7.032
5	0.9828	7.0185
7	1.3017	7.6568

Using the set of gain and bias values shown in Table 5 when calculating the radiance, the derived image is treated as an ETM+ image when calculating at-satellite reflectance and tasseled cap transformation (USGS, 2001).

Table 5. The gain and bias values used when calcuating the radiance.

Band #	Gain	Bias
1	0.7756863	-6.1999969
2	0.7956862	-6.3999939
3	0.6192157	-5.0000000
4	0.6372549	-5.1000061
5	0.1257255	-0.9999981
7	0.0437255	-0.3500004

4.4.3 Radiance, at-satellite reflectance calculation for Landsat

The purpose with a radiometric correction is to convert the DN values to absolute radiance/ reflectance values. Absolute radiance is required when utilizing temporal data that may come from different sensors (variations in sun elevation angle etc.) or when using radiation as input to mathematical/physical models.

For relatively clear Landsat data, a reduction in between scene variability can be achieved through a normalization for solar irradiance by converting spectral radiance to effective at-satellite reflectance, or in-band planetary albedo (Markham & Barker, 1986).

The complete calculation of radiance and at-satellite reflectance for the Landsat 4, 5 and 7 data is shown in appendix III.

4.5 Land use classification

A supervised maximum likelihood classification based on the spectral differences between different classes was used to classify the quantity of the two classes, crop land and fallow land. The training areas collected during the field work were used to classify pixels of unknown identity. Landsat TM and ETM+ bands 2, 3, 4 and 5 were used.

The reason that only these two classes were used is that all the areas are farming land. First, a third class, villages was included, but the spectral signature of villages in the area is very difficult to separate from fallow land. Problems that occur when doing like this are discussed in section 6.3. When starting the classification fallow land was separated into the two subclasses of fallow with grass and fallow without grass. It was apparent that the spectral signatures of these two classes were not possible to separate from each other so the subclasses were merged.

A post classification comparision was made in order to reveal any changes in land use in the study areas. The areal change of the classes between 1987 and 1999 was calculated.

4.6 Accuracy assessment

An accuracy assessment of the classification results was made. This includes an error matrix with percentage correct, which is a report of the overall proportion of correctly classified pixels in the data, users accuracy, which is the probability that an area on the map chosen by chance is correctly classified and producers accuracy, which is the probability that an area in field chosen by chance is correctly classified were also calculated. Finally, Kappa was calculated for the different areas that were classified. Kappa is a measure which expresses to what degree the pixels in the interpretated map (satellite data) differ from a class category taken by chance. The calculations follows Congalton (1991).

4.7 Landsat fitting to NOAA

In order to locate the Landsat TM and ETM+ data in the vegetation cycle, a method of image comparison was used (Runnström, 2003). Mean monthly NOAA NDVI value was calculated for two areas that were visited during the field work. This was done for the complete growing season of the same years that the Landsat data that were used in the analyses are from. In order to reduce possible noise a 3*3 pixel window was used. Graphs of the 12 values were produced. Then subsets of the same areas were made from the Landsat data. An average NDVI value was calculated for the whole area. Then this value was placed in the NOAA NDVI graph at the corresponding date (Figures 12 and 13). Comparisons of Landsat NDVI values and the NOAA NDVI values and the duration in the growing seasons were made.

Finally two areas with no vegetation, one that consists of bare sand and El Obeid airport, that should have approximately the same NDVI values both in 1987 and in 1999 were analysed in order to find out if the data are suffering from changes that should not exist. That is to say, changes that are introduced by technical or atmospherical influence (Runnström, 2000).

4.8 Change in Landsat NDVI

The reflectance values for Landsat bands 3 and 4 were put into equation 3 in order to calculate the NDVI values for the different areas. The values from 1987 were then subtracted from the 1999 values. This way all values greater than 0 indicates a NDVI increase and all values smaller than 0 show a NDVI decrease. Then the areas which have increased and decreased in NDVI were calculated.

A second approach was to implement a threshold value of 0.03 NDVI units in each direction from 0 (no change) since very small changes could be seen as no change (Runnström, 2000). This way the areal change of three categories, increased NDVI, decreased NDVI and no change in NDVI were calculated.

4.9 Tasseled cap

One limitation with the post classification image comparison method described in section 4.5 is that the accuracy of the change map will be at best the product of the accuracies of each individual classification for each date (Lambin & Stralher, 1994). A multidate tasseled cap transformation is scene independent and has been shown to be successful in detecting change (Collins & Woodcock, 1996).

The tasseled cap transformation is a linear transformation that projects soil and vegetation data into a single plane in multispectral data space; a plane in which the major spectral components of an agricultural scene are displayed in two dimensions.

The concept of tasseled cap consists of four linear combinations (TC1, brightness, TC2, greenness, TC3, yellowness and TC4, nonsuch) but the first two bands (TC1 and TC2) usually cover almost all (95% or more) of the information in an agricultural area. Therefore, the essential components of an agricultural landscape are conveyed by a two dimensional diagram (Campbell, 2002). Since this study only concerns agricultural areas it was decided that only TC1 and TC2 should be included in the analyses in order to reduce the amount of redundant information.

The brightness band is a weighted sum of all bands and can be interpreted as the overall brightness or albedo at the surface. The greenness band primarily measures the contrast between the visible bands and near infrared bands and is similar to a vegetation index (Seto et al., 2002).

The transformation was made of linear combinations of Landsat TM/ETM+ bands 1-5 and 7 at-satellite reflectance in order to produce two new variables by the use of equations 5 and 6. This generates components of greenness and brightness and defines the new coordinate system on which the analysis is based. As a pixel undergoes change during a certain time interval its position in the defined coordinate system will also change.

$$TC1 = b^1*TM1+b^2*TM2+b^3* TM3+b^4*TM4+b^5*TM5+b^7*TM7 \quad \text{(Equation 5)}$$

$$TC2 = g^1*TM1+g^2*TM2+g^3*TM3+g^4*TM4+g^5*TM5+g^7*TM7 \quad \text{(Equation 6)}$$

where:

b = brightness coefficient
g = greenness coefficient

Table 6 gives the coefficients (Huang et al., 2002). These coefficients can be considered to be universally applicable (Campbell, 2002). But, accordingly to Jensen, 2000 it is preferable to compute them based on local conditions. Jackson (1983) provides a computer program for this purpose.

Table 6. The coefficients for the derived tasseled cap transformation based on at-satellite reflectance.

Index	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 7**
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630

The differences in brightness and greenness between 1987 and 1999 were calculated by the use of equations 7 and 8 (Figure 10).

$$\Delta x = brightness\ 1999 - brightness\ 1987 \qquad \text{(Equation 7)}$$

$$\Delta y = greenness\ 1999 - greenness\ 1987 \qquad \text{(Equation 8)}$$

These images were reclassed in order to produce four new images:

- Increased brightness
- Decreased brightness
- Increased greenness
- Decreased greenness

These images were overlayed to produce four section images in the following way:

*Section 1 = Increased brightness * Increased greenness* (Equation 9)

*Section 2 = Increased brightness * Decreased greenness* (Equation 10)

*Section 3 = Decreased brightness * Decreased greenness* (Equation 11)

*Section 4 = Decreased brightness * Increased greenness* (Equation 12)

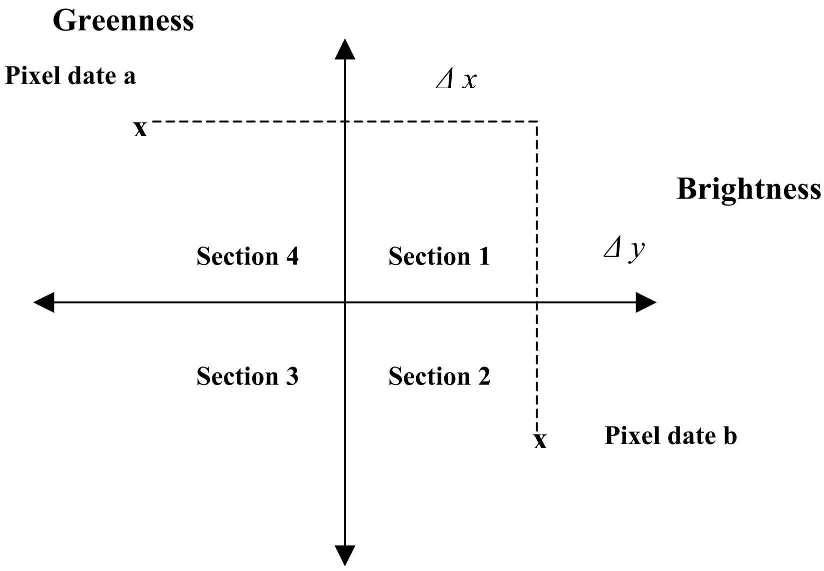

Figure 10. Change in greenness and brightness between two dates.

The tasseled cap method was performed on the areas of Abu Kamdela, El Bawabnes and Um Ganas (Figure 9).

4.10 NDVI – precipitation regression

Simple linear regression was computed to quantify the relationship between precipitation and NDVI at various time lag periods. The analyses cover the period from 1982 to 1999. NDVI was chosen as the dependent variable and precipitation as the independent variable.

Two areas, one in the northern part of the study area and one in the southern part of the study area have been used in the regression analyses since the precipitation gradient in Sahel is in the north-south direction. The areas are the Bara area in north and the El Obeid area in south (Figure 9).

The used NDVI values are the NOAA PAL data. Three different analyses were made per area. No time lag, a time lag of one month and a time lag of two months. The reason for this is that the time lags between precipitation and NDVI in the areas are unknown. The results with the highest correlation are regarded as the most accurate duration of the time lag.

As a complement of these analyses, NDVI and precipitation for the two areas were plotted in monthly diagrams both for 1987 and 1999, the years that the Landsat data are from.

5 Results

5.1 Interviews

The results from the interviews are divided in to seven categories:

1. Change in the amount of vegetation.
2. Changes in species composition and quality for livestock.
3. Changes in the amount of livestock.
4. Changes in fire wood collection time.
5. Changes in land use.
6. Changes in yield/hectare.
7. Changes in population.

According to the respondents in the villages that are situated in neutral NOAA NDVI areas the amount of vegetation has decreased between 1982 and 1999. In two of the three villages that are situated in areas with a positive trend in NOAA NDVI the villagers said that the amount of vegetation has increased, but they pointed out that they have noticed changes in species composition in the direction of decreased quality for livestock forageing. This is also true for the neutral areas. Except for Makawi (Tables 7 & 8).

The villages that are situated in positive NOAA NDVI areas had more animals 1999 compared to 1982 and the villages that are situated in neutral NOAA NDVI areas had less animals 1999 compared to 1982. In all villages, except one, they had to spend more time 1999 to collect the same amount of fire wood as before the drought in 1984. The village in which the villagers said that they do not have to spend more time is situated in a neutral NOAA NDVI area (Tables 7 & 8).

The three positive villages are growing crops on more land now compared to 1982. In the neutral villages 50% are growing crops on more land and 50% on less land. Positive change in crop yield/hectare are seen in two of the three positive villages but in non of the neutral villages (Tables 7 & 8).

In every village, except one, the population has grown between 1982 and 1999 (Tables 7 & 8). The villagers in the one (Um Ganas) that shows a decrease said that they were about 800 families before the drought in 1984. During the drought approximately 100 families moved from the area. They did not move back after the drought. Compared to the other villages that are included in this study Um Ganas is very large.

Table 7. Changes in the seven categories in the four villages that are situated in areas with a neutral trend in NOAA NDVI between 1982 and 1999. X = no data.

Village	Abdel Hai	Abu Kamdela	Makawi	Um Ganas
1.	Decrease	Decrease	Decrease	Decrease
2.	Yes, worse	Yes, worse	Yes, no quality change	Yes, worse
3.	X	Decrease	Decrease	Decrease
4.	No change	Longer collecting time now	Longer collecting time now	Longer collecting time now
5.	Increased cropland	Decreased cropland	Increased cropland	Decreased cropland
6.	Negative	Negative	X	Negative
7.	Higher population	Higher population	Higher population	Lower population

Table 8. Changes in the seven categories in the three villages that are situated in areas with a positive trend in NOAA NDVI between 1982 and 1999.

Village	El Bawabnes	El Fylia	Kalot
1.	Increase	Decrease	Increase
2.	Yes, worse	Yes, worse	Yes, worse
3.	Increase	Increase	Increase
4.	Longer collecting time now	Longer collecting time now	Longer collecting time now
5.	Increased cropland	Increased cropland	Increased cropland
6.	Positive	Negative	Positive
7.	Higher population	Higher population	Higher population

5.2 Land use classification

In the Kalot area, which has a positive NOAA NDVI trend, the crop land has increased from 32% to 37% between 1987 and 1999. At the same time the fallow has decreased from 68% to 63%. In the Abu Kamdela area, which has a neutral NOAA NDVI trend, the fallow has increased from 67% to 74% between 1987 and 1999. At the same time the crop land has decreased from 33% to 26%. In the other three areas, El Bawabnes, En Nahud and Um Ganas, the changes are insignificant (Figure 11).

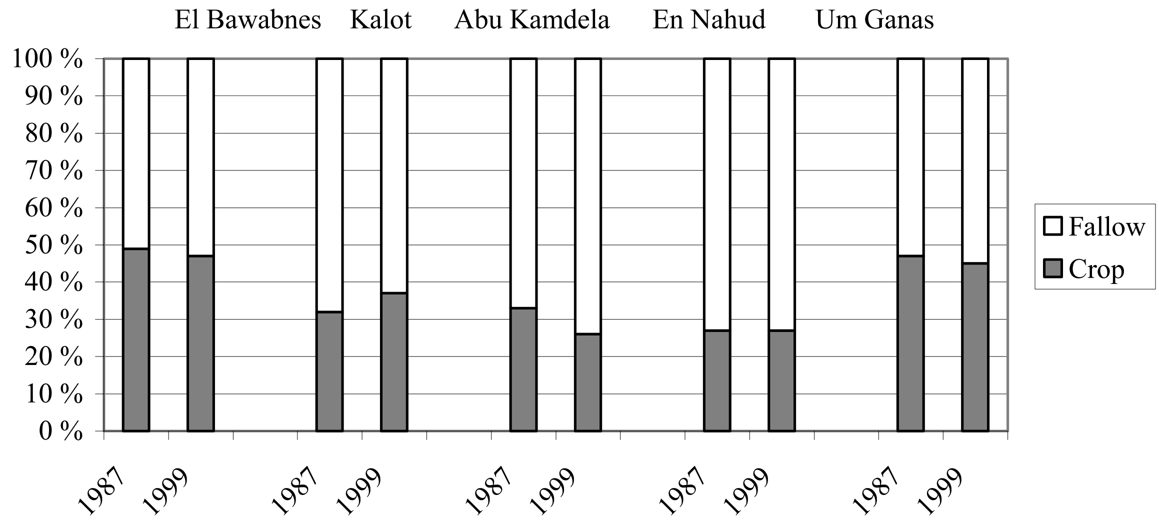

Figure 11. Changes in the crop and fallow areas in El Bawabnes (positive), Kalot (positive), Abu Kamdela (neutral), En Nahud (neutral) and Um Ganas (neutral).

Of the five areas it is only in one that the cropping area has increased accordingly to the land use classification (Table 9).

Table 9. Change in percentage in cropping and fallow area between 1987 and 1999.

Area	NOAA NDVI change	Change in cropping area	Change in fallow area	Kappa
Abu Kamdela	Neutral	-21 %	10 %	0.87
En Nahud	Neutral	0 %	0 %	0.57
Um Ganas	Neutral	-4 %	4 %	0.44
El Bawabnes	Positive	-4 %	4 %	0.16
Kalot	Positive	16 %	-7 %	0.23

The complete results from the accuracy assessments are shown in appendix IV.

5.3 Landsat fitting to NOAA

The NOAA monthly NDVI and Landsat NDVI fitting for the Um Ruwaba area show that the NDVI values of 1999 correspond better to each other than the 1987 values do (Figure 12). The Landsat data are from 15/9 1987 and 27/11 1999. The Landsat data 1987 correspond to the NOAA NDVI maximum value, but the Landsat data 1999 correspond to the NOAA NDVI declining period.

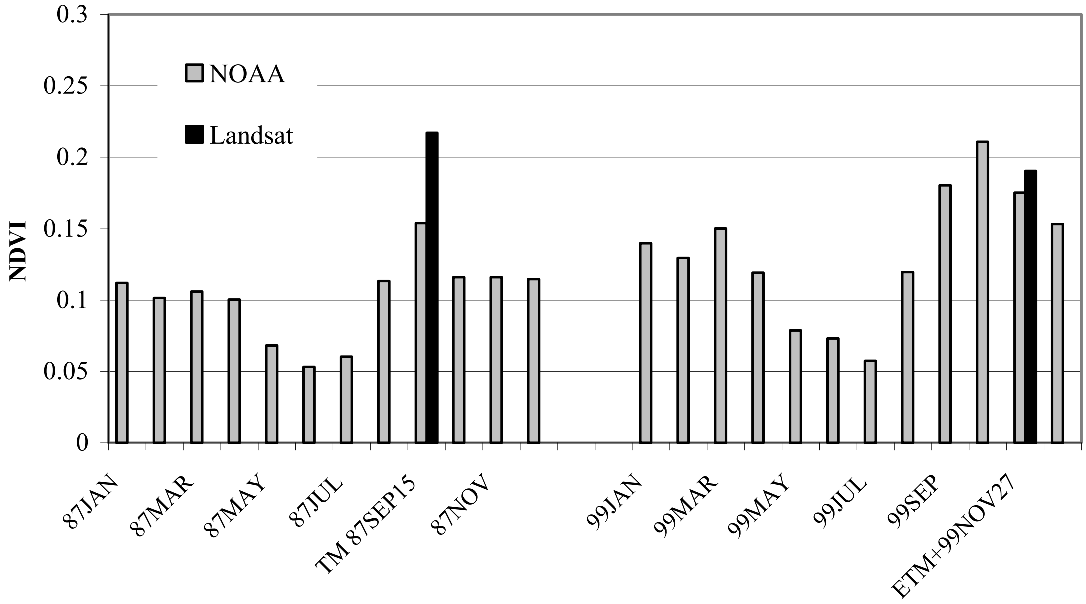

Figure 12. Landsat TM (1987) and ETM+ (1999) NDVI put into the NOAA NDVI vegetation cycle. The area is Um Ruwaba which corresponds to path 174 and row 51 in the WRS2.

Also in the En Nahud area it is evident that the 1999 NDVI values correspond better to each other than the 1987 values do (Figure 13). The Landsat data are from 23/10 1987 and 27/12 1999. The Landsat data for both 1987 and 1999 correspond to the NOAA NDVI declining period

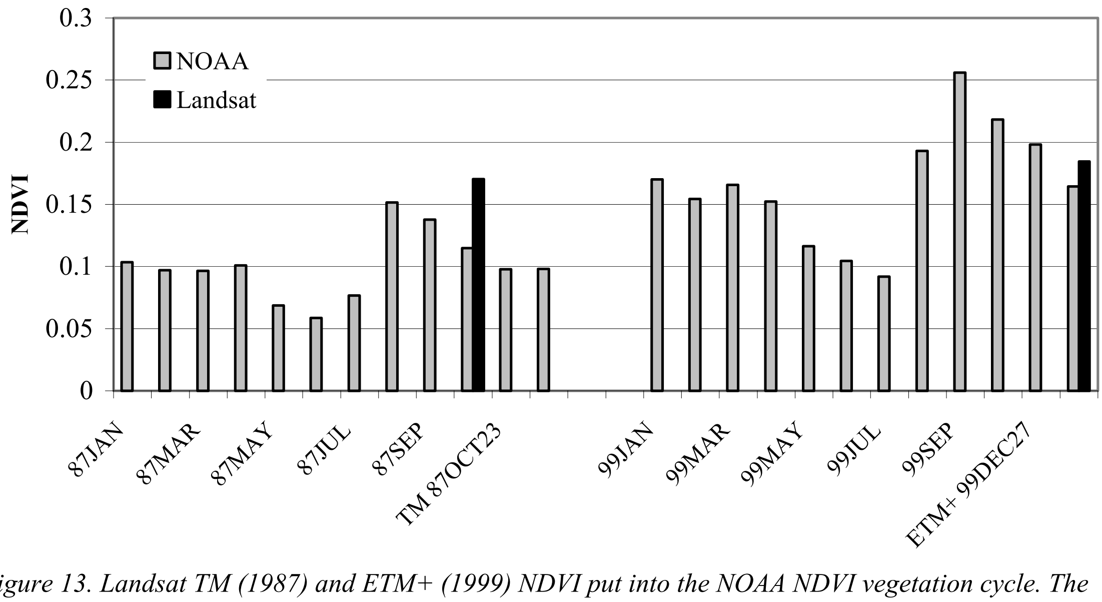

Figure 13. Landsat TM (1987) and ETM+ (1999) NDVI put into the NOAA NDVI vegetation cycle. The area is En Nahud which corresponds to path 176 and row 51 in the WRS2.

A comparison of 1987 and 1999 Landsat NDVI values on areas without vegetation does not indicate that the 1987 Landsat NDVI values are systematically too high.

5.4 Change in Landsat NDVI

The changes in Landsat NDVI from 1987 to 1999 are shown in Table 9. The areas correspond to the areas that field work has been done in. In all areas it is just a smaller part that shows an increase in NDVI. The greatest increase has occurred in the En Nahud area, which has had a neutral trend in NOAA NDVI 1982-1999 and the smallest increase has occurred in The El Bawabnes area, which has a positive trend in NOAA NDVI 1982-1999.

Table 9. Areal changes in Landsat NDVI from 1987 to 1999.

Area	Change in NOAA 1982-1999	Increase in Landsat NDVI	Decrease in Landsat NDVI
Abu Kamdela	Neutral	10 %	90 %
En Nahud	Neutral	25 %	75 %
Um Ganas	Neutral	24 %	76 %
El Bawabnes	Positive	9 %	91 %
Kalot	Positive	19 %	81 %

When applying a threshold value of 0.03 NDVI units in each direction from 0 (no change), the part of the areas that has increased in NDVI decreases. In four out of the five areas the majority of the land falls into the "no change" category. The area with the greatest increase changes from En Nahud to Abu Kamdela which also is an area with a neutral NOAA NDVI trend 1982-1999. The area with the smallest increase is still El Bawabnes (Table 10).

Table 10. Areal changes in Landsat NDVI from 1987 to 1999 with a threshold of 0.03 NDVI units in each
direction from 0 (no change).

Area	Increase in Landsat NDVI	Decrease in Landsat NDVI	No change in Landsat NDVI
Abu Kamdela	7 %	83 %	10 %
En Nahud	1 %	17 %	82 %
Um Ganas	4 %	43 %	53 %
El Bawabnes	0 %	37 %	63 %
Kalot	1 %	29 %	70 %

5.5 Tasseled cap

The tasseled cap technique was made on three different areas, two with a neutral trend and one with a positive trend in NOAA NDVI 1982-1999. In all areas the majority of the area falls into section 3, which means that both the greenness and the brightness have decreased (Figure 14).

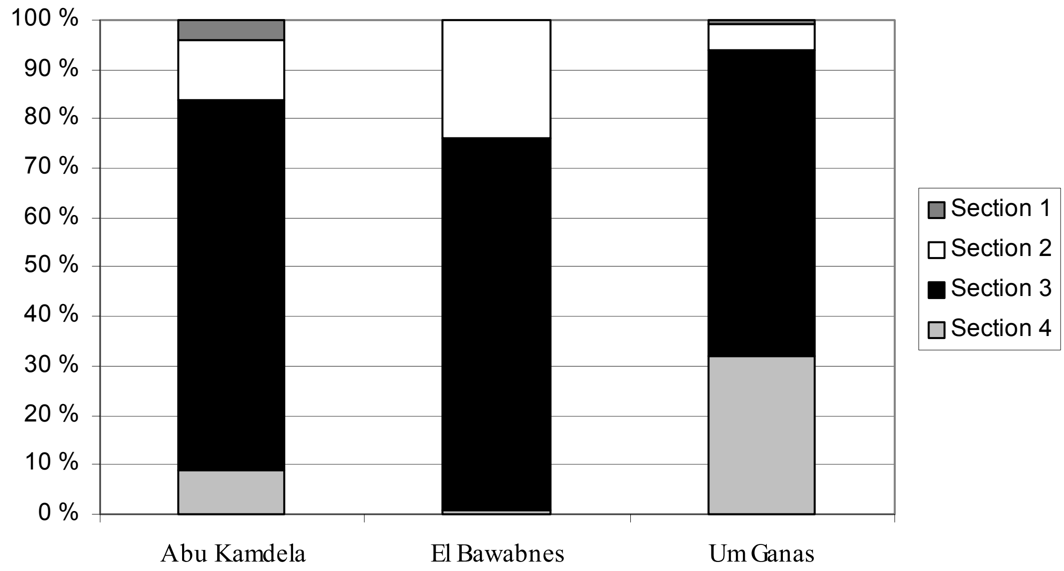

Figure 14. The percent of the different sections that the pixels fall into in the areas of Abu Kamdela (neutral NOAA NDVI), El Bawabnes (positive NOAA NDVI trend) and Um Ganas (neutral NOAA NDVI trend).

5.6 NDVI – precipitation regression

The relationship between NOAA NDVI and monthly precipitation 1987 and 1999 in the Bara area, which is situated in the northern part of the study area (Figure 15).

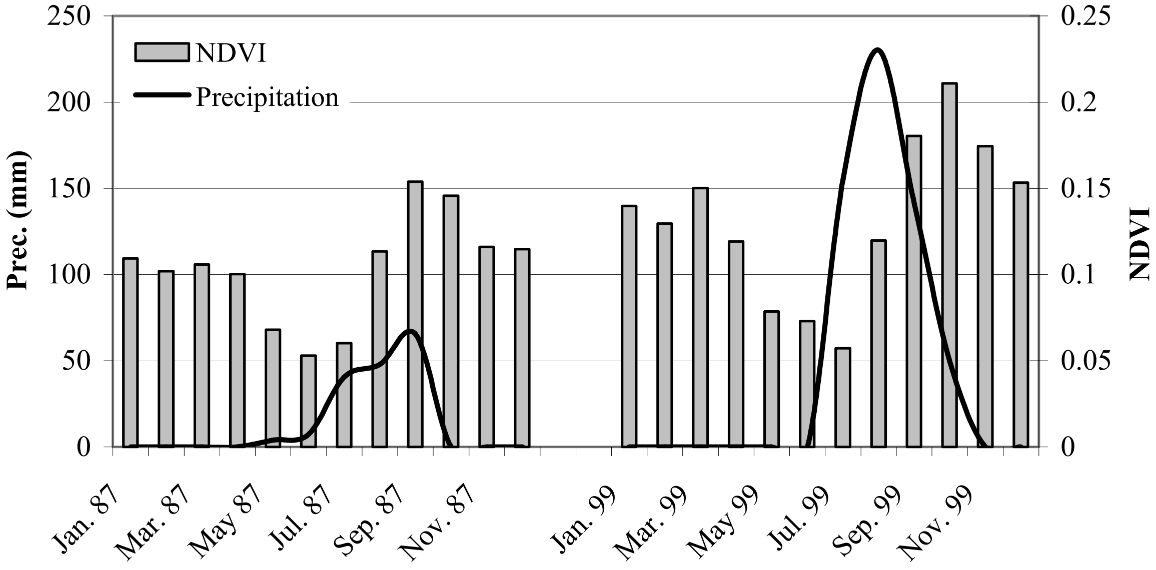

Figure 15. The relationship between rainfall and NDVI 1987 and 1999 in the Bara area that is situated in the northern part of the study area.

The relationship between NOAA NDVI and monthly precipitation 1987 and 1999 in the El Obeid area, which is situated in the southern part of the study area (Figure 16). The rain falls from May to October. A time lag between rainfall and the NDVI response is evident. The NDVI peak appears in September.

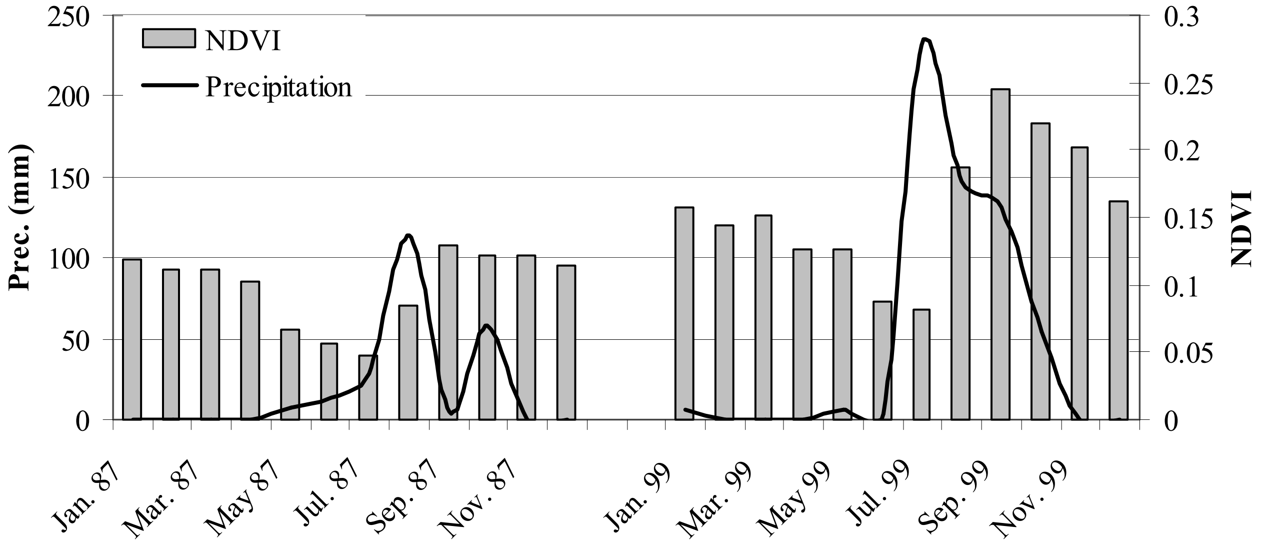

Figure 16. The relationship between rainfall and NDVI 1987 and 1999 in the El Obeid area that is situated in the southern part of the study area.

In 1999, both NDVI and precipitation are higher compared to 1987. This is true both for the Bara and the El Obeid areas.

The regression analyses between NDVI and precipitation from 1982 to1999 in the Bara and El Obeid areas show that the degree of explanation is strongest when applying a two month precipitation lag but the degree of explanation is low for all time lags in both Bara and in El Obeid (Table 11).

Table 11. NDVI and precipitation regression statistics for the Bara and El Obeid areas

Time lag (months):	Bara	El Obeid
0	r^2 = 0.01 (P=0.105;n=216)	r^2 = 0.02 (P=0.073;n=216)
1	r^2 = 0.11 (P<0.000;n=216)	r^2 = 0.21 (P<0.000;n=216)
2	r^2 = 0.23 (P<0.000;n=216)	r^2 = 0.21 (P<0.000;n=216)

6 Discussion

6.1 Satellite data

The NOAA AVHRR data set gives possibilities to study long term changes in vegetation (Tottrup & Rasmussen, 2004) but according to Cihlar et al. (2004), NOAA AVHRR data are known to be burdened with limitations that make their use for vegetation studies problematic. Discrepancy in calibration, inter-calibration between different platforms (Gutman, 1998) and changes in solar zenith angle (SZA) (Slayback et al., 2003) are known to contribute to these problems. But Kaufmann et al. (2000) concluded that the NOAA AVHRR Pathfinder data set does not have problems with trends that are introduced by changes in SZA due to orbital decay and changes in satellites. Further they said that "the NDVI data set can be used to analyze interannual variability of global vegetation activity".

The monitoring of vegetation in arid and semi-arid regions is made difficult by the dominant and variable soil signal (Huete et al., 1994). The NDVI has been shown to possess problems and limitations with the soil background signal (Huete & Tucker, 1991). This may lead to faults in the data analyses in this study.

Another problem that occurs when working with remote sensing data is the influence of the atmosphere. Aerosols and clouds lead to scattering of radiation and missing data. This is the reason that the analysis results from Landsat scene 174/50 are not presented in the results. Thin clouds cover a great part of the scene.

The Landsat TM and ETM+ sensors are geometrically and radiometrically compatible (USGS, 2001). In order to take advantage of the superior radiometric calibration of ETM+ Landsat TM DN´s were converted to ETM+ DN´s. This was done with TM 5 but not with TM 4 since no conversion model has been developed.

According to Rasmussen et al. (2001), satellite images, used with caution, do provide unique information on environmental change on the time scale of decades. However, they say, many misreadings of these data sources occur, and it is strongly recommended that field work, including interviews with local people, is performed in order to allow extraction of trustworthy information.

6.2 Interviews

The fact that the amount of vegetation has increased in two out of three villages that are situated in areas with a positive trend in NOAA NDVI and decreased in all the neutral villages supports the results of Eklundh & Olsson (2003).

In all villages a change in species composition has been recognized by the villagers. Changes in species composition in the Sahel region have also been noticed by Rasmussen et al. (2001). It is important to keep in mind that changes in species composition may occur without any detectable changes in NDVI. Kertesz et al. (2001) could not find any significant associations between species composition and biomass (NDVI) and according to Hanan et al. (1991) selective grazing frequently leads to an increase in the relative number of hardy and less palatable species. Thus, even if the area is getting greener (higher NDVI) it may be exposed to degradation processes. This is supported by the answers since the respondents in the villages with a positive NOAA NDVI trend all said that the vegetation quality for livestock fodder has decreased. The fact that the villagers in one of the neutral villages said that the quality has not changed supports Kertesz et al. (2001).

Changes in the amount of livestock were prevalent in all villages. In the neutral villages the amount had decreased between 1982 and 1999 and in the positive villages the amount had increased during the same time period. This fact could indicate that areas with a positive NDVI change can support a larger amount of livestock, even though it is easy to assume that an increase in livestock should lead to a decrease in vegetation.

Animal grazing of vegetation has both negative and positive effects on vegetation. Trampling kills sensitive species and increase the amount of soil exposure but the growth of many savanna species is stimulated by moderate grazing, faeces of livestock fertilize the rangeland and seed dispersal can be enhanced (Hanan et al., 1991).

The three positive villages in which the amount of livestock has increased have also increased their area of cropland. These results seem to be contradictionary but Mortimore et al. (1999) have noticed that the Sahelian (north-east Nigeria) agriculture system may support very high livestock densities.

All the villages that are situated in positive NOAA NDVI areas and two of the four villages that are situated in neutral NOAA NDVI areas have extented their cropping area between 1982 and 1999. Since all but one (Um Ganas) of villages show a positive population trend during the same time it is easy to assume that the increased cropping areas is a result of the growing populations demand for more food. The village that has a negative population trend is one of the two that have less cropland now compared to the time before the drought in 1984. The fact that all positive villages have increased could indicate that more cropland leads to higher NDVI. If this is true it ought to be a short time trend since nutrient depletion in the soil will appear with shortened fallow length (Drechsel et al., 2001). Eventually this should lead to decreased vegetation (NDVI).

The change in crop yield/hectare is positive in two of the three villages that are situated in areas with a positive trend in NOAA NDVI. In the neutral villages the yield has decreased between 1982 and 1999. Poor crop land fertility and a rapidly rising demand for food force Sahelian farmers to cultivate more land and shorten fallow periods. This mostly leads to a gradual decline in crop yields per hectare (Schlecht et al., 2004). So, why has the yield/hectare increased in two of the three positive villages? In Kalot the villagers said that the reason is that they have much more *Acacia senegal* trees now compared to the time before the drought in 1984. *Acacia senegal* is known to fertilize the soil (Khogali, 1991) so these trees may be the explanation. The villagers in El Bawabnes said that they had invested money in a tractor. When having a tractor the soil can be more effectively treated.

In all but one (Abdel Hai) of the visited villages the villagers said that they have to go further away now to collect fire wood compared to the time before the drought in 1984. Thus, even in the villages that are situated in positive NOAA NDVI areas they spend more time now compared to before. One reason that could explain this fact is that all areas has undergone changes in species composition. Even if the NDVI trend is increasing in an area it does not nessesary mean that the woody vegetation has increased and the villagers in all but one village (Kalot) said that the amount of trees has decreased. As said, the villagers in Kalot said that they have started to grow *Acacia senegal* trees after the drought in 1984 and that the soil has become more fertile afterwards. So of cause, they do not want to cut the trees that fertilize their soil in order to get fire wood. Another reason explaining the longer collecting time is probably the increase in population. The reason that the villagers in Abdel Hai do not have to spend more time now is unknown.

The villages in which the interviews were held were chosen so that villages in both neutral and positive NOAA NDVI areas would be represented. The fact that the villages are different in both size, the amount of inhabitants and are placed on different soils has been overlooked.

Furthermore, the amount of visited villages (seven) may be too small in order to be able to draw strict conclusions from the results.

In all the interviews but one the village leader was present. Bielders et al. (2000) said that it is best to exclude the village leaders from the group interviews in order to avoid possible dominance from them in the discussions. This fact was not known when the interviews were done. Since the interviews were held on the local language with an interpreter it is difficult to say anything about village leader dominance.

The results from the interviews are relatively uncertain, but it is probably the only way to get the information.

6.3 Land use classification

Land use changes within positive and neutral trend areas were compared and used to study the possible influence of human land use on the observed trend in NOAA NVDI.

According to Paruelo et al. (2001) land use can be more important than mean annual precipitation, mean annual temperature and soil texture in determining the dynamics of NDVI.

No clear trend in land use change could be detected from the classification analyses. But it seems that the positive areas have shown an increase in cropping areas/decrease in fallow and that the neutral areas have shown a decrease in cropping areas/increase in fallow. This is supported by the interviews. During the interviews the villagers in the villages that are situated in areas with a positive trend in NOAA NDVI said that they have increased their cropping area between 1982 and 1999. Mortimore et al. (1999) said that conversion of natural woodlands to farmland may lead to a gain of plant productivity and that the farmers should be seen as potential conservators and Uchida (2001) found that cropped areas can have as high NDVI values as densely vegetated areas during the crop growing period in Burkina Faso. Thus, it could be that increased cropping area leads to higher NDVI. One reason explaining this could be that cultivated areas have a better plant growth rate since the land is tilled which increase water infiltration rates (Kumar et al., 2002).

The reason that there are differences between the results from the land use analyses and the interviews could be that the interviews just concern the changes within the village border. The analyses cover a far greater area that include several villages.

In Kalot the villagers said that they often change between crop and fallow. Since rotation farming is common in the study area, it is more difficult to do the classifications since the newest satellite data in this study is from 1999 and the field work was done in 2004. This fact leads to problems when classifying the Landsat data and could be the reason that the accuracy assessment did not show better result than it did in some areas. The reason that the results from the accuracy assessment are so different in the different areas is probably that the rotation between crop land and fallow land has gone faster in some areas than others.

It was proved that it is very difficult to distinguish between fallow with grass and fallow without grass. Therefore these two classes were combined into one single class: fallow. This should not affect the results in a way that they are not interesting to analyse. The aim was to see changes in the farming system and the two classes fallow with grass and fallow without grass could be seen as one class in different temporal stages.

During the classification process it was recognized that it is very difficult to differ villages from fallow since their spectral signature are very similar. This may be due to the fact that the houses are built of vegetation and the natural vegetation on the fallow land often are not green.

Thus, the vegetation material in both areas are similar in their appearance. Another reason may be that the villagers save some trees in the villages as shade, giving the village an appearance like the fallow areas with scattered trees. Since many villages have grown during the period that the analyses cover, this could lead to errors in the results. That is to say, positive changes in fallow areas do not need to exist in the same extent as the classification results show. A possible way to improve the results would be to locate all the villages with the village envelopes and exclude them from the area calculations.

The maximum likelihood classification method is sensitive to variations in the quality of the training data. It is based on that the training data display normal frequency distribution.Training data that are not carefully selected may introduce errors (Campbell, 2002). When chosing training areas for the classification this was not fully taken into account. However, cropping fields with different crops and fallow areas with different amount of vegetation were used so the data do display multivarite normal frequency distribution.

Peterson & Aunap (1998) said that it is best to use multi date data from different parts of the growing season since the vegetation phenology is not the same throughout the season. They used data from three different dates during the same year, spring, summer and winter. This was not possible in these analyses and may be a source of error.

6.4 Landsat fitting to NOAA

Absolute values of calculated NDVI usually differ between Landsat TM/ETM+ and NOAA data because of slightly different width and position of the red and infrared wavebands (Tables 1, 2 and 3 in appendix I). But relative differences within the time series are comparable (Runnström, 2003).

The fitting of the Landsat NDVI values into the NOAA NDVI vegetation cycles is better when comparing the ETM+ (1999) values than when comparing the TM values (1987). This is true both when comparing Landsat 4 (TM) with Landsat 7 (ETM+) and when comparing Landsat 5 (TM) with Landsat 7 (ETM+).

The Landsat TM data show a much higher NDVI than the NOAA data in 1987. This fact could be one of the reasons that the Landsat NDVI trend between 1987 and 1999 does not look like the NOAA trend. Steven et al. (2003) found that Landsat TM NDVI values are slightly higher than NOAA NDVI. But, the NOAA NDVI values used in this study are MVC´s and Goward et al. (1993) found that the MVC method produces an upward bias in NDVI. Even so, the method did not compensate the lower NOAA NDVI values. A possible explanation contributing to the difference between NOAA and Landsat NDVI 1987 could be atmospheric disturbance.

The areas of En Nahud and Kalot, that are situated in Landsat scene 176/51, show a smaller percent of land with a decrease in Landsat NDVI than the areas of Abu Kamdela, El Bawabnes and Um Ganas, that are situated in Landsat scene 174/51. The reason for this is probably that the data for both 1987 and 1999 in Landsat scene 176/51 correspond to the NOAA NDVI declining period and that the Landsat scene 174/51 data for 1987 correspond to the NOAA NDVI maximum value and the Landsat data from 1999 correspond to the NOAA NDVI declining period (Figure 12 and 13). This fact verifies that it is important to use satellite data that are taken in the same part of the growing season since the results from Landsat scene 176/51 seem to be more trustworthy.

Even so, it is apparent that the Landsat data are not taken in the same part of the growing season. This leads to the conclusion that the results from the Landsat NDVI change analyses are not totally reliable.

6.5 Change in Landsat NDVI

In all areas, both the ones that are positive and the ones that are neutral in NOAA NDVI, the majority of the land shows a negative trend in Landsat NDVI between 1987 and 1999. When applying a threshold value of 0.03 NDVI units in each direction from 0 (no change) the result changes. A great part of the area that fell into “Decrease in NDVI” now fall into “No change in NDVI”. Thus, a great part of the change is so small that it could be regarded as no change. Even so, the area that falls into “Increase in NDVI” is very small. Both in areas that have a neutral trend in NOAA NDVI and areas that have a positive trend in NOAA NDVI. Consequently, no confirmation of the observed NOAA NDVI trend could be done with Landsat data on a local scale.

Due to the fact that the Landsat data in this study are not from the same period of the growing season, it is not possible to use the results to detect any changes in NDVI over time and get a satisfactory result. Lambin (1996) said that green biomass is problematic to study as the seasonal vegetation cycle makes measured interannual changes difficult to evaluate. This is especially important in areas with marked seasonal variations. The seasonal match and which years that are chosen are consequently critical for any change study (Runnström, 2003). According to the Landsat NOAA fit (section 5.3) it is not recommendable to compare the amount of vegetation between the two acquisition dates of the Landsat data. The difference between the two dates is approximately two months. Thus, the difference in the duration of the growing season is too long.

NDVI is higher 1987 compared to 1999. This is natural since the data from 1987 are taken at the end of the rain season, when the vegetation is most green, and the data from 1999 are taken at the beginning of the dry season.

Another fact that could explain the observed results is that the crops were harvested in the 1999 data but not in the 1987 data. NDVI values decrease very quickly in a short time period during harvest time (Kumar et al. 2002). It is difficult to observe a rapid NDVI decrease in the NOAA pathfinder data series that could indicate harvest time in the study area. This could be explained by the coarse image resolution, in combination with the landscapes small-scale heterogeneity and that these small fields are not harvested at exactly the same time.

Normally farmers start to harvest their crops in the end of November or in the beginning of December (Algfadni, personal communications). Since the Landsat data from 1987 that the results are based on are taken in September and October and the data from 1999 are taken in the end of November and in the end of December, it is most likely that the crops have been harvested between the acquisition dates.

Paruelo et al. (2001) found that different land use types show differences in the date of maximum NDVI, but the difference in time between non irrigated crops and grassland (fallow) is not very big. Anyway, this fact will affect the result since the different areas that have been analysed have different proportions of crop land and fallow land.

Twumasi et al. (2003) made a change analysis in three different Sahelian countries, Burkina Faso, Mali and Niger, between 1984/1987 and 1999/2001 using six different Landsat TM/ETM+ scenes that partly cover NOAA NDVI areas that have a positive trend. They said “a common feature of the three zones is the direction of vegetation degradation.” Thus, the regional trend in NDVI does not necessary have to be detectable on a local scale. Or, it may be that the uncertainties are too big when using the technique of comparing “snapshots” from two different dates.

Thus, no confirmation of the NOAA NDVI trend could be done on a local scale.

This may be due to the fact that the study area does not contain any large homogeneous areas that are positive. This fact may increase the possibility that the data are burdend with noise. Yet another explanation may be that the NOAA NDVI values are MVC values over 8*8 km. Thus, the choice of delimitation of the working areas in the Landsat data could influence the results since these data have a spatial resolution of 30*30 m.

Landsat data are not available at the desired temporal frequency for technical and economical reasons. This is a disadvantage when comparing data from different years and it has most certainly influenced the results. If access to Landsat data that are from the same part of the growing season were able to get, it would probably lead to another result.

6.6 Tasseled Cap

In order to reduce any sensor differences between Landsat TM and Landsat ETM+ the TM DN values from 1987 were converted to ETM+ DN values. Two neutral areas and one positive area were used in these analyses.

The majority of the pixels in all areas falls into sector three. Sector three represents decreased greenness and decreased brightness. A possible explanation for the decreased greenness is already mentioned in section 6.4-6.5. The Landsat TM data from 1987 are taken the 15:th of September and the Landsat ETM+ data from 1999 are taken the 27:th of November. Thus, the 1987 data are from the wet season and the 1999 data are from the dry season. To produce reliable results, it is recommendable to use data that are taken in the same part of the season.

The decreased brightness could be explained by the differences in precipitation between 1987 and 1999. 1999 was a much wetter year than 1987. Decreased brightness can be interpreted as a reduction in albedo. Since wet soil is known to produce a lower albedo than dry soil (Bach & Verhoef, 2003) it is natural that the brightness has decreased. However, the Landsat data from 1999 are taken in the end of November when the rain season has ended. So this is not a very likely explanation. But, it may be that the high amount of dry grass during the dry season can produce a decreased brightness. The difficulty to interpret the results is a major disadvantage with the tasseled cap analysis according to Lu et al. (2004).

It seems that the difference in the growing season is so big that it is not possible to see any differences between neutral and positive areas.

The similar results from the Landsat NDVI change analysis and the tasseled cap analysis give certain strength to the results meaning that it is most likely that the amount of green vegetation is smaller in the end of November 1999 compared to mid September 1999.

6.7 NDVI - precipitation regression

The available precipitation data do not have sufficient spatial resolution to do the NDVI-precipitation regression on the same local scale as the rest of the analyses in this study. So, the regressions were made of data from two climate stations in the study area. One in the northern part of the area, Bara, and one in the southern part of the area, El Obeid. This gives an idea of how important the climate is in the processes of land degradation/improvement or if it is other processes that are the dominating ones. The time lag between precipitation and NDVI is more evident in the El Obeid area. These results could indicate that the herbaceous part of the vegetation is greater in the Bara area than in the El Obeid area. Previous research (Wellens, 1997) has found that areas with more herbaceous vegetation contributes to the recorded satellite signals faster than areas that consist mostly of shrubs. The fact that the soil around El Obeid contains more clay than the soil in the Bara area could be another explanation since the growth rates on sandy soils are significantly greater than that on clayey soils (Kumar at al., 2002).

The method implemented in this study, compensating for the time lag between precipitation and NDVI, by moving the rainfall forward one or two months before doing the regression analysis is a simple approach, and one could criticize it since it is impossible to know the exact duration of the time lag. One could use a more statistical correct method described in Eklundh (1996) if one wants to continue this work. But, according to Diouf and Lambin (2001) there is a considerable variation in the response of vegetation to rainfall on a local scale in the Sahel region. They mention soil type, interannual variations in rain use efficiency and land use as possible reasons. Another reason of the weak temporal relationship between NDVI and precipitation could be that the rainfall is absent during a great part of the year in this part of the world leading to decreased results in the regression analyses.

Although rainfall is important for vegetation production the relationship between precipitation and NDVI was found to be indistinct. The weak relationship between rainfall and NDVI shown in this study ($r^2 = 0.21$ respectively 0.23) is supported by Diouf & Lambin (2001) and Tottrup & Rasmussen (2004), but one should consider that only two areas were used in the analysis and that other results show a strong relationship between precipitation and vegetation growth in semi-arid regions (Prince et al., 1998; Wellens, 1997).

The precipitation in 1999 was higher than it was in 1987 (Section 5.6). Despite this fact the NDVI was higher 1987. If the relationship is strong between precipitation and NDVI this should be seen in the change in Landsat NDVI (Section 5.4). At least if the compared Landsat data were taken during the same part of the growing season. This could not be seen. But one should consider that it is not only the total amount of precipitation that determines the amount of vegetation. Factors like the rain intensity and the timing of the rain are important for the vegetation growth.

6.8 Discussion summary

$H_0$1. Is the vegetation changes in areas with a significant NDVI increase = vegetation changes in areas with no significant NDVI increase.

The interview results show that the amount of vegetation partly has increased in areas with a positive trend in NOAA NDVI and that it has decreased in areas with a neutral trend in NOAA NDVI, but both the Landsat NDVI change analysis and the tasseled cap analysis show that the amount of green vegetation has decreased between 1987 and 1999 in both positive and neutral areas. Consequently, $H_0$1 can not be rejected.

$H_0$2. Is the precipitation in areas with a significant NDVI increase = precipitation in areas with no significant NDVI increase.

This hypothesis could not be completely tested due to the fact that the available precipitation data do not have sufficient spatial resolution to analyse the relation between NDVI and precipitation on the local scale in both positive and neutral areas. But the results from the regression analyses show that there is not a strong relationship between NDVI and precipitation in North Kordofan. Thus, $H_0$2 can not be rejected.

$H_0$3. Is the land cover and land use in areas with a significant NDVI increase = land cover and land use in areas with no significant NDVI increase.

In three out of the five areas that have been analysed no clear trend in land use change could be detected. But it seems that the positive areas have shown an increase in cropping areas/decrease in fallow and that the neutral areas have shown a decrease in cropping areas/increase in fallow. This is supported by the interviews. $H_0$3 can not be rejected.

$H_0$4. Are the population changes in areas with a significant NDVI increase = population changes in areas with no significant NDVI increase.

The population has increased in all villages but one. $H_0$4 can not be rejected.

$H_0$5. Is the change in amount of livestock in areas with a significant NDVI increase = the change in the amount of livestock in areas with no significant NDVI increase.

The amount of livestock has increased in areas with a significant positive NOAA NDVI increase, and the amount of livestock has decreased in areas with a neutral trend in NOAA NDVI. $H_0$5 can be rejected even though the idea was that an increase in livestock would lead to a decrease in NDVI.

7 Conclusion

The conclusion is that it is difficult to explain the observed trend in NOAA NDVI between 1982 and 1999 on a local scale, based on the data that have been used in this study. Futhermore, it is also difficult to explain way the observed changes have occurred.

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Appendix I

Table 1. Spectral and spatial resolution for the NOAA Pathfinder data used in this study.

Band #	Spectral resolution (μm)	Spatial resolution (m)
1	0.58 - 0.68	8000
2	0.73 - 1.10	8000

Table 2. Spectral and spatial resolution for the Landsat TM bands used in the analyses.*

Band #	Spectral resolution (μm)	Spatial resolution (m)
1	0.45 - 0.52	30
2	0.52 - 0.60	30
3	0.63 - 0.69	30
4	0.76 - 0.90	30
5	1.55 - 1.75	30
7	2.08 - 2.35	30

* Band 6 not used.

Table 3. Spectral and spatial tesolution for the Landsat ETM+ bands used in the analyses.*

Band #	Spectral resolution (μm)	Spatial resolution (m)
1	0.45 - 0.515	30
2	0.525 - 605	30
3	0.63 - 0.69	30
4	0.75 - 0.90	30
5	1.55 - 1.75	30
7	2.09 - 2.35	30

* Band 6 not used.

Appendix II

Interviews were performed in seven villages, three in positive areas and four in neutral areas. Between 3 and 10 respondents were present during the interviews. When a question was asked the group discussed it and gave a common answer.

Have you noticed any changes in the vegetation pattern around the village compared to the time before the drought?

Has the number of trees changed during this time?

Has the amount of grass changed?

Has the amount of plants that your animals like to eat changed since the drought 84?

Have you noticed any changes in the rain since the drought?

Do you have fewer or more animals today compared to the time of drought?

Have you changed your distribution between different animals since the drought?

Has the number of livestock markets in the region changed since the drought?

What crop do you grow most of?

Was it the same before the drought?

Do you practice rotation farming?

How many years are your fields in fallow since they have been cultivated?

Is that longer or shorter if you compare to the time before the drought?

Are you growing crops on more or less land now compared to the time before the drought?

Is the yield the same now and then?

How many people does it live in the village?

Is that fewer or more than before 1984?

If relatives send money, what are the remittances invested in?

How far do your family have to go to collect fuel wood?

Is that longer or shorter compared to before the drought?

Appendix III

Radiance, at-satellite reflectance calculation for Landsat 4, 5 and 7

Radiance is given by equation 1.

$$L_\lambda = GAIN \cdot DN_\lambda + BIAS_\lambda \quad (1)$$

which also can be expressed as equation 2.

$$L_\lambda = \frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} \cdot QCAL - QCALMIN + LMIN \quad (2)$$

where:

λ	= ETM+/TM band number
L	= Spectral radiance at the sensors aperture in watts
$GAIN$	= Rescaled gain (contained in the product header)
$BIAS$	= Rescaled bias (contained in the product header)
$QCAL$	= The quantized calibrated pixel value in DN
$LMIN$	= The spectral radiance that is scaled to QCALMIN
$LMAX$	= The spectral radiance that is quantized to QCALMAX
$QCALMIN$	= The minimum quantized calibrated pixel value
$QCALMAX$	= The maximum quantized calibrated pixel value

At-satellite reflectance is given by equation 3.

$$\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \sin(\theta)} \quad (3)$$

where:

ρ	= Unitless at-satellite reflectance
d	= Earth-Sun distance in astronomical units
$ESUN_\lambda$	= Mean solar exoatmospheric irradiances (band specific) in W m^{-2} μm^{-1}
θ	= Solar zenith angle in degrees
L_λ	= Spectral radiance in W m^{-2} sr^{-1} nm^{-1}

In Table 1 the used values for $ESUN_\lambda$ are shown (Chander & Markham, 2003 and USGS, 2001).

Table 1. Landsat TM and ETM+ solar exoatmospheric spectral irradiances ($ESUN_\lambda$). *Units = W/(m^2*μm).*

Band #	Landsat 4 (TM)	Landsat 5 (TM)	Landsat 7 (ETM+)
1	1957	1957	1969
2	1825	1826	1840
3	1557	1554	1551
4	1033	1036	1044
5	214.9	215.0	225.7
7	80.72	80.67	82.07

Appendix IV

Abu Kamdela area:			
	Crop	Fallow	Total
Crop	15	3	18
Fallow	0	33	33
Total	15	36	51
Percentage correct:		94 %	
Users accuracy:			
Crop:		100 %	
Fallow:		92 %	
Producers accuracy:			
Crop:		83 %	
Fallow:		100 %	
Kappa:		87 %	

El Bawabnes area:			
	Crop	Fallow	Total
Crop	6	27	33
Fallow	0	27	27
Total	6	54	60
Percentage correct:		55 %	
Users accuracy:			
Crop:		100 %	
Fallow:		50 %	
Producers accuracy:			
Crop:		19 %	
Fallow:		100 %	
Kappa:		16 %	

En Nahud area:			
	Crop	Fallow	Total
Crop	15	5	20
Fallow	3	14	17
Total	18	19	37
Percentage correct:		78 %	
Users accuracy:			
Crop:		83 %	
Fallow:		74 %	
Producers accuracy:			
Crop:		75 %	
Fallow:		82 %	
Kappa:		57 %	

Kalot area:			
	Crop	Fallow	Total
Crop	17	23	40
Fallow	7	30	37
Total	24	53	77
Percentage correct:		61 %	
Users accuracy:			
Crop:		71 %	
Fallow:		57 %	
Producers accuracy:			
Crop:		43 %	
Fallow:		81 %	
Kappa:		23 %	

Um Ganas area:			
	Crop	Fallow	Total
Crop	15	12	27
Fallow	3	24	27
Total	18	36	54
Percentage correct:		72 %	
Users accuracy:			
Crop:		83 %	
Fallow:		67 %	
Producers accuracy:			
Crop:		56 %	
Fallow:		89 %	
Kappa:		44 %	

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