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Land Use / Land Cover Change Detection and Quantification — A Case study in Eastern Sudan

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Abstract

Remote sensing with high temporal resolution images has become a very strong tool for monitoring the Land use/Land cover (LULC) changes. Sudan has long been experiencing intense LULC changes. These LULC changes have resulted in widespread land degradation. The conversion of natural woodland and forest is still the main source for agricultural expansion in Sudan. Rainfed mechanized farming (RMF) is not new in Sudan, it started in the early 1940s near Gadarif state the eastern Sudan. The current study examines the temporal and spatial extent of LULC changes from 1972 to 2006 in Gadarif state. This area is famous for its sorghum and sesame production. A periori defined seven LULC classes in the classification scheme were water bodies, RMF, mixed rangeland, irrigated land, dense forest, sparse forest and settlement. Individual classifications were employed using the both supervised and unsupervised classification. Iterative Self Organizing Data Analysis (ISODATA) was used to see the cluster of different classes in the images. Maximum likelihood classifier (MLC) was used in the LULC classification of the individual images. The accuracy assessment of image classification was checked by aerial photographs and high resolution images from Google maps. The overall accuracy of LULC maps for each period (1984 and 2006) range from 86, 88 and kappa statistics are from 0.84 and 0.86 respectively. For change detection post-classification technique was applied. Image pairs of consecutives dates were compared by overlaying the LULC maps and cross- tabulating the LULC statistics.

The amount of conversion from sparse forest to mixed range occurred as large as 14247 km^2 during the first period (1972-1984) and 1060 km^2 during the second period (1984-2006). The conversions to RM have mainly been occurred from mixed range land and sparse forest as large as 4063 km^2, 4701 km^2 during the first period (1972-1984) and 18743 km^2, 5449 km^2 respectively during the second period (1984-2006) of study. Conversions to RMF occurred at high amounts. A total of 29615 km^2 area changed from mixed rangeland and sparse forest to RMF. Settlement area increased in the second period from 23 km^2 to 123 km^2. The LULC change study plays an important role for better understanding of land utilization and sustainable development of the region.

Key words: Land use\Land cover changes, Landsat MSS, TM and ETM+, Sudan, Gadarif, Remote sensing, ISODATA, Maximum likelihood classifier, Post classification change detection.

Sammanfattning

Fjärranalys har med hjälp av bilder med hög temporär upplösning blivit ett kraftigt verktyg för att övervaka Land use/Land cover (LULC) förändringar. Sudan har under lång tid varit utsatt för intensiv Markanvändning/Markytsförändringar (LULC). Dessa LULC förändringar har resulterat i omfattande land degradering. Omvandlingen av naturskog och skog är fortfarande den vanligaste orsaken till expansion av jordbruk i Sudan. Regnbevattnat mekaniserat jordbruk (RMJ) är inte en ny förekomst i Sudan utan uppkom i början av 1940 vid Gadarif staten i östra Sudan. Denna studie undersöker den temporära och rumsliga omfattning av LULC förändringar från 1972 till 2006 i Gadarif staten. Detta område är känt för dess hirs och sesam produktion. En periori fastställde sju LULC klasser i klassificeringssystemet vilka var följande; vattenansamlingar, RMF, blandad betesmark, konstbevattnad mark, tät skog, gles skog och bosättning. Individuell klassificering utnyttjades vid användning av både övervakad och oövervakad klassificering. Iterative Self Organizing Data Analysis (ISODATA) användes för att se kluster eller olika klasser i bilderna. Maximum likelihood classifier (MLC) användes i LULC klassificeringen av de individuella bilderna. Utvärderingen av noggrannheten vid bild klassificeringen var kontrollerad med hjälp av flygfoton och bilder med hög upplösning från Google maps. Den övergripande noggrannheten av LULC kartor för varje period (1984 och 2006) varierar från 86, 88 och kappa statistik är från 0.84 respektive 0.86. Vid förändringsupptäckt applicerades post-klassificeringsteknik. Bild par tagna vid ett senare datum jämfördes med överliggande LULC kartor och cross-tabulating LULC statistiken.

Omfattningen av konverteringen från gles skog till blandad betesmark förekom på ytor så stora som 14247 km^2 under den första perioden och 1060 km^2 under den andra perioden (1984-2006). Konverteringen av RMJ har i huvudsak skett på blandad betesmark och gles skog med en areal så stor som 4063 km^2 4701 km^2 during the first period (1972- 1984) and 18743 km^2, 5449 km^2 respectively during the second period (1984-2006) of study. Konvertering till RMJ inträffade vid höga belopp. Totalt har ett område på 29615 km^2 konverterats från blandad betesmark och gles skog till RMJ. Bosättningsarealer ökade under den andra perioden från 23 km^2 till 123 km^2. Studien på LULC förändringar spelar en viktig roll för en ökad förståelse av markanvändning och hållbar utveckling i regionen.

Nyckelord: Markanvändning \ Växttäcke förändringar, Landsat MSS, TM och ETM, Sudan, Gadarif, Fjärranalys, ISODATA, maximum likelihood klassificerare, Post klassificering upptäckt av förändringar

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List of abbreviation

ARCS	= Agricultural Research Corporation Sudan
DOS	= Dark Object Subtraction
ETM+	= Enhanced Thematic Mapper Plus
FCC	= False Colour Composite
FNC	= Forestry National Corporation
GLCF	= Global Land Cover Facility
Ha	= Hectare
LULC	= Land Use /Land Cover
mm	= Millimeter
MLC	= Maximum Likelihood Classifier
MSS	= Multi-spectral sensor
NDVI	= Normalized Difference Vegetation Index
PCA	= Principal Component Analysis
PIF	= Pseudo-Invariant Features
RMF	= Rainfed Mechanized Farming
RMS	= Root Mean Squar
SSA	= Sudanese Survey Authority
TCT	= Tasselled Cap Transformation
TM	= Thematic Mapper
UTM	= Universal Transverse Mercator

CHAPTER 1 Introduction

1.1 Background

Land use/land cover (LULC) changes are among the most persistent and important sources of recent alterations of the Earth's land surface (Houet, Verburg *et al*. 2010). The (LULC) changes could happen due to large number of factors like, deforestation, flooding, soil erosion, unplanned urban and agricultural extension etc. (Muttitanon and Tripathi 2005). To produce the food through agricultural activities humans have been altering the earth's surface (Houghton, 1994; Squires, 2002). With the rapid increase of population in the last few decades, the conversion of grassland and forests into cropland has risen very quickly (Houghton, 1994; Williams, 1994; Hathout, 2002). Therefore, it is important to analyze the (LULC) changes for updating the land use information and to develop a sustainable land use plan. Land use changes generally expand over a long period under different environmental, political, demographic, and socio-economic conditions, it often vary and have a direct impact on (LULC) (Muttitanon and Tripathi, 2005). The natural resources in developing countries like Sudan are continuously decreasing. Most of the population in Sudan are dependent on rain-fed agriculture and removal of forests for mechanized rain-fed has increased at high rate during the last few years (Biswas, Masakhalia *et al*., 1987).

Remote sensing for many purposes provides the only way to assess habitat structure and (LULC) changes across the vast areas (Foody 2003, Turner *et al*., 2003). Remote sensing with high temporal resolution images has become a very strong tool for monitoring LULC changes (Yıldırım *et al*., 1995). For the mapping of LULC changes the use of satellite images is becoming increasingly important. (Pax Lenney *et al*., 2001;Watson & Wilcock 2001; Scanlon et al. 2002; Fuller *et al*., 2003 from Paloni, 2006). Among the optical remote sensing system, Landsat-MSS, TM and ETM+ are the most widely used sensors for extracting information about land features (Hill and Schütt, 2000; King *et al*., 2005; de Asis and Omasa, 2007). Landsat due to its long history since 1972 is the only means to study the land use/land cover changes. There are bundle of techniques/methods, like visual interpretation of digital images, unsupervised clustering and supervised classification that can be used to get information about the land feature from satellite images (Vrieling, 2006). According to (Liberti, Simoniello *et al*., 2009) the choice of the technique to be implemented should take into account different factors, such as data availability, cost and the required and attainable detail for the study in hand.

Change detection is a technique to identify the differences in the feature condition by observing it at different times (Jensen, 2007). Land use and land cover changes can be detected by comparing multi-temporal images and this can be done by comparing the temporal and spectral reflectance difference between these images (Tardie and Congalton, 2007). According to (Singh, 1989) scientific literatures reveal that digital image change detection is very hard to perform accurately. The spatial, spectral and thematic constraints can affect the digital change detection results. Even under the same environment, different methods may produce different change results/maps. The qualitative and quantitative estimation of change detection analysis can be affected by

the change detection method applied for that particular study. It is important to select an appropriate method for study in hand (Muttitanon and Tripathi 2005).
According to (Jensen, 1986; Jensen *et al*., 1993; Mas, 1997; El-Raey *et al.,* 1999) different change detection methods have developed using image differencing, multi-date image classification, normalized difference vegetation index (NDVI), principal component analysis (PCA), post classification comparison, manual on screen digitization etc.

1.2 Land Use and Deforestation

The process by which forested land is changed into non-forested land, for example agricultural land is referred as deforestation. The change in forested land is mainly related to small scale shifting agriculture or land clearing by landlords who want to expand agriculture land. Soil erosion, loss of soil fertility, salinization is the main consequences of deforestation (Cacho, 2001).
According to Hassan (2009), in countries like Sudan, conversion of natural woodland and forests is still the main source for agricultural expansion. About eighty percent of the energy consumed in Sudan is produced from biomass, i.e. charcoal, fuel wood and crop residues. According to Forestry National Corporation (FNC, 2000) statistics about nine and half million tons of oil equivalent (TOE) of biomass energy are consumed annually from around three million ha of forested land in Sudan
Deforestation is very serious issue in developing countries and has been occurring at rapid rates, primarily to clear land for agriculture and for production of wood fuel for domestic use. The agricultural intensification and excessive tree felling for energy purposes lead to a serious deforestation problem Among the most of African countries, Sudan is one of them, which has been warned by serious deforestation issues (Hassan and Hertzler, 1988).

1.3 Land Use and Rainfed mechanized farming

Agriculture is the very important sector of the Sudanese economy. Previous studies showed that social and economic growth of Sudan is directly linked with performance of the agricultural sector. About 80 percent of the labor is employed in agricultural and related practices (Mustafa 2006). Rainfed mechanized farming (RMF) is not new in Sudan, it started in the early 1940s near Gadarif state the eastern part of Sudan, with covering a very small area around about 50.4 km^2. The main purpose of this new technique was to grow sorghum to feed the British troops in East Africa during the World War II. Due to very high profit from the sorghum cultivation RMF got considerable attention in the area. Then it increased at very high rate, and about 31080 km^2 was estimated as under RMF by 1985 (Earl, 1985).
There are two types of agricultural farming in the country, irrigated and rainfed sectors. The rainfed agriculture consist of two systems mechanized farming and traditional rainfed sub-sectors. The agricultural extentsification is one of the foremost factors that cause destruction of forests in Africa. In Sudan such practices are done by clearing of land devoted to trees or other kind of vegetation (Elnagheeb and Bromley 1994) .

1.4 Aim of study

The main objective of this study is to quantify LULC changes in Gadarif state, the Sudan. The following points specify the aim and the intermediate goals:

- Quantify the rate of deforestation and expansion of rainfed mechanized farming in Sudan over last 30 years.
- Propose/investigate potential explanations for the changes

This includes the testing of following hypotheses:

H_o1. The amount of Forest cover in Gadarif in 1972 = the amount of Forest Cover in Gadarif in 1984.

H_A 1. The amount of Forest Cover in Gadarif in 1972 ≠ the amount of Forest Cover in the Gadarif in 1984.

H_o2. The amount of Forest Cover in Gadarif in 1984 = the amount of Forest Cover in the Gadarif in 2006.

H_A 2. The amount of Forest Cover in Gadarif in 1984 ≠ the amount of Forest Cover in the Gadarif in 2006.

H_o3. The area of rainfed mechanized farms in Gadarif in 1972 = the area of rainfed mechanized farms in Gadarif in 1984.

H_A 3. The area of rainfed-mechanized farms in Gadarif in 1972 ≠ the area of rainfed-mechanized farms in Gadarif in 1984.

H_o4. The area of rainfed mechanized farms in Gadarif in 1984 = the area of rainfed-mechanized farms in Gadarif in 2006.

H_A 4. The area of rainfed-mechanized farms in Gadarif in 1984 ≠ the area of rainfed-mechanized farms in Gadarif in 2006.

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1.6 Thesis outline

The thesis outline is divided into six chapters .The current chapter gives introduction and the aim of the present research work. The rest of the thesis is arranged as follows: The chapter 2 gives an overview about the study area and data used, i.e. location, climate, vegetation, soil types and topography of the study area. Chapter 3 describes the theoretical background, which gives LULC changes, geometric and radiometric corrections and NDVI. Chapter 4 describes the methods used in this study. Chapter 5 shows the results and analysis and in the last chapter 6 describes the discussion and conclusions.

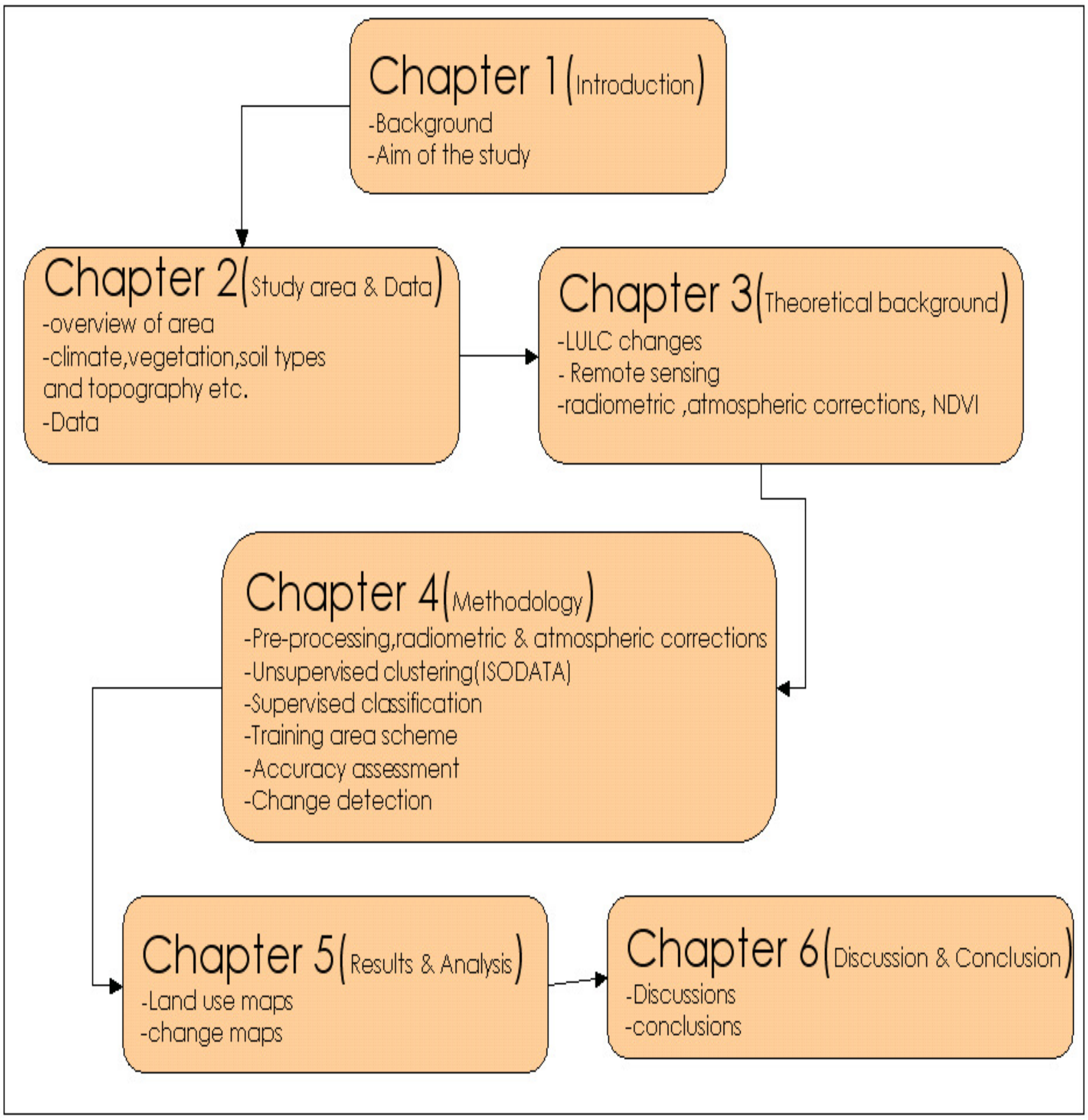


Figure 1. Flow diagram of thesis outline

CHAPTER 2 STUDY AREA AND DATA

2.1 Sudan

Sudan with around 2.5 million km^2 stretches between latitude 4 and 22 north. Despite of few mountain areas, the highest being Jebel Marra massive in the west; most of the surface of Sudan is flat plains. The rainfall in the Sudan ranges between very low in the barren deserts of the north to 1400 mm in the southern sub humid parts of the country. Sudan is one of the hottest countries in the world with topical climate and vast daily and seasonal variation in temperature.

The estimated population of Sudan in 2004 was about 39 millions, and 60% of them live in rural area of the country (Daak, 2007). Most of the population of the country depend on agriculture for their livelihood. More than 58 % population of Sudan is mainly working in agriculture or pastoral activities. Some main exports of the country are cotton, oil seeds, livestock and gum arabic (Moghraby, 2002).

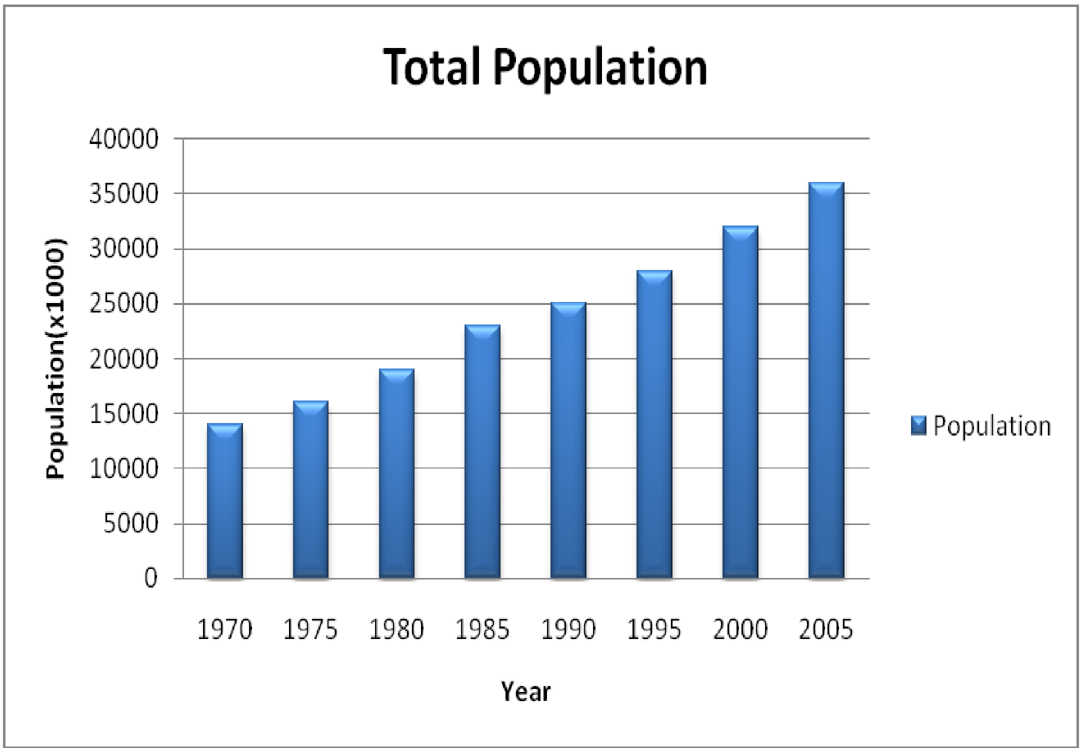


Figure 2 . Population of Sudan (1970 - 2005) (source: UNDESA,2007 from Gbenga[1],2008)

Figure 2 shows that there has been an increasing trend in the population of Sudan. The population growth has led to an increasing demand of basic necessities like, food demand, shelter and water (Internet b[2])

[1] The source of this figure 2 is available at http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-15279 (2010-06 -09)

[2] This is available at http://www.gisdevelopment.net/proceedings/mapmiddleeast/2006/poster/mm06pos_89.htm (2010-07 -09)

2.2 Gadarif

The current study is about Gadarif state, which is located in the eastern part of the Sudan. It lies between longitudes 33–36° E and latitudes 13–16 °N with an area of approximately 65,000 km².

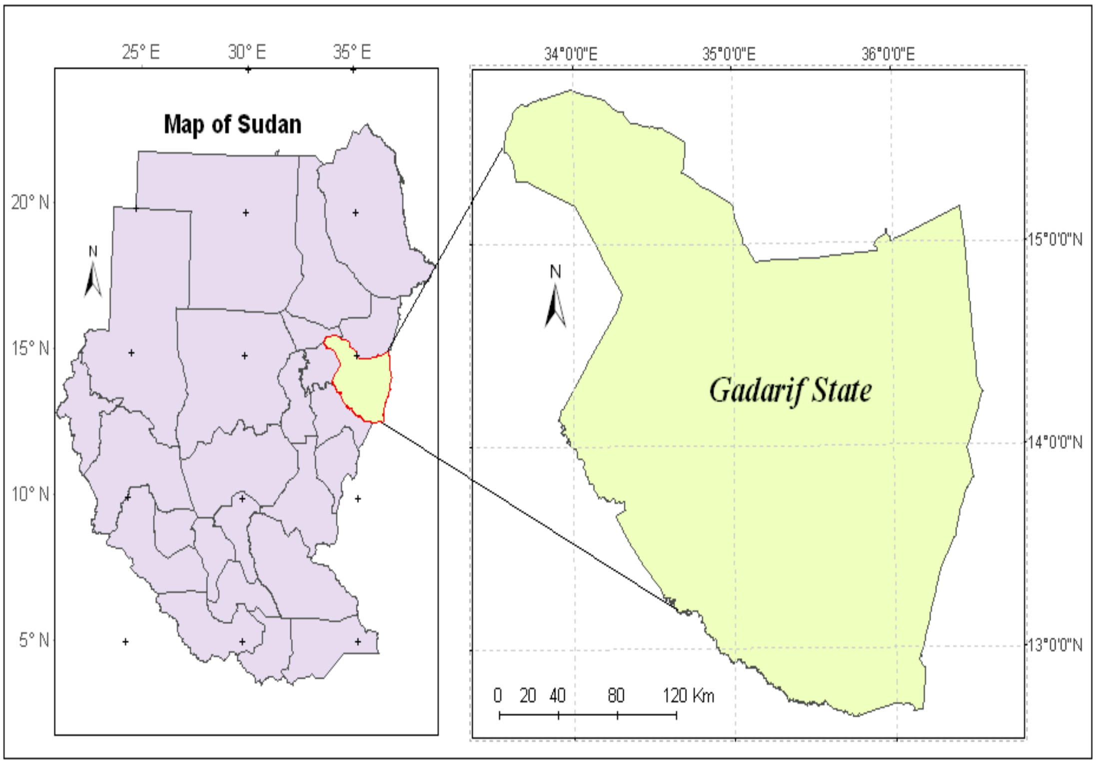


Figure 3. Location of Study area (Source: VMap0[3])

It lies between two major tributaries of the Blue Nile: the Atbara river on the east and the Rahad river on the west (Mustafa, 2006).

The estimated population of Gadarif state in 2008 was 1,143,362[4]. About 90% of the population of Gadarif are farmers. The average population density was estimated 10 people per square kilometre (Mustafa, 2006). On the basis of annual rainfall amount and main agricultural characteristics the area is divided into three main agro-ecological zones, i) southern zone with highest annual rain fall ranges from 600 to 900 mm (reformulate), ii) central zone with medium rainfall about 500-600 mm, and iii) northern zone with very little rain fall <500 mm (Mustafa, 2006). The annual rainfall in Gadarif state ranges from 400 to 800 mm. The Gadarif state has country's largest and oldest mechanized rain-fed farms since 1960s.The Gadarif region contributes well in the production of sorghum and sesame crops. The Gadarif produces 17 % and 30 % of total sesame and sorghum area in Sudan respectively (Mustafa, 2006).

[3] Source data for Figure 3 is available at http://gis-lab.info/qa/vmap0-eng.html (2010-04 -18)
[4] Source data for Figure 3 is available at http://www.sudanembassy-kl.org.my/v/index.php?id=543 (2010-09 -18)

2.3 Topography and Soils

Topography of the study area is almost flat with few mountains. From figure 4 it can be seen that in the south east there are high values, which indicate some mountains in the area.

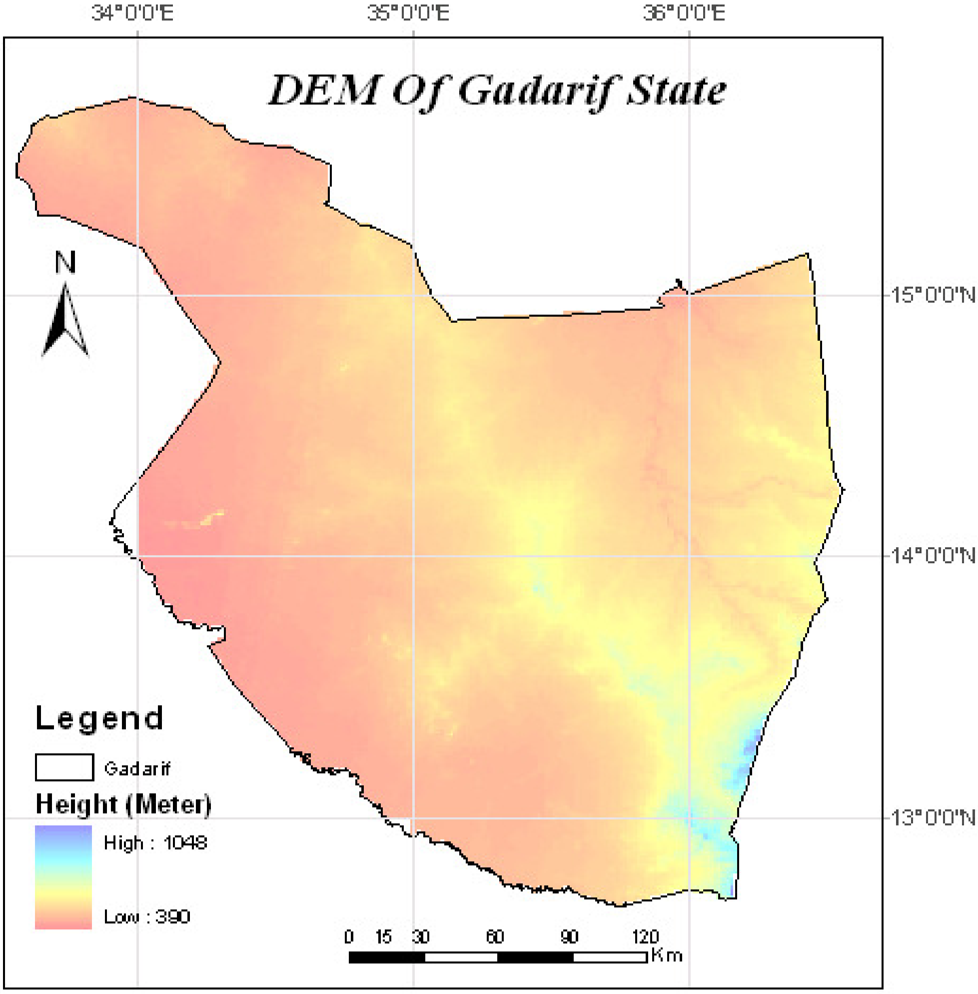


Figure 4. Topography of the study area

The soils of the Gadarif area are described as deep dark colours, high clay content and strong vitriolic properties. The area consist a large uniform clay plain intersected by small valleys. The clay content is rather high with up to 80% (Vink, 1987). A very small amount of organic matter and nitrogen content of the soil in the area exist, and soil is moderately fertile as there is no such deficiency of other plant nutrients. The soils have a very high water holding capacity. This high water holding property of the soils in this area allows crops to grow on the stored water during dry spell. The permeability of the soils is very low when wet, that can be one source of waterlogged for certain period during the rainy season. The soils are very hard in the dry season and difficult to cultivate, and also during wet season soils are very sticky (Mustafa, 2006).

2.4 Climate

Climatologically the Gadarif state lies in the semi-arid zone, with summer rains and warm winters, characterized by unimodal rainfall pattern ranging from 400 mm to 800mm with annual average of 600 mm. (Glover, *2005*). A study carried out in the Gadarif State showed that the rainfall pattern in the area is characterized by its variability from one year to another (Eltayeb, 1985) as shown in the Figure 5[5]. Almost eight months a year Gadarif state experiences a dry season. Rainfall in this area is markedly seasonal in nature; length of the rainy season fluctuates around the four months between June and September reaching its peak in August. Most of the rainfall from June\July to September\October comes in the form of heavy downpours during thunderstorms, causing heavy runoff, initiating erosion on sloping, unprotected land.

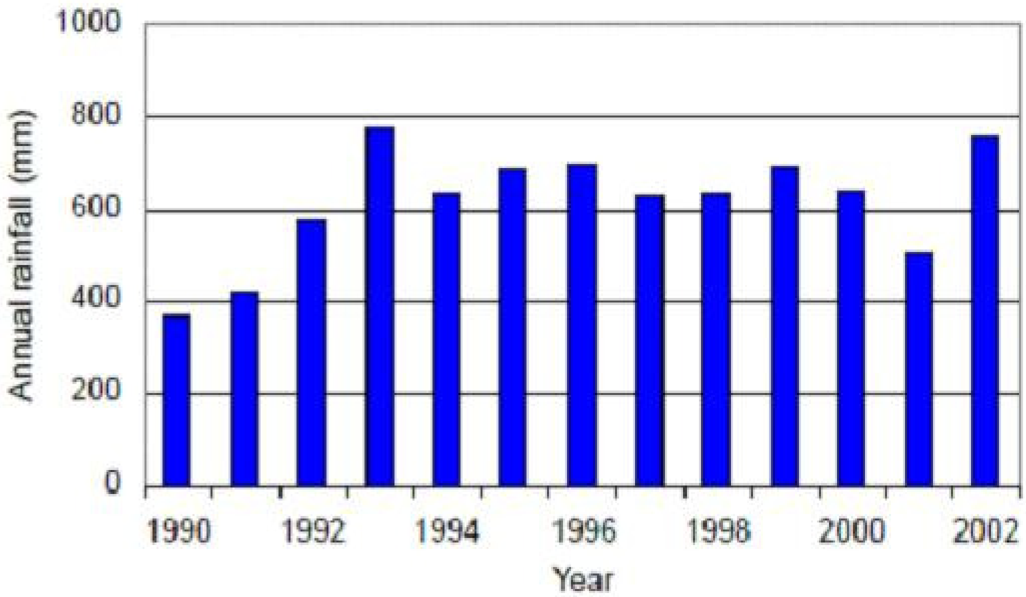


Figure 5. Annual rainfall in the Gadarif State from 1990 to 2002 (source: Glover,2005)

From November to April the area experience the northerly wind or same as the dry North East Trade winds. Temperatures are very high in summer and mild in winter. The average daily maximum temperature ranges from 25° to 40° C, while the average daily minimum temperature ranges between 13° and 20° C. Humidity in the area fluctuates from its normal level of around 20-30% through most of the year to 60-70 % in the wet season (Glover, *2005*).

2.5 Vegetation in the area

The figure 6 shows the vegetation cover map of Sudan. It shows that the Gadarif state lies in the zone of low rainfall woodland savanna on clay (Harison and Jackson, 1958 from Glover, 2005). This shows that Acacia and wooded grassland and bush land is

[5] Source data for Figure 3 is available at http://www.mm.helsinki.fi/mmeko/vitri/studies/theses/gloverthes.pdf (2010-06-18)

situated in the middle of the Gadarif along west east. There is also small portion of semi-desert and grassland and shrub land is on the north side of the study area.

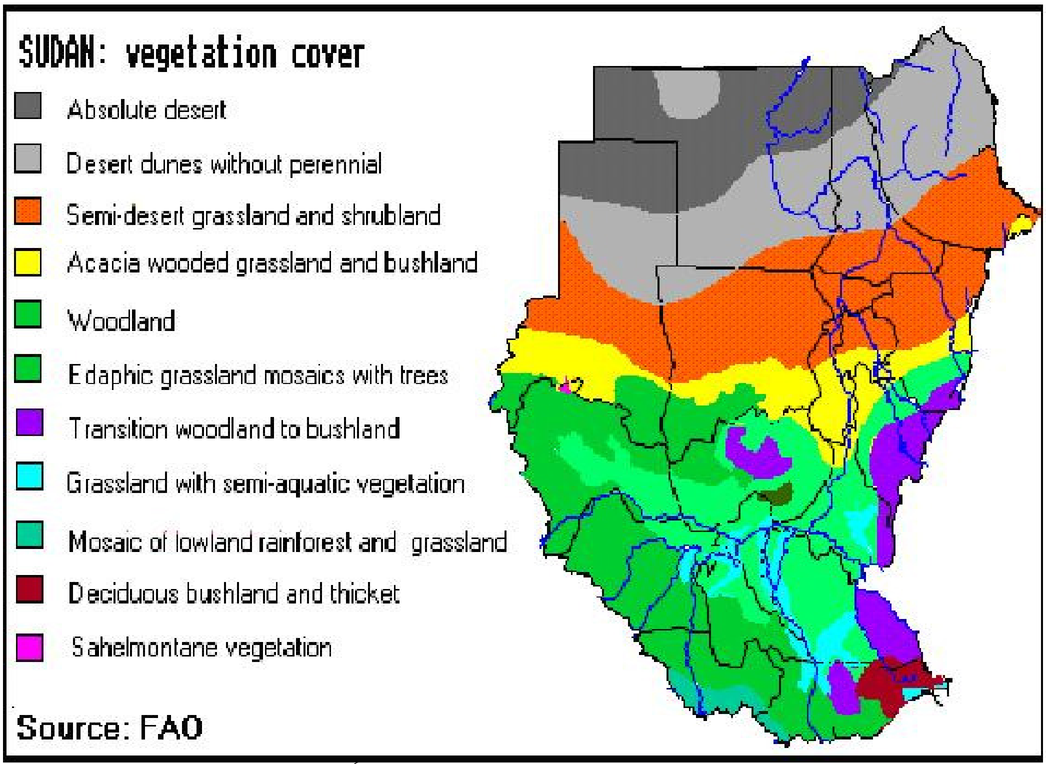


Figure 6. Vegetation cover map[6] of Sudan.

2.6 Data

Different types of data have been used for this research work and table 1 shows the details of the data. The data used here can be subdivided into remote sensing data and ancillary data. The Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) multi-spectral images are the main remote sensing data used in current study with some ancillary data.

2.6.1 Remote sensing data

The Landsat MSS, TM and ETM+ scenes of path and row that are given in table 1, were used for Gadarif state and were downloaded from Global Land Cover Facility (GLCF) from this link (http://glcf.umiacs.umd.edu/index.shtml). The table 1 shows the full detail about the data including World Reference System[7] (WRS), acquisition data and sensor etc.

[6] Source data for Figure 4 is available at http://www.sudan.net/government/vegmap.html (2010-06-18)
[7] Shape file format data of (WRS) is available at http://landsat.usgs.gov/tools_wrs-2_shapefile.php (2010-06-18)

Table 1. Satellite data used in this study.

[WRS: P/R]	Acquisition Date	Sensor	Attribute
2:171/050	2006-10-08	ETM+	Orthorectified
	1984-06-13	TM	
2:171/051	2007-10-27	ETM+	Orthorectified
	1984-06-13	TM	
2:172/049	2005-10-28	ETM+	Orthorectified
	1987-10-03	TM	
2:172/050	2005-10-28	ETM+	Orthorectified
	1987-10-27	TM	
2:172/051	2005-10-28	ETM+	Orthorectified
	1987-10-27	TM	
1:183/050	1973-06-08	MSS	Orthorectified
1:183/051	1972-11-04	MSS	Orthorectified
1:184/050	1972-12-11	MSS	Orthorectified
1:184/051	1972-12-11	MSS	Orthorectified
1:185/049	1972-11-24	MSS	Orthorectified
1:185/050	1973-01-17	MSS	Orthorectified
1:185/051	1972-11-06	MSS	Orthorectified

*WRS=World reference system, P= Path and R = Row

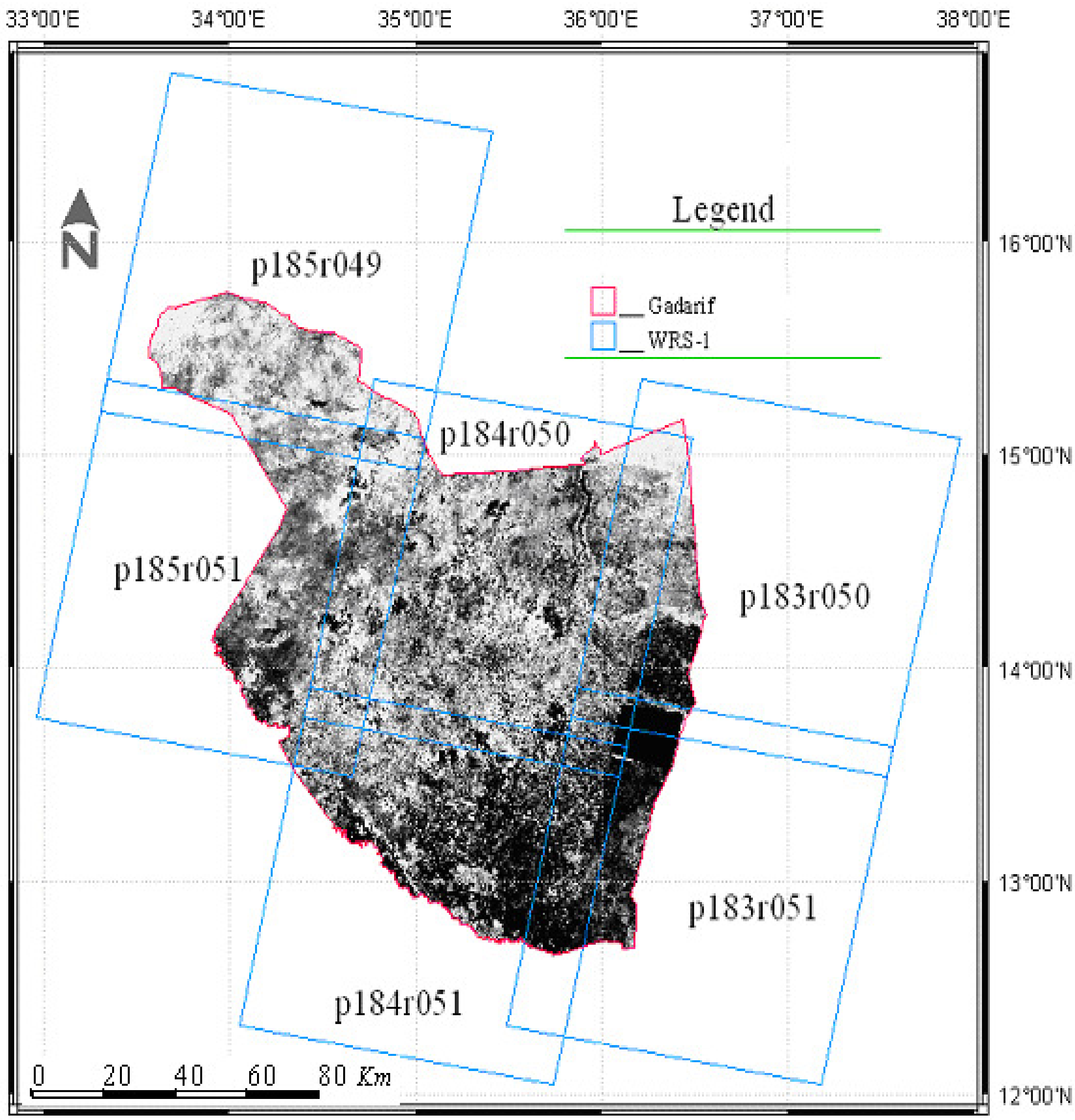


Figure 7. Landsat MSS-1972 with World Reference System (WRS-1) for Gadarif state
*P= path, r =row

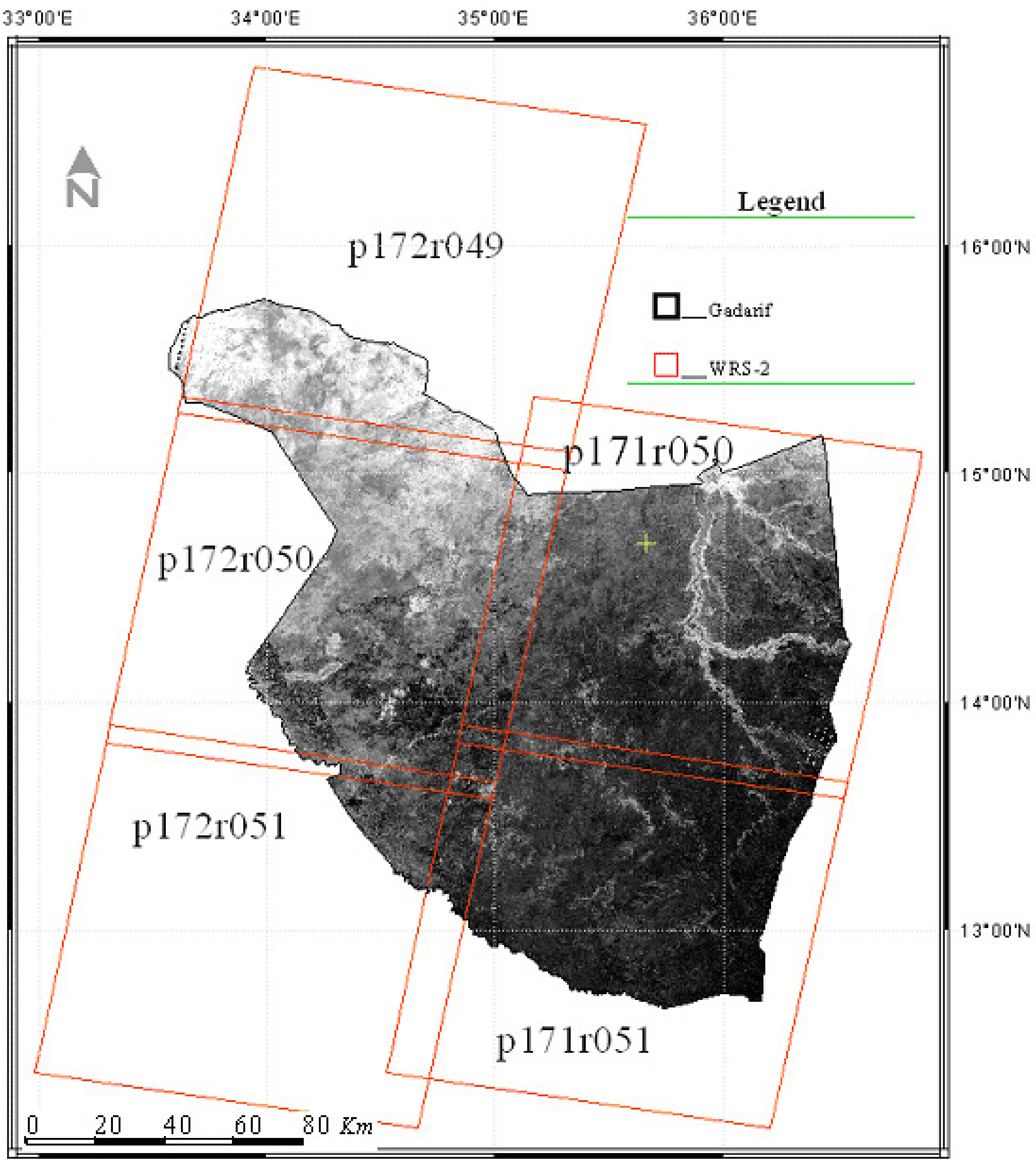


Figure 8. Landsat ETM+2006 band 2 with World Reference System (WRS-2) for Gadarif state. *P= path, r = row

The figure 7 and 8 gives the overview of Landsat MSS 1972 Landsat TM 1984 and Landsat ETM+ 2006 scenes.

2.6.2 Landsat MSS data characteristics

In 1972 Landsat 1 was launched with first onboard MSS sensor. The table 2 below shows spectral and spatial resolution details of MSS.

Table 2. Spectral and spatial resolution for the Landsat MSS bands used in this Study

Band No	Description	Wavelength (µm)	Spatial Resolution (m)
MSS 1	Green	0.5 - 0.6	57
MSS 2	Red	0.6 - 0.7	57
MSS 3	Near IR	0.7 - 0.8	57
MSS 4	Near IR	0.8 - 1.1	57

2.6.3 Landsat TM & ETM+ data characteristics

In 1982 Landsat 4 was launched with first onboard TM sensor. It based on same technical principal like MSS, but TM has better spatial and radiometric resolution than MSS with increased numbers of bands to record radiation of interest (Campbell, 2002).

In 1999 Landsat 7 was launched with on board Enhanced Thematic Mapper Plus (ETM+) sensor. The Landsat 7 ETM+ sensor has several enhancements over Thematic Mapper sensors, like better spectral information, improved geodetic accuracy, low noise, reliable calibration, and addition of panchromatic channel with improved spatial resolution. (Masek *et al*., 2001). The table 3 shows the spectral and spatial resolution of TM & ETM+.

Table 3. Spectral and spatial resolution for the Landsat TM & ETM+ bands used in study

Band No TM/ETM+	**Description**	**Spectral resolution (µm)**	**Spatial resolution (m) TM / ETM+**
1	Blue	0.45 - 0.515	28.50 / 30
2	Green	0.525 - 605	28.50 / 30
3	Red	0.63 - 0.69	28.50 / 30
4	Near IR	0.75 - 0.90	28.50 / 30
5	SWIR	1.55 - 1.75	28.50 / 30
7	SWIR	2.09 - 2.35	28.50 / 30
8(ETM+)	Panchromatic	0.5-0.9	15

Band 6 not used*

The Landsat ETM+ data have eight spectral channels; thermal band has 60m spatial resolution and panchromatic band has15 m spatial resolution, and the remaining channels are in the visible and near infrared region with spatial resolution of 30m.In this study of land use/land cover (LUCC) classification only six 30m multi-spectral images were used for the time period of 2006. The panchromatic band with 15m-resolution can provide good collateral data for visually interpreting the accuracy of the land use/land cover (LUCC) classification.

The technical details of Landsat MSS, and Landsat TM/ETM+ bands have been provided in the table 2, and table 3 respectively. For other specification of Landsat satellite; refer to the official portal of Landsat (Landsat Program[8], NASA web).

2.7 Ancillary data

The ancillary data that were used in this study including,

- ASTER Global Digital elevation model (GDEM) data with 30m resolutions was used for this study and downloaded from following link[9].
- Aerial Photographs
- Vector data, administrative boundary of Gadarif and Sudan
- Statistics on land use, production (kg), area (ha), productivity (kg/ha)(source: ARCS)

[8] More detail information about Landsat is available at http://landsat.gsfc.nasa.gov (2010-03-11)

[9] ASTER GDEM is available at http://www.gdem.aster.ersdac.or.jp/). (2010-05-20)

CHAPTER 3 THEORETICAL BACKGROUND

3.1 Land use and land cover changes

LULC changes where affecting the current and future supply of land resources, are also big sources of many different other forms of environmental change (Meyer, W.B. 1995). The various types of remotely sensed images from different types of sensors flown onboard platforms at different height above the earth surface over different time does not direct toward a simple classification system. Scientific Literature showed that no single classification system could be used for all types of satellite imagery and all scales. The classification scheme developed by Anderson *et al., (1976*[10]) is widely used and compatible for remotely sensed data, and is referred as USGS classification scheme. Since 1972, the first remote sensing satellite LANDSAT-1 was launched; land use and land cover studies were carried out at different scales (Opeyemi, 2006[11])

According to Xiaomei Y and Rong Qing L.Q.Y (1999) for updating the (LULC) maps and management of natural resources, the necessary information about change is required.
In 1998 Macleod and Congation came up with four important aspects of change detection for monitoring natural resources. These aspects are given below

- Detection of changes that have actually occurred
- Identification of nature of the change
- Extent of the change (area wise)
- Spatial pattern assessment of the change

The study by Dimyati (1995) an analysis of land use and land cover changes using the combination of MSS Landsat and land use map of Indonesia shows that land use and land cover change were estimated by using remote sensing. This was done with superimposing the land use and land cover images of different time period, 1972, 1984 and land use map of 1990.That was done to analyze the change pattern in the area of interest.
In 1992 Olsson and Ardö estimated the deforestation rate in Sudan. The main data used for this purpose was Landsat MSS and TM of three different time period, 1973, 1979 and 1987.They calculated the NDVI for each time period and derived the simple regression relation between NDVI and canopy cover. They came up with direct relation between NDVI and canopy cover. This means higher the NDVI higher the canopy covers and vice versa.

In the context of agriculture development, it is very complex and innermost issue whether or not production can be increased or maintained without decreasing the natural reources base (Whitney, 1987). To achieve increased grain production and to meet demand and supply requirement in Sudan is obtained by just expansion of RMF, not through increasing per unit yield. The expansion of agriculture land and

[10] This is available at http://www.delmar.edu/igett/08/Cohort2/LearningUnitExamplesnodata/LUDanScollon/Support_Docs/refDoc.LULC_class_system_1976.pdf (2010-04-13)
[11] This is available at http://www.gisdevelopment.net/thesis/OpeyemiZubair_ThesisPDF.pdf (2010-04-13)

woodcutting for production of fuel wood causes severe deforestation that leads to soil erosion and desertification has a very bad impact on environment (Musnad, 1983).

Sudan has suffered a number of long and devastating droughts in the past decades, which have undermined food security and are strongly linked to human displacement and related conflicts (Ayoub, 1999).

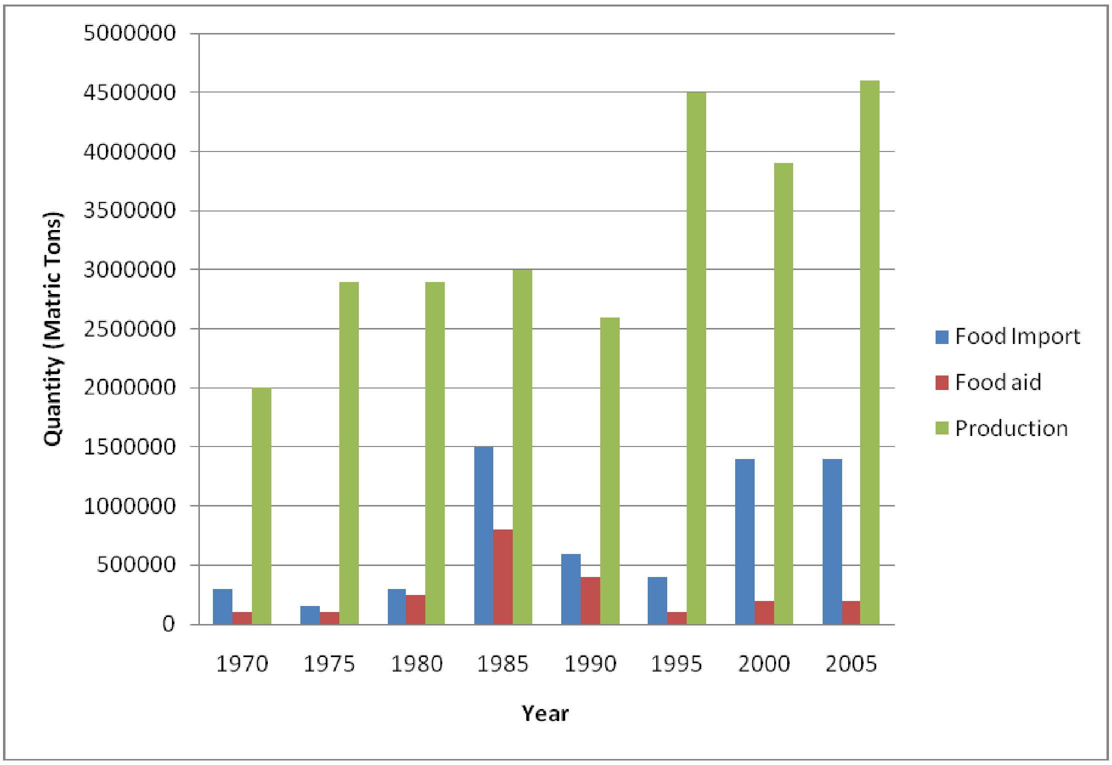


Figure 9. Comparison between crop productions, food import and food aid in Sudan (Source: UNDESA, 2007 from Gbenga, 2008[12])

Figure 9 shows the comparison of food import, food aid and crops productions in the country from 1970 to 2005.From this figure it can be seen that despite a growth in the quantity of food produced in the country, there has also been increase in the import and aid of food. There was noteable peak of food import and food aid in 1985, which may be attributed to the periods of droughts and famine incidences in the country.

3.3 Geometric correction

Geometric registration of satellite images constitutes a preliminary step to the analysis in most multi-temporal studies (Muller 1993).Satellite scenes need to be corrected for internal scan distortion, that is earth curvature effects, scan skew, nonlinearity of mirror motion and sensor altitude. Since specific data about the satellite is required for these kinds of distortion so these corrections are normally done at receiving stations (Muller 1993).Two different kind of data may be geometrically corrected to each other using Ground Control Points (GCPs) by looking some stable features like road intersections, river and corner of large building (Richards, 1986; Hill & Aifadopoulou, 1990).

[12] This is available at http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-15279 (2010-04-13)

3.4 Radiometric Correction

In generally speaking every land feature always have a specific spectral signature. These spectral signatures can vary due to different factors, such as sensor characteristics, differences in illumination and observation angles, different atmospheric conditions, topography and date of image acquisition (Paolini, Grings *et al.*, 2006). The raw digital numbers (DN) cannot represent the actual ground conditions due to above-mentioned factors. The goal of radiometric corrections is to remove or compensate for all the above effects except for actual changes in ground target. For change-detection studies some form of image matching or radiometric calibration is recommended to eliminate exogenous differences (Coppin *et al.*, 2004). In this way, radiometrically corrected images should appear as if they were acquired with the same sensor and under the same atmospheric and illumination conditions.(Paolini, Grings *et al.*, 2006).

The radiometric effects on the satellite image data can be categorized as

i) Sensor related effects
ii) Scene related effects

The sensor related correction is further divided into two types i.e. absolute and relative correction (Pilesjö, 1992). An absolute correction is very hard for the user and is done at receiving stations, as it requires optic, climatic and atmospheric parameters data. Then usually relative calibration of the data is applied (Price, 1987)
Equation (1) is used for conversions of DNs to spectral radiance (mW/cm2/sr/µm) for Landsat MSS, Landsat TM and Landsat ETM+. (Markham & Barker, 1986).

$$L\lambda = (DN / DN_{max}) \times (L_{max} - L_{min}) + L_{min}$$ -------------------- *Equation (1)*

Where

L_λ = spectral radiance (mW/cm2/sr/µm)
DN = the specific digital number from the scene in a given band
DN_{max} = maximum digital number for a given sensor
L_{min} = the sensors minimum brightness
L_{max} = the sensors maximum brightness

The conversion of at-satellite spectral radiance to at-satellite reflectance can be used to reduce scene-to-scene variability. There are three main reasons to use at-satellite reflectance instead of at-satellite spectral radiance for multi-sensor and mutidate images, i) to remove the cosine effect of different solar zenith angles because of time difference between images, ii) to compensate the solar irradiance arising from spectral band differences, iii) to correct the variation in Earth-Sun distance between different image acquisition dates.(Chander, Markham *et al.*, 2009).

The conversion from spectral radiance to at-satellite reflectance corrects for scene related effects as equation (2) (Price, 1987).

$$\rho p\lambda = (\pi \times L\lambda \times d2) / (Esun\lambda \times \cos\Theta)$$ ------------- *Equation (2)*

Where
ρp_λ = unitless at-satellite reflectance
d = earth-sun distance in astronomical units
$Esun_\lambda$ = mean solar exoatmospheric spectral irradiance in (mW/ cm^2/sr)
Θ = solar zenith angle

The atmosphere affects the electromagnetic energy that is sensed by the satellite detector, and these effects are wavelength dependent (Chavez 1988; Turner *et al.*, 1971). This is particularly true for Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) that record data in visible and near infrared portion of the electromagnetic spectrum. The atmosphere affects the electromagnetic energy in three-way, i) absorption ii) scattering iii) refraction. In addition scattering is the most dominant effect (Siegel *et al.*, 1980).
By definition, at-satellite reflectance does not remove atmospheric effects(Schroeder, Cohen *et al.*, 2006). Atmospheric effects then can be reduced by converting at-satellite reflectance to surface reflectance. There are many methods for atmospheric correction (Richards, 1986). One approach is assume that the longest wavelength band is essentially unaffected by atmospheric scattering and the minimum DN values in this band are subtracted from all pixels in all channels (Ahlcrona, 1988).
In image classification and change detection studies Dark Object Subtraction (DOS) is the simplest and widely used image based atmospheric correction method. (Paolini, Grings *et al.*, 2006) According to this approach there exists an object of zero or small reflectance in the Landsat image data. Then the minimum DN value in the histogram from the entire scene is considered as the effect of the atmosphere and is subtracted from all the pixels of the image (Chavez, 1989).

$I_{corr} = I_{sat} - I_{dark}$ ------------------------------------ ***Equation (3)***

When generalization in both time and space for classification and change detection involve (Pax Lenney *et al.*, 2000), relative atmospheric correction is generally not possible since identification of pseudo-invariant features (PIFs) is very difficult across the scenes for this kind of atmospheric correction. It is even more complicated to apply relative atmospheric correction when multiple sensor and multi-dates images are used in study (Song, Woodcock *et al.*, 2001).
The correction of topographic effect has not been done as the area of Gadarif is flat except a few minor mountains.

3.7 Normalized difference Vegetation Index (NDVI)

The use of Normalized Difference Vegetation Index (NDVI) is common for detecting vegetation for land use\land cover (LUCC). In the solar spectrum, many natural surfaces reflect equally in the red and near-infrared part with notable exception of green vegetation as can be seen in figure 10. Vegetation absorbs the red light due to photosynthetic pigments (such as chlorophyll) present in green leaves, while vegetation reflects very strongly near-infrared light due to live leaf tissues (mesophyll structure and water contents) (Kennedy, 1989). The areas of bare soil that have little or no green plant material will appear a bit similar both in red and near-infrared part of the spectrum, while the areas with green vegetation will appear bright in the near-infrared and very dark in the red portion of the spectrum. This big difference of reflectance of vegetation in red and near infrared wavelength can be used to compute different vegetation indices. The NDVI is the most common vegetation index and is calculated as (Lillesand & Kiefer, 1979).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \text{-------------} \quad \textbf{\textit{Equation (4)}}$$

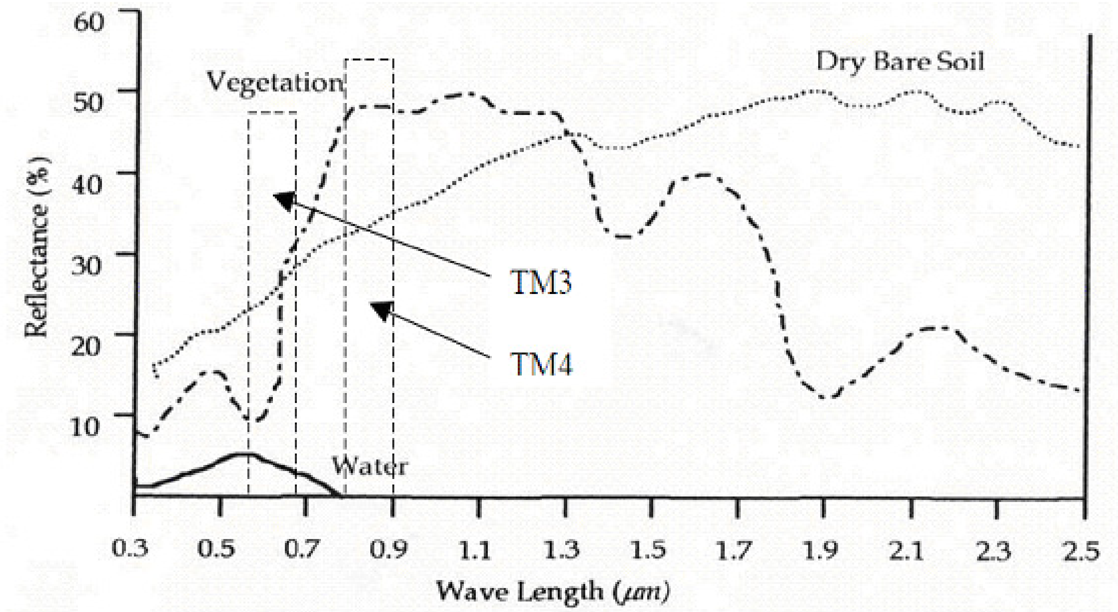


Figure 10. Spectral signatures for vegetation, dry bare soil and water and the position of Landsat TM bands 3 and 4, (Tso & Mather 2001)

The NDVI ranges from –1 to 1, a higher NDVI value indicates more vegetation and vice versa.

The NDVI method can be used for evaluating the green vegetation and is a good technique for quantitative assessment of biomass and detection of change pattern in agricultural vegetation (Todd *et al.*, 1998).

CHAPTER 4 METHODOLOGY

The methodology adopted for this study took into consideration the different image techniques including geometric correction, radiometric correction, atmospheric correction, image enhancement, and false colour composite (FCC) etc .The hybrid supervised\unsupervised classification (Kamusoko and Aniya 2009) technique was used to produce the LULC maps from Landsat MSS, TM, and ETM+ images.
Figure 11 below shows the image processing procedures that were carried out on Landsat MSS, TM and ETM+ images, aerial photographs and digital elevation model (DEM) used for this research work.

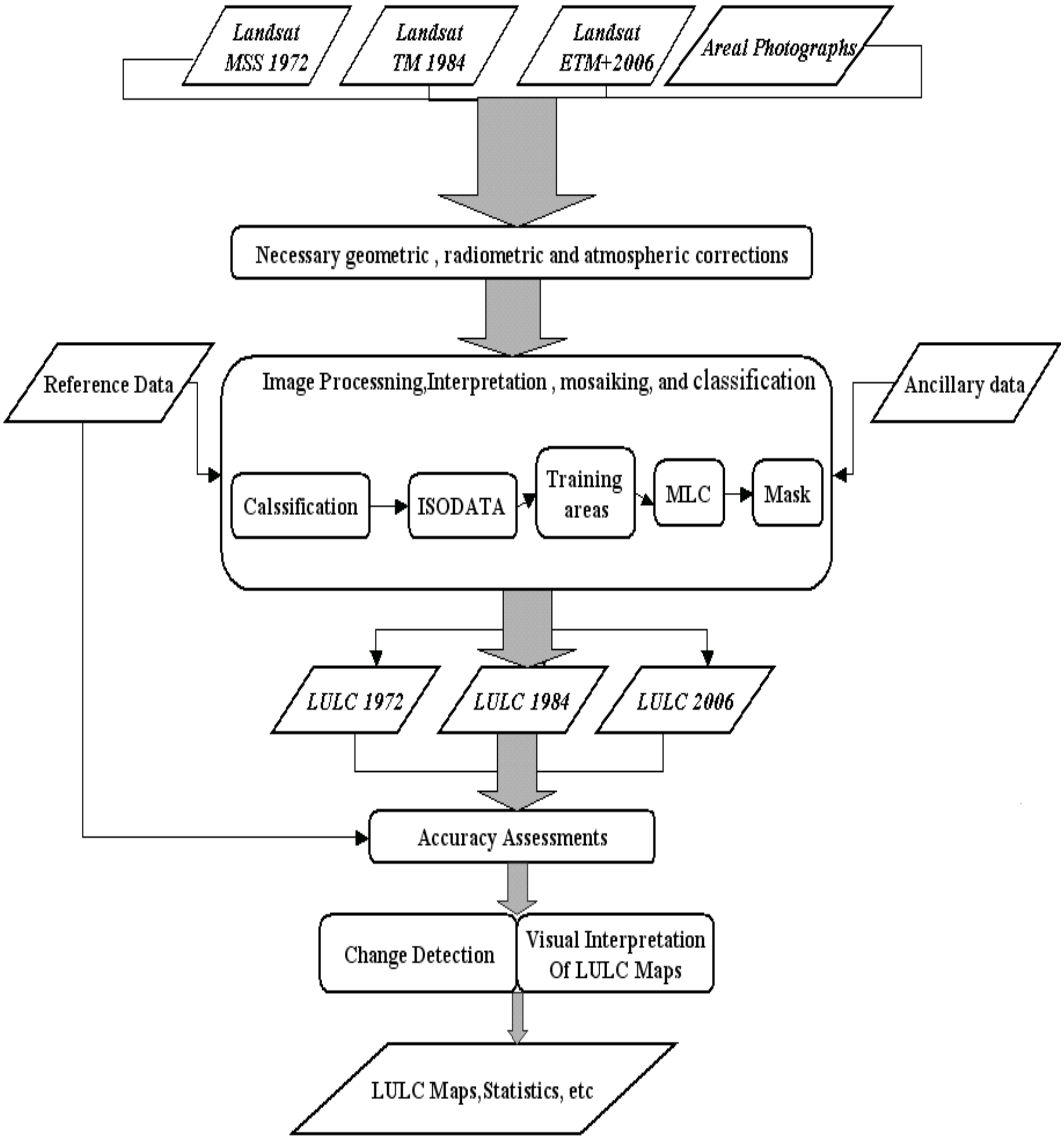


Figure 11. Overview of methodology used in this study

4.1 Data Pre-Processing

Before applying the actual classification of the remotely sensed data, pre-processing of the data is a crucial step to remove errors and make the data consistent. The geometric corrections, radiometric corrections and atmospheric corrections are some typical steps of pre-processing of the data for the current study. These steps are discussed in the coming sections.

4.1.1 Geometric Correction

Geometric correction of the data is critical for performing a change detection analysis. In this study the geometric correction of the satellite data has not been performed, it had already been orthorectified and georefernced to the (WGS_1984_UTM_Zone_36N) coordinate system. Subsequently Landsat MSS for time period 1972,the Landsat TM 1984 and Landsat ETM+ 2007 images were reprojected for clipping and resample to a 30 meter resolution using the nearest neighbor resampling method to avoid altering the original values (Jensen 1996, Yang and Lo 2000).

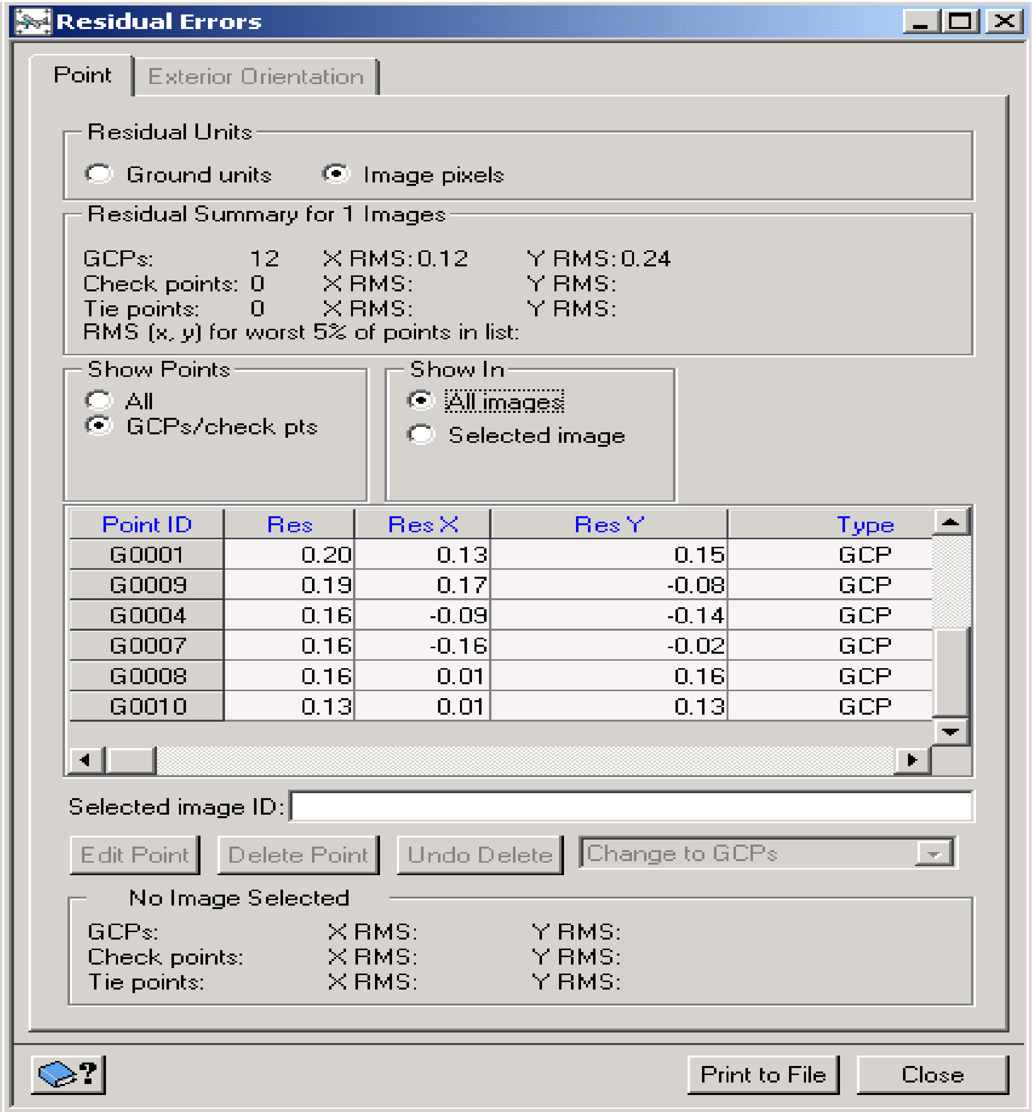


Figure 12. Screen shot of image georeferencing in PCI Geomatica v 10.3.1

The coordinates (Lattitude, Longitude) of digital elevation model (DEM) was given in (WGS_1984), and then it was projected to Universal Transversal Mercator (WGS_1984_UTM_Zone_36N) coordinate system. But the geometric correction of four Aerial photographs that were used for this study has been done with the help of Landsat ETM+ image. In this process 12 well distributed ground control points (GCPs) were selected. The root mean square (RMS) error of 0.36 (less than 0.5) was achieved. Figure 12 shows the X and Y RMS.

4.1.2 Radiometric Correction

The radiometric corrections of the satellite data were carried out in two steps. Firstly the at-satellite radiance (**$L\lambda$**) was calculated by using (**equation 1**), full detail is given in chapter 3.Secondly to compensate the effect of solar zenith angle, earth –Sun distance and solar irradiance at-satellite reflectance (**$\rho p\lambda$**) was calculated by using (**equation 2**), details are given in chapter 3.

4.1.3 Atmospheric correction

As discussed in section 3.6 the visible and near infrared portion of the electromagnetic spectrum is affected differently by the earth atmosphere. The Landsat MSS, TM & ETM+ data also recorded in visible and near infrared portion. The at-satellite reflectance cannot be assumed to remove the atmospheric effects fully. To compensate the atmospheric and haze effect at-satellite reflectance then were converted into surface reflectance. The Dark Object Subtraction (DOS) is the simple and widely used atmospheric correction method (Paolini, Grings *et al.*, 2006) was applied . It is assumed that there exists a dark objects (zero or low surface Reflectance), like (water, dense forest or shadow) etc in the image (Schroeder, Cohen *et al.*, 2006). The longer wavelengths are usually not or to a low degree affected by the atmosphere. Any DN value above zero in the dark area is assumed as effect of atmosphere. A non-zero value in longer wavelength is then subtracted from all the channels of the image. The non-zero value for each scene in MSS channel (4 0.8 - 1.1 µm) for the 1972 time period are in given in table 4.These values were subtracted from all the channels to compensate the atmospheric haze effect. For TM and ETM+ data, channel no 7 (2.09 - 2.35 µm) is assumed to have zero reflectance from the dark objects. The non-zero value for each scene in channel 7 of TM and ETM+ are given in table 4. These values are then subtracted from each channel of the scene.

Table 4. Minimum reflectance of each scene in deep water.

MSS: [P/R]	**Min Ref**	**TM: [P/R]**	**Min Ref**	**ETM+: [P/R]**	**Min Ref**
P183r050	0.02	P171r050	0.010	P171r050	0.004
P183r051	0.019	P171r051	0.003	P171r051	0.008
P184r050	0.002	P172r049	0.011	P172r049	0.005
P184r051	0.010	P172r050	0.004	P172r050	0.011
P185r050	0.019	P172r051	0.003	P172r051	0.010

P=Path=Row
Min Ref = Minimum Reflectance

4.2 Design of classification scheme

There exist many classification schemes including U.S. Geological survey LU/LC classification System, US Fish & Wildlife Service Wetland Classification System, NOAA Coast Watch Land Cover Classification System, Asian Land Cover Classification System (Jensen, 1996). The U.S. Geological survey LU/LC classification System then was chosen for current study. According to Anderson *et al.,* (1976), the MSS data are only suitable for Level 1 LU/LC classification. For this study USGS level 1 scheme was chosen and used for the classification of the satellite data. In total, seven LULC classes are considered and are given in table 5.

4.3 LULC Classes

Table 5 describes the main LULC classes used.

Table 5. LULC classes used in this study and their brief description

No	Classes	Description
1	Water	Reservoirs and Rivers
2	Rainfed Mechanized Farming	Agriculture field with no such regular pattern like irrigated land. Agricultural fields with and without crops.
3	Irrigated land	A regular pattern of land, and can be seen very clearly in the image
4	Mixed Rangeland	This class includes grazing land, area with no vegetation such as bare soil, sand (excluding RMF and Irrigated land), where soil is clearly apparent.
5	Dense forest	Area covered with more than 75% canopy covers outside the agricultural fields with dark green colour in the image.
6	Sparse forest	Sparsely vegetated area or scattered trees about 150 m apart. Also include small shrubs and bushes with varying density.
7	Settlement	Area with manmade structures and activities

4.5 ISODATA (Iterative Self-Organizing Data Analysis)

For this study a hybrid unsupervised \supervised (Kamusoko and Aniya 2009) and masking technique was used to produce the LULC maps of the study area.

An unsupervised classification is a very supporting tool in image processing for LULC applications. An unsupervised classification is very useful when a little knowledge about the area is available or when reliable training areas are expensive or not available (Memarsadeghi, Mount *et al.*, 2007)An unsupervised classification method ISODATA (Iterative Self-Organizing Data Analysis) was used to check the spectral groupings of the pixels in each image. The ISODATA techniques creates spectral groupings of pixels having similar characteristics(Idbraim, Mammass *et al.*, 2006).This technique calculates the class mean that evenly distributed in the data space by using maximum likelihood decision rule (Jensen,1996), then it uses iterative process to assign remaining pixels ,using minimum Euclidian distance from the mean

of the class. It assigns the pixels to that class and each iteration recalculates the mean of the class and reclassifies the pixels with respect to newly calculated mean. It continues until the some stability criterion is reached (Melesse and Jordan, 2002).
For MSS data 20 clusters were selected but the (ISODATA) program/algorithm just found 15 clusters of the data. The same numbers of clusters were selected both for TM and ETM+ data but the (ISODATA) program/algorithms found 16 and 10 clusters respectively. These clusters then can be helpful in finding the training areas for supervised classification.

4.6 Maximum likelihood classifier (MLC)

The maximum likelihood classifier (MLC) is widely used method for classification (Bailly, 2007, Liu 2004 and Weng, 2002). The MLC uses the Gaussian threshold that is stored in each class signature to check whether a given pixel falls within a particular class or not. If the pixel falls inside the threshold value of particular class, then it is assigned to that class. (PCI[13] help, 2010). In remote sensing images the classes are not spectrally pure, they are displayed in range of brightness values. The figure 13 shows the overlapping of different classes. For overlapping region MLC chooses the class that maximizes the chances of right classification.

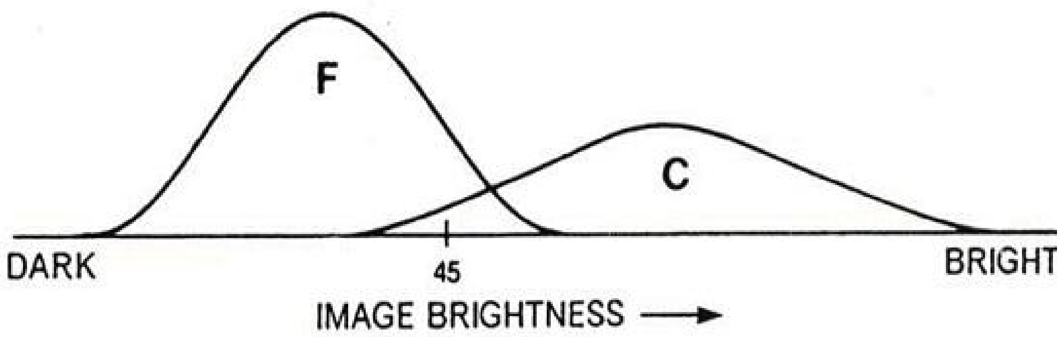


Figure 13. Frequency distribution of pixels from training area of two classes i.e. (F) fallow land and (C) cropland. The pixels in overlapping area are common to both classes. The pixels are assigned to a class according to relations of pixel to overall frequency for each class. (Adopted from Campell, 2002)

Initially a severe spectral confusion between different LULC classes were found during the supervised maximum likelihood classification, i.e. Rainfed mechanized farming (RMF) mixed with forest and bare soil as it contains both vegetated and non vegetated field, also settlement area is mixed with bare soil and up to some extent with forest as settlement area is scattered sparsely and has some trees. In Landsat TM 1984 and Landsat ETM+ 2007 images irrigated land mixed strongly with dense forest as it has lot of vegetation. So it was very hard to separate these classes from each other. After analyzing the situation, this problem was solved by using masking technique with unsupervised and supervised classification method. Mask for three classes RMF, settlement and irrigated land was created with help of image visual interpretation of the images and available reference data i.e. aerial photographs for

[13] This is available at this link http://www.pcigeomatics.com/cgi-bin/pcihlp/CLWORKS%7CClassify%7CSupervised%2BAlgorithms.

MSS 1972, TM 1984 and high-resolution images from googlemaps for ETM+ 2006 time periods. The aerial photographs for 1972 time periods is of not good quality, due to this False color composite (FCC), image enhancement and visual interpretation were use to create the mask around the RMF as shown in figure 14. In this figure RMF can easily be identified.

The selection of training area is an important step for this classification method. At the training stage for MSS 1972 images, mixed rangeland was divided into six subclasses (MRL1, MRL2, MRL3, MRL4 and MRL5, MRL6), water into three (w1, w2 and w3) and sparse forest into three (SF1, SF2 and SF3) subclasses respectively. For TM 1984 data, mixed rangeland was subdivided into six class (MRL1, MRL2, MRL3, MRL4, MRL5 and MRL6) and sparse forest into two classes (SF1 and SF2). For ETM+ 2006 images, mixed rangeland was divided into six subclasses (MRL1, MRL2, MRL3, MRL4, MRL5 and MRL6), water into three subclasses (w1, w2 and w3) and sparse forest into three classes (SF1, SF2 and SF3). After this all images were classified separately by using supervised maximum likelihood method. For each image different training areas were used to classify the images.

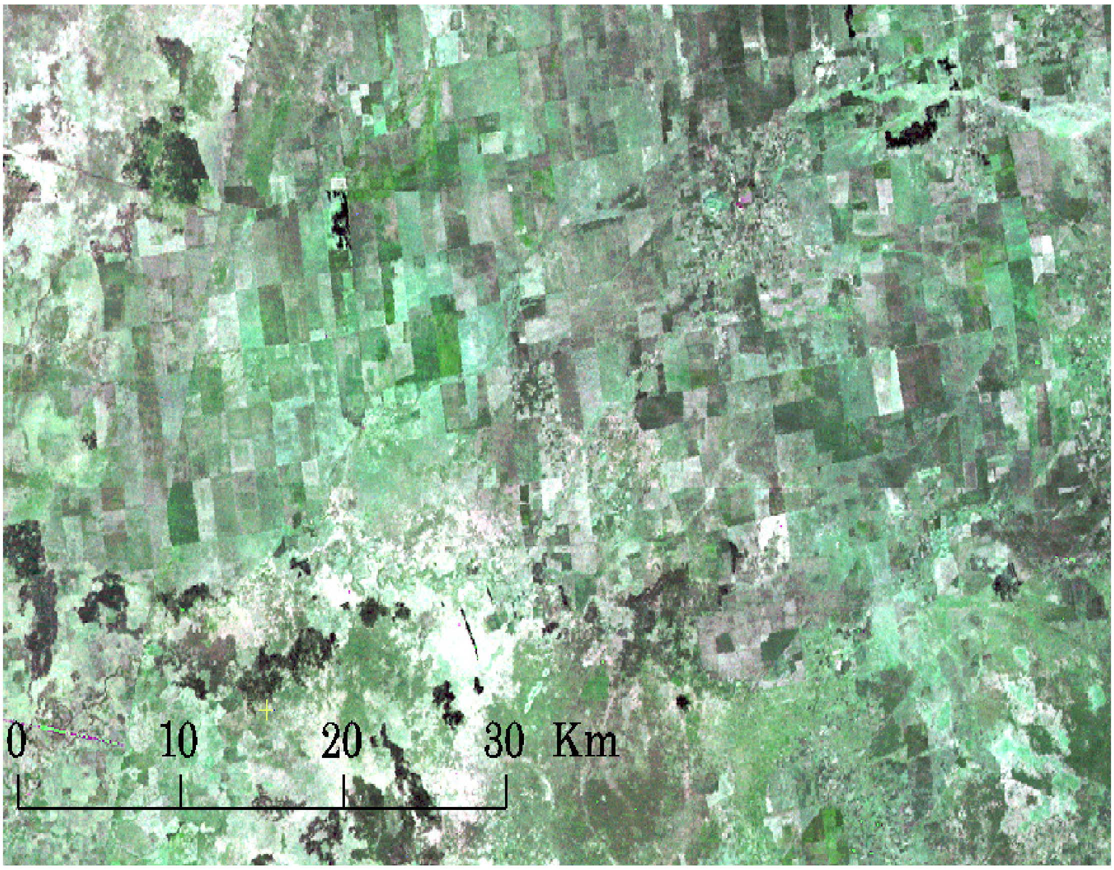
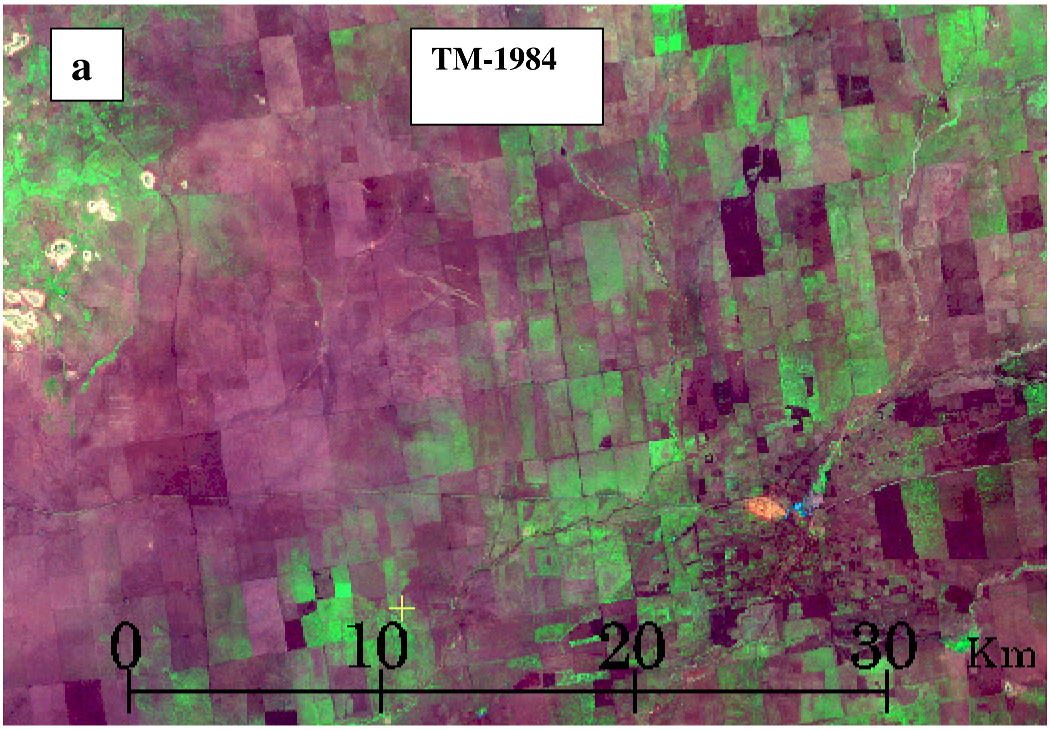


Figure 14. MSS-1972 False color composite (FCC) i.e. red =1, green=4, blue =2 shows the pattern of RMF in the area.



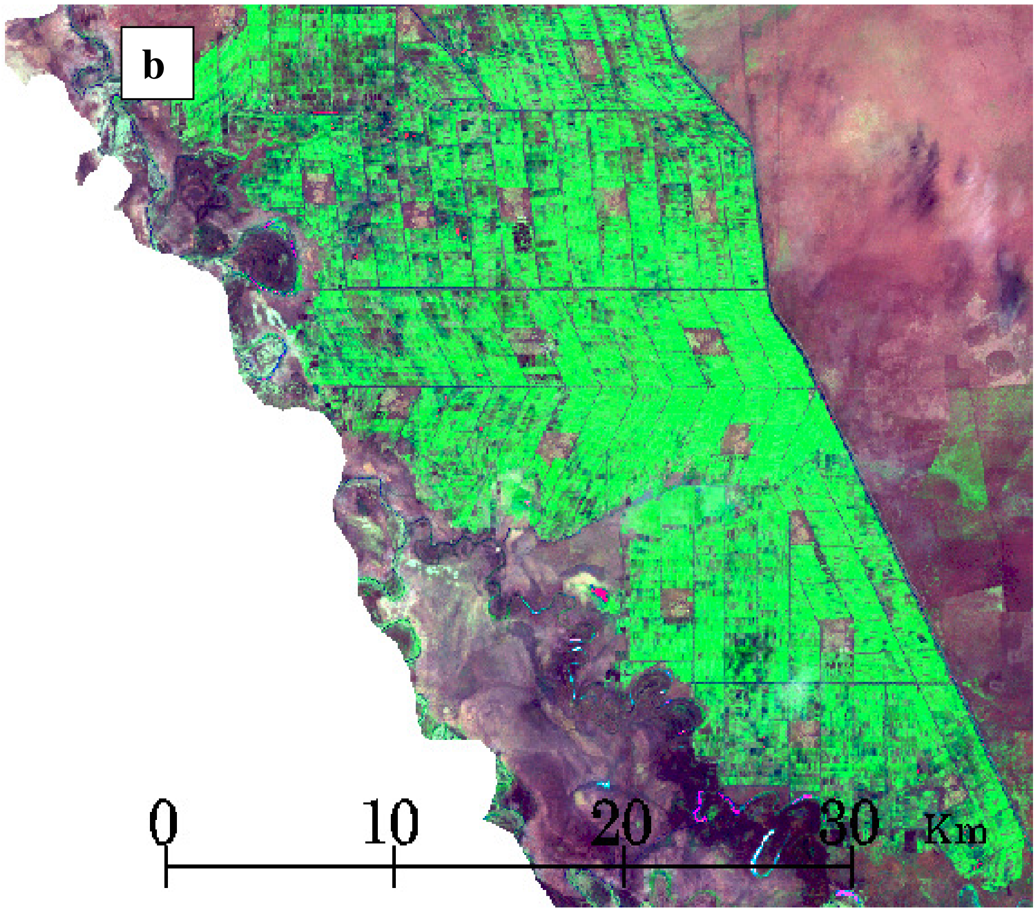


Figure 15. TM-1984 FCC (red=7, green=4, blue=2). (a) Pattern of RMF in TM-1984 data. (b) Pattern of Irrigated land in TM data

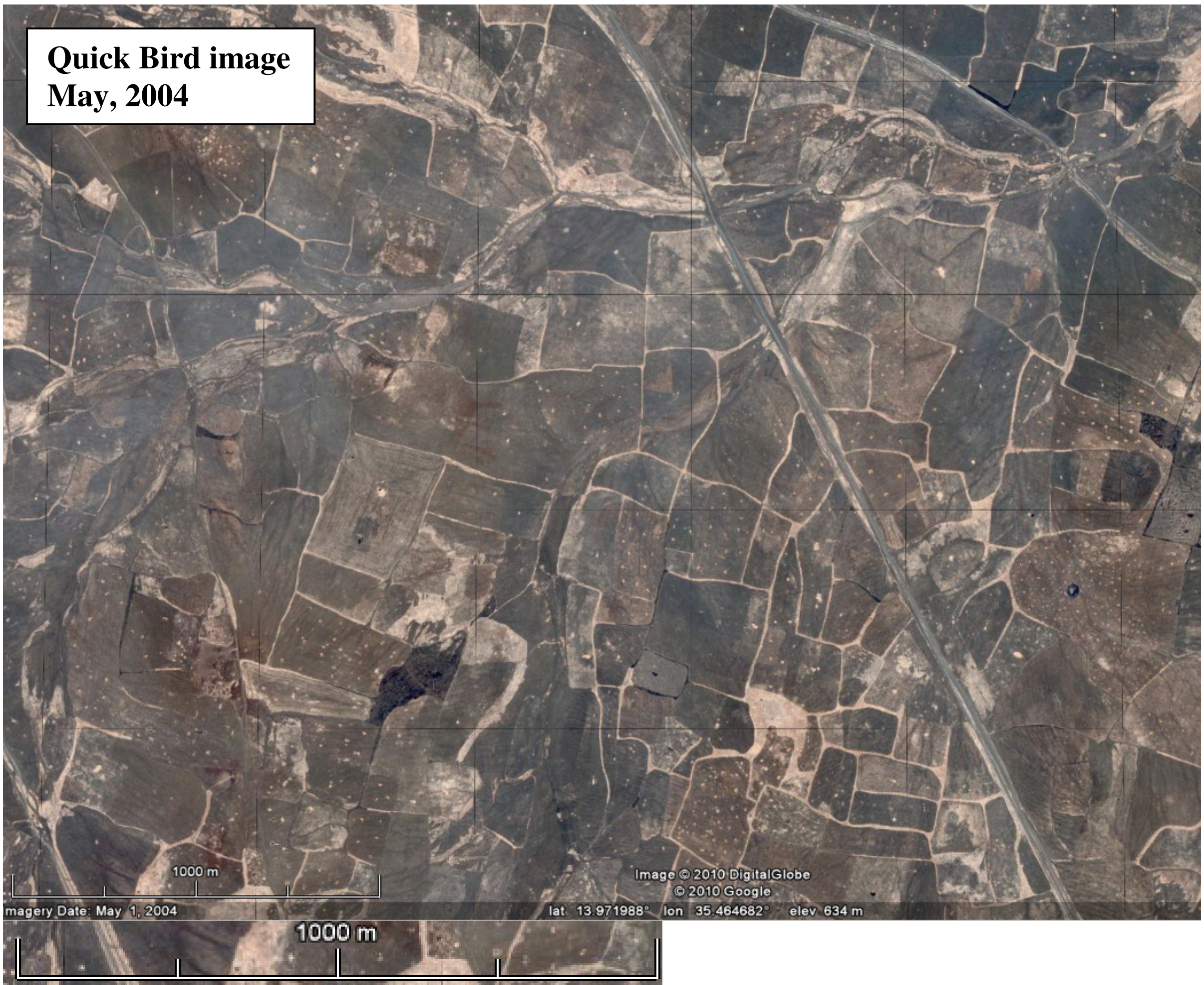


Figure 16. RMF pattern in Quick Bird[14] image May, 2004 used for masking around the RMF in ETM+ 2006 data.

Then in class editing step all the subclasses for each time period were merged into main classes as in table 5. In next step RMF, Irrigated land and Settlement classes were added and then all classes were merged under mask of that class. Finally seven classes (table 5) were classified for MSS 1972, TM 1984 and ETM+ 2006.

4.7 Accuracy assessment

The accuracy assessment of the classification was done with help of different types of reference data for each period. The accuracy assessment of classification is most reliable when the reference data collected either by visiting ground or from aerial photographs of good quality at or near the satellite data used for study (Congalton and Green 1999), however there is very rare chance of availability of such data for remote area like Gadarif. In this study the, 1984 LULC map was checked with reference to 1981 and 1984 aerial photographs, and the 2006 LULC map was checked with high-resolution imagery from google maps.i.e. Quick bird and Spot images with near date

[14] This image is taken from Google Earth maps. This is a screen shot of May, 2004 image.(2010-06-03)

to the ETM+ data. All the scanned aerial photographs were registered to Universal Transverse Mercator (UTM) map projection zone 36.
To be not biased, stratified random points were selected from the reference data for each LULC map. For 1984 LULC maps only 20 sample points were selected; however for 2007 LULC map 65 sample points were selected from the reference data. These points were projected to UTM map projection and were displayed over the data in the PCI Geomatica V 10.3.1. These points were then labeled with their corresponding classes. After this confusion matrix, classification statistics and kappa statistics were calculate.

4.8 Change detection

There exist a wide variety of methods to study LULC change (Singh 1989, Muchoney and Haack 1994). As all the images are classified separately based only on the information contained in each image, the post-classification comparison method (Foody, 2002) for change detection was used for this study. With the help of this method thematic maps of two dates are compared on pixel-by-pixel basis to extract the change that may have occurred between time periods.
There exist seven LULC classes in classified maps and every class is represented by one unique code (i.e. pixel value) range from 1 to 7 as given in table 6. To detect the change from 1972 to 1984, the LULC 1984 map is multiplied with 10 and then new pixel values are become as shown in table 6.Then both image 1972 and 1984 added together. In resulting image the pixel values 11, 22 etc as shown in table 6 represent no change in the image. All other pixel values show the change that occurred in the image. Same procedure was adopted to detect the change from 1984 to 2006. This time ETM+ 2006 image multiplied with 10 and added with TM 1984 image.

Table 6. Post classification change detection of three time periods (1972, 1984 and 2006)

Class_Id	Class	1984 Multiply by 10	Add 1972 and 1984 (No change values)	2006 Multiply by 10	Add 1984 and 2006 (No change values)
1	Water	10	11	10	11
2	Dense forest	20	22	20	22
3	Mixed rangeland	30	33	30	33
4	RMF	40	44	40	44
5	Irrigated land	50	55	50	55
6	Sparse forest	60	66	60	66
7	Settlement	70	77	70	77

The visually observed changes were highlighted for each time periods 1972, 1984 and 2006. For visual change of period 1972 to 1984 three areas were selected that were more prominent (A1, B1, C1) for time one (1972) and (A2, B2, C2) for time two (1984). For visual change of period two areas were highlighted (A1, B1) for 1984 and (A2, B2) for 2006.

4.8 Tasseled Cap Transformation (TCT)

For Landsat MSS data, calculated NDVI was not good enough to use for further analysis due to striping in data. The tasseled cap transformation (TCT) technique was adapted in MSS case and gave a better result. The concept of TCT comprises on four linear combination i.e. TC1=brightness, TC2= Greenness, TC3= yellowness and TC4 =nonesuch. In an agricultural area about more than 95% of the information lies in first two TC1 and TC2 components of TCT. In TCT, the TC1= brightness is a weighted sum of all bands and can be used for interpreting the overall brightness or albedo of the surface. On the other hand TC2=greenness band calculates the difference between visible and near infrared bands and is quite similar to vegetation index (Seto, Woodcock *et al.*, 2002).
The two component of TCT of MSS data are calculated by the following equations (5 & 6) given below

$TC1 = b^{1} *MSS1+b^{2} *MSS2+b^{3} * MSS3+b^{4} *MSS\ldots$ ***Equation (5)***

$TC2 = g^{1} *MSS1+g^{2} *MSS2+g^{3} *MSS3+g^{4} *MSS4\ldots$ ***Equation (6)***

In above equations
b= coefficient of brightness
g= coefficient of greenness

Table 7. The coefficients for the derived tasselled cap transformation based on at- surface-reflectance (PCI Geomatica, 10.3.1V)

TCT component	MSS-1	MSS-2	MSS-3	MSS-4
Brightness (b)	0.32	0.60	0.68	0.26
Greenness (g)	-0.28	-0.66	0.58	0.39

The TC2=greenness component of TCT was classified into two categories, vegetation and non-vegetation. The TC2 component values were classified into two categories as vegetation and non-vegetation.

4.9 Normalized Difference Vegetation Index (NDVI)

NDVI is very strong tool to calculate the amount of vegetation in the area. As NDVI is normalized difference of red and near infrared bands, it compensates the viewing angle and background effect of soil. For current study NDVI was calculated for TM and ETM+ data by using **(equation 4**) in chapter 3. More details about NDVI are given in chapter 3.
The NDVI of TM and ETM+ were classified into two classes, vegetation and non-vegetation.

CHAPTER 5 RESULTS

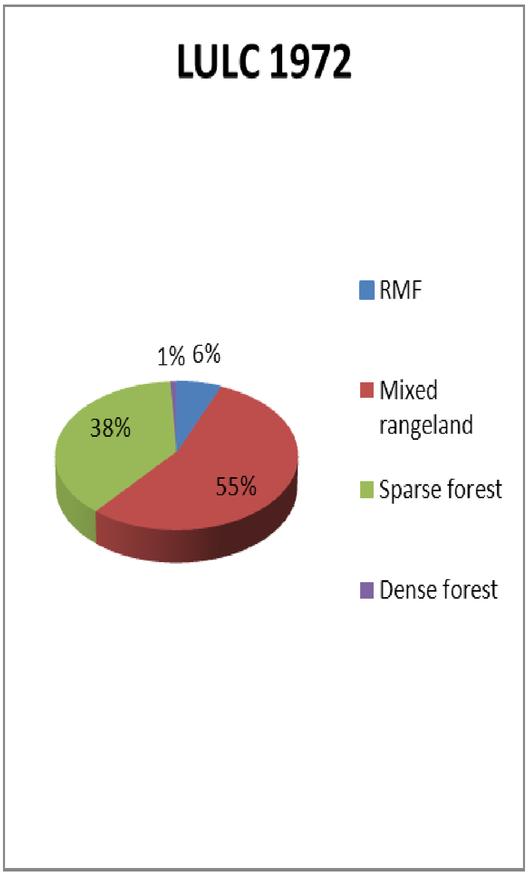
The results are presented in the form of maps, statistical tables and charts. These include the spatial distribution and change of LULC classes in each time period of the study. A comparison between two images was made both visually and digitally to identify the changes and transformation that has occurred from one class to the other over the years.

5.1 Areal distribution of LULC classes in 1972

The situation about LULC in 1972 can be seen from the table 8. In 1972 mixed rangeland and sparse forest were the most dominant classes that covered 55 % and 38 % of the total area respectively. The RMF only makes the 6% of the total area. The area under dense forest was very low. From figure 18 it can be seen that outside the cultivated area high woody biomass is only along the river. This also shows the area under commercial cultivation was small.

Table 8. Areal distribution of LULC classes in 1972

	LULC 1972	
LULC Classes	**Area** (km^2)	**% Of Total Area**
Wat	289	1%
RMF	3862	6 %
MRL	33822	53 %
IL	246	0.5%
Sett	11	0.01%
SF	23569	38%
DF	527	1%
Sum	**62326**	**100**



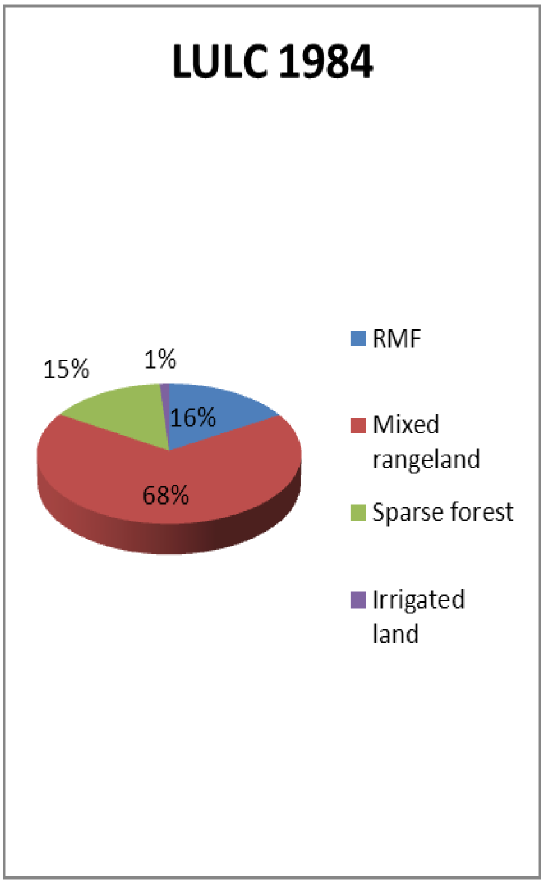
Wat=Water, RMF=Rainfed Mechanized Farming, MRL=Mixed Rangeland, IL=Irrigated Land, Sett=Settlement, SF=Sparse Forest, DF=Dense Forest

5.2 Areal distribution of LULC classes in 1984

The table 9 below shows the distribution of LULC in 1984. The most prominent classes in 1984 period were mixed rangeland, RMF and sparse forest. Mixed rangeland was the big class, which covered about 68 % of total area. The other main classes were RMF and sparse forest that covered 16 % and 14 % of the total area respectively. Irrigated land and dense forest were just covered a small portion of the area. Irrigated land was just on the west of the study area and near the Neil River that was increased much as compared to 1972 time period. The area under RMF has expanded 266% compared to 1972.

Table 9. Areal distribution of LULC classes in 1984 in km^2 and also percentage change from 1972.

LULC Classes	LULC 1984		
	Area (km^2)	% Of Total Area	% Of 1972
Wat	43	0.06%	14%
RMF	10297	16%	266%
MRL	42689	67%	126%
IL	763	1.20%	310 %
Sett	23	0.03%	209 %
SF	9425	15 %	39 %
DF	101	0.15%	19%
Sum	**63341**	**100**	

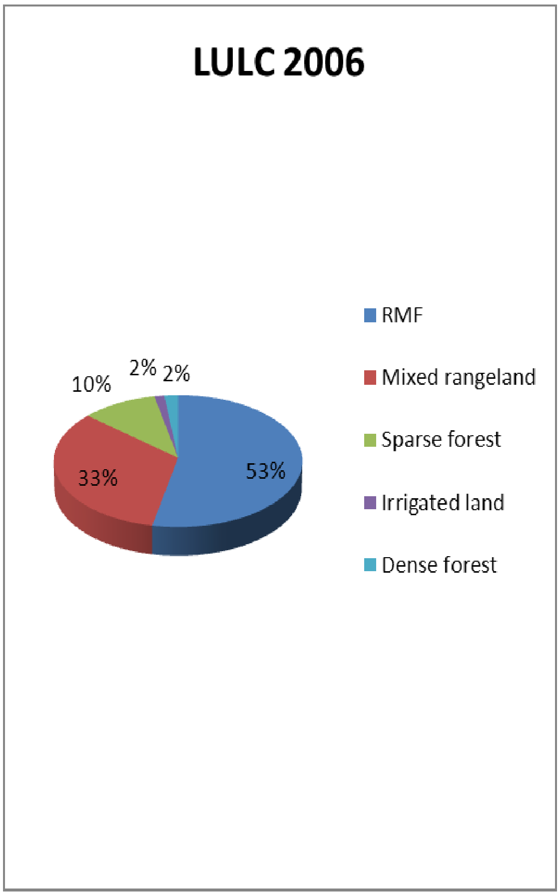


5.3 Areal distribution of LULC classes in 2006

LULC distribution in 2006 can be seen from table 10. The table 10 shows the total area and percentage of area of each LULC type in 2006. The table 10 shows that in 2006 RMF and mixed rangeland were main classes in the area that made 53 % and 33 % of total area respectively. The area under RMF expanded 866% compared to 1972.

Table 10. Areal distribution of LULC classes in 2006 in km^2 and percentage change from 1972.

LULC Classes	LULC 2006		
	Area (km^2)	% Of Total Area	% Of 1972
Wat	275	0.43%	95%
RMF	33477	53%	866%
MRL	20978	33%	62%
IL	846	1.33%	344%
Sett	123	0.20%	1118%
SF	6468	10%	27%
DF	1175	2%	222%
SUM	**63342**	**100**	



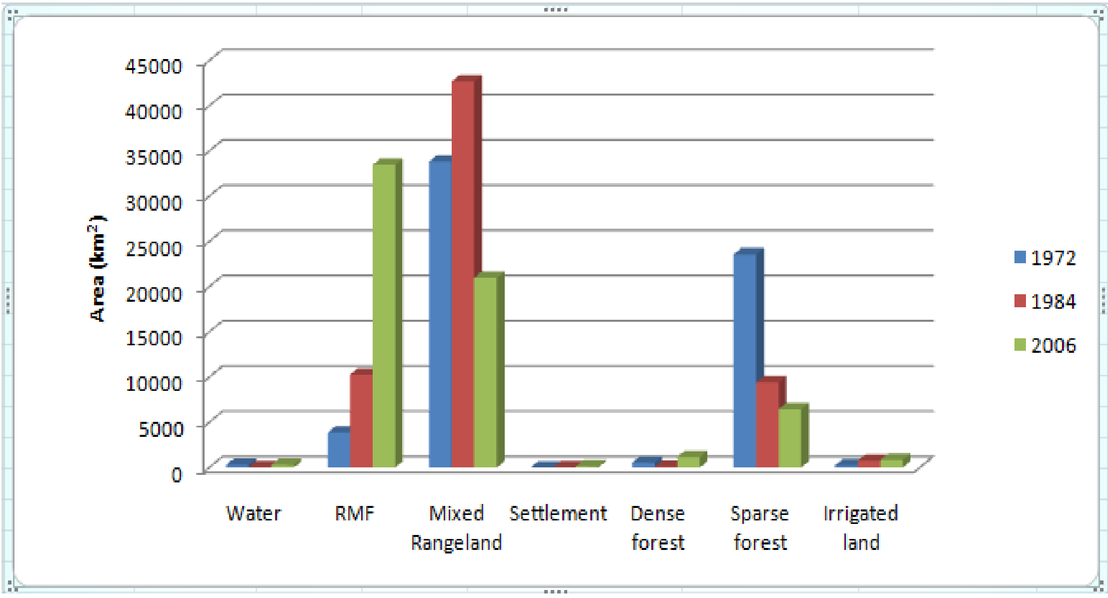


Figure 17. Areal distribution comparison of different LULC classes in 1972,1984 and 2006.

5.4 Classification accuracy assessment

The overall accuracy of LULC maps for each period (1984 and 2006) range from 86,88 and kappa statistics are from 0.84 and 0.86 respectively as shown in table 11. The overall user's and producer's accuracy ranges from 80,85. An accuracy assessment of time period 1972 was not carried out due to unavailability of reference data.

Table 11. Accuracy assessment of the LULC maps

(1) LULC 1984

Classified Data	Reference Data							
	Wat	**RMF**	**MRL**	**IL**	**Sett**	**DF**	**SF**	**Totals**
Wat	**2**	0	0	0	0	0	0	**2**
RMF	0	**2**	0	0	0	0	0	**2**
MRL	0	1	**4**	0	2	0	0	**5**
IL	0	0	0	**3**	0	0	0	**3**
Sett	0	0	0	0	**2**	0	0	**2**
DF	0	0	0	0	0	**3**	0	**3**
SF	0	0	0	0	1	0	**3**	**4**
Totals	**2**	**3**	**4**	**3**	**3**	**3**	**3**	**21**

Over all Accuracy =86.34 %
Over all User's Accuracy = 90 %
Overall Producer's Accuracy =88 %
Overall kappa statistics =0.84

(2) LULC 2006

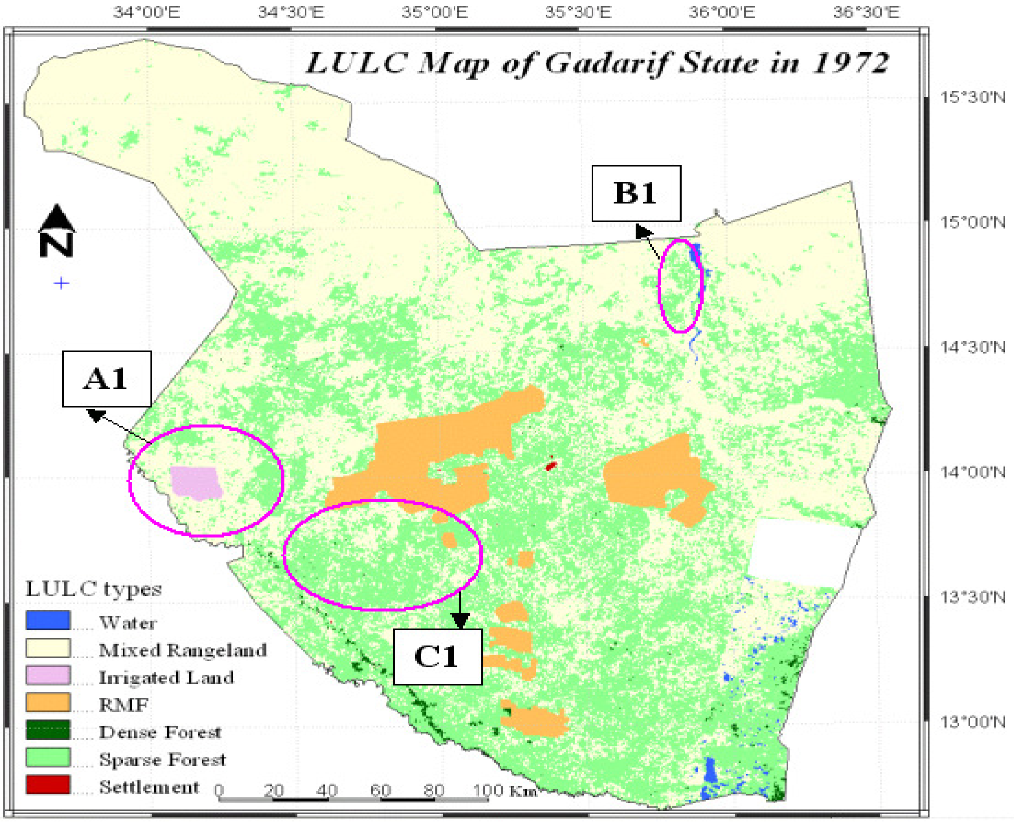
Classified Data	Reference Data							
	Wat	**RMF**	**MRL**	**IL**	**Sett**	**DF**	**SF**	**Totals**
Wat	**3**	0	0	0	0	0	0	**3**
RMF	0	**12**	0	0	0	0	0	**12**
MRL	0	0	**9**	0	2	0	1	**12**
IL	0	0	0	**4**	0	0	0	**4**
Sett	0	0	1	0	**11**	0	0	**12**
DF	0	0	0	0	0	**13**	0	**13**
SF	0	1	2	0	0	1	**10**	**14**
Totals	**3**	**13**	**12**	**4**	**13**	**14**	**11**	**65**

Over all Accuracy =88.57 %
Over all User's Accuracy = 90 %
Overall Producer's Accuracy = 80%
Overall kappa statistics =0.86

Wat=Water, RMF=Rainfed Mechanized Farming, MRL=Mixed Rangeland, IL=Irrigated Land, Sett=Settlement, DF=Dense Forest, SF=Sparse Forest

5.5 Visual interpretation of Maximum likelihood classification (1972, 1984 and 2006)

Figure 18 shows the classified image result (MSS-1972 and TM-1984) with notable



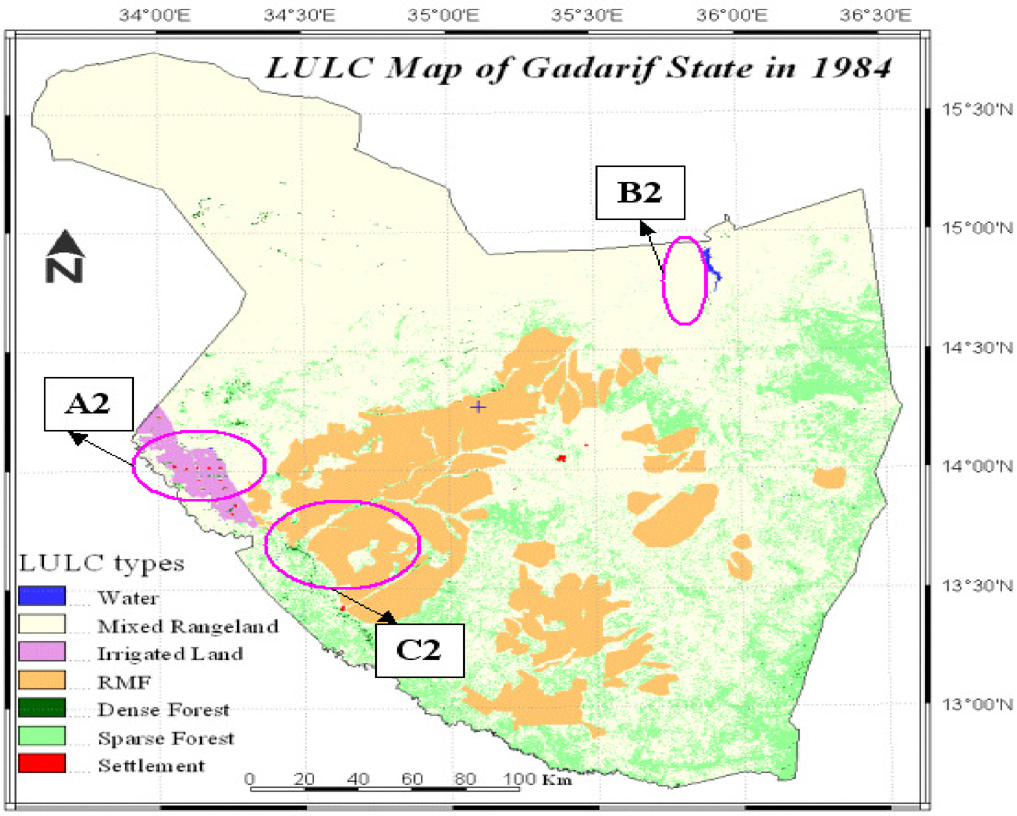
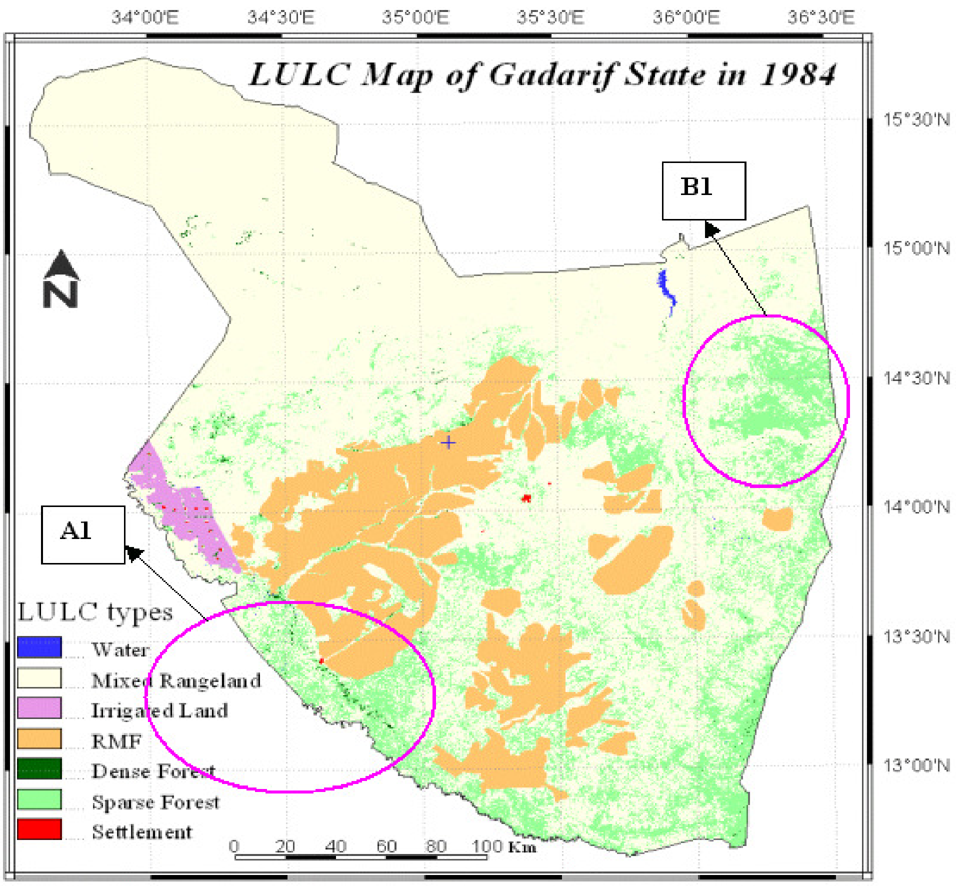


Figure 18. Visual comparison of image classification results of MSS 1972 and TM 1984

visual difference between the two images. There were remarkable visually observed changes in the TM data of 1984 time period. The point A1 and A2 shows conversion of mixed rangeland and sparse forest into irrigated land. There were also changes of LULC types from class sparse forest to class RMF (i.e. point C1 and C2). The point B1 and B2 shows the changes of sparse forest to mixed rangeland. These kinds of changes may have occurred as result of increased use of RMF and irrigation to meet the increased demand of food.

Visual interpretation of time period 1984-2006 shows the lot of area under mixed rangeland was converted into RMF and sparse forest also converted into RMF. Figure 19 shows the notable visual difference between classified image results of (TM-1984 and ETM-2006). There was remarkable visually changes of LULC classes between two time periods. The point A1 and A2 shows the sparse forest and mixed rangeland was converted into RMF along the river. There were also changes of LULC types from class sparse forest to RMF. This shows that different LULC types were converted to RMF to meet the food demand in the country.



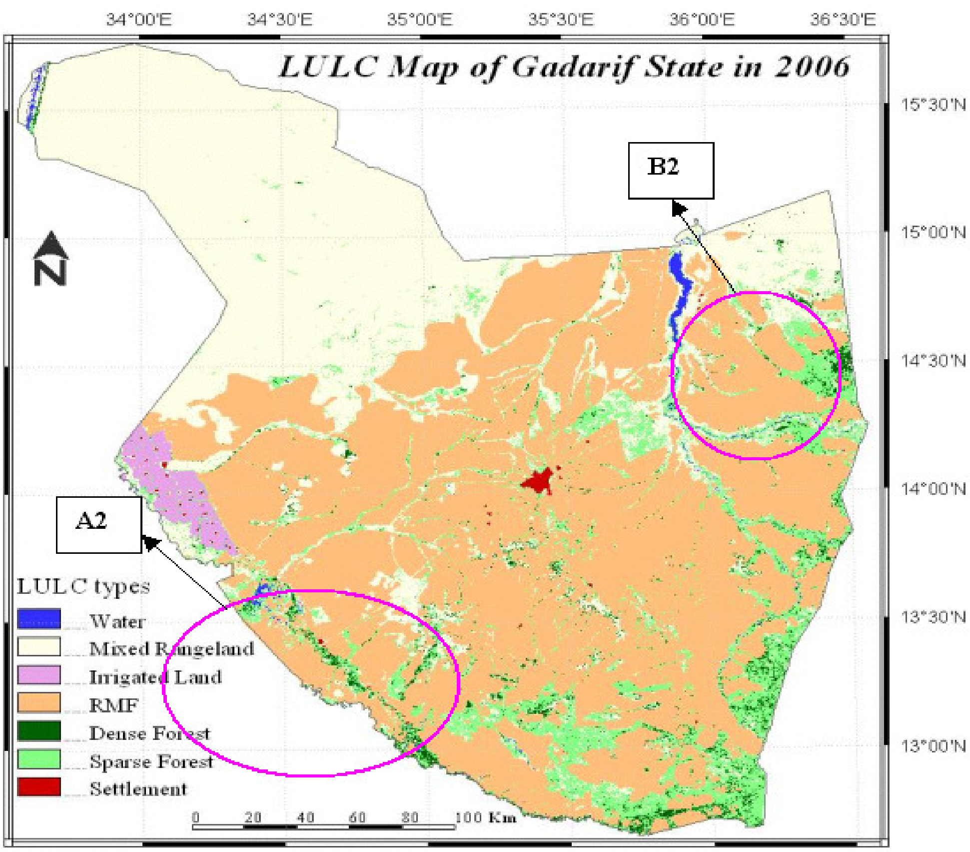
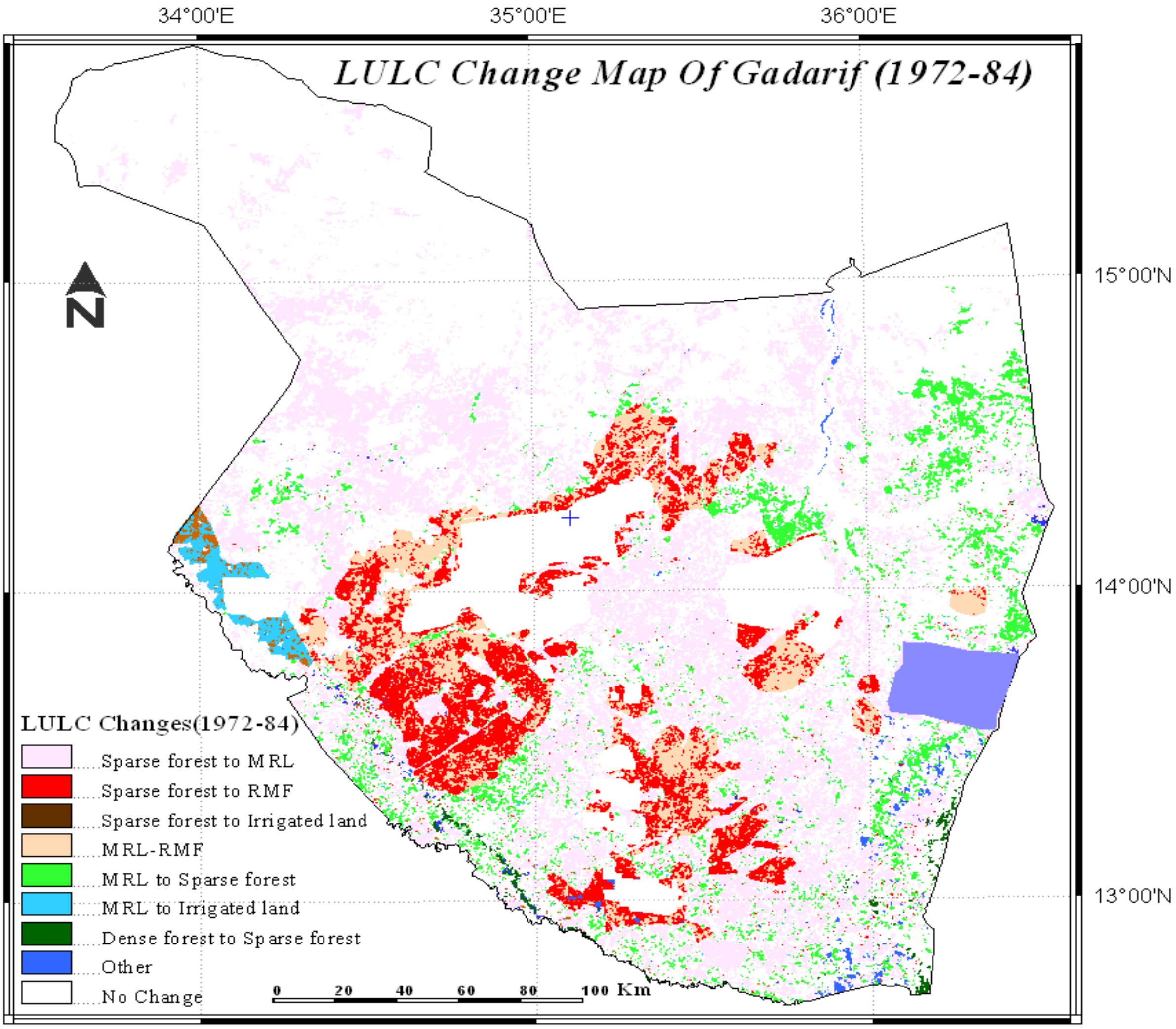


Figure 19. Visual comparison of classification results of TM 1984 and ETM+ 2006.

5.6 Digitally observed changes (1972-1984)

Figure 20 shows the results of post classification change analysis that was performed for the maximum likelihood classification of MSS 1972 and TM 1984 images.



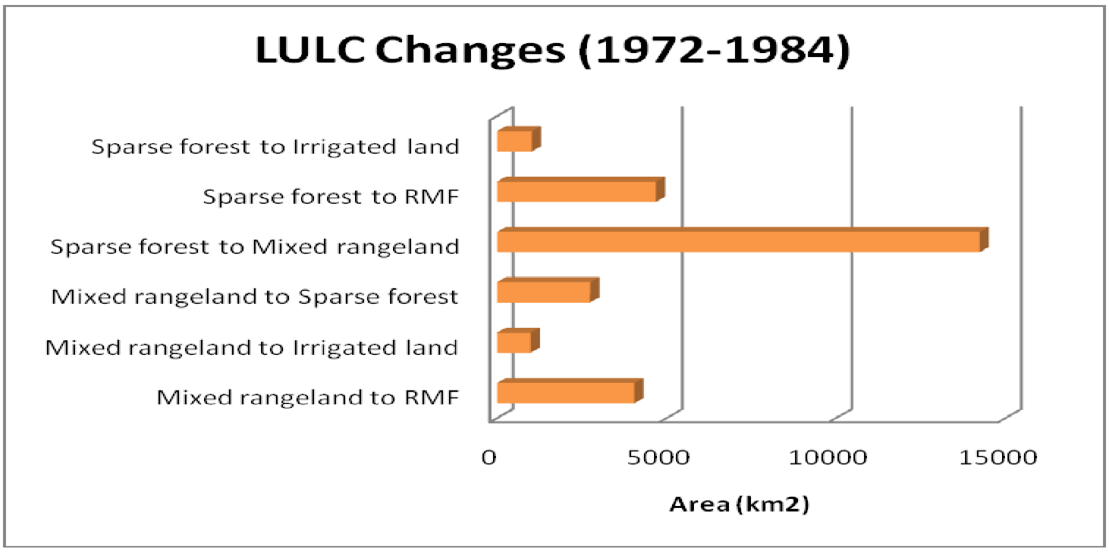


Figure 20. Post classification change analysis of MSS 1972 and TM 1984 image classification

Table 12. Conversion of classes from one class to another (1972-1984)

LULC classes (From -To)	**Area** (km^2)
Mixed rangeland to RMF	4063
Mixed rangeland to Irrigated land	994
Mixed rangeland to Sparse forest	2758
Sparse forest to Mixed rangeland	14247
Sparse forest to RMF	4701
Sparse forest to Irrigated land	1033

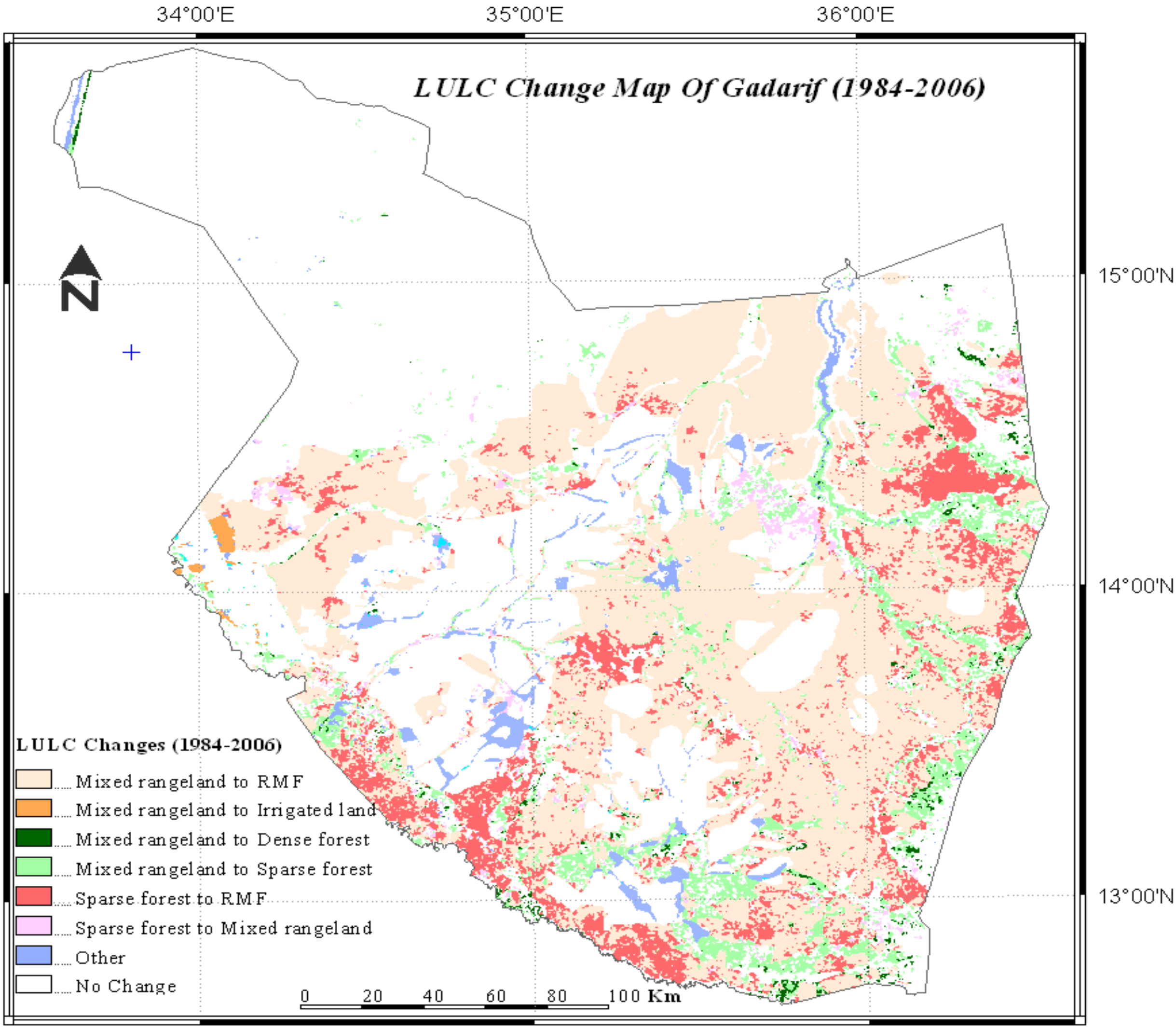
This change detection method produced a change matrix of the types of changes that has occurred and estimates the location, nature and rate of the changes. From figure 20 it can be seen that a lot of changes has been occurred from 1972 to 1984 time period. This shows that every class underwent dramatic changes through this study period. The result indicated that the most of the area under forest type was converted into mixed rangeland.

5.7 Digitally observed changes (1984-2006)

Figure 21 shows the results of change detection of maximum likelihood classification of TM 1984 and ETM+ 2006 images. This change detection method produced a change matrix of the types of changes that has occurred and estimates the location, nature and rate of the changes. From figure 21 it can be seen the specific regions where change has occurred with conversion of one type of LULC to another type and the area with no change. The result indicates that a significant change has occurred during this time period (1984 to 2006) in the study area. There has been a remarkable magnitude of change with LULC type mixed rangeland and sparse forest becoming RMF.

Table 13. Conversion of classes from one class to another (1984-2006)

LULC classes (From - To)	**Area** (km^2)
Sparse forest to Mixed rangeland	1060
Sparse forest to RMF	5449
Mixed rangeland to Sparse forest	3303
Mixed rangeland to Dense forest	519
Mixed rangeland to RMF	18743



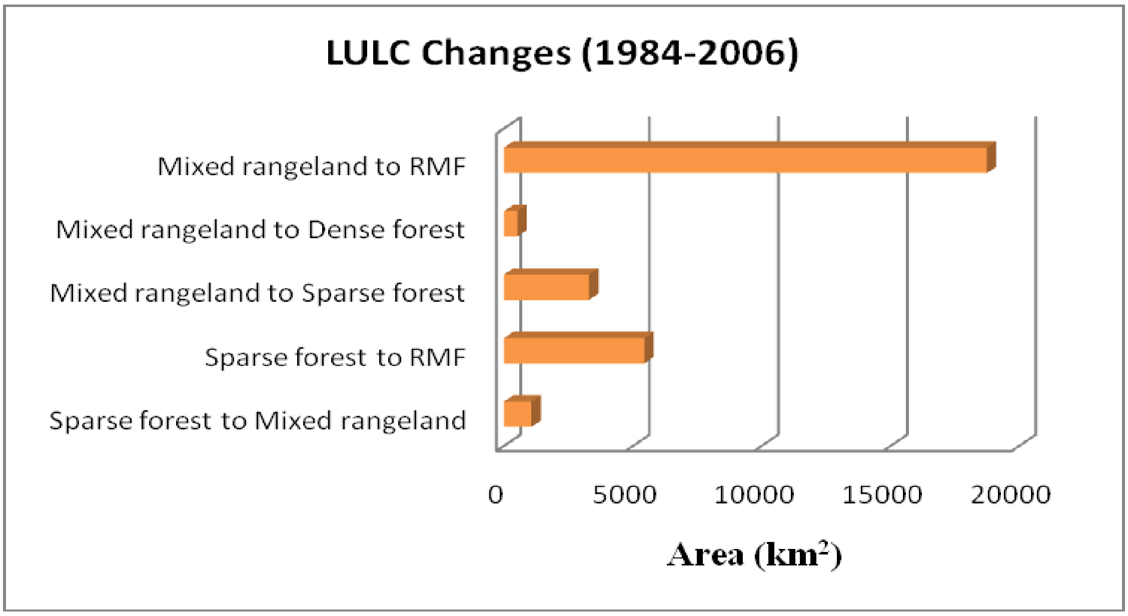


Figure 21. Post classification change analysis of TM 1984 and ETM+ 2006 image classification

5.8 TCT and NDVI

Figure 22 shows the TCT result of MSS and NDVI result of TM and ETM+ data. This shows the green

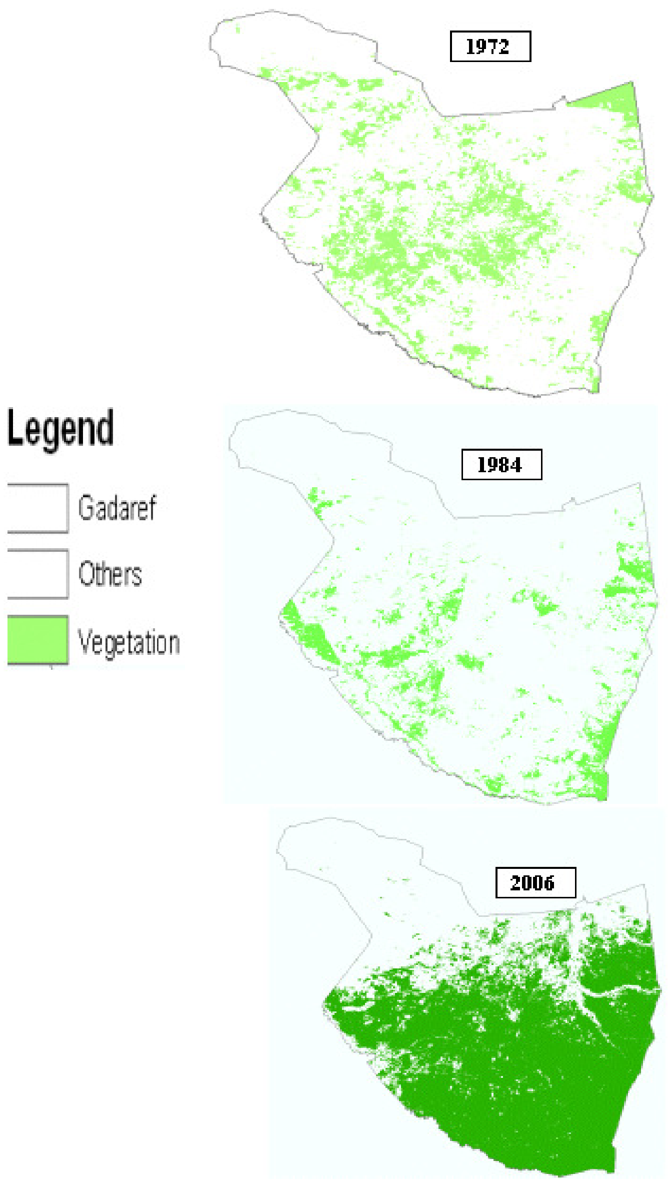


Figure 22. TCT and NDVI result of MSS, TM and ETM+ data (green=vegetation, white=others= no vegetation) 1984-1985 was one of the worst droughts during the last 50 years in this area. Maps above have different colours.

area out side the agricultural land in TM 1984 time period was less as compared to MSS 1972.The NDVI results shows the increase in vegetation in the area in 2006 time period. This is because of the ETM data is from that time when the crops are in its mature stage. So there was lot of vegetation inside the agricultural land in 2006.

CHAPTER 6 DISCUSSION AND CONCLUSION

6.1 Landsat Data and Classification

The Landsat data gives the possibility to study the LULC changes over long periods. The remote sensing data used for this study consist of six scenes of MSS and five scenes of TM and five scenes of ETM+ data. Most of the scenes are from October to December except one MSS and two TM scenes are from June, which is the beginning of rainy season in Sudan and hence the vegetation cover is very low. So there is possibility that mixed rangeland in 1984 classification could have some other class (i.e. RMF). October is in the end of rainy season and vegetation is dense and crops are mature. In MSS data there is only one scene, which makes just very small portion of the study area so it wasn't a big problem, but in TM data there are two scenes from dry season and were classified separately. It is very rare to get the cloud free Landsat data of near anniversary date. There was an overlapping error in MSS data. If we see the figure 7 that shows the overview of MSS data with WRS-1 P183r050 and p183r051 is overlapping, but in actual data there was missing area of 1000 km^2.

6.2 Maximum likelihood classifier

In PCI Geomatica software there are two options while performing maximum likelihood classification one is maximum likelihood without null class and other is maximum likelihood with null class. In the start training areas for seven classes (table 5) were selected and maximum likelihood classification without null class was performed a lot of area was misclassified i.e. mixed range was classified as forest and forest classified as mixed rangeland, shallow water classified as forest etc. Then maximum likelihood with null class was performed and these areas were classified as null class. After analyzing the situation this problem was overcame by dividing the main classes into subclasses. After classification of images these subclasses were again merged to main class.

6.3 Image accuracy

The ideal scenario for image classification accuracy assessment is to collect the reference data with GPS on the same anniversary date of satellite data, but this is not true for remote area like Gadarif state. It is very hard to find the reference data of the same anniversary date. The accuracy of the image classification was tested with help of different source of data i.e. aerial photographs and google maps.

The aerial photographs used in this study were not of good quality used for selecting training areas and validation of classification for TM 1984 data

The accuracy of the image classification is related to quality of reference data in hand

The accuracy assessment of MSS-1972 classification was not done because of unavailability of reference data. There was just only one aerial photograph of 1965 and this photo covers that area, which is missing in the MSS data due overlapping error of Landsat MSS scenes.

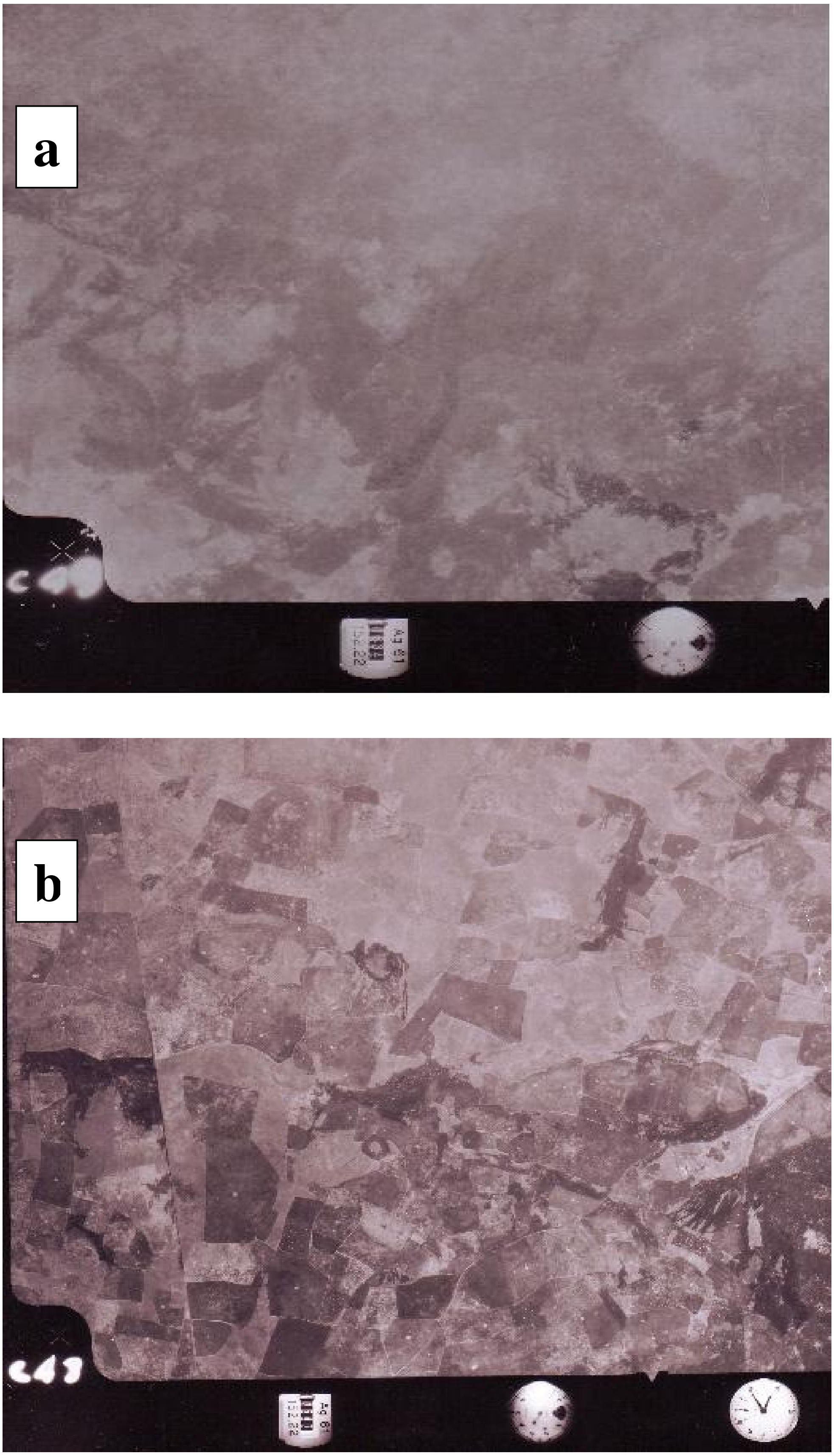


Figure 23. Quality of aerial photographs that got from Sudanese Survey Authority (SSA) **a**) bad quality, it's hard to get some information from this. **b)** Good quality, from this RMF pattern can be identified.

6.4 LULC change findings

There was significant increase in irrigated land and RMF for the purpose of agricultural production in eastern part of Sudan. The result statistics show that about 26 percent of total forested area has decreased over last thirty years. About 20 percent of total forested area in Sudan over last two decades has decreased, largely due to expansion of RMF (Elnagheeb and Bromley, 1992).
The research finding indicated that there has been a large changing of agriculture land use in the study area; there also has been a significant change in the area of land use conversion from one type to another. There has also been evidence of loss and conversion of forest to agricultural land and mixed rangeland type.
To achieve increased grain production and to meet demand and supply requirement in Sudan is obtained by just expansion of RMF, not through increasing per unit yield (Musnad, 1983).

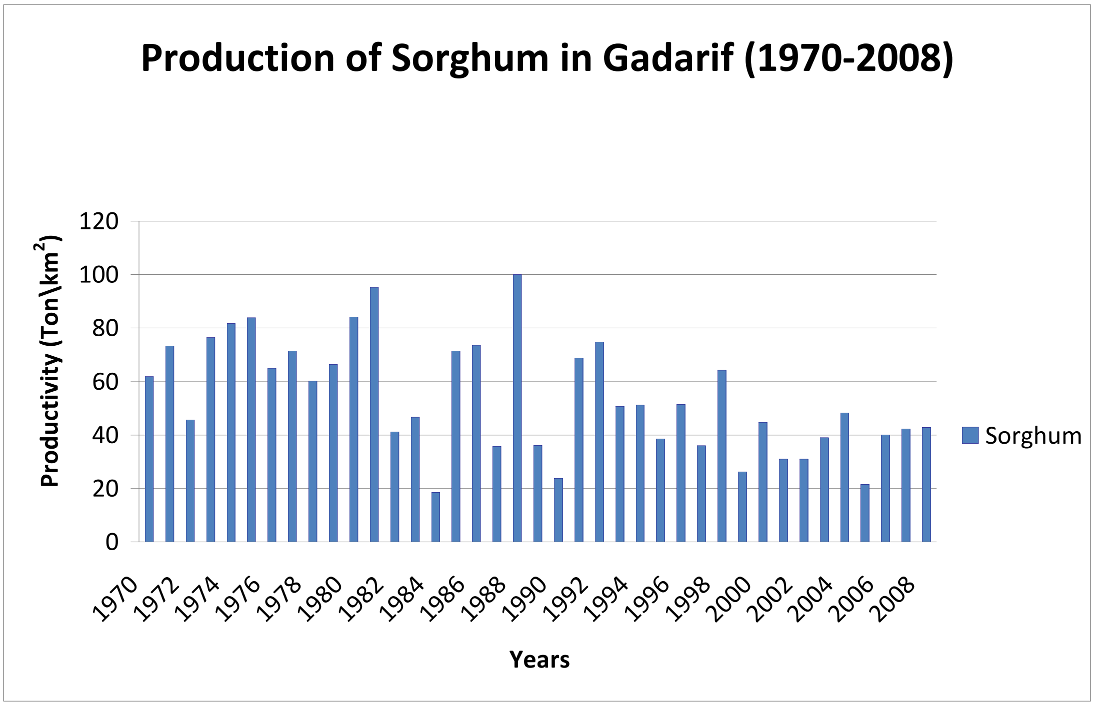


Figure 24. Productivity (Ton/Km^2) of crops (Sorghum) from 1970 to 2008 (Source: ARCS)

The figure 24 shows that productivity of crops in different years since 1970 to 2008.It can be seen from this figure the yield in 2000s was less as compare to yield in 1970s. Figure 25 shows the total area of crop in different years since 1970 to 2008.It can be seen that the total area was much higher in 2000s as compared to area in 1970s.This indicates the decreasing trend in yield per unit. On the other hand figure 25 shows that the total area of sorghum in 2008 was much higher as compare to area in 1970.

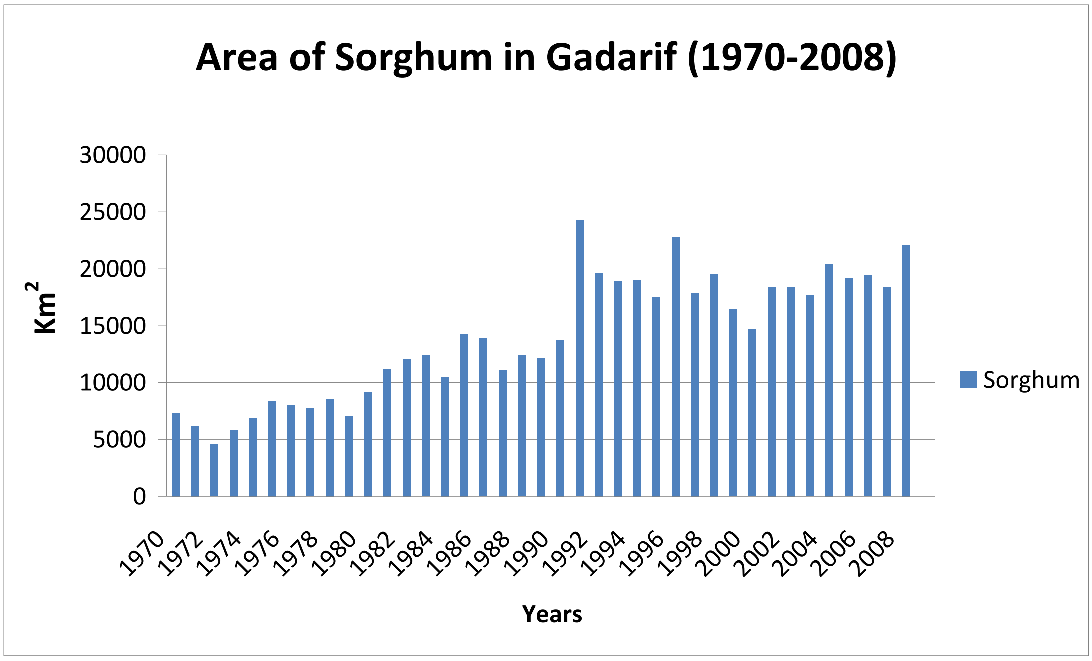


Figure 25. Total area of crop (Sorghum) from 1970 to 2008 (Source: ARCS)

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The increased use of irrigation and continuous use of land for same crops without proper planning leads to over-exploitation of the soil resources and degrading of land. This causes the decrease in yields per unit area. The flooding of irrigated land leads to water logging and salinity issue and consequently low yields (Moghraby, 2002; Osman, 2005). The results from classification of MSS 1970, TM 1984 and ETM+2006 data showed the area of RMF and irrigated land was much higher in 2006 as compared to 1972.

The result from classification indicates that the dense forest in 1972 was very low; the possible reasons for this could be first due to low spectral and geometric resolution and second it may be because of shaelian drought 1968 –1974 (Ayoub, 1999) and was along the river and in the southern part of the study area. The dense forest was decreased in 1984 and then increased in 2006. The possible reasons could be in 1984 once again areas was suffered by severe drought (Ayoub, 1999) and other reason for very low dense forest in 1984 is that TM data used has two scenes from dry seasons. The reason of increased dense forest in 2006 could be the plantation of trees along the roads.

Figure 26. Plantation of trees along the roads (Image from Google maps; Jan, 2007)

The forest in Sudan is decreasing at alarming rate. In Gadarif state, desolation of forest for the expansion of agricultural area is one of the major sources for the degradation of renewable resources (Sulieman and Buchroithner, 2009). The classification results show the sparse forest in Gadarif state has been decreasing from 1972 to 2006. The total area of sparse forest was less in both periods 1984 and 2006 as compared to 1972. The reason for that could be expansion of agricultural land to meet the food requirement.

The results indicated that the area of settlement in 2006 was much higher than the area in 1972. The result statistics indicate that the settlement area has increased 1118 % in 2006 as compared to 1972. The population of the Sudan has increased at very high rate 14 millions in 1970 to 39 millions in 2005 (Daak, 2007). The increase in population has high pressure on forested area, that mean cutting of trees for fuel wood and to expand the agricultural land.

From NDVI maps of three time periods 1972, 1984 and 2006 can be seen that vegetation inside and outside the agricultural land has increased in 2006 as compared to 1972 and 2006, the reason for this could be high quality of data for 2006 and time of acquisition of data (when the crops are mature), on the other hand 1984 has two scenes from dry season. The other reason of low vegetation in 1984 could be that the area was suffered by severe drought during this period.

6.5 Limitations to the Study

There was problem of unavailability of a recent ETM+ images as the latest available image was 2006.Thus the research work has to be limited to 2006 that made it difficult to evaluate the LULC changes for the current scenario in Sudan.
There was also problem of non availability of reliable reference data for 1972.

6.7 Discussion summary

H_o1. The amount of Forest cover in Gadarif in 1972 = the amount of Forest Cover in Gadarif in 1984.

The classification results shows that the there was significant decrease in forest cover as compared to 1972.The NDVI and TCT result shows that there was vegetation loss outside the mechanized farming. So the H_o1 can be rejected.

H_o2. The amount of Forest Cover in Gadarif in 1984 = the amount of Forest Cover in the Gadarif in 2006.

The classification results of TM and ETM+ images show the decreasing trend in sparse forest in the study area. The area under sparse in 2006 was less than area in 1984. The results show that the area under dense forest in 2006 was more than area in 1984. Hence H_o2 can be rejected.

H_o3. The area of rainfed mechanized farms in Gadarif in 1972 = the area of rainfed mechanized farms in Gadarif in 1984.

The classification result of MSS and TM data shows that there was significant increase in RMF in 1984 as compared to 1972. Thus H_o3 can be rejected.

H_o4. The area of rainfed mechanized farms in Gadarif in 1984 = the area of rainfed-mechanized farms in Gadarif in 2006.

The area under RMF in 1984 was much less than area in 2006.The results show that area of RMF in 2006 was three times the area in 1984 and H_o4 can be rejected.

6.7 Conclusions

- It is hard to explain the changes that have occurred in this area.

- The period 1972 to 2006 shows the intensive clearance of natural vegetation due to dramatic expansion of rainfed mechanized farming.

- The period 1972 to 2006 shows the high increase in settlement area, this is due to high increase in population; this leads to increase in demand of food and shelter. This increase in population could be one of the reasons of deforestation and expansion of agricultural land to meet their daily livelihood.

- The maximum likelihood classification along with masking technique has ability to produce good classification results.

6.8 Recommendations

Here is recommendation for further research on the use of remote sensing in LULC changes monitoring in Sudan.

- There is need for the further work on the use of remote sensing for LULC changes covering whole land area of Sudan. This kind of study will provide prospect for the planner in sustainable development of LULC for whole country.

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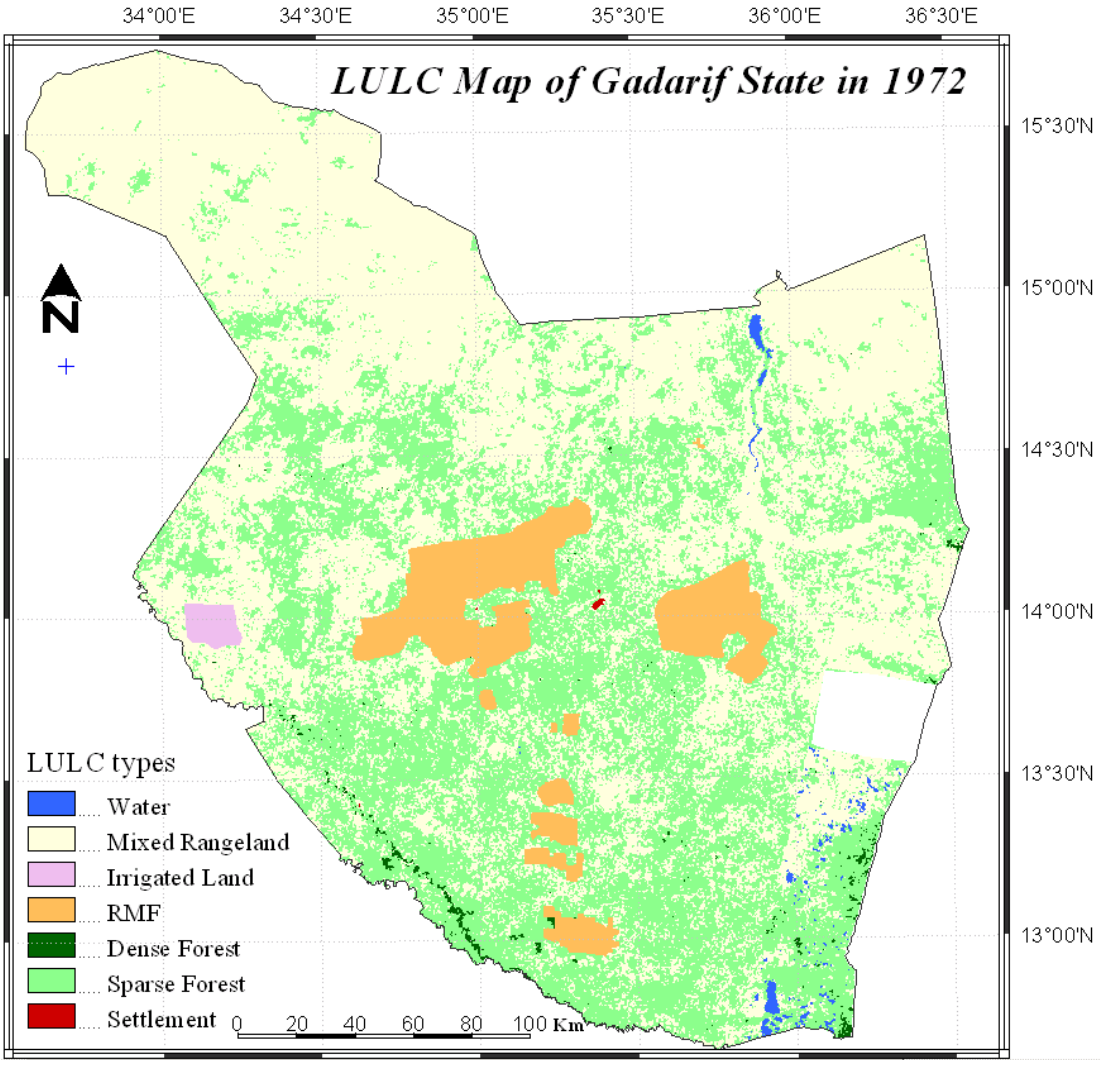
Appendices

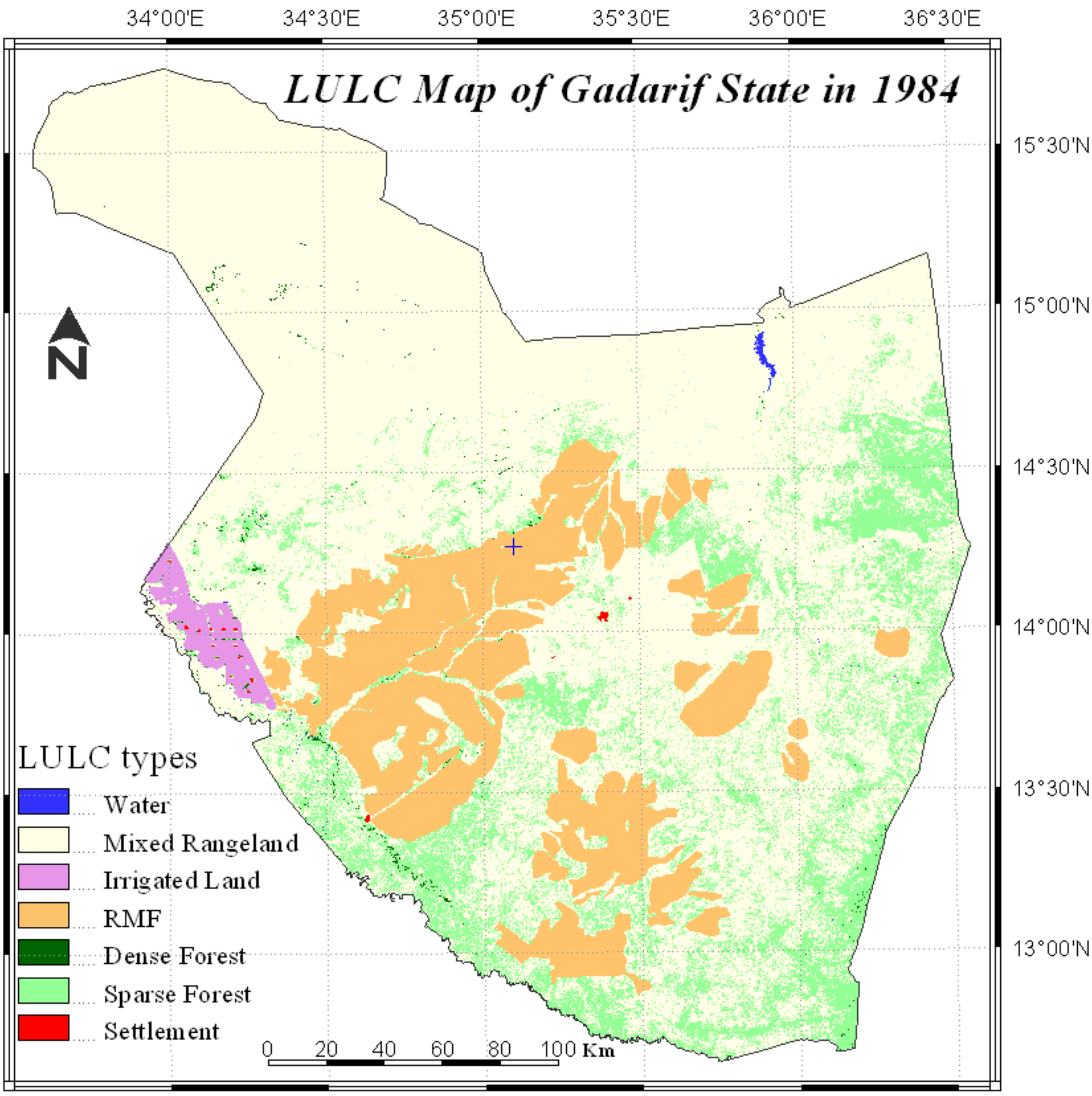
Appendix 1

LULC Map of 1972



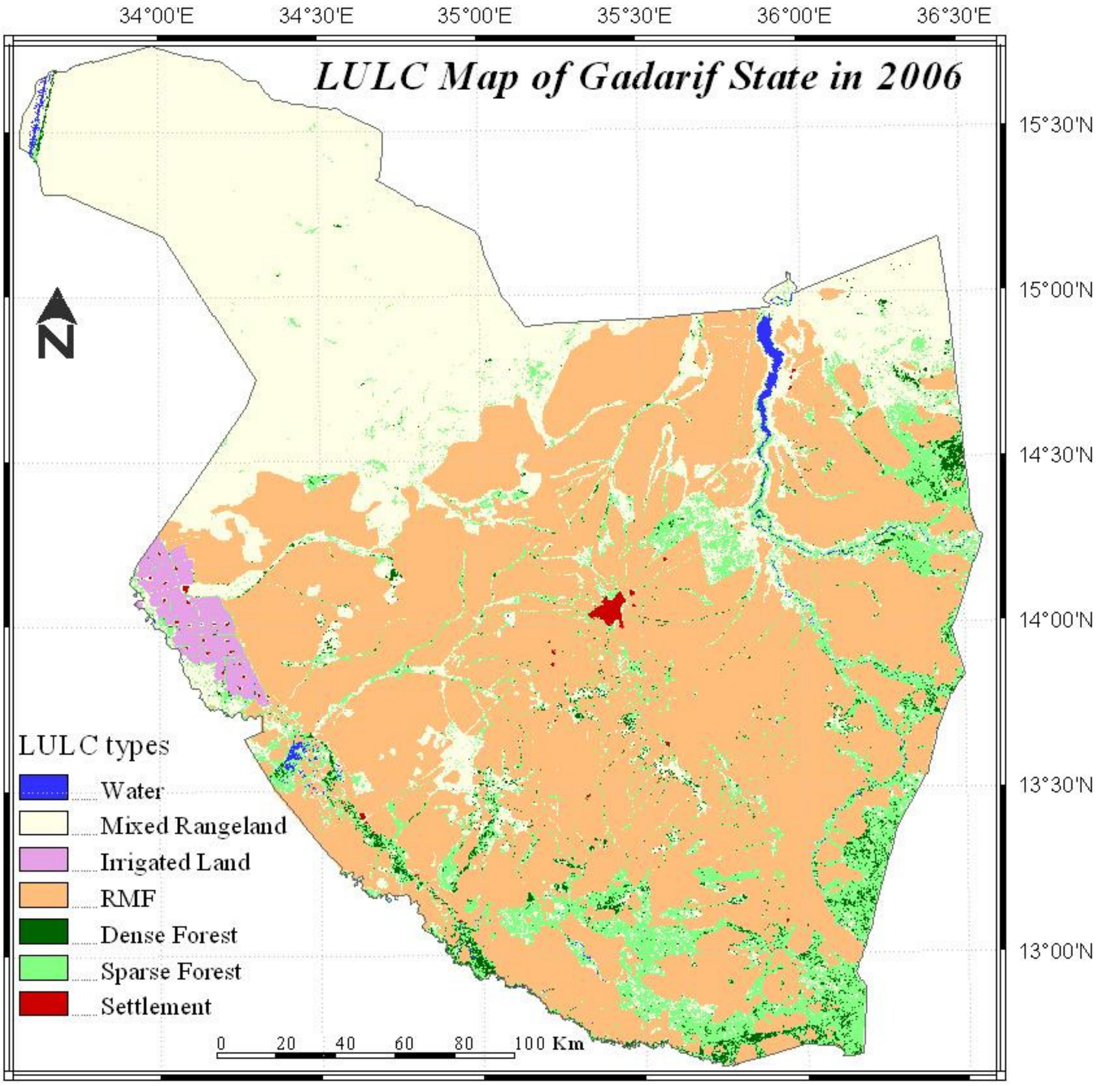
Appendix 2

LULC Map of 1984



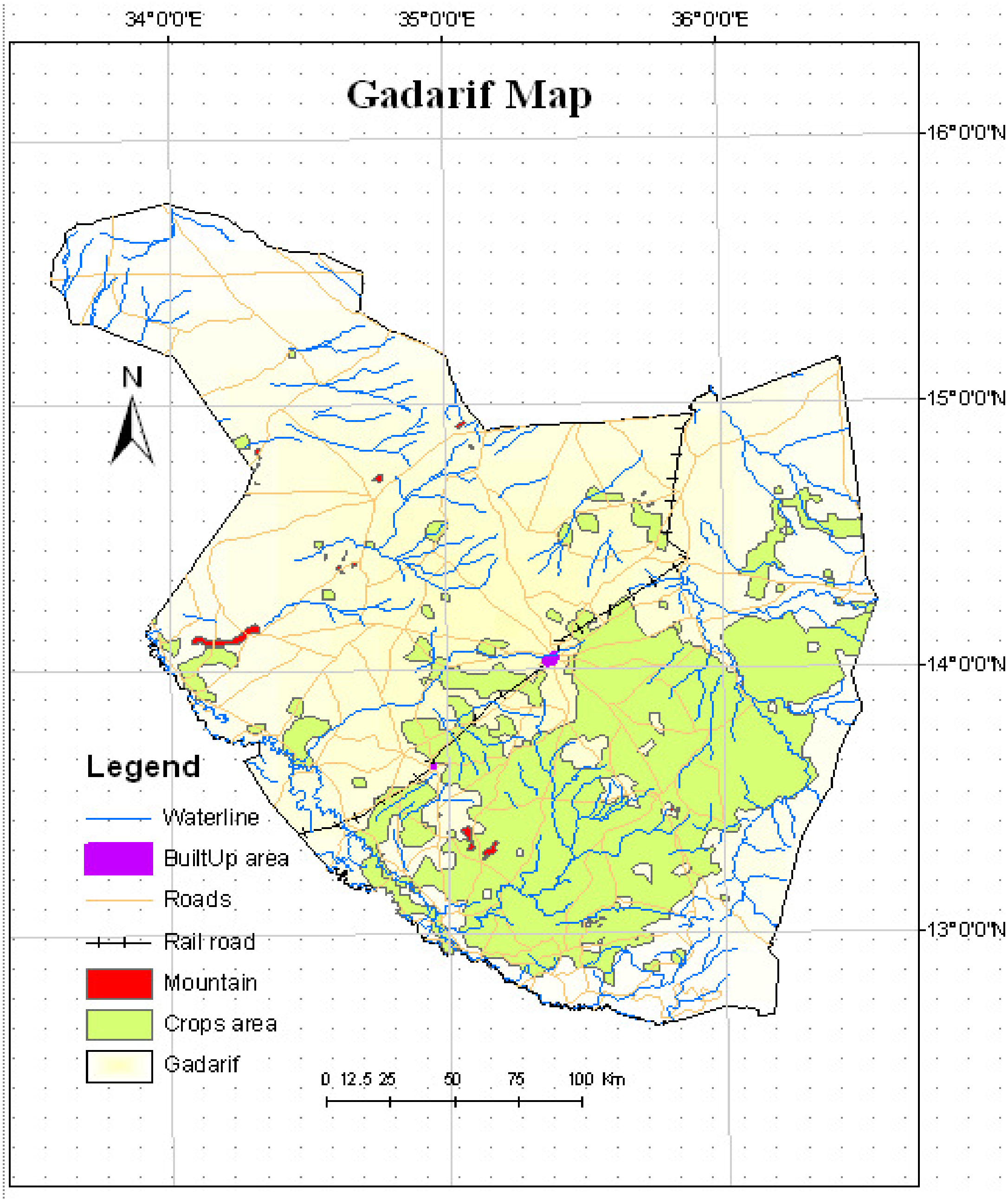
Appendix 3

LULC Map of 2006



Appendix 4

Gadarif state map with built up, river, railroad, rods, crops layers (Source: VMap0[15]).



[15] Source data for Appendix 2 is available at http://gis-lab.info/qa/vmap0-eng.html (2010-04 -18)

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