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Dedication

To my family, especially to the soul of beloved FATIMA
I would like to express my deepest gratitude and appreciation to those people who contributed in a way or another throughout the years in performing this work. I would like to thank in particular:

Dr. ElTigani Mohamed Salih and Dr. Anwar Sheikh AlDeen Abdo for being my supervisors, for their support, scientific discussion, encouragement, continuous assistance, patience, advice, kindness and generosity during the preparation of this research.

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Especial friends in NDDU, HCENR and AGU for friendship, genuine brotherhood and support.

Warm and heartfelt thanks to my wife Hanan, for inspiring my life with her love, kind-heart and support, for taking care of everything. My warm thanks to you and to our beloved kids Enass, Alaa, Awab and Ridah.
Abstract

Desertification is considered as main environmental problem in Sudan. Due to the spatial nature of desertification Remote Sensing (RS) and Geographic Information Systems (GIS) technologies, are appropriate tools of providing practical, real time analysis capabilities, which could play a significant role in assessing and monitoring desertification and thus help in providing technical options for combating by using RS the status and rate of change in land cover may be estimated through a monitoring approach.

Vegetation monitoring is essential for dealing with many environmental issues such as land degradation and vulnerability to desertification. In recent years, most mapping and monitoring of vegetation cover, especially over large areas, have been dependent on the use of remotely sensed data. Normalized Difference Vegetation Index (NDVI) data derived from Advance Very High Resolution Radiometer (AVHRR) sensor are directly related to vegetation cover density.

The NDVI data source used in the present study is the image archive covering East Africa between 1993 and 2003 obtained from Famine Early Warning Systems Network (FEWS Net), Africa Data Dissemination Service (ADDS) Website. The digital vector maps and related descriptive data and tables of Sudan were obtained from National Drought and Desertification Control Unit (NDDU) data bank in Arc/info format and both geographic, and polyconic projection.

The following stepwise methodology was used: (1) The maximum daily NDVI value over a ten-day period is computed to make decadal images; (2) The Long Term Average images (LTA) for the study period was also produced; (3) The decadal images were integrated, and an annual maximum NDVI images was produced; (4) The annually
average imagery was integrated to facilitate direct comparison from one year to the next, and: (5) New difference images were created using change detection methods. The results of this study indicate that the NDVI values are not consistent in the period, and it is changing year by year. The different change classes of NDVI values over the study period were calculated and mapped. The calculated areas of different change classes throughout the study period reflects the variations in the NDVI values or the vegetation cover in terms of decreased and increased areas. Most of the unchanged areas are related to desert areas (Northern Sudan), the permanent tree cover (woodland/forest) areas (Southern Sudan) and rangelands.

The analysis identified the following three areas where degradation has occurred: (1) Al Gedarif, Sennar, Gezira, White Nile, and Kassala States, which are the main rain-fed mechanized crop production areas; (2) Areas around major oil fields, and; (3) Areas in Western Equatoria, Bahr el Jebel, Jongli, and Southern Darfur States around the main towns (Yubu, Yambio, Maridi, Yei, Juba, and Nyala). Areas having increased vegetation cover over the last 10 years equaled 9.81% (244500.6 Km²) of the total area of Sudan. This increase in the vegetation cover is attributed mainly to the increase of rainfall, political displacement of population, and possible changes in vegetation type. The unchanged areas, are related to desert areas, and semi-arid areas (Northern Sudan), where the primary perennial vegetation cover that have existed for decades and composed of slow growing acacia species, while the unchanged areas in Southern Sudan (woodland/forest), the trend could be attributed inaccessibility for mechanized croplands agriculture, firewood collectors and charcoal production.
يعتبر التصحر المشكلة البيئية الرئيسية في السودان، حيث أدى إلى تدهور التربة و Krakoffi  
وانخفاض الإنتاجية الزراعية وإزالة الغابات ونقص الغذاء وحطب الوقود وإفقار المجتمعات 
الريفية والصراعات الإثلىية والهجرة عالية من الريف إلى الحضر وتدهيد التنوع البيولوجي. 
و نسبة للطبيعة الجغرافية للتثبيت، تعتبر تقنيات الاستشعار عن بعد ونظم المعلومات 
الجغرافية أحد التقنيات الملائمة والهامة لتوفير المعلومات عنه، حيث يمكن أن تلعب دورا 
هامًا في تقييم ورصد التصحر والمناطق المندهورة والمساعد في توفير الخيارات التقنية 
الممتعة بمكافحة تدهور الأراضي في المناطق الجافة.

في السنوات الأخيرة أصبحت مراقبة ورصد الغطاء النباتي أمرًا ضروريًا لمراقبة ورصد 
تدهور الأراضي ومن ثم التصحر خاصة في المناطق الواسعة وذلك اعتمادًا على استخدام 
بيانات الاستشعار عن بُعد مثل دليل الاختصار (دليل الفرق القياسي للغطاء النباتي) (NDVI).

تم في الدراسة الحالية استخدام بيانات (NDVI) للفترة بين عامي 1993 و 2003 في رصد 
الغطاء النباتي في السودان ودراسة التغيرات التي حدثت فيها من سنة إلى أخرى ومن ثم حساب 
مساحات هذه التغيرات وتحديد مواقعها خلال فترة الدراسة.

نتج عن هذه الدراسة حساب وتحديد المساحات التي حدث فيها إعادة تأهيل للغطاء النباتي 
والمساحات التي لم يحدث فيها تغير أثناء فترة الدراسة. حيث تبين أن هناك ثلاث مناطق 
رئيسية تعاني من تدهور في الغطاء النباتي وبالتالي تعتبر مناطق متعرضة بحوالي 0.28% 
من مساحة السودان (608,697 كيلو مترًا مربعًا) وهي (1) ولايات القضارف وسنار 
والجزيرة والنيل الأبيض وكسلا، وهي المناطق الرئيسية للزراعة الحالية. (2) مناطق إنتاج 
النفط الرئيسية و (3) مناطق في ولايات غرب الاستوائي وبحر الجبل و جونقلي، وجنوب 
دارفور حول المدن الرئيسية (يوبو ومريدي ويايبو وباي وجيوبو، ونيل). 
أما المناطق التي حدث فيها ازدياد في الغطاء النباتي خلال السنوات ال 10 الماضية بما يعادل 
1.9% (6.244532 كيلومترًا مربعًا) من إجمالي مساحة السودان. هذه الزيادة في الغطاء
النباتي تعزى أساسًا إلى الزيادة في كميات الأمطار والتغيرات في نوع الغطاء النباتي. كذلك تم تحديد المناطق التي لم يحدث فيها تغير في الغطاء النباتي أثناء فترة الدراسة بحوالي 89.9% (89.0601 كيلومتر مربعًا) وهي المناطق التي تقع في المناطق الصحراوية وشبه القاحلة في شمال السودان حيث الغطاء النباتي عبارة عن الشجيرات الدائمة والأنواع المختلفة من الأكاسيا. المناطق الأخرى هي مناطق الغابات في جنوب السودان وهي مناطق يصعب الوصول إليها بغرض الزراعة الأليه أو قطع الأشجار بغرض إنتاج الفحم.

وقد خلصت الدراسة إلى أهمية تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية في دراسة التصحر وتردد الأراضي باستخدام الصور الفضائية ذات الدقة المكانية المنخفضة (NDVI) وذلك عن طريق دراسة دليل الاخضرار (%NDVI) ونسبة للعلاقة بين كثافة الغطاء النباتي وتردد الأراضي والتصدح.

وقد أوصت الدراسة بإجراء المزيد من الدراسات باستخدام صور فضائية ذات دقة مكانية عالية و إضافة المتغيرات الأخرى إلى عمليات التحليل مثل كميات الأمطار ونوع التربة بالإضافة إلى الجوانب الاجتماعية والاقتصادية.
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<tbody>
<tr>
<td>ADDS</td>
<td>African Data Dissemination Service</td>
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<tr>
<td>AGU</td>
<td>Arabian Gulf University</td>
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<tr>
<td>ARTEMS</td>
<td>African Real-Time Environmental Monitoring and Information System</td>
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<tr>
<td>AVHHR</td>
<td>Advance Very High Resolution Radiometer</td>
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<td>DBMS</td>
<td>Data Base Management System</td>
</tr>
<tr>
<td>DCW</td>
<td>Digital Chart of the World</td>
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<tr>
<td>DECARP</td>
<td>Desert Encroachment Control And Rehabilitation Program</td>
</tr>
<tr>
<td>ERDAS</td>
<td>Earth Resources Data Analysis System</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
</tr>
<tr>
<td>FCN</td>
<td>Forest National Corporation</td>
</tr>
<tr>
<td>GAC</td>
<td>Global Area Coverage</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>GLASOD</td>
<td>Global Assessment of Soil Degradation</td>
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<td>GLCF</td>
<td>Global Land Cover Facility</td>
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<td>GOES</td>
<td>Geostationary Satellite</td>
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<td>GRID</td>
<td>Global Resources Information Database</td>
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<td>GUI</td>
<td>Geographic User Interface</td>
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<td>GVI</td>
<td>Global Vegetation Index</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change.</td>
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<td>LAC</td>
<td>Local Area Coverage</td>
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<td>MEA</td>
<td>Millennium Ecosystem Assessment</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NBSAP</td>
<td>Sudan National Biodiversity Strategy and Action Plan</td>
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<td>NDDU</td>
<td>National Drought and Desertification Control Unit</td>
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<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
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<tr>
<td>NOAA</td>
<td>The National Oceanic and Atmospheric Administration</td>
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<tr>
<td>PET</td>
<td>Potential Evapotranspiration</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>POES</td>
<td>Polar Orbiting Satellite</td>
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<td>RS</td>
<td>Remote Sensing</td>
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<tr>
<td>SOM</td>
<td>Soil Organic Matter</td>
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<tr>
<td>UNCED</td>
<td>United Nations Conference on Environment and Development</td>
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<td>UNCOD</td>
<td>United Nations Conference on Desertification</td>
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<td>UNDP</td>
<td>United Nations Development Program</td>
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<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
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<td>UNSO</td>
<td>United Nations Sudano-Sahelian Office.</td>
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<td>WA</td>
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<td>World Meteorological Organization</td>
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<td>WVS</td>
<td>World Vector Shoreline</td>
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<td>µm</td>
<td>Micrometer</td>
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Chapter One

Introduction

1.1. Background:
Sudan is the largest country in Africa with an area of 2.5 million square kilometers lying between 3°-22° N latitude and 22°-38° E Longitude. The principal environmental challenge in the Sudan is desertification. This problem is related to issues of low land productivity, food and fuel wood shortages, deforestation, range deterioration, major civil conflicts, high rural-urban migration and threats to biodiversity. Desertification in Sudan is caused by a host of complex and intertwined human and non-human factors. Sudan has seen a dramatic decline in its forest reserves, horizontal expansion of rain-fed mechanized and traditional farming, heavy reliance on forest biomass energy, overgrazing, and bush fire.
Developing the knowledge base for natural resource conservation, management and use require the availability of environmental information on, for example, vegetation, land use, soil, water, rainfall and climatic conditions and on socio economic activities that influence environmental change. Such information in Sudan is scattered, lacking and/or often outdated.
Remote sensing is a cost-effective method compared to traditional data collection from field survey or aerial photography particularly for studying large areas. Remote sensing has been applied to identify changes both in natural and man-made features in the fields of forestry, agriculture, land use, mining, marine monitoring and urban studies. Environmental inventory and monitoring are the most useful applications of remote sensing. The use of remote sensing data for drought and desertification monitoring has become wide spread since the mid 1980s.
Normalized Difference Vegetation Index (NDVI) is a traditional vegetation index used to extract vegetation abundance from remotely sensed data, and has been used to measure vegetation cover characteristics as indicator of desertification.
Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times (Singh, 1989). In remote sensing it is useful in land use/land cover change analysis such as monitoring deforestation, desertification or vegetation change.

Geographic Information System (GIS) technology can be used for scientific investigations, resource management, and development planning. The power of GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship.

In this study recent NDVI data were used to compute, compare and analyse the change in the NDVI values throughout the study period (1993 - 2003), and to find the fluctuation pattern of vegetation degradation and/or recovery using change detection method and GIS.

1.1.1. Geographic Profile

The Sudan is the largest country in Sub-Saharan Africa—with a total area of 2,492,630 km² (250 million hectares), extending north to south for more than 2000 kilometers from about 3 to 22 degrees north latitude and 1800 kilometers west to east from 20 to 38 degrees east longitude. It is bounded on the east by the Red Sea (853 km) and by nine African countries: Eritrea (605 km) and Ethiopia (1,606 km) to the East, Kenya (232 km), Uganda (435 km), and the Republic of Congo (628 km) to the South, the Central African Republic (1,165 km) and Chad (1,360 km) to the West, and Libya (383 km) and Egypt (1,273 km) to the North (The total length of land boundaries is 7,687 km). The country is divided administratively into 26 States (Map 1.1).

The country is generally flat, with gentle slopes from south to the north, featureless plain reflecting proximity to the surface of the ancient and little-disturbed Basement rocks of the African continent. The Basement is overlain by the Nubian Sandstone formation in the center and northwest of the country, and by the Umm Ruwaba formation in the south. These formations hold groundwater, which have, or will have, agricultural significance. The elevations rise to over 3000m on Mt. Kinyeti (3,187 m)
near the Ugandan border and on Jebel Marrah, an extinct volcano near the frontier with Chad (Map 1.2).

1.1.2. The soil resources

The Sudan sits on the Basement rocks of the African continent. It is overlain by the Nubian Sandstone formation in the center and northwest and by the Umm Ruwaba formation in the south. The Basement rocks appear to the surface in the eastern part of the country forming the Red Sea Hills. Soils of the Sudan are products of these parent materials plus the alluvial deposits of its rivers and their tributaries. There are few major soil types in Sudan.

   a) The sandy (goz) soils west of the Nile

   b) The heavy clays of Eastern and Central states and Nuba Mountains.

   c) The red lateritic soils of the Southern states; and

   d) The soils of volcanic origin in jebel Marrah.

A part from these there is large areas covered with alluvial deposits such as the Gash delta lands along the Nile and those along the numerous seasonal watercourses (wadis) scattered throughout the country.

According to the Food and Agriculture Organization of the United Nations (FAO, 1995), as stated by Ayoub (1998) the soil resources of the Sudan can be divided into seven broad regions as follows. Soils of the hyperarid area (about 78 million ha*) of Xerosols comprising part of the Sahara Desert and superficial deposits of sand with bare rock debris shifting consolidated dunes. Recent alluvium provides a basis for productive agriculture in the narrow Nile valley north of Khartoum. Elsewhere soils are sandy with little agricultural potential.

* ha = hectares
Map (4.4) Location Map of Sudan

Map (1.2) Elevation Map of Sudan

Source: FAO Country Profiles and Mapping Information System
To the south of this region are the soils known locally as goz and gardud soils classified as Arenosols (about 28 million ha in area). Further to the south are 12 million ha of the more weathered Arenosols in the semi-arid areas of western and central Sudan. These soils are low in nutrients and organic matter and have a high sensitivity to erosion. The sands are free draining, with some clay or ferruginous clay as a bond near the surface, making them firm after the rains. Under high torrential rains their nutrients could be easily leached.

Vertisols (about 70 million ha) have considerable agricultural potential in the semi-arid zones of the Sudan. They form the central clay plains extending southwards to the eastern part of the flood plains. Special management practices are required to secure sustained production of these Vertisols. Their problems lie in the area of physical soil characteristics and water management, while their assets are their high chemical fertility and their location in extensive level plains where mechanical cultivation is possible. The irrigated Gezira/Managil, New Halfa and Rahad schemes and the extensive forms of rain-fed mechanized cropping are classical examples of low-input agriculture increasingly confronted with soil physical deterioration, among other things.

Ferrasols (about 30 million ha) are the soils of the dry sub-humid and the moist sub-humid zones embracing the tropical rain forest of the Sudan and the lush tall grasses. These soils have good physical properties but are chemically poor. Their low natural fertility and very low nutrient retention capacity are serious limitations. Their great depth, high permeability and stable microstructure make them less susceptible to erosion than many soils in the country, other than the Vertisols.

The rocky soils of the Red Sea Hills and parts of Jebel Marrah, classified as Latosols, constitute about 18 million ha. The Red Sea Hills soils are shallow and poor in nutrients and with high gravel contents. The soils of Jebel Marra are relatively rich volcanic soils.
Because of the limited soil depth and sloping terrain these soils are liable to water erosion.

Cambisols are the smallest soil group in the Sudan (about 2 million ha), but could be among the most productive soils in the country. These soils lie along the undulating Ethiopian Highlands under dry and moist sub-humid conditions, and thus are prone to water erosion.

1.1.3. Climatic Profile

1.1.3.1. Climatic Zones

Sudan is characterized by a wide range of climatic zones, which vary from desert in the northern part of Sudan, where rain is almost zero, through a southward belt of varying summer rainfall, to an almost equatorial type of rain in the extreme southwest, where the dry season is very short.

1.1.3.2. Temperature

The mean annual temperatures varies between 26°C and 32°C, except for the elevated points of the Imatonge in the extreme south of the country (Negishot 18.1°C), Jebel Marra in the west (Nierteti 22.6°C), and the Red Sea mountains (Erkowit 22.8°C). The hottest areas, based on mean annual temperatures of 32°C, lie within the northern parts of central Sudan, within the geographic triangle of Atbara, Kassala and Khartoum, decreasing in all directions outside of this triangle, particularly towards the northwest. (Map 1.3). The highest temperature on record is 49.1°C in June of 1978, at Dongola, and the lowest was -1°C in December of 1961 and January of 1962, at Zalingei (Jebel Marra). The hottest and coldest months vary according to latitude (INC, 2003).

1.1.3.3. Rainfall

Rainfall varies significantly from the northern to the southern parts of the country (Map 1.4). Annual rainfall in the northern half of Sudan varies from almost zero near the
border with Egypt, to about 200 millimeters around the capital Khartoum. The rainy season is limited to two or three months with the rest of the year remaining virtually dry. Moreover, the rain usually comes in isolated showers, which are highly variable in time and location, with a coefficient of variation ranging between 40 and 60%. The erratic nature of rain, and its concentration in such a short season, creates a vulnerable situation, especially for rain-fed agricultural areas.

In the southern half of the country, the annual rainfall rarely exceeds 700 mm. Rains in that quarter are concentrated in less than four months of the year with a coefficient of variation between 20 and 40%. In the southern most quarter, where the annual rainfall exceeds 700 mm, the area is dominated by swamps and inhabited by the tsetse fly, which is hazardous to human and animal life (INC, 2003).

The rainfall regime in the Sudan is characterized by large variations from year to year compounded by persistent long-term drought since the early 1970s. Since the mid 1960s this region has experienced a systematic decrease in rainfall and widespread droughts affecting the larger area of Sub-Saharan Africa (Tanaka et al., 1975; Bunting et al., 1976; Nicholson, 1979; Lamb, 1982).
Map (1.3): Annual Temperature

Source: FAO Country Profiles and Mapping Information System, 2005
Map (1.4) Annual Rainfall

1.1.4. Ecological Zones

According to variations in rainfall and soil Harrison and Jackson (1958), recognized five ecological zones as follows:

(i) Desert zone:

The average rainfall is less than 75 mm/annum. The vegetation is virtually nil except for comparatively few exceptional herbs and grasses (gizzue grazing) that germinate after rare rain showers and are localized along watercourses.

(ii) Semi-desert zone:

The average rainfall is 75 -300 mm/annum received during summer season, Red Sea coastal area is included in this zone, it differs in having winter rainfall. Vegetation is a varying mixture of grasses and herbs either with or without any woody vegetation, or with variable scatter of bushes.

(iii) Woodland Savannah:

The average rainfall is 300 -1500 mm/annum. Vegetation includes many-mixed type of grasses and bushes with or without trees according to the amount of rainfall and soil. This region has been sub-divided into low rainfall woodland Savannah that covers most of the central Sudan. In the drier parts, the trees are nearly all thorny and small, dominated by Acacia spp. In the wetter parts, broad-leaved deciduous trees become predominant. It is divided into low rainfall savannah on clay and low rainfall savannah on sand, in addition to separate special areas that includes:

Toposa: An area in east Equatorial in the southern part of Sudan, vegetation classified into six separate types of vegetation, sour perennial grasses, sweet perennial grasses, annual grasses unglazed, present wet season grass land area, Acacia mellifera (Kitir) thorn land.
**Hill catena's:** These have a characteristic vegetation of their own. Generally, much moisture in character than the surrounding plains.

**Baggara catena:** Consists of two frequent alternating types of soils namely *nagaa* (flat vertisols), run-off from it is collected into shallow pools (rahads) which are the feature of the area and *Atamur* which are stabilized sand dunes of variable vegetation.

**Ragaba catena:** This has three different types of vegetation. These are known locally as gardud, very similar to nagaa, which is typical to *Acacia seyal* (Talih), *Balanities* savannah, which consists of open grassland (perennial grasses). Run-off from the gardud besides flooding, the fall collects in water channels known as ragabas.

**(IV) Flood region:**

This zone has been divided into highland, intermediate land and swamp.

**(V) Montane vegetation zone:**

Classified together as montane vegetation, which was different from vegetation in the surrounding plains because of the effect of different altitude and sometimes of higher rainfall, the four main mountains are Imatong, Mt. Kinyeti in Equatorial, Red Sea hills and Jebel Marra.

**1.1.5. Land Use Types**

The diversity in soils and agro-climatic zonations, created different patterns in land use. Table (1.1) shows land use types in Sudan. Arable land constitutes about 14% of the total area of the country, however only 25% of this arable land is actually cultivated. Over 40% of the total area of Sudan consists of pastures and forests. The annual production of animal feed is estimated at 78 million tons of dry matter. Production is subject to fluctuations from one year to another, affected by varying quantities of rainfall and fire hazards. Forests and woodlands are used to meet the population’s demand for consumption of wood products, estimated at 16.8 million cubic meters in
1996. Forests are exposed to continuous removal and clearance either for agricultural expansion or for fuel wood consumption.

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Area</th>
<th>Percent Land use type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert land</td>
<td>86.29</td>
<td>34.39</td>
</tr>
<tr>
<td>Arable land</td>
<td>35.92</td>
<td>14.32</td>
</tr>
<tr>
<td>Grazing land</td>
<td>101.62</td>
<td>40.50</td>
</tr>
<tr>
<td>Forested land</td>
<td>24.34</td>
<td>9.70</td>
</tr>
<tr>
<td>Swamps and water surfaces</td>
<td>2.72</td>
<td>1.08</td>
</tr>
<tr>
<td>Urban areas</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>250.93</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Various, including World Bank website and Ejigu (2003).

### 1.1.6. Socio-Economic Aspects

Population of the Sudan has grown from 10.26 million in 1956 to 25.6 million in 1993. At present the country's population is estimated at 31.7 million (World Bank, 2003) and its annual growth rate has increased from 1.9% to 2.7%.

According to the fourth national census (1993), rural-to-urban migration has been steady and high, with urban population growth of 4% between 1983/1993. The urban population has grown from less than one million (854,000) in 1956 to 7.5 million in 1993. The rural population in 1993 constituted 71% of the total population, (11% nomads, 60% rural settlers), whereas the urban population was 29%. At present the urban population is estimated at 37% of the total population (World Bank, 2003). It is predicted that the urban population will double every 26 years. This trend of high rural-urban migration is due mainly to recurring droughts (which are increasing in frequency), major civil conflicts, budget cuts, and declining developmental investment in the rural areas.
The rapid population growth has direct consequences for the environment, growing demand for more land crop production, for fuel wood especially around the large cities, (Undrew and Mustfa, 1992).

According to the fourth national census (1993) population density per square kilometer is estimated to be 10.2 persons. This figure, however, proves to be a misleading indicator, when population distribution is considered. In Sudan, a great deal of land is desert, desert-like, or simply non-arable (Modawi et al. 1995). Measures of population density increase to 31.4 persons/km², and increases to 370 persons/km², when considering land presently cultivated. About 35% of the population resides adjacent to the Nile in Khartoum, Gezira, Sennar, Blue Nile and the White Nile States. This is mainly due to areas being uninhabitable, or becoming depopulated with the shrinking nomadic population in the drought prone north, and the harsh desert conditions from 12°N to 16°N. Overall, population density in relation to arable land is 63-person/ km², but the central region, adjacent to the Nile Valley, is most densely populated compared to traditional rainfed areas.

Agriculture is the backbone of the national economy with about 80% of the people engaged in crop and animal production. This makes millions of people in the country directly dependent on natural resources for their livelihood and employment. This heavy dependence of Sudanese economy on natural resources is reflected in the contribution of the agricultural sector to Sudan GDP, between 29 and 46% during the period 1985 to 1997 (Table 1.2) and over 46% in 2000 (Table 1.3).
Table (1.2): Gross Domestic Product of the Sudan and of Agriculture at Factor Cost at (1981/82) Prices for the Period 1985/ 1996-97 Million Ls

<table>
<thead>
<tr>
<th>Year</th>
<th>Sudan's GDP</th>
<th>Agricultural</th>
<th>Agricultural (% GDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985/86</td>
<td>6259</td>
<td>2384</td>
<td>38</td>
</tr>
<tr>
<td>1986/87</td>
<td>6526</td>
<td>2354</td>
<td>36</td>
</tr>
<tr>
<td>1987/88</td>
<td>6276</td>
<td>1927</td>
<td>31</td>
</tr>
<tr>
<td>1988/89</td>
<td>6228</td>
<td>2076</td>
<td>31</td>
</tr>
<tr>
<td>1989/90</td>
<td>6614</td>
<td>2003</td>
<td>30</td>
</tr>
<tr>
<td>1990/91</td>
<td>6691</td>
<td>1918</td>
<td>29</td>
</tr>
<tr>
<td>1991/92</td>
<td>7447</td>
<td>2552</td>
<td>34</td>
</tr>
<tr>
<td>1992/93</td>
<td>8389</td>
<td>3188</td>
<td>38</td>
</tr>
<tr>
<td>1993/94</td>
<td>8990</td>
<td>3605</td>
<td>40</td>
</tr>
<tr>
<td>1994/95</td>
<td>9757</td>
<td>4245</td>
<td>44</td>
</tr>
<tr>
<td>1996</td>
<td>10438</td>
<td>4697</td>
<td>45</td>
</tr>
<tr>
<td>1997</td>
<td>1113</td>
<td>5235</td>
<td>47</td>
</tr>
</tbody>
</table>

Source: Min. of Finance & National Economy.

Table 1.3: Contribution of Economic Sectors In Gross Domestic Product (GDP) 1998-2000

<table>
<thead>
<tr>
<th>Sectors</th>
<th>1998 % Share</th>
<th>1999 % Share</th>
<th>2000 % Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>48.7</td>
<td>49.8</td>
<td>46.4</td>
</tr>
<tr>
<td>Industry, Manufacturing and Mining</td>
<td>8.1</td>
<td>9.1</td>
<td>15.0</td>
</tr>
<tr>
<td>Electricity and Water</td>
<td>1.8</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Construction</td>
<td>5.1</td>
<td>4.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Governmental Services</td>
<td>6.5</td>
<td>6.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Other Services</td>
<td>29.8</td>
<td>28.2</td>
<td>26.4</td>
</tr>
<tr>
<td>G.D.P</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Bank of Sudan, Annual Report 2001
Livestock accounts for 47% of the agricultural GDP and 22% of the total GDP in 2000. Between 1991 and 1999, the livestock sector grew at an annual rate of 16% as faster growing non oil sector of the economy (W.B.2005).

The share of industry, manufacturing and mining is estimated at 15%, although the emergence of oil as Sudan’s primary export commodity is likely to change the situation in the years to come. The crude oil export increased by five fold between the years 1999 to 2001. In the past few years the GDP has rise substantially due to oil production helping the country to produce one of the fastest growing economy in the world (C.I.A, 2005).

1.2. Statement of the Problem

The first serious sign of soil degradation in the Sudan was reported by Kennedy-Cooke (1944). It was reported that rapid deterioration of soil and vegetation were occurring in parts of the Red Sea Hills, which was considered as a warning that such problems might be developing elsewhere, particularly around town peripheries and settlement areas in Kordofan and Darfur Provinces of western Sudan. During the 1980s and following the Sahelian drought, several reports described the impacts of desertification and its causes in Sudan (Lamprey, 1975; DECARP, 1976; Sudan Government, 1977; Eckholm, 1977; Baumer and Tahara, 1979; Hellden, 1988).

Several global or regional attempts of land degradation/desertification assessments have covered, among other countries, the Sudan (UNEP, 1977; FAO/UNEP, 1984; Warren and Agnow, 1988; UNEP/ISRIC (GLASOD), 1990; Dregne, 1991; UNDP, 1992 and 1997; UNSO, 1992). A study made by the National Drought and Desertification Control Unit (NDDU) in 1995, reported that an area of 1,259,743 Km² (50.1%) of the total geographical area of 2,492,360 Km², are subject to different degrees of degradation (the affected area includes 13 states)(Salih, 1996).

The vastness of the Sudan, and its poorly developed communications infrastructure, pose great difficulty for the collection of data for operational use by a ground based method. Therefore, remote sensing becomes the only feasible source of data that can
be used to map desertification on large areas. GIS provides a valuable tool for information analysis, automated mapping and to overlay several types of maps to determine useful data about desertification and land degradation. There is a clear need, for a system, which can provide timely, reliable and useful information desertification and environmental change.

1.3. Objectives of the study

The main objective of this study is to assess and mapping of vegetation degradation in Sudan using NDVI data as indicator for the period 1993 to 2003.

The specific objects are:

(1) To use Geographic Information System (GIS) and Remote Sensing (RS) techniques to map Vegetation degradation and to determine the spatial distribution, direction and intensity of change that have occurred on Vegetation areas over the study period Using change detection methods.

(2) Using a simple methodology, which can be copied or modified to determine, and measure the magnitude and the annual change in the geographic extent of degradation, to identify affected areas and compute change in vegetation cover.
Chapter Two

Literature Review

2.1. Desertification

2.1.1 Historical Perspective

Desertification became well known in the 1930s, when parts of the Great Plains in the United States was hit by dust storms "Dust Bowl" as a result of drought and poor practices in farming, although the term itself was not used until almost 1950. (Wordiq, 2004)

The French geographer Andre Aubreville first used the word desertification in 1949 to describe the change in North and Equatorial Africa from productive savanna forest, grasslands, and shrublands into unproductive desert (Aubreville, 1949).

2.1.2 Definition of Desertification.

More than one hundred definitions have been recorded, and opinions vary greatly on what the concept of the phenomenon should include (Stiles, 1995). A representative sample of definitions will be presented here in order to highlight the main points of controversy concerning the concept.

Dregne (1976), defined desertification as: “Desertification is the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alteration in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy”.

The 1977 United Nations Conference on Desertification (UNCOD) defined desertification as: The diminution or destruction of the biological potential of the land, which can lead ultimately to desert-like conditions. It is an aspect of the widespread deterioration of ecosystems that has diminished or destroyed the biological potential, i.e, plant and animal production, for multiple use purposes at a time when increased productivity is needed to support growing populations in quest of development (UNCOD,1977).
FAO/UNEP (1983) offered revised definition of desertification in the context of their efforts to develop a methodology for assessing and mapping desertification: Desertification is defined as “a comprehensive expression of economic and social processes as well as those natural or induced ones, which destroy the equilibrium of soil, vegetation, air and water, in the areas subject to edaphic and/or climatic aridity. Continued deterioration leads to a decrease in, or destruction of, the biological potential of the land, deterioration of living conditions and an increase of desert landscapes”.

Nelson (1988) offered another definition, “Desertification is a process of sustained land (soil and vegetation) degradation in arid, semi-arid and dry sub-humid areas, caused at least partly by man. It reduces productive potential to an extent, which can neither readily be reversed by removing the cause nor easily reclaimed without substantial investment.”

At the 1992 United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, climatic variations were added to human impact as contributing causes in the definition. All participating governments approved Agenda 21, which defines desertification as: “Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.”

Food and Agriculture Organization of the United Nation (FAO) 1993 added biodiversity to its definition: “Desertification is the sum of geological, climatic, biological and human factors which lead to the degradation of the physical, chemical and biological potential of lands in arid and semi-arid areas, and endanger biodiversity and survival of human communities” (FAO,1993).

In 1994 the Inter-governmental Negotiating Committee (INCD) for the elaboration of the United Nations Convention to Combat Desertification, after reviewing all definitions, adopted the definition approved by the UNCED and quoted in Article 1 of UNCCD.
2.1.3 Desertification Extent

Desertification is a direct threat to over 250 million people around the world, and an indirect threat to a further 750 million people. In the last 25 years, desertification has become increasingly apparent in the dry sub-humid regions of the world, where mean annual rainfall ranges from 750 to 1,500 mm, and where the majority of the human inhabitants of the dry lands now live (Martin and Robert, 1995). Current best estimates suggest that roughly 70 per cent of all agriculturally used drylands are to some degree degraded, especially in terms of their soils and plant cover. The total area concerned is 3.5 billion hectares, and over a hundred countries are now suffering from the adverse social and economic impact of dryland degradation (UNEP, 1992 and 1997).

In Africa, arid, semi-arid, and dry sub-humid areas cover 13 million km², or 43% of the continent's land area-on which 270 million people, or 40% of the continent's population, live. Desertification in Africa has reduced the potential vegetative productivity of more than 7 million km² by 25%, or one-quarter of the continent's land area (UNEP, 1997). Areas particularly at risk include the 3.5 Million km² band of semi-arid lands stretching along the southern margin of the Sahara Desert and some nations that consist entirely of drylands, e.g. Botswana and Eritrea. The death of as many as 250,000 people in the Sahel drought of 1968-1973 (UNCOD, 1977) demonstrated the tragic results of desertification.

2.1.4 Causes of Desertification

The causes of desertification remain controversial (Hellden, 1991; Thomas, 1997; Lambin, 2001). There is a great deal of debate, not only on whether the causes of desertification lie in the socio-economic or biophysical sphere (human-induced land degradation versus climate-driven forces) but also on the degree to which causes are local or remote (Pickup, 1998; Lambin, 2001; Reynold and Staford, 2002).

Desertification has been attributed to multiple causative factors, which are:

2.1.4.1 Non-climatic Driving Forces
Unsustainable agricultural practices, overgrazing, and deforestation constitute the major anthropogenic (originated by man) factors among the forces that drive desertification. Unsustainable agricultural practices include short rotation of export crops, cultivation of marginal lands, undisciplined use of fire, and removal of protective crop residues. Overgrazing consists of running livestock at higher densities or shorter rotations than an ecosystem can support sustainably. By pounding the soil with their hooves, livestock compact the substrate, increase the proportion of fine material, and reduce the percolation rate of the soil, thus encouraging erosion by wind and water. Deforestation consists of permanent clearing of forests and cutting of trees outside forests. Forest area in Africa decreased by approximately 37,000 km² per year from 1990 to 1995 (FAO, 1999). UNDP (1997) attributes two-thirds of the area already desertified in Africa to overgrazing and the remaining third to unsustainable agricultural and forestry practices. Desertification often arises from the demands of increased populations that settle on the marginal lands in order to grow crops and graze animals. In these marginal areas human activity may stress the ecosystem beyond its tolerance limit, resulting in degradation of the land. Increased population and livestock pressure on marginal lands has accelerated land degradation and this in the final analysis has led to desertification. In some areas, nomads moving to less arid areas disrupt the local ecosystem and increase the rate of erosion of the land.

2.1.4.2 Climatic Driving Forces
Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Extended droughts in certain arid lands have initiated or exacerbated desertification. In the past 25 years, the Sahel has experienced the most substantial and sustained decline in
rainfall recorded anywhere in the world within the period of instrumental measurements (Hulme and Kelly, 1997).

Because evapotranspiration constitutes the only local input to the hydrological cycle in areas without surface water, reduction in vegetative cover may lead to reduced precipitation. Degradation of vegetation cover in moister areas south of the Sahel may have decreased continental evapotranspiration and reduced precipitation in the Sahel (Xue, 1997).

Carbon dioxide (CO₂) induced climate change might exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar insulation, and winds. Conversely, desertification aggravates CO₂-induced climate change through the release of CO₂ from cleared and dead vegetation and through the reduction of the carbon sequestration potential of desertified land. Areas that experience reduced rainfall and increased temperature as a result of CO₂-induced climate change also could experience declines in agricultural yields, livestock yields and tree cover, placing local people at risk of famine (IPCC, 2001).

Lower soil moisture and sparser vegetative cover also would leave soil more susceptible to wind erosion. Reduction of organic matter inputs and increased oxidation of soil organic matter (SOM) could reduce the long-term water-retention capacity of soil, exacerbating desertification. Moreover, increased wind erosion increases wind-blown mineral dust, which may increase absorption of radiation in the atmosphere (Nicholson, et al. 1998).

### 2.1.5 Impacts of Desertification

Desertification reduces vegetative productivity, leading to long-term declines in agricultural yields, livestock yields, plant standing biomass and plant biodiversity. These changes reduce the ability of the land to support people, often sparking an exodus of rural people to urban areas. Breaking the strong connection of people to the land
produces profound changes in social structure, cultural identity and political stability (Stiles, 1995).

Not only do local people lose the vital ecosystem services that dead trees and shrubs had provided; the loss of firewood, traditional medicine species, and emergency food species render them more vulnerable to future environmental change (MEA, 2004). Desertification reduces soil fertility, particularly base cations content, organic matter content, pore space, and water-retention capacity and accelerates soil erosion by wind and water. It increases salinization of soils and near-surface groundwater supplies, a reduction in soil moisture retention, an increase in surface runoff and stream flow variability, a reduction in species diversity and plant biomass, and a reduction in the overall productivity in dry land ecosystems with an attendant impoverishment of the human communities dependent on these ecosystems. Additional impacts include an increase in particulate and trace gas emissions from biomass burning in drylands and an increase in atmospheric dust loads. A combination of climatic stress and dryland degradation can lead in turn to extreme social disruption, migrations and famine (Martin and Robert, 1995).

On average, dryland populations have higher infant mortality rates than other regions. Child mortality in the Sahel region of Africa was found to be higher and general access to health care was found to be limited. Dryland populations are often socially and politically marginalized due to their impoverishment and remoteness from centers of decision-making (MEA, 2004).

### 2.2. Drought and Desertification in the Sudan

The principal environmental challenge in the Sudan is desertification. This problem is related to issues of low land productivity, food and fuel wood shortages, deforestation, range deterioration, major civil conflicts, high rural-urban migration and threats to biodiversity.
2.2.1 Desertification Extent in Sudan

Desertification processes is occurring in drylands all over the world. Estimates for total dryland area affected by desertification vary significantly, depending on the calculation method and on the types of land degradation included in the estimate (MEA, 2004).

The vastness of the Sudan, create difficulties for the collection of data use by a ground-based method. Remote sensing becomes the most reliable source of data that can be used as a decision tool for timely action to avert the negative consequences of drought.

Different methodologies were used for assessment of desertification in the Sudan. These assessments have helped understand the extent, nature and severity of land degradation in the country to some extent. There are large variations in these estimates due to the methodologies used. The details of some of these assessments are explained in brief in the following paragraphs.

The first serious sign of soil degradation in the Sudan was reported by Kennedy-Cooke (1944). It was reported that rapid deterioration of soil and vegetation were occurring in parts of the Red Sea Hills, which was considered as a warning that such problems might be developing elsewhere, particularly around town peripheries and settlement areas in Kordofan and Darfur Provinces of western Sudan (Ayoub, 1998).

Following the 1964-84 sahelian drought several reports described the impacts of desertification and its causes in Sudan for example, Lamprey in 1975 described the desertification in Kordofan region as follows: "It is evident that the desert southern boundary has shifted south by an average of about 90-100 km in the last 17 years...in several areas, particularly in northern Kordofan in Hamrat El Wiz and Kheiran areas, sand encroachment has moved rapidly ahead of the southern boundary of the desert and loose sand is accumulating over the formerly consolidated sandy (and locally clay) soils...Shallow sand encroachment appears to have killed nearly all vegetation except the trees Acacia tortilis and Balanites aegyptica and a small number of dune adapted
shrubs as far south as 15° N in Hamrat El Wiz area. Immediately south of this area mobile dunes are moving southwards with the prevailing wind and are becoming an increasingly serious threat to the agricultural land and several villages in the Bashiri and Bara areas of the Kheiran region. The sand dunes are being augmented by the very large area of drifting sand further north near Hamrat El Wiz.

The Ministry of Agriculture in its plan to combat desertification in Sudan reported: for the purpose of this plan, affected areas in Sudan have been divided into five treatment zones. The total areas to be treated in the five zones are estimated to be 525,000 Km² (DECARP, 1976). Desert Encroachment Control and Rehabilitation Program (DECARP), 1976 stated that: "Surveys have shown that the desert had advanced 90-100 km within a 17 years period and is currently advancing at the rate of 5 to 6 km per year" (lamprey,1975).

In a country report presented by the Government of Sudan to the United Nations Conference on Desertification, Nairobi 1977 stated “Food production has declined and continues to decline because of soil deterioration associated with desert encroachment and loss of land especially land buried by sand" (Sudan Government, 1977).

Eckholm , (1977) stated “The spread of the Sahara has probably been measured most recently in Sudan, as elsewhere; vegetation zones are shifting southward as a result of overgrazing, woodcutting and accelerated soil erosion. Steppe loses ground to the desert; it creeps into the neighboring savanna, which in turn, creeps into the forest”. Baumer and Tahara (1979), referring to Lamprey, stated that the desert is continuing to move southwards at a rate of 5-6 km per year. It was also stated that desertification is spreading like cancer in other areas including the adjacent low rainfall savanna and that it is quite clear that desert encroachment in the Sudan is mainly a man made phenomenon caused by the misuse of land. Cultivation in marginal areas was assumed to be one of the main causes of desertification.
In a study carried out within the project "Regional Studies of Desertification and its Control" initiated during 1981 in co-operation with the University of Khartoum, Sudan and completed in 1985, Hellden, reported that: It seems, however, that the desert boundary described in the vegetation map of Harrison and Jackson (1958) was defined to follow the 75 mm isohyet, located 90-100 km north of the 100 mm isohyet, rather than actually mapped (Baumer and Tahara, 1979). It might explain why Lamprey found the 1958 desert boundary to be located 90-100 km north of the boundary defined by him in 1975. There does not seem to be any evidence for the Lamprey conclusion that the Sahara desert had advanced 90-100 km in the area during the period 1958-1975. The vast Sahara dune complex encroachment mapped by Lamprey could not be found (Hellden, 1988).

In the late 1970s to the early 1990s, several global or regional attempts of land degradation/desertification assessments have covered, among other countries, the Sudan (UNEP, 1977; FAO/UNEP, 1984; UNEP/ISRIC (GLASOD), 1990; Dregne, 1991). As shown in Table (2.1), it can be concluded that: The land surface of the Sudan (excluding the hyperarid zone), of the agricultural land, pasture, and forest and woodland (170 million ha in total), nearly 75 million ha (45%) have been degraded severely to very severely by human factors in recent history. The highest estimate was that of Dregne (1991), while the estimates of UNCOD (1977) and FAO/UNEP (1984) were similar. GLASOD soil degradation assessment shows that severe and very severe degradations totaled 65 million ha. The difference between GLASOD and other assessments could be vegetation degradation without significant soil degradation (Ayoub, 1998).

Table (2.1): Various assessments of soil degradation in Sudan (million ha)

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Moderate</th>
<th>Severe</th>
<th>V. Severe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNCOD in 1977</td>
<td>45</td>
<td>47</td>
<td>28</td>
<td>120</td>
</tr>
</tbody>
</table>
Shakhatra (1987), stated “out of 2,505,200 Km² the total area of Sudan, 725,200 Km² about 28.94% are desertified areas and 650,000 Km² about 25.94% are vulnerable to desertification.

The study carried out by the NDDU in 1995 reported that 1,259,743 Km² (50.1%) of the total geographical area of the Sudan (2,492,360 Km²), are subject to different degrees of degradation (the affected area includes 13 states as reported by Salih, 1996). The study used available information and applied the GIS to classify the state of desertification in the affected areas. These areas include the following 13 states: Red Sea, North Darfur, River Nile, Northern, Kassala, Khartoum, North Kordofan, Al Gedarif, West Darfur, Gezira, White Nile, West Kordofan, and Sennar. The extent and types of land degradation are given in Table (2.2) and (Map 2.1).
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Moderate</td>
<td>82822</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>Slight</td>
<td>96038</td>
<td>3.9</td>
</tr>
<tr>
<td>6</td>
<td>Very Slight</td>
<td>305243</td>
<td>1202</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1259743</td>
<td>50.1</td>
</tr>
</tbody>
</table>

Source: NDDU Files (1997)

The Arab Organization for Agricultural Development (AOAD, 1996) estimated the desertified areas in Sudan to be about 725,200 Km\(^2\) representing 28.294% of the total area, and the area at risk to desertification to be 650,000 Km\(^2\) about 25.9 of the total area.

Ayoub, (1998), reported that: About 64 million ha of soils are degraded in the Sudan, 88% of them highly to very highly 81% of the total degraded areas are in the susceptible drylands (arid, semi-arid and dry sub-humid). Most degradation (74% of total degraded soils) are in the arid and semi-arid zones, but significant percentages of land are also degraded in the dry sub-humid and moist sub-humid zones. As percent of total area per aridity zone, the dry sub-humid and moist sub-humid zones have figures higher than the semi-arid and hyperarid zones, 28% and 29%, respectively.
Map (2.1): Areas between $10^0-18^0$ North at Risk to Drought and Desertification

Source: NDDU 1995
2.2.2 Desertification Causes in Sudan.

Human activities are characterized by severe and continuous land degradation. This is due to the continuous deterioration of the physical, chemical and biological properties of the land, decline in agricultural productivity arising from population growth, horizontal expansion of agriculture, cultivation of marginal lands, overgrazing and heavy fuel wood consumption (firewood and charcoal constitutes approximately 87.6% of Sudan wood harvest). Severe wind erosion and water erosion are the key forms of land degradation (Ejigu, 2003).

The population of Sudan is estimated at 31.7 million (World Bank.2003) growing at 2.7% per annum. About 70% of this population resides in rural areas. According to the fourth national census (1993) population density per square kilometer is estimated to be 10.2 persons. This figure, however, proves to be a misleading indicator, when population distribution is considered. In Sudan, a great deal of land is desert, or simply non-arable. Population growth in Sudan has direct consequences on the environment through the growing demands for fuel wood, and for more land to produce more food which means shortening of the fallow or resting period in the rain-fed agriculture. Recurrent drought has also forced people to migrate into relatively fertile areas carrying with them the very forest clearing and slash and burn agricultural practices that caused the recurrent drought.

According to the Strategic Studies Center, Report of 2002, Ninety four percent of Sudan’s population is below the poverty line Many of the poor are in the rural areas, and live in marginal lands and drought prone areas. They have limited access to modern agricultural inputs and also to alternative fuel wood sources of energy.

Agriculture is the mainstay of the national economy with about 80% of the people engaged in crop and animal production. This makes millions of people in the country directly dependent on natural resources for their livelihood and employment.
The Sudan Country Study on Biodiversity (2002) stated that the government of Sudan has promoted mechanized rain-fed agriculture since the 1960s, as part of its policy to encourage agricultural investment. The 1976 and 1980 Acts are considered to be instrumental for the expansion of rain-fed mechanized agriculture. Nevertheless, this unregulated expansion has played havoc to the country’s environmental resources resulting in extensive removal of trees, land degradation and destruction of habitats.

The expansion in mechanized rain fed agriculture has resulted in extensive clearance of forests and bushes for cultivation purposes, conversion of pasture into farms, and forced traditional farmers and pastoralists to overuse the land left to them for cultivation and grazing. Traditional agriculture that engages segments of the population has limited access to modern agricultural inputs that left farmers to rely on extensive farming practices as the only coping mechanism.

Rangelands cleared for mechanized rain-fed agriculture and shifting cultivation increased from about 2.0 million ha in 1954 to about 14 million ha in 1994, a rate of 300,000 hectares per year. Range fire, deliberately set by herders to improve grazing, consume annually about 35% of the natural range productivity, estimated to be about 300 million tones (Ayoub, 1998).

Mono-cropping farming system, years of extensive cultivation practices by the mechanized and traditional rain-fed sectors, with limited access to fertilizers and improved farming techniques compounded by wind and water erosion have left most soils of Sudan nutrient depleted (Ejigu, 2003).

Torbjorn Tvedt, (1983) stated that, in the twenty-five years after 1917, the numbers of cattle, goats, sheep, and camels in Sudan increased from 3.5 million to about 13 million; in the last decade of British rule, the growth rate more than doubled to a total of approximately 21 million heads (Torbjorn, 1983). In 2001 Sudan’s livestock population stands at 124 million.
The Range and Pasture Administration estimates that the minimum area of rangelands required for sustaining the national livestock herd at about 190 million ha while at present only 116 million ha of natural rangelands are available. The difference represents overgrazing.

Livestock is an important sector that provides a source of livelihood for a large segment of the population. It is also an important foreign exchange earner. But at the same time a threat to the environment. Overgrazing is now one of the primary causes of land degradation in Sudan. Pastoralists are concentrated in two regions: Kordofan and Darfur. Mainly camel and cattle owners, the pastoralists in these two areas account for 80-90% of the total number of cattle and 100% of the camel (NBSAP, 2002).

Overgrazing is the most widespread cause of soil degradation, particularly around permanent settlements and watering centers, affecting about 30 million ha (47%) of the total degraded areas. Clearance of forests and woodlands cover for fuel wood and charcoal making and overexploitation of vegetation is the second cause of soil degradation affecting 22 million ha. Cropping without appropriate nutrient inputs have degraded about 12M ha, particularly in small-scale farming on sandy and loamy soils (Ayoub, 1998).

The tree cover of Sudan was estimated to cover about 36-43% of the total land area in 1956 (Harrison and Jackson, 1958). In 1995, the tree cover has declined to 19% (FAO estimate). The World Atlas 2000, estimate that forests cover 18% of total land area, and the average annual deforestation between 1990-1995 by 0.8%. The 2000 survey undertaken by National Forest Corporation (FNC) in collaboration with the FAO placed the forest cover at 17%. But according to the FNC, if shrubs are taken into account the forest cover reaches 27%. This fast decline in the forest areas is due to a combination of factors such as, horizontal expansion of agriculture, overgrazing, population increase and heavy reliance on forest biomass as a source of energy.
The NBSAP, (2003) reports that there are about 533 tree species in the Sudan, 25 of which are exotic and 184 shrub species, 33 of that are exotic. Trees are used for timber, fuel wood, building material, fodder, honey production, gum, tannins and medicine production. It also indicated that the tree cover have shrunk due to the horizontal expansion in mechanized agriculture, overgrazing, war and civil strife, and recurrent drought.

Of Sudan’s total energy, 88% originates from fuel wood (83% wood and 5% residues). Within the household sector, which accounts for 69% of all energy consumption in 2000, the share of biomass reaches 98% (Ejigu, 2003).

Forest fuel wood provides a total of 4.11 million tons of oil equivalent. Wood is consumed in the form of fuel wood and charcoal. Vast areas of natural forest are harvested each year to provide the needed supply. Demand for fuel wood has been increasing over the past years mainly due to the increase in population, particularly in the rural areas where biomass forms the only source of domestic energy. Deforestation leads to, soil erosion, flooding (change in hydrological cycle) and sedimentation; global warming; habitat loss and reduction in biodiversity.

Climatic variations manifests itself in the form of severe droughts and occasional floods, and Sudan faces both problems. For over three decades, recurrent droughts, with occasional severe droughts, had become normal phenomenon in Sudan. In particular, the severe droughts of the early mid 1970s and ten years later of the early mid 1980s, have destabilized the population, broken down family and tribal structures, traditional practices of resource management and forced people to migrate. There were also series of localized droughts often every two years, but mainly in western Sudan in Kordofan and Darfur regions and parts of central Sudan (Ejigu, 2003).

Drought is one of the most important natural phenomena that Sudan faces Richards (1994) stated: “The climate and environment in the Sudan have shown localized changes during the course of this century, and recurrent droughts in the last 30 years.
In 1984/5, Sudan experienced a particularly severe drought and famine, resulting in widespread deaths. Despite this, there is little available information with which to monitor drought and environmental changes.


A key example of localized drought is that which affected western Sudan (Geneina and Nyala towns) in 1996. This region reported below normal rainfall while central and eastern Sudan was above normal. The most vulnerable are the farmers in the traditional rainfed sector of western, central and eastern Sudan, where severity of drought depends on the variability of rainfall both in amount, distribution and frequency. The most heavily affected are the northern Kordofan and Darfur states.

Drought threatens crop production of about 12 million hectare of rainfed-mechanized farming and 6.6 million hectare of traditional rainfed lands. It also affected the pastoral and nomadic groups in the semi-arid areas of Sudan. The rain-fed traditional and mechanized farms of western, central and eastern Sudan are most affected by drought. Wind erosion is, the most widespread soil degradation type in the arid zone, while water erosion is dominant in the semi-arid zone. Chemical deterioration through nutrient loss is affecting all climatic zones. The central clay plains and the ironstone soils of southwest were the least degraded soil types (Ayoub, 1998).
2.3. NDVI and Related Remote Sensing

2.3.1. Introduction

Remote sensing is a technique aiming at acquiring information from space. The definition of remote sensing given by the Ministerial Commission for Terminology of Aerospace Remote Sensing is as follows: “a set of knowledge and techniques used to determine the physical and biological characteristics of objects or targets through measurements performed from remote locations, without any contact with those objects or targets” (NCGIA, 1990). Sensors onboard satellites record the radiometric properties of objects observed on the Earth surface in forms of digital images. This technique has the advantage of supplying information over a long period of time and intervals depending on the satellite itself.

The applications of satellite imagery increases all the time. Remote sensing is a cost-effective compared to traditional data collection from field survey or aerial photography particularly for studying large areas. Remote sensing has been applied to identify changes both in natural and man-made features in the fields of forestry, agriculture, land use, mining, marine monitoring and urban studies. Environmental inventory and monitoring are the most useful applications of remote sensing.

Environmental applications of satellite imagery have greatly exceeded early expectations. Satellite monitoring is being used throughout the world and in near real-time. The use of remotely sensed data for crop and drought monitoring has become wide spread since the mid 1980s. This has been due mainly to the efforts of the FAO and its ARTEMIS program (African Real-Time Environmental Monitoring and Information System), as well as the work carried out by USAID/FEWS (Bonifacio and Grime, 1998).

Today the application of remotely sensed data in vegetation studies is widely operational. Applications as sophisticated as highly accurate yield estimates and crop disease and water stress detection at sub-pixel level have been operational in northern
America and Europe (Cracknell, 1997; Rasmussen, 1998; Tucker and Nicholson, 1999; Logica, 1999), while its application for drought monitoring is operational worldwide (Kogan, 1997). The increasing use of satellite remote sensing for civilian use has proved to be the most cost effective means of mapping and monitoring environmental changes in terms of vegetation, rainfall and non-renewable resources (Richards, 1994).

2.3.2. How Satellites work

2.3.2.1 The Electromagnetic Spectrum:

The electromagnetic spectrum Figure (2.1), comprises a number of spectral bands (atmospheric “windows” of wavelength ranges) ranging from gamma rays and x-rays with the shortest wavelength through to radio waves with the longest wavelength that allow multispectral detection of reflected light and emitted thermal energy from earth.

\[\mu m : \text{micrometer} = 1 \times 10^{-6} \text{ Meter}\]

Figure 2.1: The electromagnetic spectrum

Adapted from Logica, 1999
2.3.2.2 Interaction with the atmosphere

Different gases absorb solar radiation at different wavelengths. For instance, the visible radiation from the sun passes through the whole atmosphere to the surface with little attenuation, but the ultra-violet radiation is strongly absorbed by a thin layer of ozone at a height of 20-25km. The absorption of the atmosphere as a function of wavelength is shown in Figure (2.2).

![Atmospheric Window](image)

Figure 2.2: The absorption of solar radiation by the atmosphere
Adapted from Logica, 1999

The spectral reflectance expresses the percentage of the solar radiation reflected by the earth compared to incident energy. In Figure (2.2), 100% means atmosphere totally opaque, 0% means atmosphere totally transparent. Those parts of the spectrum in which the atmosphere is transparent (atmospheric window) are used to observe the characteristics of the Earth's surface by remote sensing.

In addition to being absorbed, radiation is also scattered by the atmosphere. Scattering occurs when radiation is deflected by interaction with molecules or particles. In the earth's atmosphere, scattering of radiation is more likely at short wavelengths (less than 0.5 µm). For instance, the shorter blue wavelengths (0.4 µm) in the visible range are scattered by the atmosphere more than red wavelengths (0.7 µm), resulting in the
appearance of blue sky (Souffet et al., 1991). Important scatterers in the atmosphere are water vapour and dust particles. Scattering by the atmosphere acts to reduce the intensity of radiation, which will be received by the satellite sensors.

### 2.3.2.3 Satellite sensors

All satellites are equipped by a sensor or radiometer. The radiometer produces an image that looks like a photograph but is actually in digital format made up of a series of rows and columns. The intersection of rows and column forms a series of regular cells called pixels. When a sensor acquires satellite imagery, every elementary surface observed at ground emits electromagnetic radiation converted to pixel in the final image, whose radiance in one or several spectral bands is represented by a numerical value (“digital number”: DN) ranging from 0 to 255 or 8 bits.

The radiometer measures the intensity of the energy reflected by the earth's surface and the atmosphere in a selected wavelength band, or channel. Radiometers are usually equipped by several bands, the area viewed instantaneously by the sensor on the earth surface called the footprint, Figure (2.3). The total radiation from the footprint is assigned to a pixel (or picture element) centered in the middle of the footprint. It is an average of the characteristics within the footprint where some of the details are lost. The size of the pixel is known as the spatial resolution. As the pixel size gets smaller, the resolution gets higher (NCGIA, 1990).

![Figure 2.3: The footprint and pixel](image)

Adapted from (UCAR, 2003)
The resolution depends on the field of view, the altitude and the viewing angle of the radiometer. Usually, the radiometers use a narrow instantaneous field of view (IFV) to obtain high-resolution imagery. In order to build up an image of a sizeable area of the Earth, a scanning system must be employed to physically change the direction in which the radiometer is pointing. The radiometer scans across along track, and the corresponding pixel is assigned a value. A complete image is built up by the radiometer when all the pixels in the image have been assigned values. Scanning systems vary according to the satellite.

**2.3.3 Satellite Coverage and Orbits:**

There are literally an infinite number of possible orbits for earth observation by remote sensing satellites. While there are special orbits that are designed for specific purposes, two main orbits are mostly used for earth observations: geostationary and sun-synchronous near-polar orbits. In spite of the qualifiers, the sun-synchronous orbits are normally referred to as polar orbits.

**2.3.3.1. Geostationary satellites (GOES)**

Geostationary satellites rotate with the earth in a west-to-east direction over the equator at an altitude of 35,800 km (22,300 miles). Since the satellite rotates at the same speed and in the same direction as the earth, it always has the same view of the earth’s surface. These satellites are in a higher orbit than polar orbiting satellites (POES); therefore each image covers a much greater area. While GOES records less detail than POES, it captures many images (at least 48) of the same locations every day. The scanning system allows about 42% of the Earth's surface to be viewed from a single satellite, so a network of five satellites gives the global coverage. The geostationary satellite can monitor developments in the field of view continuously and in almost real-time.
The geostationary satellites were first launched during the 1970's. Each satellite has a lifetime of approximately 5 years. Satellites have been launched and maintained by NOAA (GOES E+W), and the European space agency (METEOSAT), Japan (GMS), India (INDSAT), Russia (Elektro) and China (FY-2). The coverage available with the current satellites in orbits as shown in Figure 2.5.
2.3.3.2 Polar Orbiting Satellites (POES)

Polar orbiting satellites differ from geostationary satellites in several important ways. Instead of orbiting around the equator, the orbit is in an almost north-south direction, and crosses close to both poles Figure (2.6). Polar orbiting satellites orbit at a much lower altitude than geostationary satellites (between 800 and 1000 km) so they travel much faster completing about fourteen orbits per day. With each orbit, the satellite covers an area that is west of the previous pass. Because these satellites are in a low orbit and look directly down, the images recorded show great details (Kidwell, 1991).

Figure 2.6: The Polar orbit

Adapted from (UCAR, 2003)

Source: http://www.rap.ucar.edu/~djohnson/satellite/coverage.html#global_coverage

Most polar orbiting satellites lie in a sun-synchronous orbit. The plane of the satellite's orbit is fixed relative to a line from the center of the Earth to the Sun. The Earth rotates within the orbit as shown in Figure (2.6). The satellite moves from south to north on the sunlit side of the Earth (ascending pass) Figure (2.7), and from north to south on
the darker side (descending pass) Figure (2.7). On every ascending pass the satellite passes over an area slightly westward of the previous ascending pass, because the Earth has rotated. The ground track (area directly below the satellite) of polar orbiting satellite produced in a day is shown in Figure (2.8). The satellites pass over the same region on the Earth's surface twice a day, at 12-hour intervals. The time the satellite crosses a region is called the pass time. Usually the satellite is defined by its pass time at the equator.

Figure (2.7): Ascending pass and Descending pass

Adapted from (UCAR, 2003)

Figure 2.8: The Polar orbiting satellite ground track

Adapted from (UCAR, 2003)
2.3.4. National Oceanic and Atmospheric Administration (NOAA) satellites

The first NOAA polar-orbiting satellite in the current series was TIROS-N launched in 1978. Several satellites have been launched since then, with lifetimes of up to seven years. Today there are two in operation, NOAA-15 and NOAA-16. Their orbits are arranged so that every point on the Earth's surface is surveyed every 6 hours (Hutchinson, 1991).

Each satellite is equipped with the Advanced Very High Resolution Radiometer (AVHRR). The nominal altitude of the spacecraft is about 850 km (528 miles). All spectral channels of the AVHRR scanner are geometrically registered so that they simultaneously measure reflected sunlight and emitted energy (heat) from the surface as the satellite orbits the Earth (Kelly and Hood, 1991). It has an angle of view of 1.4 milliradians and therefore has an instantaneous field of view at the sub-point of 1.1km Figure (2.9), called the 'footprint' of the satellite. The radiation received from a footprint is averaged to give a single pixel value. The instrument scans across the ground track below, viewing some 1500 km on each side. This region swept out is called the swath Figure (2.10). At the edge of the swath the footprint covers a much larger region on the surface (about 5 Km) so the radiation from a larger area is condensed into a single pixel. This means that a greater amount of detail is lost, so generally the 200 pixels at the edge (about 3,000 Km wide imaging swath) are ignored in the quantitative work.
The NOAA polar orbiting satellites constantly transmit full resolution data, which can be received at any point within the field of view of the satellite. A worldwide network for data ground receiving stations receives the real-time data for the surrounding areas. This is called Local Area Coverage (LAC)(Anyamba and Tucher, 2005). In Africa, receiving stations can be found in Niamey, Harare, and several other places. The AVHRR is able to store on board 10 minutes of full resolution (1.1km) data. This can be downloaded to the user during the orbit or the subsequent orbit only. NOAA uses this capability to obtain selected scenes of strategic areas where there are no ground receiving stations.
The AVHRR is also able to store on board re-sampled data from the whole preceding orbit, which can be downloaded at any point. This is known as Global Area Coverage (GAC). To reduce the amount of disk space necessary on board the satellite, GAC data is re-sampled to a coarser resolution of approximately 7.6km.

The instrument measures reflected sunlight and emitted radiation (heat) from Earth in the visible (Channel 1), near-infrared (Channel 2), and thermal infrared (Channels 3, 4, and 5) regions of the electromagnetic spectrum Table (2.3).

Table (2.3): The AVHRR spectral bands

<table>
<thead>
<tr>
<th>AVHRR Bands</th>
<th>WAVELENGTHS (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.58-0.68</td>
</tr>
<tr>
<td>2</td>
<td>0.725-1.10</td>
</tr>
<tr>
<td>3</td>
<td>3.55-3.93</td>
</tr>
<tr>
<td>4</td>
<td>10.3-11.3</td>
</tr>
<tr>
<td>5</td>
<td>11.5-12.5</td>
</tr>
</tbody>
</table>

Source: http://earthobservatory.nasa.gov/Library/MeasuringVegetation/

2.3.6. NOAA Data Pre-processing Methods

NASA does most of the data preprocessing techniques such as Radiometric calibration, Atmospheric correction, Geometric registration Computation, and NDVI Synthesis. NASA developed correction procedures to correct AVHRR images. The following is a discussion of the methods and parameters that have been applied to NOAA/AVHRR data, (NASA, 2004).
2.3.6.1. Atmospheric Correction

Sun radiation is scattered in all directions by particles in the atmosphere. Scattering tends to increase the amount of red radiation received by the satellite as red is more readily scattered in the atmosphere than near infrared. The impact of atmospheric effects on the AVHRR channel 1 and 2 data and NDVI can be significant. Four principle atmospheric factors, water vapor, aerosols, ozone, and Raleigh scattering, are considered to have the most impact (Teillet, 1990).

This has the effect of reducing NDVI values. For short periods, this problem is minimized by taking the maximum value composite because each pixel's maximum value is likely to have occurred when scattering was at a minimum (Mas, 1996). However, in extreme cases of long-term, large-scale aerosol events, the correction procedure, which was developed by NASA, is not of high quality (Jensen, 1996).

2.3.6.2. Radiometric Correction

Radiometric error is another type of error in satellite imagery. It is difficult to maintain radiometric consistency between images obtained on different dates. Radiometric errors are caused by different atmospheric conditions, variations in the angle of solar illumination, and changes in sensor calibration (Du et al., 2001). Radiometric normalization is especially important when the objective is to detect changes.

Radiometric errors result from atmospheric attenuation or noise, which is a result of light scattering and absorption as it travels through the Earth's atmosphere (Jensen, 1996). Atmospheric attenuation in multi-date imagery can also result from changes in the radiometric performance of the sensor over time, variation in sensor angle, changes in solar illumination (angle and intensity), soil moisture variability, and the presence of clouds (Jenson 1996; Mas, 1999; Singh, 1989).

The thermal channels of the AVHRR have internal system of calibration, but the visible channel (1) does not. The simplest technique for calibration of channel 1 is to use
stable targets on the Earth's surface such as desert sands and oceans surface. Corrections are applied directly to the NDVI using the deviation from the expected values found in the Sahara desert (Teillet and Holben, 1993). Most land cover related to remote sensing projects ignores the atmospheric correction problem, because the signals from the objects being studied are strong enough that they can be detected despite atmospheric attenuation (Jensen, 1996).

2.3.6.3. Geometric Correction

The broad-scale spatial coverage of satellite imagery results in geometric distortions. Geometric distortions occur because the imagery is representing the curved surface of the Earth in two dimensions (Jensen, 1996). In order to analyze images using change detection it is essential to correct for geometric errors (Singh, 1989).

Geometric registration involves precise transformation of the image from the sensor-based projection to an earth surface-based projection. This process includes calculating a satellite model, matching ground and image-based control points, and transformation and resampling the data to a map projection coordinate system. Using ground control points multi-date imagery can be adjusted to a standard geographic coordinate system or one image can be registered to the other (Cracknell and Paithoonwattanakij, 1989; Kelly and Hood, 1991; Brunel and Marsouin, 1987).

The problem with this approach is the identification of enough control points on a global basis to ensure the required registration accuracy. Precise geometric registration can be difficult to achieve, especially if accurate ground control points are not available (Singh, 1989). The problem is complicated by the presence of clouds that prevents a successful correlation process. The problem is, minimized by having an extremely dense and distributed set of control points. Control points for AVHRR data are commonly identifiable features along coastlines, lakes, and rivers. Control points are chosen from a near-nadir, cloud-free base image of 1-km AVHRR data. Another possible approach is to select the control points from Landsat data and then degrade the image to AVHRR
resolution. Another approach is to use hydrologic features from vector data sets such as the Digital Chart of the World (DCW) and the World Vector Shoreline (WVS).

2.3.6.4. Normalized Difference Vegetation Index (NDVI)

To determine the density of green cover on a patch of land, the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants must be observed. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are reflected, respectively (Goward et al. 1991).

Vegetation absorbs, transmits and reflects energy differently in the red and infrared portions of the electromagnetic spectrum (Lyon et al. 1998; Jenson, 1996). The infrared spectral bands are useful for identifying changes in vegetation because the brighter a pixel is, the greater the amount of photosynthesizing vegetation present. Several ratios of the red and infrared bands of satellite imagery have been created to make use of this relationship (Lyon et al. 1998; Jenson, 1996).

The NOAA /AHVRR instrument has five spectral bands, two of which are sensitive to the wavelengths of light in the range between 0.55–0.70 and 0.73–1.0 micrometer. With AHVRR’s detectors, measure the intensity of light coming off the Earth in visible-red and near-infrared wavelengths and quantify the photosynthetic capacity of the vegetation in a given pixel of land surface (Holben et. al., 1990; Kelly and Hood, 1991).

This unique spectral property of green vegetation is used in various indexes ranging in complexity from applying correction coefficient to brightness value of a near-infrared band, to multi-band ratioing combined with complex algorithms (Jenson, 1996). The most successful and commonly used of these techniques is Normalized Difference Vegetation Index (NDVI), which calculated using near-infrared (Channel 2) radiation
minus visible radiation (Channel 1) divided by near-infrared radiation plus visible radiation, this formula was first proposed by Kriegler in 1969 (Kriegler et. Al., 1969), it is written mathematically as follow:

\[ \text{NDVI} = \frac{\text{NIR} - \text{VIS}}{\text{NIR} + \text{VIS}} \] or  \[ \text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \]

NDVI thus theoretically takes values ranging from -1.0 to +1.0. Positive NDVI values (NIR>RED) indicate green, vegetated surfaces, and higher values indicate increases in green vegetation. Studies have related NDVI to biophysical variables such as leaf area, canopy coverage, productivity, and chlorophyll density as well as to vegetation phenology (Goward et al., 1985; Justice et al., 1985; Tucker et al., 1985; Townshend and Justice, 1986; Spanner et al., 1990; Yoder and Waring, 1994; Peters and Eve, 1995; Prince et al., 1995).

This technique was developed for identifying the health and vigor of vegetation and for estimating green biomass (Hayes and Sader, 2001). The absolute value of the result will be between zero and one (Jenson, 1996). Ratios that compare the red and near-infrared bands can be used to estimate and monitor green leaf biomass (Jenson, 1996; Singh, 1989).

This technique can also be used to detect changes in vegetation biomass (Hayes and Sader, 2001). Singh (1989) compared several methods of change detection and found NDVI ratio to be one of the most accurate techniques. In addition, Lyon et al. (1998) found this method to be less affected by topographic features than other change detection techniques.

2.3.6.5. Off-nadir effects

As the radiometer scans across the Earth, there is only one point, in the center of the scan; which is directly underneath the radiometer (called the sub-point or nadir). The distance from the radiometer to the ground increases away from the sub-point. This results in increased atmospheric interference, as the light must pass through more atmospheres before reaching the radiometer, and therefore reduce NDVI values. These
'off-nadir' effects are limited by simply dropping the pixels too far from the nadir. For quantitative work, only 400 on each side of the sub-point can be used.

In addition, the viewing angle at which the radiometer surveys vegetation has an influence on the NDVI value. For example, above a region of crops the soil will be visible to the radiometer. However, viewed at an angle, the region may seem to have continuous vegetative cover. In this case, the NDVI values will be lower directly beneath the radiometer.

### 2.3.6.6. Synthesis

The first factor to consider in the synthesis process is the length of the synthesis period. Synthesis periods of 7, 10, and 14 days have been used most commonly. The choice of the period is usually based on the length of time necessary to obtain a composite image with minimal cloud contamination and/or the amount of time necessary to observe meaningful changes in surface characteristics. The synthesis period that is recommended for the prototype products is approximately 10 days. Thus, January has three composites of 10, 10, and 11 days; February has 10, 10, and 8 or 9 depending on whether it is a leap year or not. This procedure has the advantage of creating the calendar month composites, which is a common reporting period for agronomic and biophysical characteristics.

The recommended method is the maximum NDVI synthesis. The NDVI is examined pixel by pixel for each observation during the synthesis period to determine the maximum value. The retention of the highest NDVI value reduces the number of cloud-contaminated pixels and selects the pixels nearest to nadir (Holben, 1986).
2.4. Geographic Information System

2.4.1 Introduction

Arial photography and Remote Sensed imagery have allowed photogrammetrists to map large areas with great accuracy. The same technology gave the earth resource scientists enormous advantage for reconnaissance and semi-detailed mapping (Burrough et. el., 1998). This resulted in growing demand for a powerful tool that have the capacity to store, retrieve, manipulate, and analyze huge volumes of spatial data. Roger Tomlinson first used the term "Geographic Information System" for the Government of Canada in the early 1960s (Coppock and Rhind, 1991).

GIS are relatively recent phenomena. Throughout the last 30 years there has been a very rapid rate of theoretical, technological and organizational development in the GIS field. Coppock and Rhind (1991) argue that the history of GIS development can be linked to more general advances in hardware and software, although other factors such as education, awareness, and the actions of key individuals have also been important.

GIS is integrate system, which brings together ideas developed in many areas including the fields of agriculture, botany, computing, economics, mathematics, photogrammetry, surveying, zoology and, of course, geography.

The Geographic Information Systems (GIS) is widely used for many in businesses, and governments where they are now used for many diverse applications. GIS provides a valuable tool for information analysis, automated mapping and data integration. Numerous applications for GIS technology exist in state and local government (e.g., land records management, land use planning, infrastructure management, natural resources planning and management). A common use of GIS is to overlay several types of maps to determine useful data about a given geographic area.
2.4.2. Defining a GIS

Geographical Information Systems (GIS) generate great interest worldwide. Its rapid rate of development, commercial orientation and diversity did not help assisted in producing a clear and unambiguous definition of GIS. It is also difficult to define GIS because there are many different ways of defining and classifying objects and subjects (Maguire, 1990). Like the field of geography, the term Geographic Information System (GIS) is hard to define. It represents the integration of many subject areas. Accordingly, there is no absolutely agreed upon definition of a GIS (DeMers, 1997).

There are many definitions (technical definition, “toolbox” definition, information system definition, science definition, business definition) of what GIS is and most of them have some common parts. All include spatial data, make distinguish from Management Information System and all include link between spatial data and maps (Dawn, 1997).

Here are some of the most used definitions of GIS:

ESRI (Environmental Systems Research Institute, Inc.) defines GIS as a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies.

GIS is a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from real world (Aronoff, 1989).

An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific
capabilities for spatially referenced data, as well as a set of operations for working (analysis) with the data. (Jaffrey and John, 1990).

A system of hardware and software for capturing, storing, checking, integrating, manipulating, analyzing, modeling and display of spatially referenced data for solving complex planning and management problems (Cowen, 1989).

The Association for Geographic Information defines GIS as a system for capturing, storing, checking, integrating, manipulating, analyzing, and displaying data, which are spatially referenced to the Earth.

A broadly accepted definition of GIS is the one provided by the National Center of Geographic Information and Analysis: a GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (NCGIA, 1990).

### 2.4.3. GIS components

A GIS is a very powerful tool that can be used to capture, store and analyze geographic data but it is not, a stand-alone system. There are several other components to make up a GIS. It has three important components – computer hardware, set of application software modules, and a proper organization context (Burrough, 1986). Dickinson and Calkins (1988) argue that GIS comprise three key components: GIS technology (hardware and software), a GIS database (geographical and related data) and GIS infrastructure (staff, facilities and supporting elements).

GIS comprise four basic elements, which operate in an institutional context: computer hardware, computer software, data and liveware (Franklin, 1991).

The hardware element can be almost any type of computer platform, including personal computers, high performance workstations and minicomputers and mainframe computers. In addition to the standard input, storage and output devices. Specialist
peripherals are required for data input (e.g. scanners, digitizers), data output (e.g. plotters, printers). Inter-computer communicating can also take place via a network system.

GIS software provides the functions and tools needed to store, analyze, and display geographic information. The key software components are:

- Tools for the input and manipulation of geographic information;
- A database management system (DBMS);
- Tools that support geographic query, analysis, and visualization;
- A graphical user interface (GUI) for easy access to tools.

Burrough (1986) stated that, the software package for GIS consist of five basic technical modules. These basic modules are sub-systems for:

- Data input and verification;
- Data storage and database management;
- Data output and presentation;
- Data transformation;
- Interact with user.

The third important element in a GIS is the data. Mounsey, (1988) argue That respects data are a crucial information resource, geophysical data are very expensive to collect, store and manipulate. Goodchild, (1991) stated Data are the heart of any GIS, through which questions such as what a feature is, where it is, and how it relates to other features can be answered.

The final and most significant GIS element is the liveware; without properly trained personnel with the vision and commitment to a project little will be achieved. Without well trained, competent personnel operating and supporting a GIS the system would not function. Skill in selecting and using tools from the GIS toolbox and an intimate
knowledge of the data being used are essential to your success as GIS user (Aronoff, 1989; Bracken and Webster, 1989).

2.4.4. GIS Data: Structure, Format and Sources

The database concept is central to a GIS and is the main difference between a GIS and other drafting or computer mapping systems, which can only produce a good graphic output.

2.4.4.1. Structure and Format

GIS usually stores geographic features in two ways, geospatial data (or called geometric data) and attribute data (or called thematic data).

Burrough 1986 stated that; all geographic data can be reduced to three basic topological concepts, the point, the line, and area. Every geographical phenomenon can in principal be represented by point, line or area plus a label saying what it is.

2.4.4.1.1. Geospatial data

Geospatial data, made up of points, lines, and areas, is at the heart of every GIS. Geospatial data forms the locations and shapes of map features such as buildings, streets, or cities.

Digital Representation of geospatial data

There are two contrasting, but complementary ways used by GIS to store and represent geospatial data in digital format, which are RASTER and VECTOR data structure.
A. The Vector data model

Vector representation of geographical data is an attempt to represent the object as exactly as possible. With a vector model, each feature is defined by x, y locations in space (the GIS connects the dots to draw lines and outlines, creating lines and areas).

The main geographical entities of the vector representation can be defined as follows: Points represent anything that can be described as a pair of geographic coordinates. Lines represent anything having a length, such as streets, and rivers are represented as a series of coordinate pairs. Areas or polygons, describe anything having boundaries, such as the boundaries of countries or states. Vector data represents each feature as a row in a table, and feature shapes are defined by X,Y locations in space.

B. The raster data model

Another model is the raster model. With the raster model, features are represented as a matrix of cells in continuous space. A point is one cell, a line is a continuous row of cells, and an area is represented as continuous cells. Each grid cell is referenced by a row and column number, and contains a number indicating the feature type, which it represents. Raster GIS data structures are preferred for digital elevation modeling, statistical analysis, remotely sensed data, simulation modeling and natural resource applications.

The raster data model represents features as a matrix of cells in continuous space. Each layer represents one attribute (although other attributes can be attached to a cell). And most analysis occurs by combining the layers to create new layers with new cell values. The cell size used for a raster layer will affect the results of the analysis and how the map looks. The cell size should be based on the original map scale and the minimum mapping unit. Using too large a cell size will cause some information to be lost. Using a cell size that is too small requires a lot of storage space, and takes longer to process.

2.4.4.1.2. Attribute data
Besides the spatial data GIS can store non-spatial or attribute data, which is related to the spatial entities. Attributes records what the geographic features represent (Burrough, 1986). Each special entity type may incorporate one or more attributes that describe the fundamental characteristics of the phenomena involved (Bernhardsen, 1992).

The GIS stores both spatial and non-spatial data in a database system which links the two types of data to provide flexible and powerful ways of querying or asking questions about the data. Bernhardsen, (1992) argue that attribute data are usually most easily and expeditiously stored in tabular form. Each line in the table represents an object, each column an attribute. Attribute data therefore often call tabular data and are normally stored in relation database.

2.4.4.1.3. Topology

Another property of a GIS database is that it has "topology," which defines the spatial relationships between features. When topological relationships exist, its easy to perform analyses, such as modeling, combining adjacent polygons that have similar characteristics, and overlaying geographic features (Peuquet, 1994).

Topology is the way in which geographical elements such as points, lines and polygons are connected with each other or related to each other. It is a mathematical approach that allows to structure data based on the principles of feature adjacency and feature connectivity. It is in fact the mathematical method used to define spatial relationships. Without a topologic data structure most GIS data manipulation and analysis functions would not be practical or feasible.

2.4.4.2. GIS Data: Sources (Input)

Data input is the operation of encoding data for inclusion into a database. The creation of accurate databases is a very important part of GIS. Data collection, and the maintenance of databases, remains the most expensive and time consuming aspect of setting up a major GIS facility. This typically costs 60-80% of the overall costs of a GIS project.
There are no single methods of entering the spatial data to a GIS. Rather, there are several methods that can be used singly or in combination for entering spatial data into a GIS, including:

- Manual digitizing and scanning of analogue maps.
- Image data input and conversion to a GIS.
- Direct data entry including global positioning systems (GPS).
- Transfer of data from existing digital sources.

Davies, (1974) stated, the choice of methods is governed largely by the application, the available budget, and the type of data available.

**Analogue Maps**

Maps are a form of analogue geographical database, and a very important source of digital geographical data, but they are certainly not the only source. Maps are often designed for purposes that have little to do with geographical databases, a primary purpose of map design being the communication of information to the reader through visual perception (Robinson 1953).

Most of the contents of geographical databases continue to be derived from paper maps, digitizing and scanning are the two main methods of input analogue maps. The input of data from analogue maps required the conversion of the features into coordinate values.

**Digitizing**

Digitizing requires a human operator to position a map on a table, and move a cursor over it, thus capturing the positions of points, and building up digital representations of line and area features. Digitizing is error prone, tedious, time consuming and expensive (Fisher 1991).
Digitizing is the transformation of information from analog format, to digital format, so that it can be stored and displayed with a computer. Digitizing can be manual, semi-automated (automatically recorded while manually following a line), or fully automated (line following). Manual digitizing involves an operator using a digitizing table (or tablet) (known as heads-down digitizing), or with the operator using a computer screen (heads-up digitizing) (USGS, 2005).

Scanning

Another approach is to use a scanner to convert the analogue map into a computer-readable (digital) form automatically. One method of scanning is to record data in narrow strips across the data surface, resulting in a raster format. Other scanners can scan lines by following them directly. Maps are often scanned in order to use digital image data as a background for other (vector) map data or to convert scanned data to vector data for use in a vector GIS.

Scanning captures the entire contents of the document automatically. However, the process of interpreting features from the scanned image of the map is error prone, requiring frequent human intervention, and it is often necessary to redraw the document to provide a sufficiently clean image (USGS, 2005).

Image data

Image data includes satellite images; aerial photographs and other remotely sensed. Image data is in a raster data. Each grid-cell, or pixel, has a certain value depending on how the image was captured and what it represents. Data from remote sensing are mainly used for change detection and thematic mapping (Lee, 1994).

Global Positioning System
A Global Positioning System (GPS) is a set of hardware and software designed to determine accurate locations on the earth using signals received from selected satellites. Location data and associated attribute data can be transferred to mapping and GIS (Dana, 1997). GPS will collect individual points, lines and areas in any combination necessary for a mapping or GIS project. More importantly, with GPS you can create complex data dictionaries to accurately and efficiently collect attribute data. This makes GPS a very effective tool for simultaneously collecting spatial and attribute data for use with GIS. GPS is also an effective tool for collecting control points for use in registering base maps when known points are not available (Trimble, 2000). GPS can be used for georeferencing, positioning, navigation, and for time and frequency control. GPS is increasingly used as an input for Geographic Information Systems particularly for precise positioning of geospatial data and the collection of data in the field (Schaeffer, 1998).

**Digital data from other sources**

Many computer databases can be directly entered into a GIS. Different kinds of data in map form can be entered into a GIS. A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. Likewise, census or tabular data can be converted to a map like form and serve as layers of thematic information in a GIS (USGS, 2005).

Digital data can be imported from other sources. Often data are obtained already in digital format from government agencies, and other sources. Some data is being made available on the Internet by many organizations and agencies (Mounsey, 1988). The Internet contains links to hundreds of websites that maintain and provide GIS data, both in the US and around the world. In some cases, you can download the data directly and use it in GIS software such as ArcView. ESRI’s web page (http://www.esri.com) also contains links to organizations that maintain and provide GIS data. From the web page you can access the Data Hound, a good place to search.
for data. The Data Hound offers links to other GIS sites that offer free, downloadable data.

The data obtained from other sources should contain meta-data, that is data about the data, or a sort of "data quality report" from the provider. This will provide a description of exactly what is in the file, how the information was compiled (and from what sources), and how the data was checked.

### 2.4.5. GIS Analysis and Visualization

GIS technology can be used for scientific investigations, resource management, and development planning. The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship.

GIS can be applied to many types of investigations problems. Steinwand (1990) sets out a general classification of the types of generic questions, which GIS are frequently used to investigate. The location question involves querying a database to determine the types of features, which occur at a given place. The condition question is really the converse, since it involves finding the location of sites, which have certain characteristics. Where more than one type of data are involved this is sometimes referred to as the 'intersection' question since it necessitates finding the intersection of data sets (Maguire 1989). The trend question involves monitoring how things change over time. The other questions are more complex and involve some type of spatial analysis. The routing question requires calculation of the best (fastest, quickest, shortest, most scenic, etc.) route between places. The patterns question allows environmental and social scientists and planners to describe and compare the distribution of phenomena and to understand the processes, which account for their distribution. The final question allows different models of the world to be evaluated.

The user may also query the GIS by the textual attributes in the tabular database and then display the map features, which correspond to these attributes. Spatial analysis is
a set of analytical procedures applied to GIS data to describe, predict, or assess environmental or social issues. Spatial analysis techniques include methods for: Reclassifying map overlay features, measuring distance and area, interpolating values, and identifying the co-occurrence of values on different map themes (overlay analysis). GIS also have sophisticated graphic capabilities for map overlay production and data visualization in plan and perspective. Conventional techniques for producing cartography are automated in Geographic Information Systems. In addition, most systems will provide methods for displaying maps in three dimensions. There are also other techniques for representing spatial data, including charts, histograms and statistical tables. Traditional maps are abstractions of the real world; each map is a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Graphic display techniques in GIS make relationships among map elements more visible, heightening one's ability to extract and analyze information.

A critical component of a GIS is its ability to produce graphics on the screen or on paper to convey the results of analyses to the people who make decisions about resources. Wall maps, Internet-ready maps, interactive maps, and other graphics can be generated, allowing the decision makers to visualize and thereby understand the results of analyses or simulations of potential events (USGS, 2005).

Through a process known as visualization, a GIS can be used to produce images—not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that they never could before. The images often are helpful in conveying the technical concepts of a GIS to nonscientists. GIS is a powerful tool for environmental data analysis and planning. GIS stores spatial information (data) in a digital mapping environment. A digital base map can be overlaid with data or other layers of information onto a map in order to view spatial information and relationships. GIS allows better viewing and understanding physical features and the relationships that influence in a given critical environmental condition. Factors, such as steepness of slopes, and vegetation, can be viewed and overlaid to determine various environmental parameters and impact analysis (Wiegand and Adams, 1994).
On completion of data analysis GIS helps in planning and managing the environmental hazards and risks. In order to plan and monitor the environmental problems, the assessment of hazards and risks becomes the foundation for planning decisions and for mitigation activities. GIS supports activities in environmental assessment, monitoring, and mitigation and can also be used for generating Environmental models (Sharma, 2004).

**2.5. NDVI for measure vegetation cover characteristics**

NDVI is the traditional vegetation index used by researchers for extracting vegetation abundance from remotely sensed data (Tucker, 1979). It divides the difference between reflectance values in the visible red and near-infrared wavelengths by the overall reflectance in those wavelengths to give an estimate of green vegetation abundance (Tucker, 1979).

NDVI has been used extensively to measure vegetation cover characteristics on a broad-scale worldwide, and has been incorporated into many large-scale forest and crop assessment studies (Peterson et al., 1987; Asrar et al., 1984; Bausch, 1993; Benedetti & Paolo, 1993; Wanjura & Hatfield, 1987). It is used to provide weekly vegetation maps, monitor crops over large regions, monitor vegetation change in much of the tropics, and estimate biomass. Shih (1994) used it to monitor agricultural areas in the Everglades, Dejong (1994) used it in a model of soil erosion, Wood (1993) used NDVI to help monitor water and energy fluxes for a climate model, and Dymond et al. (1992) used NDVI to estimate rangeland degradation.

Since the early 1980s data from NOAA AVHRR have been used extensively to monitor and to study dryland vegetation (Millington et al., 1994). Previous studies (Tucker et al., 1985, 1986; Prince & Tucker, 1986; Kennedy, 1989; Belward, 1991; Prince, 1991; Maselli et al., 1992; Garcia, 1993; Groten, 1993; Fuller, 1998) have shown the
usefulness of the NOAA-AVHRR-normalized difference vegetation index (NDVI) for monitoring vegetation at different scales.

Previous research on the African Sahel (Tucker et al., 1985; Prince & Tucker, 1986; Taylor et al., 1986; Hiederer & Wyatt, 1990; Prince, 1991; Groten, 1993; Fuller, 1998; Sannier et al., 1998b), showed good correlations between the NDVI derived from NOAA AVHRR data and vegetation productivity. Furthermore, Mout et al. (1997) used the NDVI as an indicator of desertification since it related to vegetation greenness.

In Figure (2.11), in visible light (top), vegetated areas are very dark, almost black, while desert regions (like the Sahara) are light. At near-infrared wavelengths, the vegetation is brighter and deserts are about the same. By comparing visible and infrared light, scientists measure the relative amount of vegetation.

Source: [http://earthobservatory.nasa.gov/Library/MeasuringVegetation/](http://earthobservatory.nasa.gov/Library/MeasuringVegetation/)

Figure (2.11): Vegetation differences at visible and near-infrared wavelengths
In Figure (2.12) healthy vegetation (left) absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (right) reflects more visible light and less near-infrared light. The numbers on the figure are representative of actual values, but real vegetation is much more varied.

![Figure (2.12): NDVI values in healthy and unhealthy vegetations](http://earthobservatory.nasa.gov/Library/MeasuringVegetation)

Source: http://earthobservatory.nasa.gov/Library/MeasuringVegetation

In general, if there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the vegetation in that pixel is likely to be dense and may contain some type of forest. If there is very little difference in the intensity of visible and near-infrared wavelengths reflected, then the vegetation is probably sparse and may consist of grassland, or desert. If there is very low value of the reflection in near-
infrared wavelengths than in visible wavelengths, then that pixel is likely to be barren areas, sands or snow.

Figure (2.13), shows the spectral signatures of three features, green grass, dead grass, and dry soil. A unique characteristic of healthy green vegetation is the presence of the distinctive near-infrared "shoulder." The shoulder results from low red light reflectance caused by chlorophyll absorption and high near-infrared reflectance caused by the plant’s spongy mesophyll leaf structure; both of which are present in actively growing vegetation. This abrupt change in reflectance from red to near infrared creates the unique spectral shoulder.

In a typical vegetation cover setting each image pixel will be a mixture of various types of green healthy vegetation, dead vegetation, and soil; each with their own unique spectral signature. However, the dominance of one over the others will determine how these pixels will appear. A pixel dominated by green vegetation, for example, will have
a higher NDVI value of about 0.8 compared to a pixel dominated by dead vegetation or dry soil which will have lower NDVI values of about 0.3 to 0.1.

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8).

Table (2.4), shows typical reflectance values in the red and infrared channels, and the NDVI for typical cover types. Water typically has an NDVI value less than 0, bare soils between 0 and 0.1 and vegetation over 0.1.

Table (2.4): Typical NDVI values for various cover types

<table>
<thead>
<tr>
<th>COVER TYPE</th>
<th>RED</th>
<th>NIR</th>
<th>NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense vegetation</td>
<td>0.1</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Dry Bare soil</td>
<td>0.269</td>
<td>0.283</td>
<td>0.025</td>
</tr>
<tr>
<td>Clouds</td>
<td>0.227</td>
<td>0.228</td>
<td>0.002</td>
</tr>
<tr>
<td>Snow and ice</td>
<td>0.375</td>
<td>0.342</td>
<td>-0.046</td>
</tr>
<tr>
<td>Water</td>
<td>0.022</td>
<td>0.013</td>
<td>-0.257</td>
</tr>
</tbody>
</table>

Source (Holben, 1986)
2.6. Change detection

Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times (Singh, 1989). In remote sensing it is useful in land use/land cover change analysis such as monitoring deforestation, desertification or vegetation change.

Remote sensing provides important data for monitoring land cover changes on regional and global scales (Skole et al., 1997; Hansen et al., 2000). While methods for detecting, mapping and analyzing land cover changes are diverse and well established in the remote sensing literature (e.g., Collins & Woodcock, 1996; Song et al., 2001; Rogan et al., 2002),

Change detection is a major remote sensing research endeavor (e.g., Jensen et al., 1993; Ridd & Liu, 1998; Lunetta & Elvidge, 2000). The goal of remote sensing change detection is to (a) detect the geographic location of change found when comparing two (or more) dates of imagery, (b) identify the type of change if possible (e.g., from forest to agriculture), and (c) quantify the amount of change (e.g., 100 ha). Jensen (2005) reviews several important considerations when performing change detection, including:

1. Remote sensing system considerations such as spatial, spectral, radiometric, and temporal resolutions, and

2. Environmental considerations such as atmospheric conditions, soil moisture, natural and man-made phonological cycle characteristics, and tidal cycle (for coastal applications), and

3. Image processing resources, analyst’s skill and experience, and time and cost constraints must also be considered (Johnson & Kasischke, 1998).

Numerous remote sensing change detection algorithms have been developed. Yuan et al. (1998) divide the methods for change detection and classification into pre-classification and post-classification techniques. The pre-classification techniques apply
various algorithms, including image differencing and Image ratioing, to single or multiple spectral bands, vegetation indices or principal components, directly to multiple dates of satellite imagery to generate “change” vs. “no-change” maps. These techniques locate changes but do not provide information on the nature of change (Ridd & Liu, 1998; Singh, 1989; Lyon et al., 1998). On the other hand, post-classification comparison methods use separate classifications of images acquired at different times to produce difference maps from which “from-to” change information can be generated (Jensen, 2004).

Change detection techniques can be broadly grouped into two general types (Chan et al., 2001):

- Change enhancement methods, and
- “From-to” change information extraction methods.

Mausel et al., (2003) grouped the change detection methods into seven categories:

1. Algebra,
2. Transformation,
3. Classification,
4. Advanced models,
5. Geographical Information System (GIS) approaches,
6. Visual analysis, and
7. Other approaches

In the algebra-based change detection category, image differencing is the most often-used change detection method in practice. Vegetation index image differencing has shown to be suitable for change detection in semi-arid and arid environments, but it is not clear that this is true in other environments such as moist tropical regions (Mausel et al., 2003).

Change enhancement methods (e.g., image differencing) provide information on the possible existence of change and perhaps the relative magnitude of the change. They
do not identify the nature of the change. Conversely, “from-to” change detection algorithms (e.g., post-classification comparison) provide detailed information about the type of land cover change (e.g., from forest to agriculture) for every pixel and/or polygon under examination.

It is not easy to select a suitable algorithm for a specific change detection project. Hence, a review of change detection techniques used in previous research and applications is useful to understand how these techniques can be best used to help address specific problems. When study areas and image data are selected for research, identifying a suitable change detection technique becomes of great significance in producing good quality change detection results.
Chapter Three
Materials and Methods

3. Background
This chapter will focus on how materials and data has been collected and processed, and how desertification information was extracted, interpreted and analyzed.

3.1. Materials and Data Acquisition Methods

3.1.1. Location
The study area lies between 3°-22° N latitude and 22°-38° E Longitude.

3.1.2. NDVI Data
The most recent NDVI data sets for East Africa from NASA (Version 3, NOAA-16 calibration) were used in this study. These data sets were obtained from Famine Early Warning Systems Network (FEWS Net), Africa Data Dissemination Service (ADDS) Website. These NDVI data are structured for direct use in several image processing and geographic information systems and for easy import and export into other packages. These data sets have the following spatial, temporal, data values, parameters and projection:

Pixel size (for all spatial extents):
X-direction: 8000 m
Y-direction: 8000 m
NROWS: 540
NCOLS: 490
Data Format: Band Interleaved by Line (Bil)
Data Type: Unsigned 8 Binary digits (Bit)
IMAGE TYPE: 200, User Defined
Projection: ALBERS (Albers Equal Area Conic)
Units: METERS
Spheroid: CLARKE1866
Data value parameters:
Lower Limit: 0
Upper Limit: 255
Temporal Coverage
The data are comprised 360 images for the period from January 1993 through December 2003.

3.1.3. Digital Maps of Sudan
The digital vector maps and related descriptive data and tables of Sudan, as the: The Sudan borders, and state boundaries were obtained from the National Drought and Desertification Control Unit (NDDU) data bank in Arc/info format and both geographic, and polyconic projection.

3.2. Software Used
The choice of Software used for the image processing and spatial analysis was limited to those available in Arabian Gulf University (AGU). Four software packages are used namely: Map and Image Display and Analysis System (WINDISP 5.1), this software is used to display NDVI dataset using a look-up table, edit header file, process image series and processes image window.

Earth Resources Data Analysis System (ERDAS Imagine ver.8.7) is used to import Generic Binary data, display image, and perform geometric correction, and image analysis and conversion.

ArcView and ArcGis (ver. 9.1) software’s with the Spatial Analyst, IMAGINE Image support and Geoprocessing extensions were used to view raster and vector data, Overlay polygon, Prepare, edit and geocoding descriptive information, topology building, overlay, and calculate change detection.

3.3. Data Processing
Pre-digital processing includes radiometric calibration, atmospheric correction, computation of NDVI values, geometric registration to the ALBART Azimuthal Equal Area map projection, are done by NASA. The FEWS Project provides calibrated NDVI imagery on decade basis (every Ten days).

The data processing flow is generally a stepwise process (Fig. 4.1). The first step was to compute the monthly maximum NDVI. The maximum daily NDVI value over a ten-
day period is computed to make a decade image, known as Maximum Value Composite (MVC). Such maximum values are assumed to present the maximum vegetation (greenness) during the period.

These images were produced by selecting pixels with the highest NDVI values from each of the daily images. Taking the highest pixel value for the month from all the 3 decades images to produce monthly maximum value composite NDVI images. This minimizes cloud cover and water vapor effects since both strongly reduce NDVI value. The use of maximum value composites reduces some of the extraneous variability inherent in the NDVI caused by differences in atmospheric conditions, position of the sun or scan angle of the satellite (Holben, 1986). One image per month for the period from 1993 to 2003 since January 1993 were produced and archived.

The second step was to produce Long Term Average image (LTA) for the study period. The decadal images was integrated, annual maximum NDVI images are computed, the annually average image for the study period was produced.
Figure 3.1: Data Processing Flow
The resulted (LTA) image and annually average imagery were subseted using Sudan image Window parameters (Table 3.1). This function was used to extract Sudan window out of large image of East Africa. The resulted Sudan window image files were edited to change the image type to Generic Binary, so it can easily be imported into ERDAS software. All the above mentioned steps were done using (WINDISP 5.1) software.

Table 3.1: Sudan Image subset parameters

<table>
<thead>
<tr>
<th>Window Coordinates</th>
<th>Screen Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1 of window</td>
<td>88</td>
</tr>
<tr>
<td>Y1 of window</td>
<td>10</td>
</tr>
<tr>
<td>X2 of window</td>
<td>324</td>
</tr>
<tr>
<td>Y2 of window</td>
<td>302</td>
</tr>
</tbody>
</table>

The resulted images were imported to ERDAS Imagine software using Import Generic Binary data (Table 3.2). The imported images are a single band data set in ERDAS format (Figure 3.2).

Table 3.2: Sudan image Importing Parameters

<table>
<thead>
<tr>
<th>Data Format</th>
<th>Bil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Type</td>
<td>Unsigned 8 Bit</td>
</tr>
<tr>
<td>File Header Bytes</td>
<td>521</td>
</tr>
<tr>
<td>Image Record Length</td>
<td>237</td>
</tr>
<tr>
<td>Line Header Bytes</td>
<td>0</td>
</tr>
<tr>
<td>No. of Rows</td>
<td>293</td>
</tr>
<tr>
<td>No. of Columns</td>
<td>237</td>
</tr>
<tr>
<td>No. Bands</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 3.2: The single band imported image
All images were re-projected to Geographic projection to obtain successful matching between the time series images and Sudan boundaries map. In order to analyze images using change detection it is essential that they be corrected for geometric errors (Singh 1989). Using control points, all images were adjusted to a standard geographic coordinate system. This was done using Sudan geographic location parameters (Table 3.3) and data preparation model in ERDAS.

Table 3.3: Sudan geographic location parameters

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude $^\circ$</td>
</tr>
<tr>
<td>Upper Left corner</td>
<td>21.23 N</td>
</tr>
<tr>
<td>Lower Left corner</td>
<td>21.23 N</td>
</tr>
<tr>
<td>Upper Right corner</td>
<td>39.39 N</td>
</tr>
<tr>
<td>Lower Right corner</td>
<td>39.39 N</td>
</tr>
</tbody>
</table>

In attempting to assess the changes in vegetation cover using Image differencing technique over the study period, the 10 annually average imagery were integrated to make direct comparison from one year to the next, and new difference images were created. Image differencing is a simple process of subtracting one image from another. In this analysis, annually average NDVI images were subtracted to determine changes in the pixel values over time. Subtraction was done with the Change Detection module of ERDAS.
This technique can be useful for identifying temporal changes using multi-temporal remotely sensed imagery. Change detection can be particularly useful in remote locations where changes may occur over large areas and where long-term monitoring is required (Howarth and Wickware 1981; Lyon et al., 1998; Hayes et al., 2001).

The re-projected annually differences images, that resulted from Image differencing process, were converted to vector data format, which can be analyzed in GIS software. The resulting maps in Shapefile format that contained information about the pixel values were used for statistical and spatial analysis.

The extraction of Sudan area out of the total area at risk maps and the annually change maps were accomplished using the Clip option in the Geoprocessing Wizard, where the maps containing Sudan data were extracted using Sudan boundary map in geographic projection.

The overlay operation (clip) allows the polygon features of one layer to be overlaid on the polygon feature of another layer. Features from each input layer were combined to create new output feature. Attributes of each input feature were combined from the two layers, thus creating new attribute.

The boundaries between adjacent polygons that have the same values of attribute were removed using the Dissolve wizard. The resulted areas at risk were filtered using ELIMINATE command to remove isolated pixels and to obtain more reliable areas and to make the map more homogenous.

Using polyconic projection parameters of Sudan the resulting maps were re-projected to Polyconic projection so the areas will be in meters and to minimize distortion on such large-scale area like Sudan. The annual change was calculated using annually difference maps. Five classes were used to classify the annual change (Table 3.4).

<table>
<thead>
<tr>
<th>Change classes</th>
<th>Annual change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>More than 25%</td>
</tr>
<tr>
<td>Some Decreased</td>
<td>1% to less than 25%</td>
</tr>
</tbody>
</table>
Using Union in the Geoprocessing wizard the change map for the period 1993 to 2003 (the resulting map). That was accomplished to produce a new map containing the features and attributes of two overlaid maps. The resulting map is used to identify differences in the state of areas at risk to drought and desertification by observing it at different times. Statistics for the differences in the different classes were calculated.

### 3.4. Uncertainty

The uncertainty involved in this analysis enters in many steps of the process. An important limitation in this analysis is the coarse spatial resolution of the 8-km pixel of this long-term AVHRR record. Many local areas of degradation certainly fall below the size threshold of 8X8 km pixels. An area of 64 km² inherently contains variability, either in soil, vegetation, land use, or other surface characteristics. In addition to this, processes such as registration or geometric correction do alter the data, adding small levels of error. However, generally errors in registration should not affect differences seen in NDVI values.

NDVI data may be affected by a number of phenomena that contaminate the signal, including clouds, atmospheric perturbations, and variable illumination and viewing geometry. Each of these phenomena reduces the NDVI.

It is this "averaging" characteristic of a satellite image pixel that creates the problem known as mixed spectra or spectral mixing because each pixel will record a mixture of spectral signatures unique to the various features present within the area of the pixel. The features that may be present within a single pixel could be numerous and include many types of vegetation, soils, and other natural or constructed features, or less numerous as in a agricultural setting dominated by a single crop. Also, the large image pixels (for example, 8-km AVHRR images) will generally contain a greater variety of features than small image pixels (for example, 30-m Landsat Thematic Mapper images).
Chapter Four

Results and Discussion

In this chapter the main findings and results from NDVI data series change detection analysis will be illustrated in forms of tables, maps, statistics and figures. In the second section of the chapter a discussion of results will be performed to highlighting the categories. The discussion will be supported by comparing the results with earlier studies in Sudan and other parts of Africa.

4.1. Results

Desertification is a dynamic process and Remote Sensing is of great value in monitoring these dynamic processes through, and in particular, changes in land cover. By comparing NDVI images taken on different dates, at an interval of 10 years, one can determine the areas where land cover has changed and to interpret these changes in terms of negative change (desertification) or positive change (recovery).

The main findings and results from NDVI data series change detection analysis will be illustrated, and the maps, statistics and figures will discussed.

Tables 4.1 and Figure 4.1 and 4.2, shows the NDVI Mean and Standard Deviation values of the study period for each year. This means that the NDVI values are not standardized in the period, and it looks to be changing year by year with a dramatical reduction during 1994 and 1998. The tendency fluctuation pattern of vegetation degradation and/or recovery years can be found throughout the study period spans.

Table 4.1 The NDVI Mean and Standard Deviation values of the period 1993 – 2003

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>82.908</td>
<td>85.823</td>
<td>85.811</td>
<td>84.226</td>
<td>85.424</td>
<td>85.523</td>
<td>86.761</td>
<td>83.46</td>
<td>83.65</td>
<td>82.011</td>
<td>81.809</td>
</tr>
</tbody>
</table>
Figure 4.1: NDVI Mean Values 1993 – 2003

Figure 4.2: NDVI Standard Deviation Values 1993 – 2003
The Maps 4.1 to 4.10 shows the different change over the study period. The different change classes areas were calculated. The areas of Unchanged means “no change in the NDVI pixels value” (colored in yellow), where the Decreased areas means “areas of more than 25% decrease in the NDVI pixel value” (colored in red), the Some Decreased areas shows, ” areas of 1% to less than 25% decrease in the NDVI pixel value” (colored in light red), the Some Increase areas shows “ areas of 1% to less than 25% increase in the NDVI pixel value” (colored in light green), and the Increased areas shows “areas of more than 25% increase in the NDVI pixel value” (colored in green).

These Maps resulted from comparison of the annually NDVI images of the study period with an image of reference year (1993) from which drought conditions are well known (Richard, 1995, UNEP, 2002; HCENR, 2003). In this case, the comparison would allow the detection of long-term change in NDVI pixel value throughout the study period, and look at year-to-year variations in the vegetation cover.
Map 4.1: Change in Vegetation Cover between 1993 and 1994
Map 4.2: Change in Vegetation Cover between 1993 and 1995

Change Classes

- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Areas

Scale: 250,000 - 500,000 Kilometers
Map 4.3: Change in Vegetation Cover between 1993 and 1996
Map 4.4: Change in Vegetation Cover between 1993 and 1997
Map 4.5: Change in Vegetation Cover between 1993 and 1998

Change Classes:
- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Area

Legend:
- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Area

Scale:
- 250,000 0 250,000 500,000 Kilometers
Map 4.6: Change in Vegetation Cover between 1993 and
Map 4.7: Change in Vegetation Cover between 1993 and 2000

Change Classes
- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Area

Legend:
- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Area

Scale:
- 250,000
- 500,000 Kilometers
Map 4.8: Change in Vegetation Cover between 1993 and 2001

Change Classes:
- Decrease Areas
- Some Decrease Areas
- Unchange Areas
- Some Increase Areas
- Increase Area

Legend:
- 250000
- 0
- 250000
- 500000
- Kilometers
Map 4.9: Change in Vegetation Cover between 1993 and 2002
Tables 4.2 to 4.11 show the calculated areas of different change classes throughout the study period.

**Table 4.2** Change between 1993 - 1994

<table>
<thead>
<tr>
<th>Change Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased 3102.851</td>
</tr>
<tr>
<td>Some Decrease 360127.388</td>
</tr>
<tr>
<td>Unchanged 430807.399</td>
</tr>
<tr>
<td>Some Increase 1655541.999</td>
</tr>
<tr>
<td>Increase 42780.423</td>
</tr>
<tr>
<td>Total 2492360.061</td>
</tr>
</tbody>
</table>

**Table 4.3** Change between 1993 – 1995

<table>
<thead>
<tr>
<th>Change Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased 8442.969</td>
</tr>
<tr>
<td>Some Decrease 438637.735</td>
</tr>
<tr>
<td>Unchanged 287950.775</td>
</tr>
<tr>
<td>Some Increase 1712050.504</td>
</tr>
<tr>
<td>Increase 45278.753</td>
</tr>
<tr>
<td>Total 2492360.737</td>
</tr>
</tbody>
</table>

Table 4.12 shows the statistical results derived from Table 4.2 by summarizing the areas by percentage compared to the total area of Sudan (2.492.360 km²). The Figure 4.3 shows the different change classes diagram. The values show average value of (26.482) for the total Declined areas (Decreased and Some Decrease), and average of (55.854) for the total Increased areas (Increased and Some Increase).

Map 4.10: Change in Vegetation Cover between 1993 and...
Tables 4.2 to 4.11: The calculated areas of different change classes throughout the study period.

**Table 4.2 Change between 1993 - 1994**

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>3102.851</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>360127.388</td>
</tr>
<tr>
<td>Unchanged</td>
<td>430807.399</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1655541.999</td>
</tr>
<tr>
<td>Increase</td>
<td>42780.423</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.061</strong></td>
</tr>
</tbody>
</table>

**Table 4.3 Change between 1993 – 1995**

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>8442.969</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>438637.735</td>
</tr>
<tr>
<td>Unchanged</td>
<td>287950.775</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1712050.504</td>
</tr>
<tr>
<td>Increase</td>
<td>45278.753</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.337</strong></td>
</tr>
</tbody>
</table>

**Table 4.4 Change between 1993 – 1996**

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>35318.266</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>591335.897</td>
</tr>
<tr>
<td>Unchanged</td>
<td>407691.884</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1394999.270</td>
</tr>
<tr>
<td>Increase</td>
<td>63015.090</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.407</strong></td>
</tr>
</tbody>
</table>

**Table 4.5 Change between 1993 – 1997**

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Sq Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>30564.252</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>472543.500</td>
</tr>
<tr>
<td>Unchanged</td>
<td>338431.441</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1604041.284</td>
</tr>
<tr>
<td>Increase</td>
<td>46779.618</td>
</tr>
</tbody>
</table>
### Table 4.6 Change between 1993 – 1998

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>23893.026</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>365807.641</td>
</tr>
<tr>
<td>Unchanged</td>
<td>263029.781</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1797749.830</td>
</tr>
<tr>
<td>Increase</td>
<td>41879.774</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.094</strong></td>
</tr>
</tbody>
</table>

### Table 4.7 Change between 1993 – 1999

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>5781.850</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>243552.298</td>
</tr>
<tr>
<td>Unchanged</td>
<td>407996.242</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1810606.013</td>
</tr>
<tr>
<td>Increase</td>
<td>24423.816</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.220</strong></td>
</tr>
</tbody>
</table>

### Table 4.8 Change between 1993 – 2000

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>35152.012</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>769417.637</td>
</tr>
<tr>
<td>Unchanged</td>
<td>574648.237</td>
</tr>
<tr>
<td>Some Increase</td>
<td>1004221.517</td>
</tr>
<tr>
<td>Increase</td>
<td>108920.774</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.176</strong></td>
</tr>
</tbody>
</table>

### Table 4.9 Change between 1993 – 2001

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>12627.822</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>981741.171</td>
</tr>
<tr>
<td>Unchanged</td>
<td>538574.083</td>
</tr>
<tr>
<td>Some Increase</td>
<td>947888.272</td>
</tr>
<tr>
<td>Increase</td>
<td>11528.669</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.017</strong></td>
</tr>
</tbody>
</table>
### Table 4.10 Change between 1993 – 2002

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>52828.349</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>939362.016</td>
</tr>
<tr>
<td>Unchanged</td>
<td>574426.500</td>
</tr>
<tr>
<td>Some Increase</td>
<td>918146.809</td>
</tr>
<tr>
<td>Increase</td>
<td>7596.534</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.209</strong></td>
</tr>
</tbody>
</table>

### Table 4.11 Change between 1993 – 2003

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>191568.489</td>
</tr>
<tr>
<td>Some Decrease</td>
<td>1038381.680</td>
</tr>
<tr>
<td>Unchanged</td>
<td>578699.504</td>
</tr>
<tr>
<td>Some Increase</td>
<td>620064.932</td>
</tr>
<tr>
<td>Increase</td>
<td>63645.451</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2492360.056</strong></td>
</tr>
</tbody>
</table>

Table 4.12, shows the statistical results derived from Tables 4.2 to 4.11 by summarized the areas by percentage compared to the total area of Sudan (2.492.360 Km²). The Figure 4.3 shows the different change classes diagram.

Table 4.12, Areas of different change classes by percentage compared to the total area of Sudan, 1993 -2003

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decreased</strong></td>
<td>0.12%</td>
<td>0.34%</td>
<td>1.42%</td>
<td>1.23%</td>
<td>0.96%</td>
<td>0.23%</td>
<td>1.41%</td>
<td>0.51%</td>
<td>2.12%</td>
<td>7.69%</td>
</tr>
<tr>
<td><strong>Some Decrease</strong></td>
<td>14.45%</td>
<td>17.60%</td>
<td>23.73%</td>
<td>18.96%</td>
<td>14.68%</td>
<td>9.77%</td>
<td>30.87%</td>
<td>39.39%</td>
<td>37.69%</td>
<td>41.66%</td>
</tr>
<tr>
<td><strong>Unchanged</strong></td>
<td>17.29%</td>
<td>11.55%</td>
<td>16.36%</td>
<td>13.58%</td>
<td>10.55%</td>
<td>16.37%</td>
<td>23.06%</td>
<td>21.61%</td>
<td>23.05%</td>
<td>23.22%</td>
</tr>
<tr>
<td><strong>Some Increase</strong></td>
<td>66.42%</td>
<td>68.69%</td>
<td>55.97%</td>
<td>64.36%</td>
<td>72.13%</td>
<td>72.65%</td>
<td>40.29%</td>
<td>38.03%</td>
<td>36.84%</td>
<td>24.88%</td>
</tr>
<tr>
<td><strong>Increase</strong></td>
<td>1.72%</td>
<td>1.82%</td>
<td>2.53%</td>
<td>1.88%</td>
<td>1.68%</td>
<td>0.98%</td>
<td>4.37%</td>
<td>0.46%</td>
<td>0.30%</td>
<td>2.55%</td>
</tr>
</tbody>
</table>
Table 4.13, shows the statistical results of the sum values of Decreased, Unchanged and increased areas percentage, derived from Tables 4.2 to 4.11. The Figure 4.4 shows the sum areas of Decrease, Unchanged and Increase areas percentage chart.

The values show average of (26.482%) for the total Declined areas (Decreased and Some Decrease), and an average of (55.854%) for the total Increased areas (Increased and Some Increase).

Table 4.13. Sum of Decrease, Unchanged and Increase areas percentage

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>14.57%</td>
<td>17.94%</td>
<td>25.14%</td>
<td>20.19%</td>
<td>15.64%</td>
<td>10.00%</td>
<td>32.28%</td>
<td>39.90%</td>
<td>39.81%</td>
<td>49.35%</td>
</tr>
<tr>
<td>Unchanged</td>
<td>17.29%</td>
<td>11.55%</td>
<td>16.36%</td>
<td>13.58%</td>
<td>10.55%</td>
<td>16.37%</td>
<td>23.06%</td>
<td>21.61%</td>
<td>23.05%</td>
<td>23.22%</td>
</tr>
<tr>
<td>Increase</td>
<td>68.14%</td>
<td>70.51%</td>
<td>58.50%</td>
<td>66.24%</td>
<td>73.81%</td>
<td>73.63%</td>
<td>44.66%</td>
<td>38.49%</td>
<td>37.14%</td>
<td>27.43%</td>
</tr>
</tbody>
</table>
Map 4.12, reflects the result of the overlaying of the decreased areas over the study period, the result was the areas which indicate low NDVI values or decline vegetation cover throughout the 10 years period. The Long-term change in vegetation is an index of primary desertification.

Map 4.13, shows the result of the overlaying of the increased areas over the study period, the result was the areas which indicate high NDVI values or net increase vegetation cover throughout the 10 years period.

This map estimates not only the direction of the change but also the change magnitude, and the rate and extents of vegetation cover change.

The areas showing net increased, decreased and unchanged throughout the study period were mapped and calculated to examine whether there has been any change in the vegetation cover as an indicator of land degradation/desertification over the record period. Table 4.14, shows these areas and the percentage of each compared to the total area of Sudan.
Map 4.11: The Unchanged, Increased and Decreased areas (1983 – 2003)
Table 4.14 Total areas of different change classes and their percentage, 1993 – 2003

<table>
<thead>
<tr>
<th>Change</th>
<th>Area Km$^2$</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged Areas</td>
<td>2,240,631.64</td>
<td>89.90%</td>
</tr>
<tr>
<td>Increased Areas</td>
<td>244,500.516</td>
<td>9.81%</td>
</tr>
<tr>
<td>Decreased Areas</td>
<td>6,978.608</td>
<td>0.28%</td>
</tr>
</tbody>
</table>
4.2. Discussion

Although the assessment of land-degradation/desertification are pointed out in Agenda-21 however, the methodologies of these assessments by means of Remote Sensing and GIS technologies were not discussed.

The uncertainty involved in this analysis enters in many steps of the process. An important limitation in this analysis is the coarse spatial resolution of the 8-km pixel of this long-term AVHRR record. Many local areas of degradation certainly fall below the size threshold of 8X8 km pixels. An area of 64 km² inherently contains variability, either in soil, vegetation, land use, or other surface characteristics In addition processes such as registration or geometric correction do alter the data, adding small levels of error. However, generally errors in registration should not affect differences seen in NDVI values.

The findings of the studies about drought and desertification in Africa using NOAA AVHRR indicate that long-term observations for several decades are required for the assessment of desertification and land degradation on global and continental scales. (Justice, et al. 1985, Tucker, et al.1985). The present study was based on vegetation degradation rather than land degradation as vegetation can be assessed using remotely sensed data and it closely related to land degradation and desertification.

Image differencing is a simple process of subtracting one image from another. In this analysis, changes in NDVI were the desired outcome, so NDVI images were subtracted to determine changes in the pixel values over time. This is the most common approach to change detection (Jensen, 2004).

In the following section the main results of the application of RS and GIS techniques will be discussed.

4.2.1. The Net Decreased Areas:
Map (4.12), and Table (4.14) shows the net decreased areas (1993 – 2003), their spatial distribution, areas (6,978.608 Km$^2$) which is 0.28% of the total area of Sudan. These have been marked as areas with low NDVI values throughout the last 10 years. The analysis identified three areas of poor performance where degradation has occurred which are:

1. Al Gedarif, Sennar, Gezira, White Nile, and Kassala States, where the main rain-fed mechanized farming which is often shifting in nature and land clearing practices are used for land preparation and commercial activities (charcoal production).
2. Areas around major oil fields of Unity, Heglig, and Bahr el Arab in the Northern Bahr el Ghazal State as a result of oil industry development.
3. Areas in Western Equatoria, Bahr el Jebel, Jonglei, and Southern Darfur States around the main towns (Yubu, Yambio, Maridi, Yei, Juba, and Nyala).

These three areas are located in high rainfall areas, but still they have interpreted as degraded areas. These findings agree with what have been stated by Hurrington (1998). High rainfall coupled with low NDVI provide an indicator of areas of low production and possible degradation.

4.2.2. The Net Increased Areas:

Map (4.13), and Table (4.14) shows the net increased areas (1993 – 2003), their spatial distribution, areas (244,500.516 Km$^2$) which is 9.81% of the total area of Sudan. These have been marked as areas with high NDVI values throughout the last 10 years. These observed increased in the vegetation cover is due mainly to the increasing rates of rainfall.

These findings confirm with the results of studies conducted by many researchers for example, Rasmussen et al., (2001), stated that, study of vegetation change has demonstrated that, the recovery of vegetation cover started immediately after the drought year of 1984. Hulem (2001) stated that, rainfall in the Sahel has generally increased over the last 5-8 years. The strong secular trend of increasing vegetation
greenness over the last two decades across the Sahel can be explained by increase in rainfall. Nemani et al., (2003). Recent findings based on analyses of satellite images report an increase in greenness over large areas of the Sahel since the mid 1980s, which has been interpreted as a recovery of the vegetation from the great Sahelian droughts and stress the importance of natural fluctuations in rainfall and consequently vegetation response (e.g. Tucker and Nicholson, 1999; Olsson and Eklundh, 2005).

Many studies that have analyzed the relationship between NDVI trends and rainfall indicated that there is a linear relationship between the two (Prince, 1991a, b; Farrar and Nicholson, 1994). Several other studies have also shown a positive relationship between NDVI and rainfall. According to Borak et al. (2000), under dry eco-climatic conditions, the relationship between NDVI and rainfall data is particularly strong because rainfall has a prevalent effect on vegetation conditions.

NDVI trends follow rainfall with varying time lags dependent on environment factors such as soil type (Richard and Poccard, 1998). Further more, Malo and Nicholson(1990), and Justic et al., (1991) investigate the relationship between NDVI values and rainfall data in the semi arid Sahel of Mali and Niger, and concluded that the relationship is long linear.

A preliminary study by Tucker (1988), observed changes in vegetation cover along the semi-arid margins of the sahara in relation to variation in annual rainfall using NOAA-AVHRR data. Tucker et al., (1991), confirmed the earlier findings and demonstrated the highly elastic response of vegetation cover to growing season rainfall, with the desert margin vegetation cover expanding or contracting from year to year depending on annual variation in rainfall.

Increasing rainfall does explain some of the changes but not conclusively. Another possible factor is political unrest and armed conflicts. The vast belt of significantly increasing vegetation across the Central Sudan corresponds to a large extent to states with large numbers of internally displaced people. Almost 2 million people are internally
displaced, (Olsson et al. 2005). That means people have left their homes and live elsewhere away from their normal source of incomes, often around towns. As a result, agriculture is neglected and livestock dispersed. The consequence for the vegetation is often abandoned fields and reduced grazing pressure. Rural-to-urban migration is a very common coping strategy in Sub-Saharan Africa (Schrieder and Knerr, 2000; Mortimore and Adams, 2001; Tiffen, 2003).

The third factor could be the changes in vegetation properties. In semi-arid grasslands and woodlands, annual and perennial species differ in their NDVI response (Karnieli et al., 2002). In particular, the possible increasing amplitude trend may indicate a change in the dominant vegetation cover type.

4.2.3. The Unchanged Areas:

The calculated areas of different change classes throughout the study period reflects the variations in the NDVI or the vegetation cover in term of decreased and increased areas, while most of the unchanged areas (89.90601639 Km²) which is 89.90% of the total area of Sudan (Map 4.11), are related to desert areas (Northern Sudan), the permanent tree cover (woodland/forest) areas (Southern Sudan) and rangeland.

The unchanged areas trends of Northern Sudan (semi-arid and arid areas), shows that the primary perennial vegetation cover that have existed for decades are composed of slow growing Acacia species, that dose not show high densities except along Wadies and Khors. Grazing of nomadic tribes and wildlife that make use of the semi-arid and arid resources closely controls the sparsely distributed perennial vegetation. Consequently controlling vegetation growth and its cover, which could explain the trend of unchanged.

Within the unchanged areas in Southern Sudan (woodland/forest), the trend could be attributed to the fact that the permanent tree cover woodland and forests were inaccessible for mechanized croplands agriculture, slow perennial vegetation recovery rates and inaccessible to firewood collectors and charcoal production.
5.1 Conclusions

It has been shown that Remote Sensing (RS) is a very important technique for understanding desertification and land degradation. While Jensen, (1996) stated, Satellite imagery is very useful for environmental monitoring, because it provides repeated observation of large areas over time.

Long-term observations using NOAA AVHRR for several decades is required for the assessment of desertification and land degradation. It is possible to assess vegetation degradation instead of land degradation by Remotely Sensed data, since it is considered to be very closely related with land degradation and desertification.

The main advantages of the use of the NDVI for monitoring vegetation are:

(i) The simplicity of the calculation;
(ii) The high degree of correlation of the NDVI with a variety of vegetation parameters; and
(iii) The extensive area coverage and high temporal frequency of NOAA-AVHRR data.

Change detection studies, in most cases, is the most effective and economic regular monitoring method for land degradation (Lyon et al., 1998). Application of change detection techniques shows that:

- The presence of vegetation in the arid and semi-arid zones of Sudan is highly variable throughout time and space.
- Overall positive trends in NDVI as indicator of vegetation cover over the period 1993 to 2003 is confirmed, nonetheless the NDVI reflected increase and decrease of the rainfall quantity in the study area. Rainfall is the most important constraint to vegetation growth in this semi-arid zone, which justifies the attempt to predict vegetation greenness from rainfall estimates through linear regression (Herrmann et al., 2005).
- The negative trends in the NDVI are clustered in small areas. Here, vegetation cover has fallen behind what would be expected from the increase in rainfall. These small areas are located in high rainfall areas, but still have been interpreted as degraded areas. This is mainly due to human-induced land degradation.
The unchanged areas were also calculated most properly the trend of unchanged areas were mainly attributed to many factors including the rainfall values, vegetation cover type, and inaccessibility for mechanized agriculture and firewood collectors.

5.2. Recommendations

- Geomatics technology, such as Remote Sensing (RS) and Geographic Information Systems (GIS), are means of providing practical, real time analysis capabilities, which could play a significant role in assessing and monitoring desertification, and providing technical options on combating land degradation in the drylands. A combination of RS, GIS, GPS (Global Positioning System) and ground observations are recommended for building data bases for long term monitoring of land degradation / desertification.

- Additionally RS, GIS, derived information and indexes are also required, to refine the analysis of the other desertification driving forces; such as farming practices, or socio-economic indicators (population, poverty, income,) within GIS data (land use, soil types, and ecological zones maps). The RS will never see and understand socio-economic factors. This is generally true, and solid socio-economic surveys will always be needed.

- The effectiveness of RS, GIS, within Sudan will depend largely on the skills of the experts involved. So it is recommended that the RS, GIS, specialists do not work in isolation, but involve, when possible, land resources and socio-economic experts, even if they are not familiar with RS, GIS, to build integrated analysis.

- For a better understanding of precipitation – vegetation relationship in time and space, it is recommended that, NDVI and rainfall data over a long time series (10 years minimum) should be processed to identify areas of decreasing and increasing vegetation activity compared with the rainfall occurrence in order to try
to differentiate between the climatic drought effect and the land degradation impact.

- It is also recommended to integrate “high-resolution” spatial and spectral satellite imageries such as LANDSAT or SPOT, combined with those from satellites with higher temporal frequency and low spatial resolution, such as NOAA into GIS and spatial models and complemented by new methods of gathering ground data through GPS to improve the effectiveness of NDVI as an indicator of change in land degradation /desertification.

- An important limitation in this analysis is the coarse spatial resolution of the 8-km pixel of this long-term AVHRR record. Many local areas of degradation certainly fall below the size threshold of 8X8 km pixels. An area of 64 km$^2$ inherently contains variability, either in soil, vegetation, land use, or other surface characteristics. Current programs at Earth Resources Observation System (EROS) Data Center are reprocessing 1-km NDVI for Africa, in conjunction with NASA Goddard Space Flight Center. These data will provide an archive of time series data available to the public for detailed analyses of land cover performance at a resolution of 1 km. Therefore additional analysis, using higher resolution (1-km) NDVI data, is highly recommended.


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Appendix

Definitions of Terms:

Analysis
The process of identifying a question or issue to be addressed, modeling the issue, investigating model results, interpreting the results, and possibly making a recommendation., (ESRI, 2004).

Arid Lands
Include those lands where ratio of precipitation to potential evapotranspiration ranges from 0.65 to 0.05.

Band
A measure of a characteristic or quality of the features observed in a raster. Some rasters have a single band; others have more than one. Satellite imagery commonly has multiple bands representing different wavelengths of energy along the electromagnetic spectrum, (USGS, 2004).

Classifying
The process of sorting or arranging attribute values into groups or categories; all members of a group are represented on the map by the same symbol, (USGS, 2004).

Clip
Extracts features from a coverage that overlaps another coverage using the clip coverage as a 'cookie cutter', (ESRI, 2004).

Control points
Points you establish on a paper map whose coordinates represent known ground points or specific locations. Control points are used to register a paper map before you begin digitizing features on it using a digitizer, (USGS, 2004).
Conversion
A Spatial Analyst function. The process of converting input data from one representation to another, such as raster to vector, (ESRI, 2004).

Coordinate
A set of numbers that designate location in a given reference system, such as X, Y in a planar coordinate system or X, Y, Z in a three-dimensional coordinate system. Coordinate pairs represent a location on the earth's surface relative to other locations. (ESRI, 2004).

Data format for digital satellite imagery:
Digital Remote Sensing data are often organized using one of three common formats used to organize image data (ERDAS, 2001). These common formats are:
- Band Interleaved by Pixel (BIP)
- Band Interleaved by Line (BIL)
- Band Sequential (BQ)

Desertification
The United Nations Convention to Combat Desertification (UNCCD) defines desertification as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1994).

Dissolve
Merges adjacent polygons, which have the same value for a specified item, (ESRI, 2004).

Drylands:
Drylands include all terrestrial regions where shortage of water is the dominant factor limiting the production of crops, forage, wood and other ecosystem services. Formally, the definition encompasses all lands where the climate is classified as dry sub-humid, semi-arid, arid or hyper-arid.
Drought

The United Nations Convention to Combat Desertification (UNCCD) defines Drought as “The naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels. Causing serious hydrological imbalances that adversely affected land resources production systems.” (UN, 1994).

Eliminate

Merges selected polygons with neighboring polygons by dropping the longest shared border between them, (ESRI, 2004).

Erase

Erases features from a coverage that overlaps another coverage, (ESRI, 2004).

Format

The pattern into which data is systematically arranged for use on a computer. A file format is the specific design of how information is organized in the file. For example, ArcInfo has specific, proprietary formats used to store coverages. DLG, DEM, and TIGER are geographic datasets with different file formats, (USGS, 2004).

Image processing and analysis:

Image processing and analysis can be defined as the "act of examine image for the purpose of identifying objects and judging their significance", (USGS, 2004).
Land Degradation:

The UNCCD defines land degradation as a "reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation." (United Nations, 1994).

Layer

A collection of similar geographic features such as rivers, lakes, countries, or cities in a particular area or place referenced together for display on a map. A layer references geographic data stored in a data source, such as a coverage, and defines how to display it, (ESRI, 2004).

Map units

The units of the map for example, feet, miles, meters, or kilometers in, which the coordinates of spatial data are stored, (USGS, 2004).

Milliradians

Unit of angular measure equal to one-thousandth the angle subtended at the center of a circle by an area of length equal to the radius of the circle, (USGS, 2004).

Projection

A mathematical formula that transforms feature locations between the earth's curved surface and a map's flat surface. A projected coordinate system includes the information needed to transform locations expressed as latitude and longitude values to X,Y coordinates. Projections cause distortions in one or more of these spatial properties: distance, area, shape, and direction, (USGS, 2004).
Raster
A cellular data structure composed of rows and columns for storing images. Groups of cells with the same value represent features. See also grid, (USGS, 2004).

Rectification:
The process by which an image or grid is converted from image coordinates to real-world coordinates. Rectification typically involves rotation and scaling of grid cells, and thus requires resampling of values, (ERDAS, 2001).

Shapefile
A vector data storage format, for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class, (ESRI, 2004).

Union
A topological overlay of two polygonal spatial datasets that preserve features that fall within the spatial extent of either input dataset; that is, all features from both coverages are retained, (ESRI, 2004).

Vector
A coordinate-based data structure commonly used to represent linear geographic features. Each linear feature is represented as an ordered list of vertices. Traditional vector data structures include double-digitized polygons and arc-node models, (USGS, 2004).