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Assessment and Mapping of Desertification in Western Sudan Using Remote Sensing Techniques and GIS

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Abstract

This study was an attempt to assess and map desertification in the western Sudan (Kordofan and Darfur). The Objective of the study was to develop a methodology using remote sensing and Geographic Information System (GIS) in assessment and mapping of desertification. The Western Sudan is of considerable importance to the Sudan's economy. It is ecologically vulnerable and has been exposed to recent desertification with very serious biological, social and financial losses. For these and other reasons the western Sudan has been chosen as a study area.

Field data were gathered from sites of the research by the aid of GPS and interpreted satellite images. The remotely sensed data used in this study were NDVI images created from AVHRR sensor on board NOAA Satellites.The results produced from these NDVI images gave good indicators of vegetation degradation through the period 1982 – 1994 in the form of image maps. The final result was an image map of assessment of desertification, which gives good indication of areas descertified and those under risk of desertification. The areas desertified were divided into four classes including Light, Moderate, Severe and very Severe. The area of each class was assessed for each state and for the study area. The total area influenced by desertification, about 200000 km, was divided into four grades as follows Light=101836 km, Moderate =68367 km, Severe= 20817 km and Very Severe=8163 km. In 1982 (Reference Year) the boundary of desert shifted about 200 km south of the desert boundary estimated by Harrison and Jackson, (1958). The study also showed that the desert area in western Sudan has increased from 205000 km, (Harrison and Jackson, (1958), to 34000 km, in 1982; and that the Shifting southwards took place at the rate of 8 km per annum.

To sum up it can be stated that remote sensing and geographic information system techniques for assessment and mapping of desertification over large areas of dry lands like western Sudan has been used with acceptable result. In conclusion the study strongly recommended the use of these new techniques in assessment and mapping of desertification in the Sudan so that its control can be achieved effectively.

Introduction

Descertification

1.General

Desertification, which is a progressive environmental degradation terminating in desert-like conditions, have been given different definitions and names. The preliminary evaluation of desertification conducted in 1975/76 preparatory to the United Nations Conference on Desertification (UNCOD1977),came up with he figure of 6 million ha of land lost worldwide annually to desertification.

Dregne (1983/84), not only confirmed the figure but also added that 21 million ha of land were reduced to zero or negative productivity annually .In Sudan , Lamprey,(1975),indicated that a great advance of the desert has been made compared to the situation in 1958 as described jointly by Harrison and Jackson.

He stated that the desert southern boundary had shifted south by an average of about 90-100km in the last seventeen years .He concluded that the desert had therefore advanced at a rate of 5-6 Km per year during the period 1958 to 1975. For assessment purposes. the simplest definition of desertification was given by UNEP Ad Hoc Consultation Group in 1990 as follows:-

2.Definations

The term "desertification" should be used side by side with the term "land degradation". Hence "desertification" in the context of assessment is land degradation in arid; semi arid; and sub-humid areas resulting from adverse human impact. According to the United Nations Conference on Environment and Development(UNCED,1992),Agenda 21 defines desertification as "land degradation in arid, semi arid and dry sub-humid areas resulting from various factors including climatic variations and human activities".

2.1.Land

In this concept land includes soil an local water resources; land surface; and vegetation or crops.

2.2.Degradation

Implies reduction of resources potential; by one or a combination of processes acting on the land. These processes include water erosion, wind erosion, sedimentation, reduction in the amount and diversity of nature vegetation where relevant, salinization and sodication.

Indicators For Assessment and Mapping of Desertification

The processes acting on the land and causing degradation of resources can be used as desertification indicators. However , some of these indicators were found by FAQ/UNEP (1990) to have wider application and could be successfully used in developing desertification assessment and mapping models. These are as follows:

A: vegetation degradation status: which includes actual herb production, potential herb production and annual rainfall,

B: Range carrying capacity status: which includes available herb biomass and predicted livestock consumption.

Statement of the problem

1. Desertification in Western Sudan

The Sudan falls within the zone where the risks of desertification are great. A total area of 65 million hectares, lying between latitude 12°-18° N extending across the country from east to west has been decertified (DECARP,1976). The reduced production of dura, sesame , millet and gum Arabic in western Sudan, combines with overgrazing and dominance of less palatable grasses as well as the extinction of wildlife species as all strong indicators of the seriousness of the problem. The present study is a contribution towards assessing the magnitude of the problem in western Sudan and suggesting possible solutions.

2. Objectives

1- To develop a methodology using remote sensing technique and geographic information system (GIS) and to assess and map Desertification.
2- To Apply this methodology to the study of land degradation in western Sudan.
3- To investigate method and techniques as how to stop, decrease or ameliorate desertification.

Study Area (Western Sudan)

1. Location, Area and Population

The study area, referred to as western Sudan, includes both kordofim and darfur states (before division into six states). Fig.(1). Its longitudes extend from 9.5° N on the border of Behar el Ghazal State and 19.0° N on the border of the northern state and Libya. Their western extremity is at lontigude 21.75° E on the border with Chad and in the west is in longitude 32.o° E on the border of Khartoum and White Nile states.

The area is about 8769400 km ^{2} or 34% of the area of the Sudan. It includes Kordofan(380500 km^2) and darfur 496400 km^2 (World Bank, 1986). The total population was estimated from the 1993 population census as 7.77 million and represents 31.7% of the total population of the sudan; 3.14 million being in kordofan and 4.63 million in darfur states. More than 60% of the total populations are rural, settled in small villages scattered all over the area. Their main occupations are agriculture and grazing. Nomads made 24% of the total population.

2 Ecological Zones

The ecological zones in the western Sudan are classified by Harrison and Jackson (1958) according to the rainfall characteristics into desert, semi desert and low-rainfall savanna woodland. Fig. (2).

Materials and methods

Materials

Materials for research include site of the research and remote sensing materials.

1. Site of the Research

Site of the research, which is part of the study area, is the area covered by the standard Sudan survey 1.250000 scale map sheets for Quelat, Muglad and Abu Gabra Fig. (3).

2. Remote sensing materials

2.1. Normalized Difference Vegetation Index

The study area was investigated with the Normalized Difference Vegetation index (NDVI) images created from the Advanced Very High-Resolution Radiometer (AVHRR) sensor on board the national oceanic and Atmospheric

Administration (NOAA) satellites. The images are available for a time series of 1982 to 1994. Site of the research within the study area (Quelat, Muglad and Abu Gabra) and sample plots were located with the help of landsat TM images and Global Positioning System (GPS). The Normalized Difference Vegetation Index (NDVI) is one of common type of vegetation indices. It is sensitive to change in green leaf biomass and is required for the production of vegetation maps. It is usually represented in the followed mathematical manner ;(Deering, et al, 1975; SDSD, 1982; Pietroniro and Solomon, 1986).

$$NDVI = \frac{Ch2 - Ch1}{Ch2 - Ch1}$$

where

Ch1=visible channel (Red) in AVHRR.

Ch2=near infrared channels (NIR) of AVHRR.

The (NDVI) data range is -1 to +1 and it is unit less. Green vegetation will have positive NDVI values opposite to clear deep water, which has low negative. The NDVI of soils is near zero.

Remote sensing research suggests that emerging vegetation in an area begins between 0.04 and 0.07 NDVI, values; higher than 0.6 are seldom found.

NDVI relates to the amount of photo synthetically active or standing green biomass; therefore NDVI can detect differences between stressed and non-stressed vegetation.

Methods

1. Methods of Data Collection

The methods of data collection in this study included a reconnaissance sample plots, a questionnaire, slides, maps and records and the use of GPS and TMl and sat imagery.

1.1 Reconnaissance and sample plots

Over a period of three months data about forestry , range , soil, and wildlife have been collected with the aid of the Global Positioning System (GPS) and TM images using satellite images as base map covered by a suitable overly; then latitude longitude, and bearing on which sample plots oriented were selected randomly.

2. Methods of data analysis

The methods of data analysis and interpretation included composite procedure from temporal AVHRR data, cover type stratification of composite images, methods of images enhancement (density slicing, arithmetic operation, de-emphasize abrupt changes operations and contrast stretch).

2.1 Composite Procedure from Temporal AVHRR Data

The problem that influence the single data remote sensing studies such as cloud contamination, atmospheric attenuation, surface directional reflectance, off-nadir viewing effects, sun-angle and shadow effect and aerosol and water vapor effects; have been minimized using the composite procedure from temporal AVHRR data.

The composite procedure requires that a series of multi-temporal geo-referenced satellite data be processed into NDVI value and then examined and only the highest value is retained for each pixel location. This procedure Is called the Maximum value composite(MVC). The MVC images in this study were produced for a period of 30 days i.e. Maximum values of each pixel from 30 images through 30 days were taken as one image. Also the MVC images in this study were produced for period of one year.

2.2. Cover-Type Stratification of Composite Images

The stratification of cover classes is the classification of vegetation into different levels and separated from other scene components such as clouds, bare soil, rocks, and surface water.

Depending on the stratification of Holben and Fraser, 1986, the investigator used for this average NDVI values, calculated from maximum, value composite image, for a variety of cover types to demonstrate this stratification.(See Table 1).

Table 1: Stratification of the NDVI images. Adapted from Holben(1986).

Cover Type	NDVI
Deense Green-leaf vegetation	0.500
Medium green-leaf vegetation	0.140
Light green leaf vegetation	0.090
Bare soil	0.025

Fig. (1) The Sudan Location Map

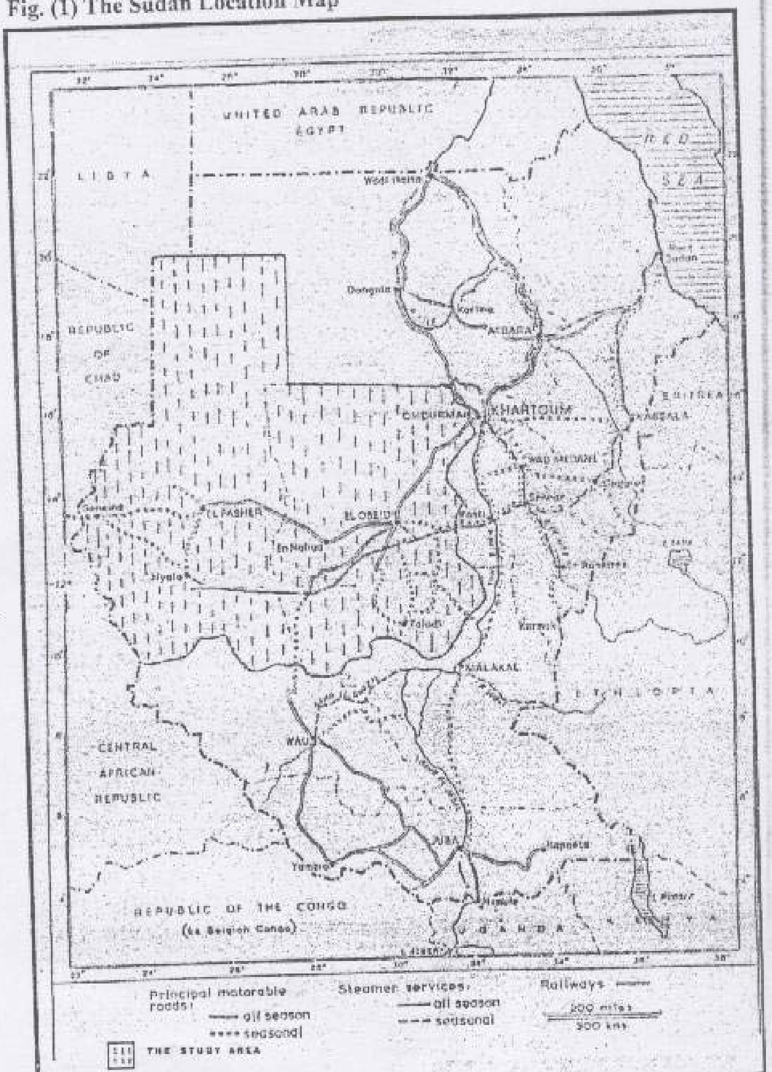


Fig. (2) Sudan Vegetation Map, Harrison and Jackson, 1958.

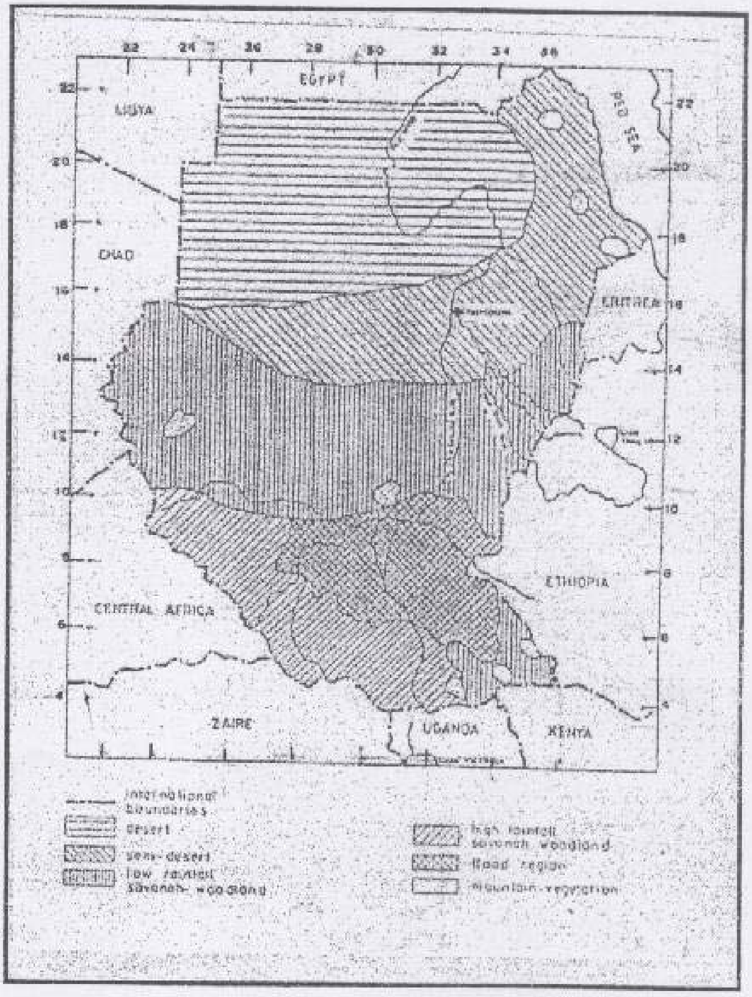
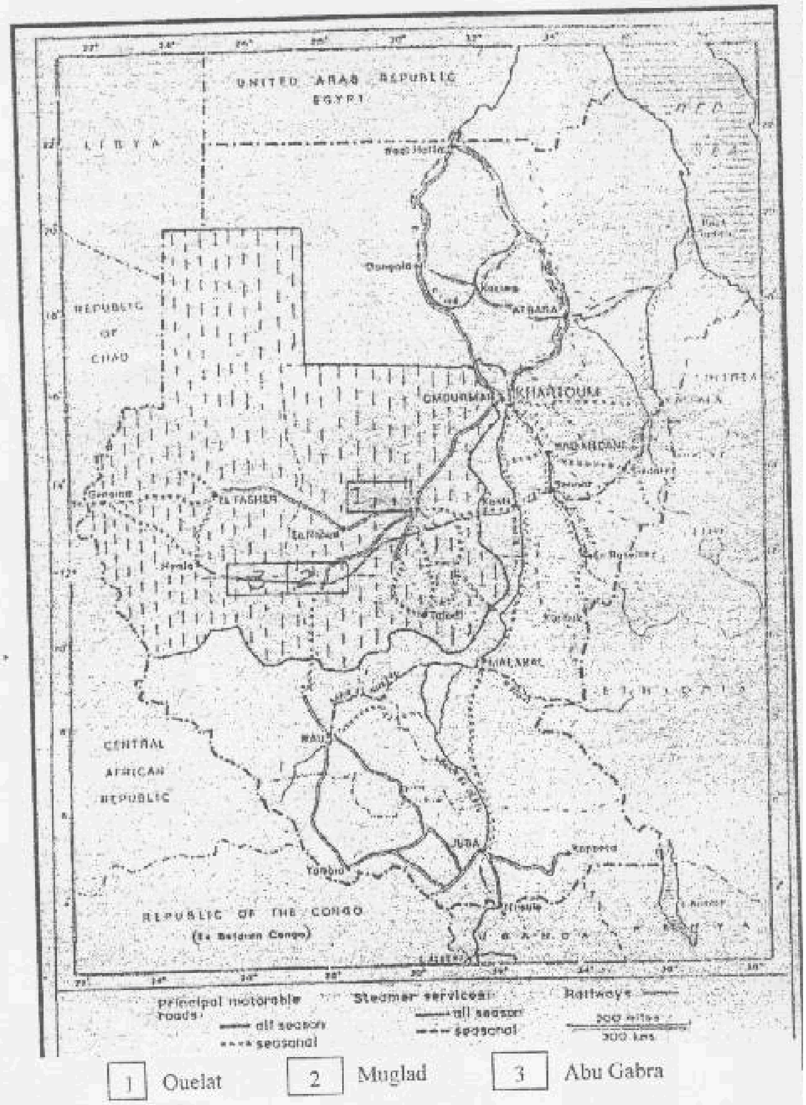


Fig. (3) Site of the Research, Location Map



3. Methods of image enhancement

Enhancement operations are the modification of an image to alter its impact on the viewer.

They are intended to improve the interpretability of an image by increasing the apparent contrast between the features in the scene. A wide variety of enhancement techniques may be employed. Different categories and types are shown as follows; point operations, local operations and auxiliary enhancement. Most enhancement techniques may be characterized as either point or local operations. Point operations modify the brightness values of each pixel in an image date set independently. Local operations modify the value of each pixel in the context of the brightness values surrounding it. In this study, the following operations were used; density slicing, arithmetic operations change detection techniques, de-emphasize abrupt changes operations and contrast stretch.

3.1. Arithmetic operations

3.1.1. Change detection techniques

The arithmetic operations are the processes of subtraction, multiplication and division performed on two or more co-registered images of the same geographical area in this study change detection depends on image subtractions which provides information about seasonal or other changer acquired at different times . The digital numbers (DNs) of one image are subtract from those of an image acquired earlier or later. The resulting value for each pixel will be positive, negative, or zero, zero resulting value indicates no change. This difference, which is called "absolute difference gives magnitude difference. When displaying was needed the quantizing level of the sensors and the capability of displaying devices should be taken into consideration to host the full dynamic range of negative and to re-scale the quantizing level according to the projection device. However the difference image can be expressed mathematically by the following equation:

$$\text{Image Difference} = \frac{255+\text{Iages1} - \text{Images2}}{2}$$

The adding of 255 is done to avoid a negative result and division by two to avoid a number larger than 255.

The resulting values for each pixel range between 0 to 255, where 0 and 255 indicate maximum negative and positive changes respectively. And 127 indicated no change.

To plot these values as an image in black and white manner. Neutral grey tone may represent 127. Black and white tones represent 0 to 255 respectively.

The clouds, shadows, and missed data present only in one image, produce no data in difference image.

Difference images have been used in this study for detecting the degradation of vegetation cover and for assessment of desertification.

Results and discussion

The assessment of desertification. Which is depend on the assessment of vegetation changes using remote sensing techniques, indicated that there has been negative and positive changes since 1982 which appear through figs.(4.a) to (4.f). Gradually it reached its highest negative values in 1984; there are few pockets (wadis) that did not show changes. The situation of vegetation cover started to recover reaching its maximum in 1988.

Comparison of satellite data with ground survey shows that the results obtained by remote sensing , regarding assessment of vegetation changes holds well with the actual ground vegetation in the study area.

Construction maps for desertification assessment depends on the NDVI values. Again Figs (4.a) to (4.f) show that the vegetation condition in 1984 was deteriorating i.e. high negative change was reported. This result conforms well with the official reports of the rainfall which was far below the mean. Also reports of the agricultural statistics department indicate that there was a deficiency in food production during 1984 compared to 1986 and 1988 values.

Average NDVI values (fig.5) demonstrated stratification of variety cover types. These data showed a consistent stratification such that different vegetation classes from dense to sparse have different NDVI values and which are higher than bare soil and are higher than water. However, stratification for large areas of dry lands thus reducing time and money consumed compared to the traditional methods Fig(5) shows the vegetation cover based on the NDVI values. The results showed a high correlation between the integrated image of vegetation cover (fig.5) and the vegetation cover suggested by Harrison and Jacson. (1958), (Fig 2) i.e. the highest values of NDVI correspond to the forest and high rainfall savanna, and the lowest NDVI to desert and semi-desert areas. So to produce a desertification map which represented the effected areas put under risk of desertification through different years and showed bad recovery , an average image of these relative changes images (difference images) has been obtained as illustrated in the analysis. The digitized boundary map of the study area was then placed as an overlay on average image, the negative value was qualified to four classes as follows: light desertification, moderate desertification, severe desertification . However, the result presented in fig (6) indicated that the greatest desertification risk within the study area exist in zones in the semi-desert between 15°n – 16° N North of the latitude 16° N the landscape shows no changes because it is desert.

The northern limit of grass and bush vegetation in accordance with the NDVI image analysis presented in Fig. (6) shifted southwards compared to Harrison and Jackson's (1958) desert boundary, according to this result fig.(6) which is based on remotely sensed data the northern limit of vegetation desert has advanced southwards since 1958 however the examination of desertification map fig (7) shows pockets

Fig. (4) Relative Changes Through 1984 For the Study Area

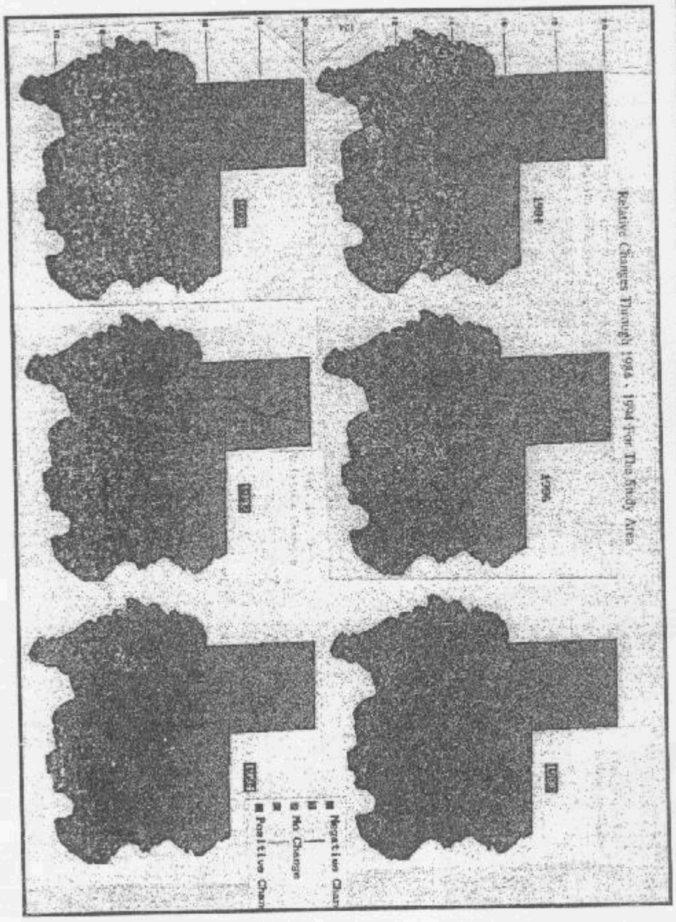


Fig. (5) Stratification of Vegetation Based on NDVI values, Sudan

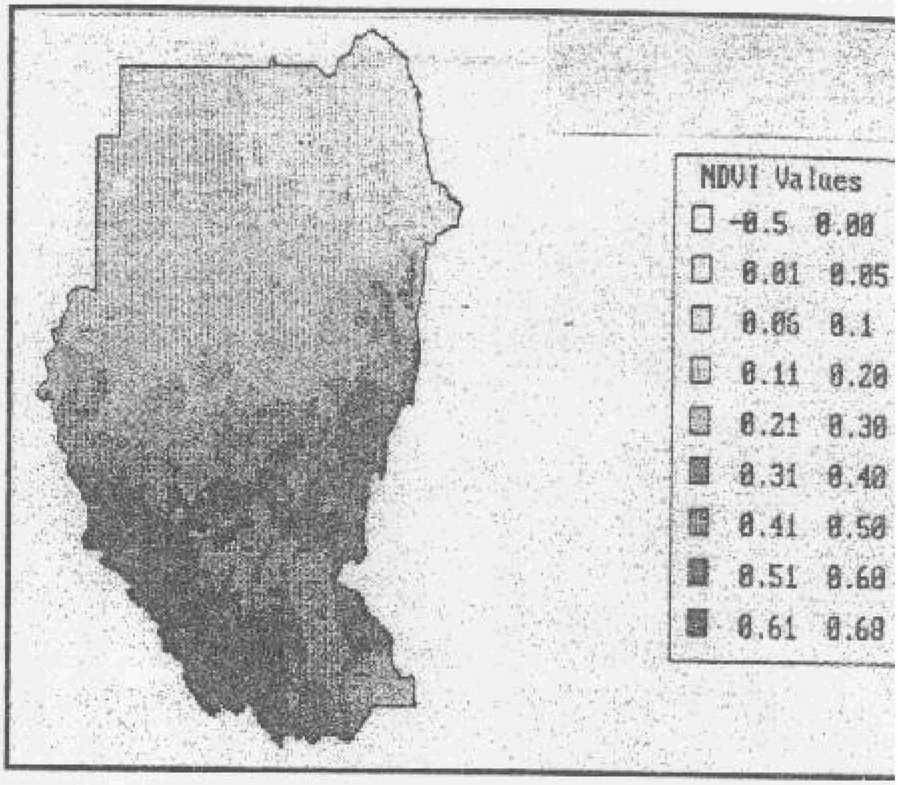


Fig. (6) Map of Desertification, Western Sudan

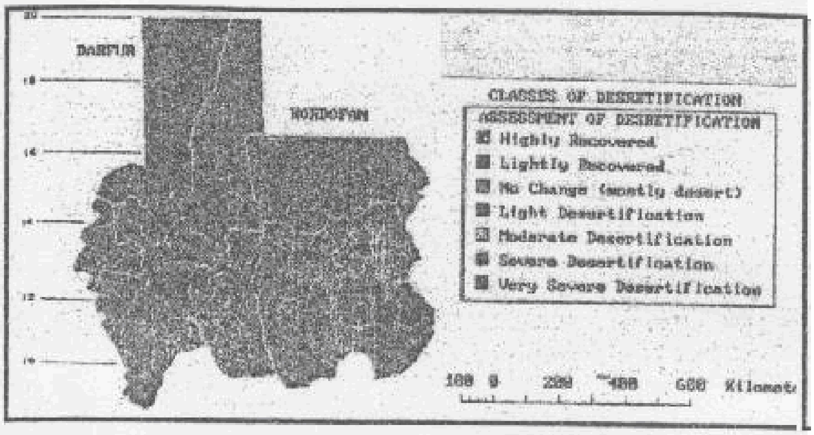
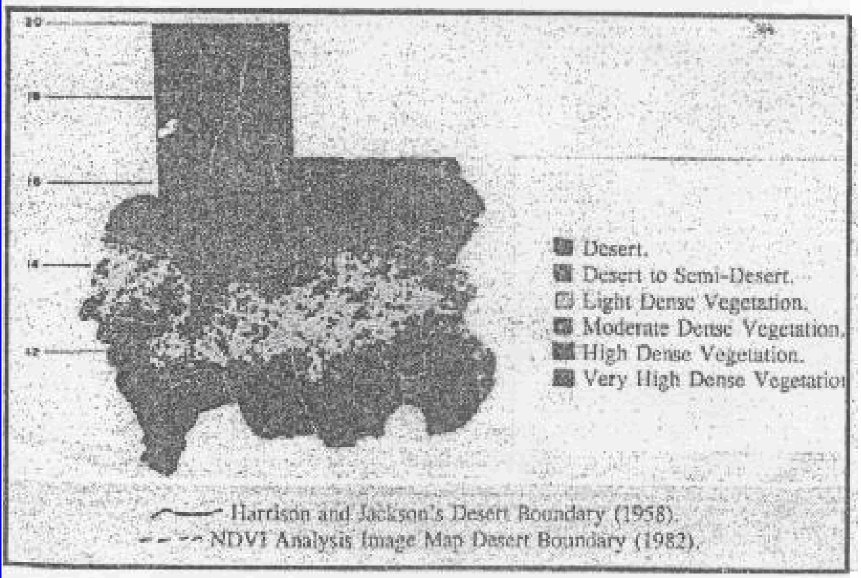


Fig. (7) Comparison Between Desert Boundary 1958 and 1982.



south of the desert boundary begin decertified in circles these patches due to over – exploitations of different natural resources around settlements and water centers are also show in fig (8).

Result show that 22.71% of the western Sudan has been influenced by various degrees of desertification during the period. Fig (7) shows that desertification mainly took place in the semi-desert and low-rainfall sacanna region.

However, the study concluded that some 1991 83 km² (47 million feddans) have been lost to desertification (Table 2 and 3) and their productivity will be reduced to zero. When we compare the vegetation map fig. (7) And the vegetarion map of Harrison and Jackson's natural vegetation boundary shifted about 200 km southwords and the desert area in western Sudan increased from 205000 km²to 340000 km². See table (3).

Table (2): Calculation of Desertified Area in study area according to the Desert Classes.

Desertification Classes	Light		mealerule		severe		Very severe		Total desertified rea	
	Km2	%	Km2	%	Km2	%	Km2	%	Km2	%
Kardofan (280500 km2)	54693	14.37	30612	8.06	8980	2.36	4694	1.23	98979	26.01
Darfur (496400 km2)	27143	9.50	37756	7.65	11837	2.38	3496	0.70	100204	20.19
Total (study area 876900 km2)	101836	1161	68367	7.80	20817	2.32	3163	0.93	199183	22.71

Source Own Calculation

N.B: the areas of desertification show averages of relative changes for the period 1984-1994 . taking 1982 as baseline(reference)year.

Table (3) Land Use of Western Sudan Based on Remote Sensing Data (NDVI).

Land Use	Kardafan		Darfur		Total (Study Area)	
	Km2	%	Km2	%	Km2	%
Desert Area	100000	29.4	240000	70.6	340000	38.8
Desertified Area	98979	49.7	100204	50.3	199183	22.7
Undesertified	118152	53.7	156196	46.3	337717	38.5
Total Area	380500	43.5	496400	56.5	876900	100

Source: Own Calculation

N.b:1. Area of desert estimated by Harrison and Jakson . 1958 was about 180000 Km2 in darfur and 25000 Km² in Kordofan compared to 240000 Km² and 100000 Km² in 1982 respectively.

2.the areas of desertification show averages of relative changes for the period 1984 -1994 , taking 1984 as baseline (reference) year

Coclutions and recommendation

The NOAA-AVHRR Vegetation Index (Normalized Difference Vegetation Index) has proven to be a computable tractable indicator for detecting changes in the vegetation zones and for the assessment of desertification in western sudan and has given good results in the form of image maps. Also the integration of Remote Sensing data (i.e. NDVI images used in monitoring of vegetation changes) and the Geographical Information System (GIS) proved to be an equally efficient system for the assessment of desertification.

Other than the production of image maps it has been possible to assess the areas of land in western Sudan that has been lost to desertification. The NDVI images analysis shows that about 47 million feddans (200000 square kilometers) in western Sudan have been lost to desertification since 1958.

The study recommends usage of remote sensing (NDVI images techniques and Geographic Information System (GIS) in future assessment and mapping of desertification and also puts forward some suggestions as how to reduce desertification through a forestation techniques.

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