Sudan Vegetation Cover Assessment, Using NOAA-AVHRR Data, for the Period “Between 1982-1999”

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Abstract: The objective of this study was to assess changes in the vegetation of Sudan between 1982 and 1999 by using remote sensed images and to compare the vegetation with that of Harrison and Jackson of 1958. NOAA-AVHRR data was used and processed by Maximum Value Composite of the Normalized Difference Vegetation Index. Vegetation maps were produced for the years 1982, 1984, 1987, 1990, 1993, 1996 and 1999. Also, maps for differences using 1982 as reference map were produced. The maps didn't show differences between 1982 and 1999 except in the southern parts where the vegetation got denser with the years. Large change was observed when compared with Harrison and Jackson 1958. The area north of latitude 16° has changed to desert while that between Latitudes 12°N and 16°N changed from low rainfall savanna to desert and semi-desert.

INTRODUCTION

Vegetation changes are attracting the attention of environmentalists and socio-economists. Such changes have been occurring rapidly, especially in developing countries, and their influence on environmental conditions may be as large as the effect of climatic change (Tuner et al., 1995).

In 1948 the first attempt to produce a description and map of the vegetation of Sudan was made (Andrews, 1948). A year later, it was followed by classification with slight modifications (Smith, 1949). A decade later, the combined ground surveys of Harrison & Jackson (1958) classified the vegetation zones of Sudan that became the most cited reference. The classification includes from north to south: desert, semi-desert scrub, low rainfall savanna woodlands, and high rainfall savanna woodlands and flood region (Figure 1). It agrees with later survey based on photo-interpretation (Wickens, 1981). However, the classification differs from that simulated for Sudan before twelve monthly.

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thousands years (DECARP, 1976) where the desert had moved considerably to the south pushing the other zones southwards.

Natural resources inventories are conventionally done using ground based and aerial surveys. Ground survey is expensive, time consuming and prone to errors. Also, acquisition and interpretation of aerial photography is costly, about ten times more expensive than space borne remote sensing (Zeichert 1986).

Images derived from remotely sensed data can be a good source for the evaluation of land-cover change, considering both regional and/or global scales (Dobson et al., 2001; Carreiras, 2002). The data of the Advanced Very High Resolution Radiometer (AVHRR) of National Oceanic and Atmospheric Administration (NOAA) is widely used for land-cover characterization and the mapping of daytime and nighttime clouds, snow, ice and temperature of the surface of the earth and the sea (Defries et al. 1995; Kwasteng & Chavez, 1998; Lyon et al., 1998, Yang et al. 1998; Hope et al., 2003). The AVHRR collects data in five spectral bands: two reflective channels, the red (0.58-0.68 μm), and the near infrared (0.72-1.10 μm); and three thermal infrared channels (3.55-3.93, 10.30-11.30 μm, 11.5-12.5 μm). Also, vegetation indices derived from satellite data provide spatial and temporal quantitative information on vegetation reflectance that reflects the environmental factors that influence the biodiversity of a region (Lillesand and Kiefer, 1994; Diniz et al., 2000).

Figure 1: Solar Vegetation Map (Harrison & Jackson 1958)
Among the several vegetation indices is the Normalized Difference Vegetation Index (NDVI). The NDVI is based on a relationship between the response of vegetation in the red visible (R) channel and near-infrared (NIR) channel. Green vegetation has a low reflectance in the red band due to absorption by chlorophyll and other leaf pigments, and a high near-infrared reflectance due to characteristics of the spongy mesophyll layer of the leaves. The magnitude of NDVI value, ranges between (-1) and (+1), A high reflectance in the NIR channel and low reflectance in the red channel observed for dense green vegetation produce a positive NDVI value, and negative NDVI values indicate the presence of clouds, snow, water, or a bright non-vegetated surface (FEWS, 1999; NASA, 1997; Jensen, 2000).

In Sudan NDVI values were used to compare vegetation between periods of time to detect anomalous conditions (FEWS, 2000). The study of NDVI images and ground survey in Western Sudan revealed that NDVI images gave good indicators of vegetation degradation during the period of the study (1982 - 1994) (Ali 1996). Vegetation zones were reported to be shifting southward with accelerating soil erosion and desert creeps (Erkholm, 1977). Hassaballah and Nimir (1985) stated, “The largest threat to natural ecosystem is desertification, particularly in the North of Sudan. It is assumed that there is decline in vegetation cover and changes in species composition, especially for forest tree species due to drop and fluctuation in annual rainfall (Radi, 2004), overstocking of animals in Western Sudan (Ali, 1996).

The objective of this study is to investigate the vegetation changes in Sudan between 1982 and 1999, and to compare that with the vegetation zones delineated by Harrison and Jackson (1958) using NDVI derived from AVHRR images.

MATERIALS AND METHODS

Study area

The study covers the whole area of Sudan, which lies between latitude 3°53'N and 21°55', and longitude 21°54' E and 38°31’ E. The changes in vegetation were studied for the period between 1982 and 1999.
Materials
The data used in this study were obtained from the National Remote Sensing Center and Early Warning System Unit of the Humanity Aid, Khartoum, Sudan. The data was captured by AVHRR sensors onboard NOAA meteorological satellites. The National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) processed the data. The datasets were containing images spanning 18 years from 1982 to 1999. For each year, 36 images were used and the pixel size of each image is 80 x 80 km.

Methods
To obtain complete cover of the land surface, a 10-days maximum is obtained and selection was made for the maximum NDVI value (greenest) from each 10-days period (dekad). Maximum Value Composite (MVC) procedure selects the greenest value that generally represents the least cloud-contaminated pixel for each dekad period (Holben, 1986). Also, the MVC procedure was used to obtain the maximum value for each year from each pixel of the 36 images.

The first (year 1982) was considered as a base year for this study. The years 1984, 1987, 1990, 1993, 1996 and 1999 were selected by interval of three years to detect more discernable changes.

The NDVI is calculated as the difference of two wavelength channels (near infrared and visible red), which is then normalized by the sum of the two channels (NASA, 1997):

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

Where:
- \( \text{NDVI} \) = Normalized Difference Vegetation Index
- \( \text{NIR} \) = Near Infrared Band
- \( \text{VIS} \) = Visible red Band

NDVI values range between (-1) and (+1), the positive values are referred to as “greenness maps” since they represent the vegetative vigor of plants. Images color composites were used to represent vegetation index value ranges corresponding to vegetation densitier.
The Image Display and Analysis software (IDA) was used in this study. The IDA system is mostly used for regional analysis and monitoring of vegetation using NDVI images (Pfirman, 1991). The analysis of data consists of the computation of the difference of NDVI values between the years under consideration. Differences between year 1982 as a base year and the years 1984, 1987, 1990, 1993, 1996 and 1999 were computed. The difference acquired by subtracting the value of each pixel of the two years can be expressed by the following equation, which is (Pfirman, 1991):

\[
\text{Image difference} = \frac{255 \times (\text{Image 1 pixel value} - \text{Image 2 pixel value})}{2}
\]

The addition of 255 is to avoid a negative result and division by 2 is to avoid a number larger than 255. The values obtained ranged from 0 to 255, where 0 means maximum negative change and 255 maximum positive changes in vegetation change, where the 127 values indicates that there is no change in vegetation (Pfirman, 1991).

Maps for MVC-NDVI and MVC-NDVI difference were prepared using IDA program. Each map provides a legend that consists of colours for each range of values that represent type of vegetation according to Famine Early Warning System standards for satellite vegetation analysis definition (FEWS, 1995) as shown in the figures 2 to 15.

Data analysis
First, the prepared maps for the years 1982, 1999, 1984, 1987, 1990, 1993, 1996 and 1999 were used to describe the vegetation in Sudan. The countrywide principle components analysis was undertaken to detect the overall tendencies of variation of NDVI. The spatial pattern has been identified, which coincides with the vegetation zones and was compared to Harrison and Jackson (1958).

Secondly, the country was divided into four regions from North to South: North latitude 16°N, between latitude 16°N and 12°N, between latitude 12°N and 8°N and South of latitude 8°N. Description vegetation in each region was made for the years as in the first step using the maximum vegetation complex NDVI and the difference analyses maps depending on the legend colours. Vegetation status for
each region was then compared to that of Harrison and Jackson
(1958).

RESULTS AND DISCUSSION
Sudan countrywide (1982 to 1999)
Figures (2) to (8) show consistent features in the Southern and
Northern parts of the country. In the Southern region the NDVI values
were high (between 0.5 to 0.68), particularly in the west parts between
latitudes 4°N and 8°N where natural vegetation is dense and
comparatively less influenced by human activities. In the Northern
region the NDVI values were low, ranging between 0.0 and 0.2, where
desert is dominant North latitude 16°N. As NDVI reflects the
relationship between the absorption of the visible red and the near-infrared
radiations by plants, the high NDVI values in southern region
compared to that of the northern region show that the southern region
is highly vegetated. This is not surprising as the southern region is
characterized by high rainfall and fertile soil. Also, it is apparent that
the NDVI values has similar trend to that of the rainfall. The classic
cumulative total amounts of rain in Sudan shows latitudinal gradient.
Rainfall increases from North to the South. Sudan can be divided into
5 rainfall zones: desert (rainfall between 0 and 50 mm), semi-arid (50
to 200 mm), arid (200 to 600 mm), sub-humid (600 to 900 mm), and
humid (more than 900 mm).

The distribution of the vegetation zones in the years 1982-1999 differ
from that described by Harrison and Jackson (1958) figure (1). The
difference may be due to the drought that prevailed in the area since
late 1970’s beside desert encroachment, which caused major changes
on the land cover. The desert moved southwards to dominate all the
area north latitude 12°N while the semi-desert shrank to a narrow belt
adjacent to the desert. It is clear that there is dense vegetation in Sudan
in the southern part of Sudan between latitude 4°N and 8°N where
moderate dense and high dense vegetation were dominant in the area
throughout the years of the study.

Figures 9 to 14 show maps of the difference analysis of the MVC-
reference to 1982. The maps showed minor changes in the Northern
parts of the country (North latitude 16°N) and periodic change in the
central and Southern parts of the country. This is expected since the Northern parts are desert and the amount and the duration of the rainfall between years are variable in the central and southern parts of Sudan.

Sudan sub-regions (1982 to 1999)

North latitude 16° N

This region is characterized by low values of MVC-NDVI that can be described as desert area shown in figures 2 to 8. The difference analysis of the MVC-NDVI for the years showed little change in vegetation index, which is represented by grey colour in Figures 9 to 14 with reference to 1982.

Comparing of Harrison and Jackson map (1958) with the MVC-NDVI maps (Figures 2 to 8) shows clear advancement of the desert to the south at the expense of the semi-desert areas. The Eastern part of the semi-desert is completely converted into desert.

Between latitude 12° N and latitude 16° N

Most of this area is desert and semi desert (Figures 2-8). The west and middle parts have low MVC-NDVI values that can be described as desert followed by a narrow band of semi desert and light vegetation cover (Figures 2 to 8), whereas, the Eastern part has higher MVC-NDVI values.

The MVC-NDVI difference analysis demonstrates that the years 1984 and 1990 (Figures 9 and 11, respectively) have less vegetation in the region, mainly due to low rainfall during these years. On the other hand, the years 1987, 1993, 1996 and 1999 (Figures 10, 12, 13 and 14, respectively) showed improved vegetation cover.

The most Northern part of this region was characterized by semi desert and the Southern with low rainfall woodland savanna in Harrison and Jackson (1958) (Figure 1). The MVC-NDVI maps for the years 1982 to 1999 (Figures 2 to 8) showed that the northern part of this region is complete desert and the southern part are semi-desert, indicating clear change of vegetation in this region.
Between latitude 8° N and latitude 12° N

The MVC-NDVI values showed dense to high dense vegetation in 1982 to 1999 as shown in Figures 2 to 8. However, in 1990 scattered spots of denser vegetation, especially in the southwest were observed (Figure 5).

The MVC-NDVI difference analysis as compared to 1982 indicates that 1987, 1990, 1993 and 1999 (figures 10, 11, 12 and 14) showed less vegetation. But the years 1984 and 1996 (Figures 9 and 13) showed improved vegetation cover in the region. The common characteristics of this region are stable vegetation during the period of the study.

When comparing Harrison and Jackson map (1958) with the MVC-NDVI for 1982 to 1999 represented by Figures (2-8), it was clear that there is no apparent change in vegetation cover.

South latitude 8° N

The MVC-NDVI values fluctuated between moderate to high dense vegetation during 1982 to 1999 (Figures 2 to 8). In some areas it reached high dense vegetation during 1990 (Figure 5), especially in the Western parts. The most Eastern part was characterized by low MVC-NDVI between 1982 and 1999.

The analysis of the MVC-NDVI ranged between lightly recovered to highly recovered vegetation cover during the period of the study, except in the years 1984 and 1999 (Figures 9 and 14) where deterioration in the vegetation cover in most of the Eastern part of this region was observed.

When comparing the MVC-NDVI maps (2-8) with the map of Harrison and Jackson (1958), it was clear that there are no apparent changes in the vegetation.

CONCLUSIONS

The AVHRR data for the years 1982, 1984, 1987, 1990, 1993, 1996 and 1999 provided spatial, temporal, and radiometric quantitative information that were used to derive NDVI which was translated into vegetation maps for the Sudan. This indicates the possible use of...
NDVI images is detection of vegetation changes in Sudan. The NDVI values decreases northward following the amount of rainfall which shows latitudinal gradient.

There is no apparent change in vegetation cover in the periods studied except, in the years 1984 and 1990 which were characterized by low rainfall. However, there is a clear difference between the vegetation zones of the map of Harrison and Jackson (1958) and the maps derived from the AVHRR data, particularly in the region north latitude 12°N where there is a clear advancement of the desert southwards. The results of this study showed that further investigation is needed to include recent years, to discuss in detail the relationship between the boundaries of the vegetation zones and the rainfall zones, as well as the boundaries of Jackson’s vegetation map.

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تقييم التغير في الغطاء النباتي في السودان باستخدام تقنيات الاستدلال عن بعد خلال الفترة بين الأعوام 1982 و 1999

هادي كمال الدين أحمد و عصام الدين إبراهيم وراق