Assessment of Natural Vegetation Clearing and Re-Growth in Southern Gadarif (Sudan) Using Change Vector Analysis Based on Remote Sensing and Field Data

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KEY WORDS: Natural Vegetation, Clearance, Re-Growth, Change Vector Analysis

ABSTRACT:

There is a global increase in the recognition of environmental, social and economic values of native vegetation, particularly in terms of both sustainability of agricultural production and maintenance of natural resources. The rapid growth of the human population in Sudan (2.6 % per year) stimulated the evolution of mechanized agriculture in the Gedarif Area from 500 ha in the 1940s to about 2.3 million ha in 2003. Nearly one third of Sorghum (*Sorghum bicolor*) and Sesame (*Sasemum indicum*) produced in Sudan is cultivated in this area. Destruction of natural vegetation to provide agricultural land, associated with poor agricultural practices has resulted in a continuous degradation of the natural resources. A significant amount of agricultural land is now abandoned. Within this context, the objectives of the present study are to analyze the historical changes of natural vegetation due to agricultural expansion and to assess the present condition of natural regeneration on the abandoned agricultural land.

Multi-temporal Landsat (MSS and ETM) data has been utilized to detect the historical vegetation changes using Change Vector Analysis (CVA). Image transforms (NDVI and TCT), supervised classification and field data have been used to quantify different land-use/land cover-classes and for assessing the present condition of the natural vegetation on abandoned agricultural land in the study site. Field survey has been conducted using stratified random sampling. All sample plots have been registered using GPS. Number and composition of trees/shrubs and above-ground herbaceous biomass were recorded. The field data has been combined with the satellite imagery using regression technique.

The results demonstrate the capacity of the CVA to stratify different historical land-use/land-cover dynamics with a measurable direction and magnitude. Results showed a fast process of deforestation within critical levels. The remaining natural vegetation of 2003 represented approximately one fifth of the total natural vegetation of 1972. Field data has proven to be important to increase classification accuracy and to assess the vegetation attributes which otherwise could not be estimated using the Landsat imagery only.

1. INTRODUCTION

Presently a global increase in the recognition of environmental, social and economic values of native vegetation, particularly in terms of both sustainability of agricultural production and maintenance of natural resources can be noticed. The relationship between agricultural productivity and economics has driven patterns of human land use and population distribution throughout the history and this close relationship has only recently been disturbed by potentially motivated economic subsidies (Huston, 1995).

Although Sudan is one of the wealthiest countries of Africa in terms of natural resources, the conflicting goals between increased production and sustainable resource management became evident in the rain-fed agriculture, particularly in the large-scale mechanized farming. After over half a century of unsustainable use, however, studies indicate that about 120 million ha of land are degraded to varying degrees (Ayoub, 1999). The rapid growth of the human population in Sudan (2.6 % / year; UNFPA, 2003) stimulated the evolution of mechanized rain-fed agriculture in the Gadarif Area from 500 ha in the 1940s to about 2.3 million ha in 2003 (Figure 1).

Nearly one third of Sorghum (*Sorghum bicolor*) (The primary stable crop) and Sesame (*Sasemum indicum*) produced in Sudan is cultivated in this area. Like most developing countries, Sudanese economy depends largely on agriculture (70 % of the population of the country work in agriculture. 90 % of them live in rural areas). In order to achieve sustainable agricultural development, priority has to be put on maintaining and improving the capacity of the higher potential agricultural lands to support an expanding population and on conserving and rehabilitating the natural resources on lands with a lower agricultural potential (Hassan, 2002).

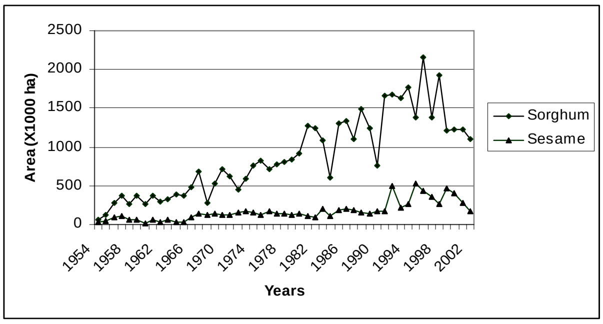

Figure 1: Total area under two main crops in Gadarif region for the period 1954 – 2003 (Source: Mechanized Farming Corporation, Gadarif Office)

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The recent Global Forest Resource Assessment (FRA, 2005) Report showed that 28.4 % (67 546 000 ha) of Sudan is forested. The change in forest cover between 1990 and 2000 was averaged to 589 000 hectares of forest per year, which amounts to an average annual deforestation rate of 0.77 %. Measuring the total rate of habitat conversion (defined as change in forest area plus change in woodland area minus net plantation expansion) for the 1990 - 2005 interval, Sudan lost 11.6 % of its forest and woodland habitat. According to SCSB (2001) there are 112 plant species of which 91 species are endangered and three species almost extinct in the study area.

Land-cover mapping using remotely sensed data not only provides a current inventory of resources and land-use, but also provides an opportunity to identify and monitor changing patterns in the landscape. Traditional methods for monitoring land-cover change relying on field data and aerial photography can be costly and time-consuming for relatively large areas (Peterson *et al*., 2004). The cost of such traditional field survey could be one of the limitation factors for countries like Sudan. However, satellite imagery gives unique indispensable capabilities for assessing and monitoring of natural resources at comparatively moderate costs.

Recently, remote sensing and GIS have improved significantly the capability to monitor processes of land-use and land-cover change and therefore become fundamental tools for the understanding and monitoring of deforestation and secondary succession processes particularly in the tropics, the area with the most promising research opportunities (Westman et al., 1989). Analysis of the recent history of the present patterns of land-cover offers a present-day baseline for assessing future landscape patterns and their consequences (Zheng et al., 1997). Within this context, the objectives of the present study are to analyze the historical changes of natural vegetation due to expansion of mechanized rain-fed agriculture and to assess the present condition of natural regeneration on some of the abandoned agricultural land using remote sensing imagery and field data.

2. STUDY AREA

The study area of approximately 55 X 40 km^2 is located in the vicinity of the rural city of Doka, southern Gadarif (eastern Sudan) (Figure 2). The area falls within the Sudano-Sahelian climate zone of Africa. Soils are dark, heavy, deep cracking *vertisol*. Annual rainfall is concentrated in a single relatively short summer season during June to September, and amounts to around 680 mm per annum. Temperatures ranges from a mean minimum of 17° C in January to a mean maximum of 40° C in April and May. Harrison and Jackson (1958) classified the natural vegetation of the study area as an *Acacia seyal* and *Balanites aegyptica* Savannah. Sorghum grasses, *Cymbopogon spp* and *Sporobolus* grass species dominate areas of fallow or abandoned crop-land (SKAP, 1992). The vegetation is marked by a clear intra-annual seasonal variations This natural vegetation has largely been destroyed in the course of widespread clearance for crop cultivation and only scattered fragments remain. There is no recent reliable and comprehensive data for vegetation cover of the study area and the few surveys carried out in the past have become outdated because of the dramatic changes in the environment. However, despite these changes of the natural vegetation sufficient traces remain (e. g. tracks between farms, abandoned farms, areas around water courses) to permit a description of the dominant plant communities in the region.

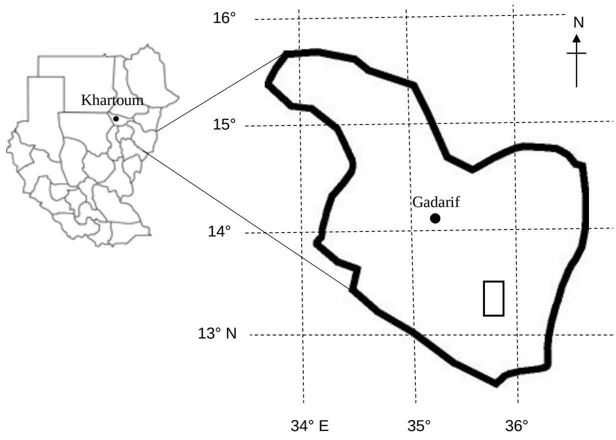

Figure 2: Location of the study area

3. DATA

Multi-spectral cloud-free Landsat MSS (Dec. 1972 and Nov. 1979) and ETM (Nov. 1999 and April 2003) imagery, acquired from the Global Land Cover Facility (GLCF), has been utilized. Pre-processing techniques are applied to attenuate geometric and radiometric variations. Accurate geometric registration and radiometric normalization are the two most critical pre-processing requirements for successful change detection (Singh, 1989; Coppin and Bauer, 1996 and Coppin et al., 2004). In order to get a cartographic uniformity of the different scenes, the geometric correction was based on 17- 20 ground control points from the pre-registered 1999 Landsat ETM image. For the normalization of the reflectance values for all images, Markham and Barker's (1987) relationship has been implemented. Field survey using stratified random sampling was conducted during March and April 2005 on the abandoned agricultural land. A total of 77 sample plots (20 x 20 m^2) have been registered using GPS.

4. ALGORITHMS

Change vector analysis (CVA)

Since its application by Malila (1980) which aimed at a detection of changes in forested areas, CVA has often been applied and advanced. Examples are for instance given by Lambin and Strahler (1994) and Johnson and Kasischke (1998) to characterize change magnitude and direction in spectral space between different dates for the same area. To overcome some drawback of this change detection technique, many authors suggested a modified CVA (Narckaerts *et al*., 2005 and Warner, 2005).

CVA is a multivariate change detection technique that processes the full spectral and temporal dimensionality of the image data and produces two outputs: change magnitude and change direction. A major advantage is its capability to simultaneously analyze change in all data layers as opposed to selected bands (Coppin *et al*., 2004). CVA offers its greatest potential in situations where full-dimensional radiometric change information is desired (Johnson and Kasischke, 1998). Lambin and Strahler (1994) defined change vector as the vector differences between successive time-trajectories, each represented as a vector in a multidimensional measurement space. The length of the change vector indicates the magnitude of the inter-annual changes, while its direction indicates the nature of the change. In their work they used a principle component analysis of calculated change vectors for a Sudanian-Sahelian region in West Africa. It results in four classes of change magnitude and four general contrasting types of change. The magnitude of change vector which measures the intensity of the change in land cover can be computed as the Euclidean distance between two points in the *n*-dimensional space. Johnson and Kasischke (1998) mentioned that change vector direction is most indicative and interpretable when phenomenologically relevant spectral features (e. g. Tasseled Cap Transformation – TCT) are used as input data rather than raw data. For example, loss of vegetation would be primarily associated with features characterized by an increase in TCT brightness and a decrease in TCT greenness.

For this study, a multi-spectral CVA has been applied to assess the natural vegetation clearance on the basis of greenness and brightness components derived from a Kauth and Thomas (1976) TCT. In this case, greenness is associated with the amount and vigor of the vegetation and brightness is with the variation of soil reflectance. TCT is one of the valuable standardized satellite data transformations for enhancing spectral information content of the satellite imagery. It especially optimizes data exploration for vegetation studies. However, when specific changes of interest can be anticipate in advance, it is sometimes possible to develop and implement specific spectral features which enhance the ability to detect and label those changes (Johnson and Kasischke, 1998). The two output bands of the CVA (direction and magnitude) can be handed over to a statistical change feature extraction using different classification algorithms (Groß, 2003 and Nackaerts *et al*., 2005).

Classification of land cover changes

To perform a quantitative analysis of the change vectors, direction and magnitude channels have been utilized as input for a maximum likelihood supervised classification to discriminate and quantify different land cover changes. The type of the change is identified using the angle of the vector. In the case of the magnitude channel, the high negative numbers illustrate a natural vegetation clearance and high positive values indicate natural regeneration areas. Accordingly, land-cover classes and change types have been grouped into four types (Table 1).

The selection of representative training data for the supervised classification was based on field survey, visual comparison of the original images and the author's background knowledge. Richards and Jia (1999) stated that the major step in a straightforward supervised classification is the selection of training pixels. Prior to identification of training pixels an intensive field survey (March and April 2005) was carried out and historical land use information was collected from pioneer farmers who were among the first group to invest in mechanized farming in the area. The second group interviewed was the staff of the Forest National Corporation (There exist no recent maps and records concerning the land use activities for the study area). For the visual comparison with the original images, different viewing utilities and the signature editor, both of ERDAS Imagine (Version 8.7) were used.

During the field work the number and composition of trees/shrubs and above-ground herbaceous biomass were recorded. Linear regression was used to relate land-cover types to a 3 x 3 pixel window generated from the NDVI image to evaluate which ground-based measures might relate to satellite data.

Land-cover class	Description
Natural vegetation (NV)	Natural forest and woodland savannah. The only remaining forests are Saref-Said National Forest and some small private forests on some unsuitable or low-fertility soils. Woodland savannah occurs along seasonal water courses and some depressions.
Natural vegetation converted to agricultural land (NV to AL)	Deforested areas under rain-fed mechanized farming. In general, they include bare soils, very sparsely vegetated areas, areas covered with crop residue or late emerging grass species debris. Theses areas are cultivated with Sorghum and Sesame.
Agricultural land (AL)	
Abandoned agricultural land (AAL)	Former agricultural land having been abandoned 3 – 10 years ago. These areas represent the naturally regenerated parts.

Table 1: Land-cover classes and change types

5. RESULTS & DISCUSSION

Changes in land-cover and land-use have been determined by computing the differences in land-cover and land-use statistics over the study period. Field data has been utilized to quantify vegetation attributes on the abandoned agricultural lands. Table 2 depicts the land-use/land-cover changes for the period 1972 – 2003. Figure 3 shows a comparison of supervised classification results for the CVA channels.

Analysis of the change image 1972 - 1979

The period 1972 to 1979 shows an intensive clearance of natural vegetation due to a dramatic expansion of mechanized rain-fed agriculture. It reached to 11.4 % per year and the total area under the plow was about 210 600 ha (85.9 %). According to the information collected from the farmers, the seventies were the golden time of the rain-fed mechanized agriculture in the region, and the high initial profitability encouraged many farmers to clear new areas from its natural vegetation. Moreover, opening new areas has double benefit, gaining a new fertile agricultural land and at the same time selling the harvested wood at local market as fire wood and or building materials. Woody materials are still the main building material in the region. Abandoned agricultural land could not been detected at this period.

Analysis of the change image 1979 - 1999

The land-cover changes the period for the 1979 - 1999 show an

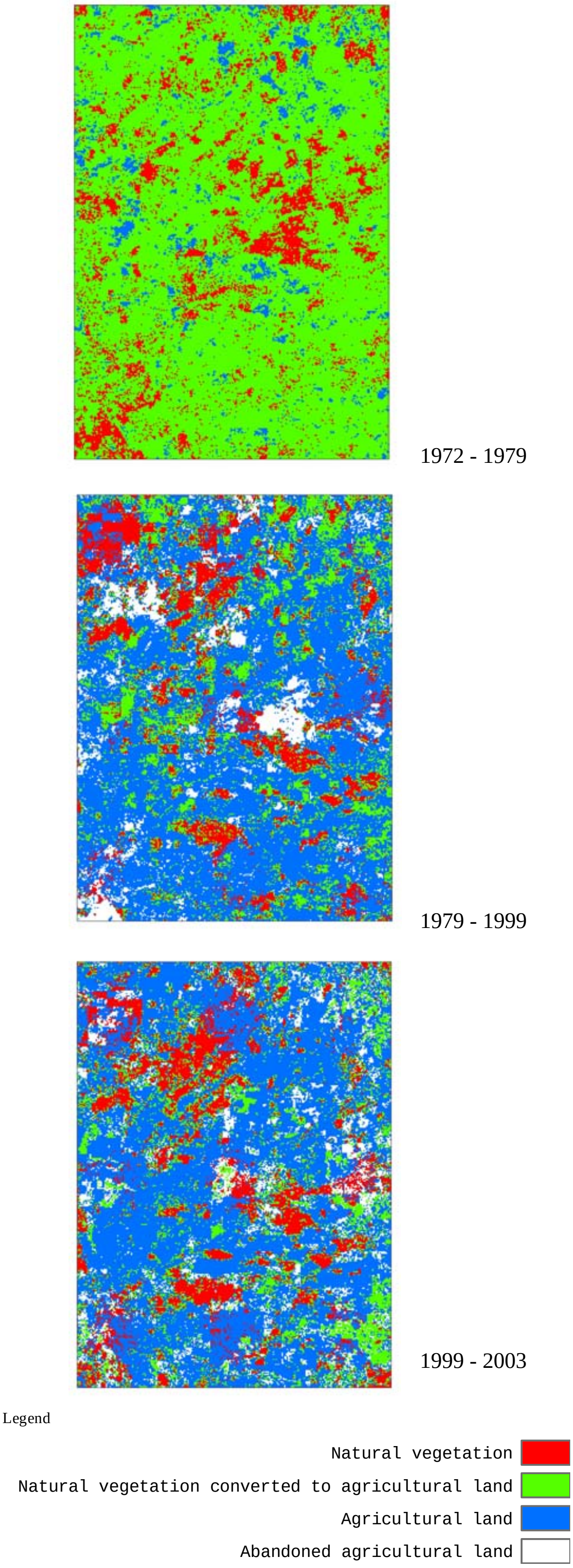

Figure 3: A comparison of supervised classification for CVA channels

increase of the natural vegetation with about 4.6 % from the seventies and also of the abandoned agricultural land (e.g. natural regeneration areas) represent 10.8 %. It is clear that the agricultural expansion reached its culmination during this period, and farmers started to abandon parts of their land due to drops in crop yield or weed invasion. However, analysis of additional scenes from the late eighties could help to ascertain when the farmers started to abandon their land. SKAP (1991) reported that about 25 % of the agricultural land remained as fallows during the 1990 season. Natural re-vegetation on abandoned agricultural land has been observed by many researchers (El Houri, 1993 and Mohamed *et al*., 1996).

Analysis of the change image 1999 - 2003

The conversion of natural vegetation to agricultural land continued to slow down. Only about half of the area was under cultivation, whilst the natural vegetation (the already existing one and the parts which could naturally re-establish) makes up about a quarter of the area. The abandoned agricultural land which represents about 14.8 % of the area could be managed as natural restoration sites. Following appropriate silvicultural strategies that could enhance the productivity of abandoned areas for producing firewood or building materials, whilst maintaining or enhancing habitat and conservation benefits of the natural re-growth could serve as one of the attractive options for the farmers. Asefa *et al*. (2003) stated that land abandonment are the common conservation strategies to promote restoration of biodiversity in degraded agricultural and grazing lands.

Class	1972 - 1979		1979 - 1999		1999 - 2003	
	*Area	%	Area	%	Area	%
NV	34.5	14.1	45.9	18.7	54.3	22.2
NV to AL	194.8	79.5	27.6	11.2	19.2	7.9
AL	15.8	6.4	144.9	59.2	134.9	55.1
AAL	-	-	26.4	10.8	36.2	14.8
Total	245.0	100	245.0	100	245.0	100

* Area in 1000 ha.
- indicate that the conversion is not likely occurred.

Table 2: Land-use/land-cover change for the period 1972 – 2003

A total of 13 trees/shrubs species were recorded during the field survey. The overall composition of a plant community is a reflection of the condition or health of the landscape. Although the area is classified as *Acacai seyal* and *Balanites aegytiaca* savannah zone, *Ziziphus spina-christi* is the dominant species (frequency = 26) followed by *A. Senegal*. Indeed this could reflect the high potential of theses two species to regenerate naturally on abandoned degraded fields. The small forest patches on some agricultural land and the scattered tracks of land between the large mechanized farms which left in their

undisturbed status are more or less the remained areas for in-situ conservation and seed resources for natural regeneration.
The results of the linear regression of NDVI against above ground herbaceous biomass showed high correlation ($r^2 = 0.62$) while the number of trees / shrubs shows weak correlation ($r^2 = 0.22$) and there is almost no relation with the trees/shrubs composition. However, using linear as well as a number of non-linear regressions against different vegetation indices (e. g. ASVI, VCI) may provide better results than using simple regression and NDVI only.

6. CONCLUSIONS

Generally, one may conclude that the result showed the capability of CVA to detect different historical land-use/land-cover changes in vegetation gain and loss due to the expansion of rain-fed mechanized farming with a measurable direction and magnitude. Results showed a fast process of deforestation within critical levels. The remaining natural vegetation represents approximately one fifth of the total natural vegetation of 1972. The newly emerged vegetation on the abandoned agricultural land could serve as potential sites for restoration and nature conservation. Field data has proven to be important to increase classification accuracy and to assess the vegetation attributes which otherwise could not be estimated using the Landsat imagery only.

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