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Desertification watch in Tunisia: Land surface changes during the last 20 years and onwards

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ABSTRACT: This study of desertification is based on ground measurement of reflectance properties of the different land degradation levels recognised by field ecologists in Southern Tunisia. Landsat MSS images from 1972 onwards recorded have been superimposed after geometrical correction. Using the field reflectance data ground features of low temporal variability were taken as radiometric references. This allowed to adjust for the differences in radiometry of the images and to detect temporal variations of image-derived indices. These indices, i.e. brightness, vegetation and colour were found to be correlated with land surface parameters such as roughness, green vegetation density and soil surface composition. As a result fluctuations of areas with degraded soil and mobilised sand could be monitored as well as areas treated by wind barriers or exclosure which appear darker. The overall trend is currently a significant recovery of the ecosystems after the severe drought and eolisation of the 80's. This experiment demonstrates the feasibility of long term monitoring of arid ecosystem changes, and its potential for the implementation of desertification control programmes.

1 INTRODUCTION

In Tunisia, desertification has been recognised as a serious threat since many years. Several ground based ecological studies have been carried out to understand its mechanisms, (Floret and Pontanier, 1982). Recently, important action plans have been implemented to stabilise moving sands and to restore degraded areas (Aronson et al., 1993). Significant results have been obtained as recently summarised in an international conference on degraded lands restoration (Pontanier et al., 1995). However, a synoptic perspective is needed to assess the impact of these actions and the overall extent of desertification in space and time. Therefore, the Centre National de Télédétection of Tunisia has undertaken a satellite-based desertification monitoring program, in co-operation with ORSTOM and national institutions. In this programme three test sites representing the diversity of soil, vegetation and land use types have been selected (see fig. 1). A first experiment on long term monitoring of local changes over the test site 1 (« Menzel Habib » area) is described in this paper.

2 METHODOLOGY

The methodology used is based on characterising the reflectance properties of the land surface components. Different land degradation levels recognised in the ground by field ecologists have been characterised using the soil surface description method designed by Escadafal (1981) and adapted to remote sensing data after Otterman et al. (1987). In the main ecosystems, spectra of soil and plants in various conditions have been recorded using a field spectroradiometer. These spectra as well as soil analysis results and digitised field photographs have been integrated into a database (see Escadafal et al., 1993 for a complete description of the methodology used for spectroradiometric measurements).
This database is the hub of the overall approach, from the analysis of the spectral features of degraded ecosystems spectral indicators of desertification have been designed (Escadafal et al., 1994). In this study the database has been used for image radiometric rectification.

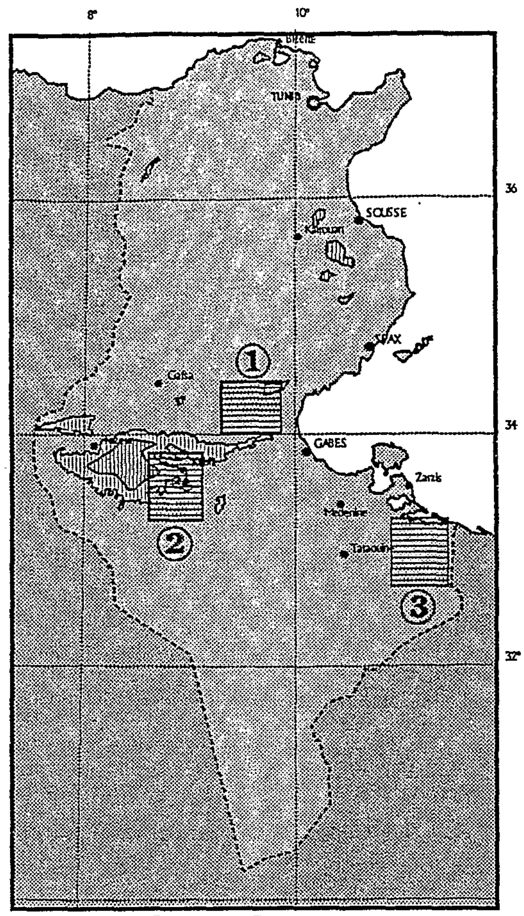


Figure 1. Situation map

11/08/1972
07/02/1973
30/11/1975
22/04/1976
14/06/1976
19/06/1977
08/02/1978
15/07/1979
16/06/1981
24/05/1984
22/09/1987
30/03/1993

Table 1 Listing of Landsat MSS images gathered over the Menzel Habib test area (by date)

3 IMAGE PRE-PROCESSING

In order to evaluate land surface reflectance changes over the largest time span possible, the earliest available remote sensing data have been used (Landsat MSS from 1972 onwards). Several data sources have been consulted to build an archive over our 3 test areas in southern Tunisia (EROS-DATA Center, USGS, USA ; EURIMAGE, Italy and various remote sensing laboratories). In fact , despite the large amount of images collected by the Landsat satellites series, only a few are available, because we are only interested in cloud free images, and because only a limited number of interesting images have been properly archived. Also part of the images stored in research laboratories on magnetic tapes were found to be not readable anymore (loss of support properties).

Finally, around 10 images per test area recorded at different dates have been collected. Table 1 displays the list of images in the series over the test site 1. It shows the difficulty to build a proper time series, gaps are existing and images have been recorded at very different seasons of the year, leading to difficulties in comparing the images (different sun elevations). The twenty years of time span obtained still makes this time series quite interesting.

After the struggle to gather data, the first difficulty to solve was the large variety of formats of the tapes, some of them -as the « historical » format from U.S.G.S.- are not documented. After detailed analysis of the tape records structure and by a system of trial and errors raw images were obtained.

Then, the next step was to adjust the geometry of these images, which was also very diverse : the first MSS images were made from rectangular pixels without correction for skew, e.g. The most detailed topographic maps available on the area (at 1/100 000) have been used as reference for ground controls points to perform geometric correction of the images using a bicubic interpolation and « closest neighbour » resampling. As a result a stack of superimposed images was obtained.

4 RADIOMETRIC RECTIFICATION

Radiometric intercalibration was the critical point to allow detection of changes between dates. Due to the lack of data on instrument and atmospheric parameters absolute conversion of image data into reflectance values could not be achieved by radiative transfer models. Using our field reflectance database, ground features recognised as having low temporal variability (central part of dune fields, ancient oasis, rocky pediments,..) were taken as radiometric references (Schott et al., 1988 ; Caselles and Lopez-Garcia, 1989).

This technique using pseudo-invariant features allow to perform a radiometric correction based on simple linear stretch and offset.

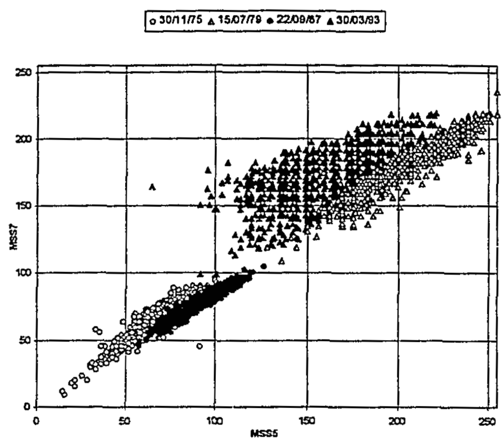
Raw digital counts are translated into reflectance values by a linear function :

$$R_k = a_k.C_k + b_k \qquad (1)$$

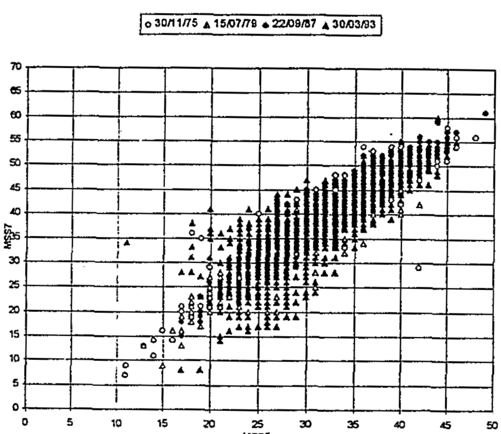
where = k = channel number
R = reflectance (%)
C = digital counts (0 to 255)
a = gain
b = offset

Average digital counts from two pseudo-invariant targets selected in the image, one dark and one bright, are used with the corresponding reflectance values retrieved from the database on ground measurements. The coefficients a and b are then computed by solving a simple systems of two equations.

The results obtained by this procedure are illustrated on figure 2. Scattergrams of raw data from channels 7 and 5 at four dates show large differences in data structure (a). After applying the correction procedure, the four clouds of points are superimposed (b).



a) raw Digital Counts



b) after radiometric normalisation and conversion into reflectance values (%)

Figure 2. Scattergrams channels MSS5 and MSS7 of four different images over the area of test site 1

The first analysis of changes performed on this radiometrically rectified time series was based on computation of the classical vegetation index. A part from images recorded shortly after humid periods, the NDVI showed little variations. This is not surprising as the typical steppic vegetation of the area is mostly non-green (Floret &Pontanier, 1982). In fact the effect of the radiometric correction can be seen on these NDVI values as illustrated by fig.3. In this figure temporal changes of the NDVI values have been computed for an area showing a bare soil surface (outcropping gypsiferous material). The fluctuations are minor and the concept of pseudo-invariants appear to be a reasonable hypothesis.

Two other indices have been applied to the data : the brightness index and the colour or « redness » index (see Escadafal et al., 1994). Both show larger variations related with degradation level, the application of these parameters to the images is currently under investigation and will be reported in a forthcoming paper. The general trends of changes are discussed hereafter.

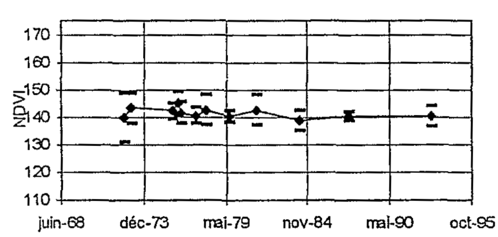


Figure 3. NDVI values obtained over the same area of bare soil for the 12 dates of table 1 (average values stretched between 126 and 255, dashes show minima and maxima)

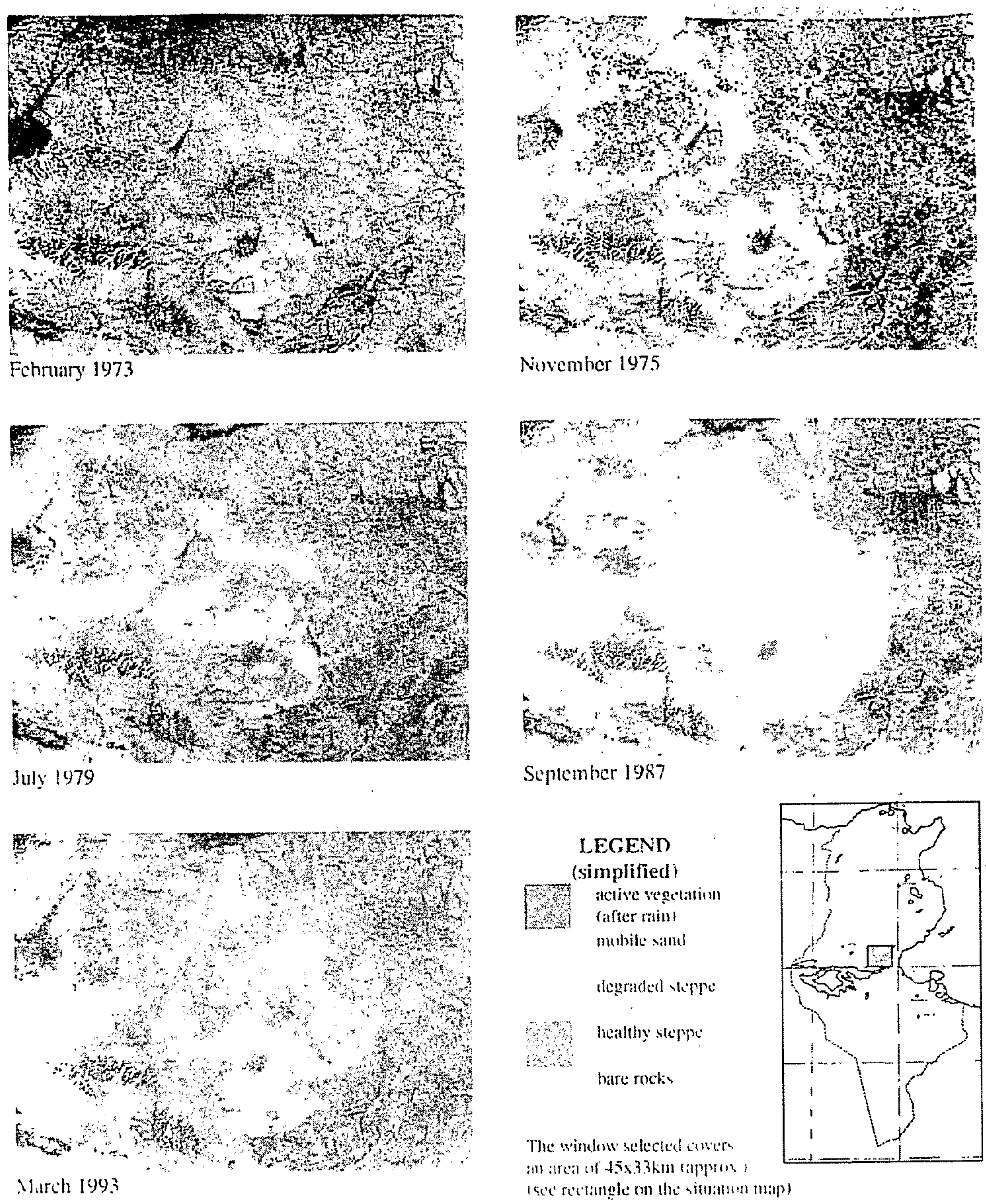


Plate 1. False colour composite of Landsat MSS images over the Menzel Habib area (Southern Tunisia) at five different dates from 1973 to 1993 (after geometric correction and radiometric rectification) (colour plate, see page 353).

5 RESULTS : A FIVE IMAGES SERIES *(see color plate)*

A first analysis of the changes has been made by simply displaying the whole series of normalised images with the same visualisation parameters. On the colour plate (see 1) five images are represented in false colour composite , i.e. channels 7 , 5 and 4 displayed respectively in red, green and blue ; the same look up table has been used for all of them.

Visually the effect of the normalisation is clear as all less variable features such as rocky hills and mountains or sand appear with the same colour in each image. The first image of 1973 is slightly different, besides its poorer quality (missing pixels) it has been acquired just after heavy rain, so that the soil surface is wet , and even rocks and sand have a lower reflectance than normal. In this case the normalisation technique using pseudo invariants is biased, in a further refinement we will try to use values from field spectra recorded over wetted surfaces.

6 ECOLOGICAL INTERPRETATION

The changes evidenced on the colour plate show clearly a decrease of areas with healthy steppe whereas the mobile sand extends, between 1975 and in 1979 with a maximum in 1987. This corresponds to intense degradation phase linked to a dryer period as documented by the precipitation records (fig. 4). This figure shows a long period from 1979 to 1989 of annual precipitation inferior to the mean (150 mm).
The last image of the colour plate recorded in 1993 shows on the contrary the remarkable recovery of the steppic vegetation. Particularly, dark geometric shapes appear around the centre of the image. This correspond to areas treated with sand fixing barriers and protected from grazing (exclosures).

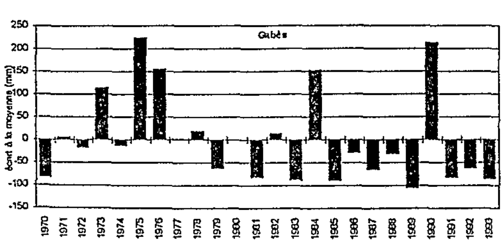


Figure 4 . Deviation from mean annual precipitation (1970-1993, Gabès meteorological station)

The results of the large effort to combat desertification undertaken in this area since 1987 appear clearly from this time series, the extension of areas covered by mobile sand has also drastically diminished.

7 CONCLUSION- PERSPECTIVE

The detection of various degradation levels from space is known to be feasible with remote sensing and recent sophisticated image processing techniques applied to Landsat TM data have also shown very encouraging results in other parts of the Mediterranean region (see Hill & Mégier, 1994).
The results presented here indicates that even with simple processing applied to images of medium definition (spectrally and spatially) it is possible to monitor land surface changes which have an ecological significance in terms of desertification. This is particularly striking in the last image of the series studied, demonstrating that the effect of restoration of degraded land can be clearly seen from space and quantified (intensity and extent).

However, to discriminate the effect of climatic variability typical of arid lands from long term trend and from human impact, further investigation is needed, including input of socio-economic spatial data and inter-comparison with land surface changes in similar biomes of the same eco-region.

Moreover, a large range of satellite imagery is now available (SPOT, ESRS1,..) and will continue to expand in the near future (VEGETATION, ENVISAT,...). The next challenge is to develop a comprehensive approach for long term desertification watch integrating data from different sensors.

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