沙漠研究 **19**-1, 73 - 76 (2009)
Journal of Arid Land Studies
"Desert Technology IX "
Refereed Paper

Radiometric Indices for Monitoring Soil Surfaces in South Tunisia

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Abstract: Due to wind erosion, the Hamma plain of Gabès (southern Tunisia) is considered an important source of sand for the surrounding areas. This erosion is a direct result of population pressure resulting in overgrazing and overexploitation of marginal lands which this plain has known for the last decade. The aim of this study is to develop a reliable methodology that uses Landsat satellite imagery to show the evolution of soil surfaces. This study was conducted using two Landsat scenes for the periods 1987 and 2000. This work is articulated according to the following axes: a) the use of the radiometric indices: vegetation Index NDVI, Brightness Index BI, and Colour Index CI and b) differences between the 2 years of the calculated radiometric indices. The results show that only 11% of the BIs, 9% of he CIs and 3% of the NDVIs were stable, the general changes of these indicators show that the study area has known degradation between these 2 dates. However, it would be more efficient to study changes with more satellite data in order to be more affirmative concerning the evolution of the study area

Keywords: Brightness Index, Colour Index, Normalized Vegetation Index, Satellite image

1. Introduction

In the last decade land degradation is considered one of the most important manifestations of desertification. This phenomenon has concerned southern Tunisia since the second half of the twentieth century (Le Houérou, 1959; Floret and Pontanier, 1982). These authors defined land degradation as the direct result of climatic factors coupled with inappropriate management of natural resources.

Satellite images are considered to be a powerful tool for mapping and monitoring land degradation in arid regions, Rogan *et al*. (2004), Hill *et al*. (1995). A complete global database of images that span a time period from at least 1972 is available in these days via internet (source: Global Land Cover Facility: www.landcover.org). These data enable the users to perform near continuous historical or retrospective monitoring in time and space of phenomena like desertification and its aspects at large spatial and reasonable temporal (> 30 years) scales. The period after 1970 up to present coincides with the period when overgrazing and overexploitation by the local population of the arid steppes of Oglat Merteba, Tunisia occurred (Long *et al*. 1977). Because this event provides an opportunity from which a methodology to monitor the effect of all these factors on soil surfaces using remotely sensed data and field investigation techniques can be developed.

2. Materials and Methods

2.1. Study Zone

The study zone is called "Oglat Merteba". It is situated in the Jeffara natural region and located at about 35 km far from El Hamma town. It is limited in the west by the Jebels Tebaga, Hallouga in the North-west and the Matmata chain in the south (**Fig. 1**). The mean temperature is about 19 ˚C during winter and 31 ˚C during summer season. The mean annual rainfall is 190 mm. The Oglat Merteba plain is essentially formed by clayey gypsy sandy soils of the Miopliocène, the erosion of these soils in the mountains form locally gypsy crusts in their glacis. In the middle of the plain, important sand deposits are encountered especially between the Oued El Merteba and Oued Gourai. The vegetation is composed by chamephytic shrubs represented by gypsophyl and psamophyl species that cover 5 to 30% of the soil in spring season. During humid periods the vegetation cover can reach 60% due to the development of annual vegetation. The land use noticed to be the most dominant is grazing, thus 90 to 95% of the surface is reserved to the sheep, goat and camel livestock that are especially concentrated around human habitations creating overgrazing zones where others remain underexploited.

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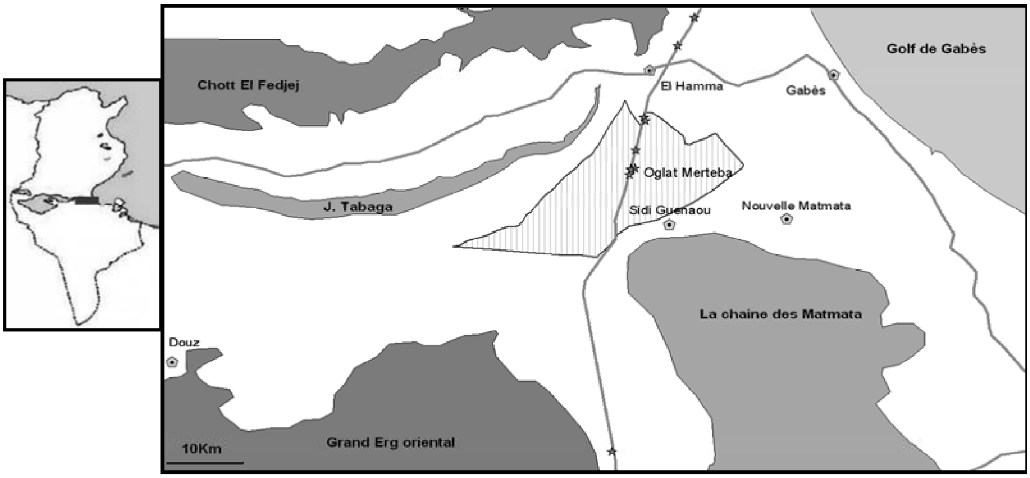

Fig. 1. The location of the study area.

2.2. Data

Two satellite images covering almost the same period were used; their characteristics are reported in the **Table 1**. To be compared, they were first corrected geometrically based on the topographic map of the study area. Then, an atmospheric correction was elaborated using the 6S model (Second Simulation of Satellite Signal in the Solar Spectrum) to eliminate the atmospheric and illumination effects.

A number of maps were also used to conduct this work: the soil maps, the land use map and the geologic maps of the study area. These maps were scanned, georeferenced and digitized to be integrated under a Geographic Information System together with the satellite images in order to build a complete spatial database.

Table 1. Satellitery data used.

Path/ Row	Date of acquisition	Sensor	Spatial resolution
191/037	18 June 1987	TM of Landsat 5	30×30 meters
197/037	10 April 2000	ETM^+ of Landsat 7	30×30 meters

2.3. Methodology

The methodology is based on the calculation of radiometric indices and the change detection between the 2 periods of 1987 and 2000. The principal steps are the following:

- Selection of the less correlated radiometric bands to collect the maximum of data and avoid redundant information (band number1, 5 and 7)
- Non supervised classification for estimating the heterogeneity of the radiometry of the image
- Calculation of radiometric indices: Brightness Index (BI) (Escadafal *et al*., 1994), Colour Index (CI) (Escadafal *et al*., 1997; Escadafal, 1993) and Normalized Difference Vegetation Index (NDVI) (Singh *et al*., 2004)
- Unsupervised classification for extracting 5 classes of the calculated indices

2.4. Indices

2.4.1. Brightness Index (BI)

The Brightness Index (BI) is calculated as: $(B^2 + G^2 + NIR^2)^{1/2}/3$, where C1 and C2: reflectance in the visible domain and C3: reflectance in the near infrared band.

It represents the average of the brightness of a satellite image. The result looks like a panchromatique image with the same resolution of the original image. This index is therefore sensitive to the brightness of soils which is highly correlated with the humidity and the presence of salts in surface (Escadafal, 1989).

2.4.2. Normalized Difference Vegetation Index (NDVI) and the Coulor Index(CI)

Vegetation indices are combinations of reflectance in different domain of wavelengths. They are used in order to reduce the variability of the radiometric data that is due to external factors as the solar illumination. They are also used because of their correlation with vegetation parameters. Among the different indications the one that is the more frequently used is Normalized Difference Vegetation Index (NDVI) (Singh *et al.*, 2004). The NDVI is calculated by subtracting the near-infrared channel (NIR, where the plant cover has strong reflectance) from the red channel (R, where mineralized surfaces have strong reflectance):

$$NDVI = (NIR-R) / (NIR+R)$$

The NDVI is dependent on the optical properties of soils; consequently the Colour Index (CI) was calculated because it was developed to differentiate soils in the field (Escadfal, 1989). CI is calculated as:

$CI=(R-G) /(R+G)$, where G and R are reflectance in green and red bands

Low valued CIs have been shown to be correlated with the presence of a high concentration of carbonates or sulfates and higher values to be correlated with crusted soils and sands in arid regions (Escadfal, 1989). In most cases the CI gives complementary information with the BI and the NDVI. Used for diachronic analyses, they help for a better understanding of the evolution of soil surfaces.

3. Results and Discussion

The images generated by the calculation of the radiometric indices for the two dates were subject of unsupervised classifications using the isodata method. Isodata unsupervised classification calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. The outputs for the year 1987 are represented by the **Figure 2**, between its minimum and maximum values each index is classified into 5 classes (from very high to very low index). To make the results comparable, the same classification thresholds were then applied to classify the other indices covering the year 2000 (**Fig. 3**).

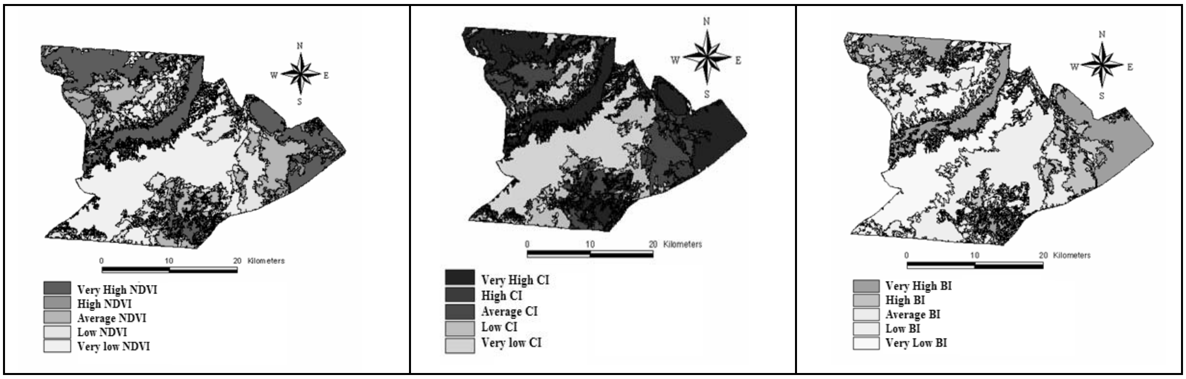

Fig. 2. Distribution maps of the Normalised Difference Vegetation Index (NDVI), Colour Index (CI) and Brightness Index (BI) for 1987.

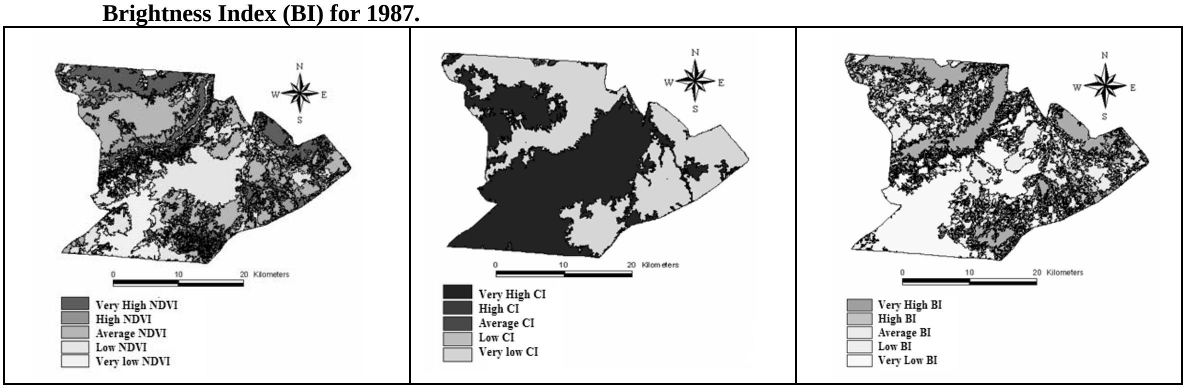

Fig. 3. Distribution maps of the Normalised Difference Vegetation Index (NDVI), Colour Index (CI) and Brightness Index (BI) for 2000.

The Figures 2 and 3 show that the study zone is represented by a very heterogeneous NDVI values, this variety is the direct result of a different vegetation canopy and abundance during the period between 1987 and 2000. In fact, the statistics of the different NDVI classes generated by post classification reveled that 28.62% of the study zone is represented by a very low NDVI in 1987 whereas 8.7% of the study zone is represented by a very high NDVI. It also showed that only 10.74% represents very low NDVI in 2000 whereas 18.03% of the image is represented by very high NDVI.

The Brightness Index (BI) varied also greatly between 1987 and 2000. This variation is due to the variation of the vegetation canopy. Thus, the more soil surfaces are covered by the vegetation the less bright is the image. In this case, statistics showed that:

- In 1987: The dominant class is "low BI" with 21.41%; the less represented class is the "average BI" with 12.22%.
- In 2000: 26.42% of the study zone belongs to" very low Brightness index" and dominates largely the class of "high BI" with 10.6.

The classification of the Colour Index (CI) image for 1987 showed that each of the 2 classes of “very high CI” and "very low CI" represent almost 25% of the image. The rest of the image is almost equally represented by the other classes of CI. For the second image: year 2000, the dominating class is "very high”.

The global variation of the radiometric indices were calculated, the results show that only 11% of the BIs were stable, the other pixels were prone to change: 73% to positive change (augmentation of BI) and 27% to negative change. In the other hands 9% of the CIs were stable, 91% of the indices vary, mostly to increase (61% of positive change). For the NDVI 97% of the area was subject to change: almost 79% of the pixels decreased their NDVI whereas 21% increased their NDVI values. These variations are the direct result of the landuse changes. According to Pontanier and zante, 1976, many wells were managed in the area during the period of the seventies, and the local population was driving their livestock around these water points, moreover, many steppes were progressively disappearing whereas new fields of cereals were developed, unfortunately and due to the salinity of the water that exceeds 7 g/l these managements were left letting in place vulnerable soils to wind erosion.

4. Conclusion

This study showed that radiometric indices are very useful to perform a soil surface changes monitoring in arid regions. In fact, between 1987 and 2000 the radiometric indices changed showing degradation, this degradation has been showed by the increase of brightness and colour indices (BI and CI) and a decrease of the Normalized Difference Vegetation Index (NDVI). However, at this point of the study, it would be more efficient to study changes with more satellite data in order to be more affirmative concerning the evolution of the study area.

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