沙漠研究 **19**-1, 313- 317 (2009)
Journal of Arid Land Studies

The Role of Remote Sensing in the Monitoring of Arid Ecosystems Dynamics
-The Case of Bouhedma National Park-

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Abstract: The exceeded and traditional techniques of the monitoring of arid ecosystems become futile. The great evolution of remote sensing with higher resolution images and its large scale utilization in natural resources monitoring and assessment has shown good results all over the world. It can be therefore considered as an efficient technique for ecosystems dynamics monitoring through a diachronic analysis of data satellites (Landsat images, Radar, etc.).

The aim of this work is to monitor the ecosystem dynamics in Bouhedma national park, a biosphere reserve considered as the most important protected area in southern Tunisia.

To meet this objective, two radiometric indicators, the soil adjusted vegetation index (SAVI) and the soil brightness index (SBI) were determined from three Landsat images (1985, 1995 and 2003).

The characterisation of environment degradation is necessarily based on diachronic studies so that physical and biological changes affecting the components of ecosystems can be detected. The Multitemporal analysis in Bouhedma National Park showed that the SAVI is mostly influenced by both grazing with introduced fauna and precipitation whereas the SBI is influenced by the soil moisture. Therefore, the ecosystems of study area alternated between regression and regeneration cycles.

Keywords: Dynamics, Ecosystems, Remote sensing, SAVI, SBI

1. Introduction

Remote sensing techniques have long been applied for the quantitative and qualitative evaluation of the ecosystems dynamics in the southern of Tunisia. Many studies have demonstrated the ecologic importance of the “protected areas” in reserving biosphere, by remote sensing techniques and, visible and Near Infrared (NIR) multispectral images, following their very useful data to examine vegetations patterns and corresponding ecological process at regional and global scales.

Radiometric indicators, derived from remotely sensed data have frequently been proposed as a method for predicting ecosystems situations, and they become efficient because of the large-scale surveys required to monitor the ecosystems dynamics, and for an economically and logistically reasons. However, no attempts have been made to use these indicators to monitor ecosystems in the study area (Bouhedma national park). To achieve this objective, we should choose some indices, that they can study all components of an ecosystem (principally soil and vegetation), and in the same time they could show the relation between these components. There are many techniques of remote sensing which can show the response of an ecological system live has screw the changes related to different parameters of the environment, but many of these techniques can’t respond to the fixed objectives, especially when we are looking for monitoring the evolution of arid ecosystems, and that’s correlated with many conditions and obstacles dependent on the image processing and the necessary corrections to extract wished information, as well as the difficulties of access to the ground, if one has a method of follow-up by inventory of ground and mapping. In this study, we apply and evaluate a vegetation index (the SAVI: Soil Adjusted Vegetation Index), in order to estimate the vegetation dynamics between 1985 to 1995 and 1995 to 2003. This radiometric indicator represents the second generation of indices, it’s much evolved when we talk about compensation of the effect of the soil. In addition to *SAVI*, we try to apply the Soil Brightness Index (SBI) in the aim to show the evolution of the second component of the ecosystems: the soil. The importance of this index appears principally in its potential to show the different situations of soils, by representing their different reflectance and brightness, and the principal changes.

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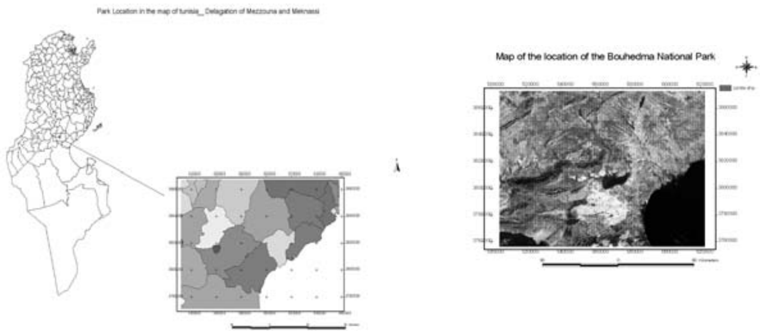

Fig. 1. Maps of Bouhedma national park's location in Tunisia

Fig. 2. Georeferenced satellite images of the park.

2. Materials and Methods

2.1. Study Area

The study area was Bouhedma National Park, a biosphere reserve considered as the most important protected area in Tunisia. This park is located in a zone called Bled Talah, because of the specifity of this zone by the presence of the *Acacia tortilis.* This area was considered, along the time as the most successful reserve for rehabilitation and reintroduction of some species in danger. The Park is located in central Tunisia, in the natural region of eastern plain low Bled Talah and Seguis (Le Houerou, 1959). The geographical coordinates of the Park are: 34°15' to 34°30'North and 9°15' to 9°40'Est. The territory of the observatory is part of the core protected area of Bouhedma national Park which covers an area of 16488 ha, of which 3660 ha are fully protected (protected zone) and 11625 ha have the status of biosphere reserve (Mab Unesco) since 1977.

2.2. Satellite Data Processing

We used 3 Landsat 7 Thematic Mapper (TM) images of the study region with a spatial resolution of 30 m. The satellite images represent the end of rainy season (March-April) of the years 1985, 1995 and 2003. The pre-processing of the Landsat TM data in this study includes several correction algorithms carried out in several steps, including radiometric and geometric corrections of the Landsat TM data.

2.2.1. Radiometric correction

This is the conversion of the TM 8-bit digital numbers into physical quantities of radiance and reflectance (Markham and Barker 1986 and Thome et al. 1997). Digital Numbers (DN) are converted to spectral calibrated radiances (L) using the following formula:

$$L = Gain * DN + Offset$$

The lower and upper radiance limits are related to their correspondent digital number, respectively the lower digital number (Q_{min}) and the upper digital number (Q_{max}) that are respectively equal to 0 and 255. In our case, L_{min} and L_{max} are determinated from the sensor in the moment of tacking image by satellite.

Table 1. Main characteristics of studied images.

Sensor \ Images	Image 1985		Image 1995		Image 2003	
	L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}
3	**-12**	**2043**	**-12**	**2043**	**-50**	**2344**
4	**-15**	**2062**	**-15**	**2062**	**-51**	**2411**

2.2.2. Geometric corrections

Geometric corrections were done so that the Landsat TM data had the same geometrical information as the ground observations (Jensen 1986). These errors were correcting using ground control points (GCPs) on the surface of the earth where both image coordinates could be identified with acceptable accuracy.

2.2.3. Satellite Data Analysis

Many different methods were developed for monitoring arid ecosystems dynamics, but in our case we used 2 indices, from 2 groups that characterize the vegetation cover and soil condition. The first index belongs to the group of vegetation indices (VI_s) based on the Red/Near-infrared (R/NIR) slope. This group of VI$_s$ is used when there are strong influences of soil (background) brightness on vegetation indices, and special VI$_s$ must be applied in order to reduce the background noises (Huete, 1986; Huete and Jackson, 1987). From this group we selected Soil Adjusted Vegetation Index (SAVI: Huete, 1988) is defined by an additional soil adjustment factor (*L*). In our case *L*=0.5, because of the sparse vegetation cover.

$$SAVI = \left(\frac{NIR - R}{NIR + R + L} \right) \times (1 + L)$$

The second index represents the first axis of model "Tasseled Cap" (Jackson, 1983). Indeed, this author defined this index as the first axis of the model, whish represents the right soil owner to the soil pixels on the satellite image.

$$SBI = \sqrt{G^2 + NIR^2 + R^2}$$

Where: "G" is the green slope.

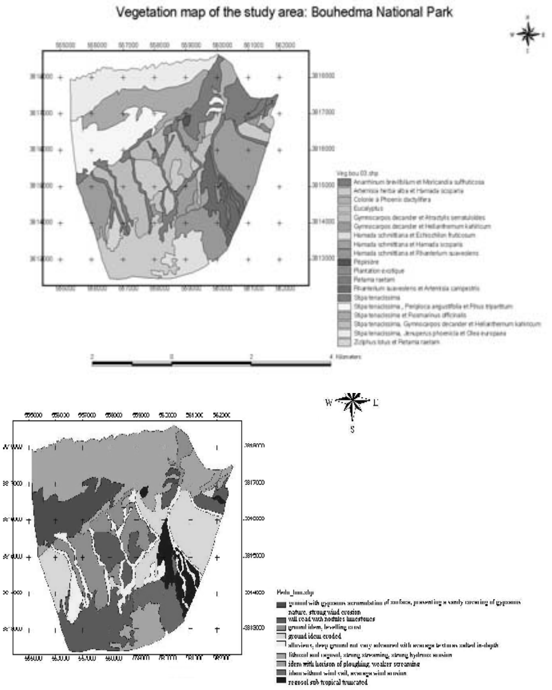

Fig. 3. Vegetation and soil maps of the protected area of the national park of Bouhedma.

2.3. Undirected classification

2.3.1. Ecosystems mapping

Referring to studies of Tarhouni *et al.* (2003), to plan of Bouhedma national park March 2007 and to the truth of land, it was able to identify the different vegetal groups that are in the protected area. This map will serve as the support to determinate statistic values of indices. It will also serve, as the technical support to apply the different process of the VI; The SAVI. With regard to the study of the SBI, we will refer to the soil map.

2.3.2. Choice of drives pieces

In this part of the study, we are interested to delimit a whole of the pieces, which appear most homogeneous on the various images. The choice of these areas is not arbitrary, since, starting from the soil map and that of the vegetation communities, we could identify that each group is a piece of drive on which we will represent ROIs (Region Of Interest).

Fig. 4. Representation of the Regions Of Interest.

After identifying the pieces of the drives, we will represent, in each of them, 3 polygons. These polygons take the shape of rectangle, and by identifying their statistics, we take the weakest standard deviation like parameter of homogeneity. In fact, the choice of the weakest standard deviation is not arbitrary because it seems necessary to highlight the homogeneity of such or such grouping, and moreover, the choice of 3 polygons in each piece has as a utility to show the SAVI and the SBI variations even within only one grouping.

3. Results and Discussion

3.1. Results of SAVI processing

After different analysis of the vegetable index, it seems so important to classify images in order of panchromatic appearance. In fact, the procedure is so usually, we have only to show the statistics of the index after calculations of the VI$_s$. This statistics will help us to identify different histograms, in the raison to show how dynamics of ecosystems alter between progressive and regressive.

Since the average recovery of the dynamics of vegetation taken in this study is the SAVI index, it seems important to represent the results of the classification, in other words the results of the variation of this index, in the raison to assess changes in this area through a survey Diachronic (variation of such a test on a given area for a period of time or slightly less extent). The average reflectance weaker, developed by the statistics of ROIs in classification will be taken as a reference for the treatment of the change in SAVI.

3.2. Multitemporal analysis of SAVI

3.2.1. Regression between 1985 and 1995

This phenomenon of regression is also explained by the high grazing pressure exerted at the plant groups, mostly perennial grasses. Indeed, grazing pressure of introduced fauna to the park, can lead to regression of species with high pastoral value. We can validate the rate variations affected during the period between 1985 and 1995, through the histograms analysis, in order to have an argument about the regressive dynamic between these two dates. Indeed, the regression histogram shows that there are significant variations in plant groupings in the period under review, but what is more important is that these variations have a negative effect on vegetation in the study area. That's why the percentages of changes in ecosystems seem negative figure below.

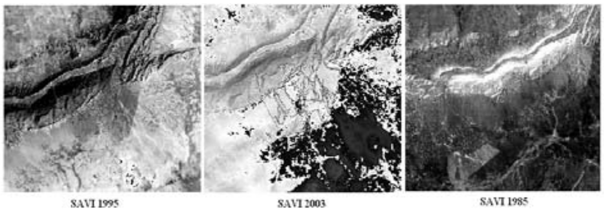

Fig. 5. Delimination of homogeneous units on the basis of SAVI index.

Table 2. Annual rainfall of the studied region between 1985 and 1995.

year	rainfall	Remark
1985	169	Normal year
1990	96,2	Deficit year
1995	84	Deficit year

Source: Metrological station of "Mezzouna"

Table 3. Annual rainfall of the studied region between 1995 and 2003.

Year	Rainfall	Remark
1995	84	Deficit year
2000	110	Deficit year
2003	158	Normal year

Source: Metrological station of "Mezzouna"

3.2.2. Progression between 1995 and 2003

After analyzing the values of SAVI, it was able to clarify ideas well suited to the dynamics of vegetation between these two dates. In fact this increase is mainly due to significant changes in weather conditions, especially between these two dates, as the **Table 3** shows excellent rainfall precipitation values that promote the development of different plant species groups registered in this area.

3.3. Results of SBI processing

The results of calculations of SBI from the images are presented in **Figure 6**. As an indicator used to evaluate changes in ecosystems in the region of Bouhedma, mainly the protected area, it seems very important to analyze the data and values acquired by SBI. Therefore, it seems that a diachronic study is needed to clarify the ideas for changes affected on this area and identify the causes of those changes. The soil brightness index on his part reflects changes in shades of bare soil and rocks. The passage of dark-tinted shades is accompanied by a simultaneous increase in radiometric values in both channels. The index also varies inversely proportional manner with moisture and soil roughness. The value of soil brightness index varies mainly between 0 and 1.

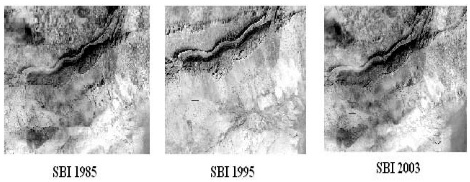

Fig. 6. Test of homogeneous units on the basis of SBI index.

3.4. Multitemporal analysis:

3.4.1. Regression between 1985 and 1995

This increase of SBI is explained by the fact that soil moisture fell between these two dates, since these parameters are inversely proportional. In fact, **Table 2** shows that during the period 1985-1995 there was a decrease in rainfall, which justifies the increase in values of this index. Based on the rising values of the SBI, which was explained by the fact degradation of ecosystems of this area, we can deduce such a relationship between this index and vegetation index (SAVI). Because as it was explained that such elevated values of SBI reflects an increase in the percentage of bare soil compared to covered soil, which leads us to confirm the results presented by the SAVI, as regards the degradation of vegetation cover.

3.4.2. Progression between 1995 and 2003

The analysis of the progression histogram shows that the values of SBI decreased during the period from

1995 to 2003, which leads us to affirm the progressive dynamics between these two dates. In fact, the analysis of these values shows that the space occupied by the bare soil in this area, declined during the period between 1995 and 2003, and it reflects the presence of plants that cover these soils. This has already been proven by analysis SAVI during this period, which shows that there is a regeneration of different plant groups with very important chlorophyll activities because of the occurrence of rainfall. The diminution of SBI values is also explained by an increase in the humidity of different classes of land, as Table presenting data rainfall between 1995 and 2003 shows that during this period the study area has received significant rainfall, which may have a direct effect on soil moisture. The histogram below represents the rate of change (%) of soil types recorded between 1995 and 2003.

4. Conclusions

This study was conducted in the Protected area of Bouhedma National Park aiming at quantifying ecosystem dynamics during the years 1985, 1995 and 2003 on the basis of two space parameters namely Soil Adjusted Vegetation Index (SAVI) and the Soil Brightness Index (SBI). The main findings of this study are as follows.

The multitemporal studies related to SAVI results show that changing values of this index is linked to rainfall and grazing by introduced wildlife while neglecting the effect of human intervention since the study is done within the protected zone of the park. Analysis shows that the increase in SAVI values indicates that there is a progressing dynamic and there is a regeneration level of plant groups and a very important chlorophyll activity. This is due to good rains and a moderate grazing pressure and the absence of human intervention. This phenomenon described has already been identified for the time period going from 1995 to 2003. On the other hand, lower values of SAVI in a few plant groups shows the degradation of vegetation cover.

Regarding SBI, diachronic studies shows that this index is inversely proportional to soil moisture, and for this reason that in the period between 1985 and 1995 has identified a dynamic regressive because of drought unlike the period between 1995 and 2003, relatively humid, where there was a progressing dynamic. At this stage, it was noted that these two indices are complementary, in other words we can combine the results of this indices to study the dynamics of arid ecosystems, to have a clear idea about changes affecting two components of an ecosystem (soil, vegetation), which are both in direct relation (sol = support; vegetation = supported).

Finally, the results obtained in this study show the importance of these indices in assessing the dynamics of dry land ecosystems. Further work on the relevance of these indices as indicators of environmental monitoring space seem necessary.

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