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# Spatio-temporal dynamics of vegetation cover in North-West Algeria using remote sensing data

**Abstract.** Land cover change is the result of complex interactions between social and environmental systems which change over time. While climatic and biophysics phenomena were for a long time the principal factor of land transformations, human activities are today the origin of the major part of land transformation which affects natural ecosystems.

Quantification of natural and anthropogenic impacts on vegetation cover is often hampered by logistical issues, including (1) the difficulty of systematically monitoring the effects over large areas and (2) the lack of comparison sites needed to evaluate the effect of the factors.

The effective procedure for measuring the degree of environmental change due to natural factors and human activities is the multitemporal study of vegetation cover. For this purpose, the aim of this work is the analysis of the evolution of land cover using remote sensing techniques, in order to better understand the respective role of natural and anthropogenic factors controlling this evolution.

A spatio-temporal land cover dynamics study on a regional scale in Oranie, using Landsat data for two periods (1984–2000) and (2000–2011) was conducted. The images of the vegetation index were classified into three classes based on Normalized Difference Vegetation Index (NDVI) values and analysed using image difference approach.

The result shows that the vegetation cover was changed. An intensive regression of the woody vegetation and forest land resulted in -22.5% of the area being lost between 1984 and 2000, 1,271 km$^2$ was converted into scrub formations and 306 km$^2$ into bare soil. On the other hand, this class increased by around 45% between 2000 and 2011, these evolutions resulting from the development of scrub groups with an area of 1,875.7 km$^2$.

**Keywords:** land cover, spatio-temporal dynamics, remote sensing, NDVI, Oranie

## 1. Introduction

The forest ecosystems of the arid and semi-arid zones are subject to a disturbing and, above all, accelerated degradation under the anthropogenic and animal pressure in addition to the water stress and the fluctuation of precipitation with a tendency to decrease. It is mainly the action of humans and their flocks that cause both quantitative and qualitative disturbances to forest ecosystems (K. Benabdeli 1996). From year to year, natural and even modified areas are decreasing and undergoing a transformation in the industrial, agricultural and commercial development of the region.

Detection of changes in land cover characteristics provides an understanding of the interactions between human and natural phenomena to better manage and utilize resources (D. Lu et al. 2004).

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Landsat data has been the most widely used for mapping land cover and providing earth observation data to address a wide range of information needs since 1972 (D.L. Williams et al. 2006). Landsat TM high-resolution, decametric accurate data can be used to perform land use mapping at the plot scale, with analysis, of changes occurring on the watershed scale (L. Hubert-Moy et al. 2004).

The Normalized Difference Vegetation Index (NDVI) is often considered an effective method to improve the difference between the spectral characteristics (D. Lu et al. 2005). The NDVI is often used to monitor vegetation dynamics (e.g. Y. Julien et al. 2006, L. Zhou et al. 2001 and R.B. Myneni et al. 1997).

This index is a normalised difference ratio using the near-infrared band and red band to distinguish differences between vegetation and non-vegetation. NDVI has been widely used to measure the change in vegetation because it explains variations in shadow due to the elevation angle of the sun, and less is influenced by topography (W.L. Stefanov 2001, L.G. Lyon et al. 1998 and A. Singh 1989).

Satellite imagery is an important tool that must be taken into account when planning and managing the environment. According to T. Pouchin (2001), the images are descriptive and they provide an important visual information in relation to the human activities.

Any policy for the preservation and development of these degraded areas must necessarily involve an inventory of their physical and biological potential, based on a good knowledge of the resources in place. It was difficult to envisage a classic scientific approach to biodiversity conservation without trying to uncover and identify the causes of this catastrophic situation, to define new notions adapted to our realities. In order to do so, it is essential to understand the behaviour of spaces in their dynamism, in their composition, in their process of degradation and especially in their integration into the socioeconomic development programmes imposed by politicians. All the efforts made over the past three decades have proved unsuccessful because natural spaces are considered an inexhaustible resource where all interventions were allowed even those with a political or social tinge.

Any land use planning requires state the art technology, which can be achieved quickly through remote sensing and geographic information systems. These tools are useful because they can fill the gap in reliable information.

In Algeria, the climate and the reliefs are fairly diversified over short distances. Oranie is distinguished from North to South by the remarkable landscape in the country: the Tell, the High Steppe Plains, the Saharan Atlas and the Sahara. It also presents certain peculiarities, as P. Boudy (1948) points out "... we enter Oranie, which is a world apart, with a somewhat steppe landscape attested by the presence of Alfa and salt lakes (sebkha). Drainage of the plain is insufficient, erosion is in conflict with the orogenic uprising, for the country has not yet acquired its definitive relief, resulting in severe flooding due to a defect in the model".

This study was carried out in order to achieve the following objectives: 1) enable effectiveness in monitoring spatial change in forest cover, and 2) give managers the means to have updated data for the management and protection of natural resources.

## 2. Study area

The study area is located in the North-West of Algeria, located at 02°13' W, 01°05' E and 34°08' N, 36°20' N. It is limited to the North by the Mediterranean Sea, to the south by the mountains of the Saharan Atlas, to the East by the territories of the Department of Relizane and Tiaret and, to the west by Morocco (fig. 1).

According to K. Benabdeli (1996), the area is distinguished by the following points:

− Three types of reliefs parallel to the sea with an ascending elevation from north to south, according to the configuration of the terrain through which the Sahel, the folded Atlas and the tabular Atlas are traversed. The altitude in these two orographic forms increases from East to West;

− The link between the high and low plains, the high Tellian plains and the high steppe plains is present between breaches facilitating this communication. However, only the low plains communicate with the sea;

− The geographical and physical differences are less marked between Oranie and Morocco than between Oranie and Algiers.

The soils of the region can be classified into three main groups: limestone, red soil and calcareous soils (K. Benabdeli 1996).

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Fig. 1. Localisation of the study area

The limestone soils are formed on more or less compact calcareous rocks and contain a certain proportion of organic matter which allows to divide them into two subtypes according to the importance of this element. The areas where these soils dominate are mostly pebbly, rock banks appearing on ridges. It is the most often light, permeable soil, with scanty humus being transformed rather quickly.

Red soils can be distinguished by three types characterised generally by a richness of free iron, a clay-silty texture and a friability resulting in non-calcareous Terra Rossa (Ca $CO_3$ less than 1%), Terra Rossa little limestone ($CaCO_3$ less than 10%) and red rendzines. J.H. Durand (1954) observed that: "Terra Rossa is used as a source rock for actual soils, which may be calcareous, unsaturated, solonetzic or even podzolic". The term red Mediterranean soil is also often used, and this author rightly proposes to reserve it to the association of soils that form on Terra Rossa, in the karstic zone under the influence of microclimates.

In reference to the rendzines, C. Alcaraz (1982) notes: "They originate from a reworking of Terra Rossa and fragments of calcareous rocks, which originated on soft calciferous soils, such as marls".

The calcareous soils are concentrated in the steppe plains and sometimes on the depressions of the high Tellian plains. They are characterised by a single horizon, not very thick, more or less rich in limestone, with an appreciable percentage of organic matter (between 5 and 8%) (K. Benabdeli 1996).

The monthly precipitation heights, as well as the annual rainfall, may differ from the average and the distribution over the twelve months of the year is different both from one year to the next and from the general average. The rainfall distribution in Oranie per season is about 35% in winter, 30% in autumn, 10% in summer and 25% in spring, which gives the region a rainfall regime of the HAP E type.

Rainfall in the region is mostly stormy and sometimes even torrential. In spring, especially, thunderstorms increase as latitude declines and continentality is present.

In this region, the presentation of the main floristic characteristics is sufficient to understand the dynamics of the main vegetation group, limiting themselves to highlighting the main features of forest vegetation alone.

The main woody plants of Oranie were listed and then classified first by a botanical aspect then physiognomic. The present taxonomics groups can only represent the main lines, but even modified and disturbed, they retain an important indicator aspect for the reconstruction of the vegetation.

An inventory of the principal and subordinate species, using the terms of P. Boudy (1948) in Oranie, gives the following list:

− main species: *Pinus halepensis*, *Quercus coccifera*, *Quercus suber*, *Quercus rotondifolia*, *Quercus faginea*, *Tetraclinis articulata and Pinus pinaster*;

− subordinate species: *Juniperus oxycedrus*, *Olea europea*, *Laurus nobilis*, *Rhus pentaphylla*, *Prunus avium*, *Pistacia lentiscus*, *Arbutus unedo*, *Pistacia therebentus*, *Erica arborea*, *Ilex aquifolium*, *Phillyrea angustifolia and Acer campestris.*

## 3. Materials and methods

### 3.1. Satellite data

The satellite data used to perform this land cover monitoring study are scenes acquired by the Landsat sensor (TM and ETM) (tab. 1).

With five images to cover the entire area, we therefore use a total of 15 images for the three

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Table 1. Characteristics of data used

| Sensor | Path | Row | Date |
|---|---|---|---|
| TM5 | 197 | 35 | 01/08/2011 |
| | 197 | 36 | 01/08/2011 |
| | 198 | 35 | 23/07/2011 |
| | 198 | 36 | 23/07/2011 |
| | 199 | 36 | 28/06/2011 |
| ETM+ | 197 | 35 | 25/07/2000 |
| | 197 | 36 | 25/07/2000 |
| | 198 | 35 | 04/08/2000 |
| | 198 | 36 | 17/08/2000 |
| | 199 | 36 | 05/06/2000 |
| TM4 | 197 | 35 | 12/06/1984 |
| | 197 | 36 | 12/06/1984 |
| | 198 | 35 | 28/07/1984 |
| | 198 | 36 | 28/07/1984 |
| | 199 | 36 | 03/07/1984 |

periods. The images acquired by the Landsat satellites were used in the study, five images from the Landsat 7, ETM sensor from 2000, five images from the Landsat 5, TM sensor in 2011 and the last five from the Landsat 4, TM sensor in 1984. The images were downloaded from the site: https://glovis.usgs.gov

### 3.2. Data processing

In a change detection study, the data used have characteristics as homogeneous as possible in order that the differences in their comparison can be related to actual changes in land cover and not to image-related artefacts.

An analysis of changes detection of land cover using multi-temporal remote sensing data requires precise radiometric and geometric correction. These pre-processing requirements typically present the most challenging aspects of change detection studies and are most often neglected, particularly with respect to precision and accurate radiometric calibration and atmospheric correction (P.S. Chavez 1996).

#### *3.2.1. Geometric corrections*

The images were georeferenced to the UTM coordinate system, datum (WGS 84). The Root Mean Square (RMS) indicates an error of 0.2 pixels between the images, which is within the required limit (0.50 pixel) for detecting changes between two satellite images (J.R. Jensen 1996).

#### *3.2.2. Radiometric calibration*

It is a matter of converting the digital number of the raw images into luminance and then into reflectance. The radiometric information contained in a raw Landsat image is digitally encoded from 0 to 255 (8 bits). It is necessary to reduce the digital number to a physical quantity (luminance or reflectance) in order to study the spectral behaviour of the studied objects.

Landsat-5 images were converted to at-satellite radiance using Eq. (1)

$$L_\lambda = (Gain \cdot DN) + Bias \qquad (1)$$

where:
$L_\lambda$ − the radiance at the sensor,
$DN$ − digital number.

The gain and bias are provided in the header file attached to the images, while the coefficients of the other variables are found on the Landsat 7 Science Data User's Handbook website (G. Chander and B. Markham 2003).

The impact of sensor degradation on the gain parameter was explained to use data published by P.M. Teillet et al. (2001) and K. Thome et al. (1997), while the revised earnings parameters published by 2003 were used for images acquired and processed after May 5, 2003. The bias reported by B.L. Markham et al. (2006), was used for all images.

Landsat 7 data were converted to at-satellite radiance using Eq. (2)

$$L = (L_{max} – L_{min})/(DN_{max} – DN_{min}) \qquad (2)$$

where:
$L_{max}$ − the spectral radiance of the measured band of DNmax (Wm-2 sr -1 μm-1),
$L_{min}$ − the spectral radiance of the measured band of DNmin (Wm-2 sr -1 μm-1),
$DN_{max}$ − a maximum value of the digital number,
$DN_{min}$ − a minimum value of the digital number.

Then conversion to reflectance using Eq. (3)

$$\rho_\lambda = \pi \cdot L_\lambda \cdot d^2/ESUN_\lambda \cdot \sin(\theta) \qquad (3)$$

where:
$\lambda$ − the number of the spectral band,
$l$ − the radiance at the sensor,
$p$ − the reflectance at the sensor,
$d$ − the distance between earth and sun in astronomical units,

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ESUN − mean solar exo-atmospheric irradiance,
$\theta$ − the solar zenith angle.

*3.2.3. Atmospheric correction*

Using the Quick Atmospheric Correction (QUAC) method, determines atmospheric compensation parameters directly from the information contained in the scene (Pixel observed spectra), without the need for auxiliary information. QUAC is based on radiative transfer models (L.S. Bernstein et al. 2005, 2006), which typically produce reflectance spectra in approximately more or less to fifteen percent of physical approaches (L.S. Bernstein et al. 2005). This method is based on the empirical evidence that the mean reflectance of a collection of spectra of various materials, e.g. endmember spectra in a scene.

**3.3. The Vegetation Index**

Among the most widely used vegetation indices, Normalized Difference Vegetation Index (NDVI) (M.-C. Girard and C.-M. Girard 1999), a standardized difference vegetation index that closely correlated with the chlorophyll activity of the plant surfaces. It is based on the difference of the reflectance measured in red and near infrared:

$$NDVI = (PIR - R) / (PIR + R) \quad (4)$$

where:
NDVI − the value of a pixel in the resulting image,
PIR − the digital value of the same pixel in the near infrared band,
R − the digital value of the same pixel in the red band.

The values are on a scale of (–1 to 1) where the value of the pixels increases with the presence of vegetation.

The images were classified into three classes, compared to the NDVI values (J.A. Sobrino et al. 2000). The three classes are chosen according to the density of vegetation cover (dense, medium and clear):

• Class 01: NDVI < 0.2, are the zones where the vegetation cover is absent, presents urban areas, bare soil, water surface, etc.

• Class 02: 0.2 < NDVI < 0.5, open and fragmented forest formations with a density less than 40%, include fragmented forests, holes, clear and degraded shrubs, scrub and other low canopy formation.

• Class 03: NDVI > 0.5, closed forest and pre-forest formations with a cover density greater than 40%, including forests, scrub, dense and closed shrub.

**3.4. The masking**

The masking operation consists of covering up part of the image and keeping the other parts intact (M.C. Girard and C.M. Girard 1999). Often, for a given thematic application, only part of the image is targeted to avoid confusion in the classification of certain phenomena. Using a mask designed to eliminate all non-forest areas in the study area, the mask is made on the basis of a vector file that contains only forest land, in order to avoid confusion between natural vegetation and agricultural vegetation; the surface of the mask covers agricultural areas, urban areas, bare soil, water surfaces etc. The processing will only cover the part of the image identified in order to remove the untreated geographic space. In order to do this a geometric type cutting on the image is carried out by drawing the limits of the zone to be treated and eliminating the rest.

**3.5. Detecting change**

The difference method is the most common approach used to compare data from different sources and dates (C. Mundia and M. Aniya 2006, J.R. Jensen 2004). The advantage of post-classification, the comparison is that it poses the difficulties associated with the analysis of images acquired at different times of the year and/or by different sensors (F. Yuan et al. 2005, P. Coppin et al. 2004 and H. Alphan 2003). In addition, the post-classification method also responds to the quantity, location and nature of the changes (P.J. Howarth et al. 1981).

A quantitative analysis of the spatial dynamics of forest cover was carried out by comparing the images of the vegetation index two by two: 1984−2000 and 2000−2011. It was possible to determine the degree of change of the vegetation cover in each period using a class-by--class comparison technique implemented in the ENVI 4.7 software. This method makes it

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possible to know the gradual or regressive evolution of each class.

## 4. Results and discussions

### 4.1. Distribution of the forest cover between 1984 and 2011

The results of the analysis and interpretation of the LANDSAT data for each period show a variation of the areas occupied by the natural plant groups (fig. 2). The area occupied by the forest and the dense scrub has declined sharply to 22.5%, from 2,661.7 km$^2$ in 1984 to 2,062 km$^2$ in 2000 (tab. 2), of which 1,271 km$^2$ have been transformed into shrub and 306 km$^2$ into bare soil. This regression can only be explained by human (clearing, fires, illegal cutting) and animal (overgrazing, trampling, eradicating species) pressures and improper land use.

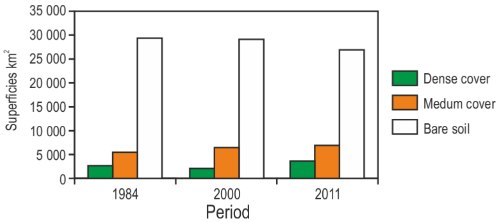


Fig. 2. Distribution of land cover superficies

On the other hand, these areas experienced a progressive dynamic, estimated at 45% (figs. 3 and 4) during 2000–2011, from 2,062 km$^2$ in 2000 to 3,777.8 km$^2$ in 2011, including 1,875.7 km$^2$ of shrubs and 138.8 km$^2$ of bare soil being transformed into a shrub, at the same time it lost 259 km$^2$ which was transformed into shrubs and 40 km$^2$ into bare soil.

This increase can only be explained by the fact that during this period human and animal pressure was totally absent in the natural space.

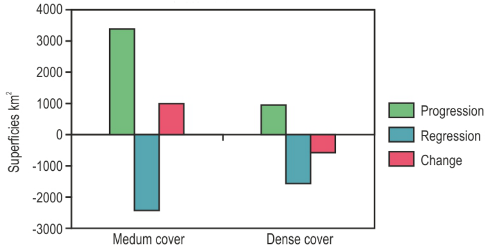


Fig. 3. Quantities of changes of land cover, 1984–2000

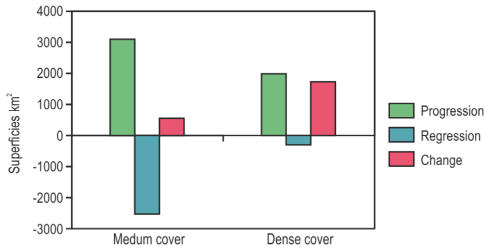


Fig. 4. Quantities of changes of land cover, 2000–2011

The areas occupied by the shrub group increased between 1984 and 2011, even if they are in a very advanced state of degradation; quantitative aspects take precedence over qualitative aspects. The total area of these forest spaces increased from 5,430.6 km$^2$ in 1984 to 6,392.2 km$^2$ in 2000 representing a gain of 17.7% – which is significant. In 2011, it recorded more than 6,951.8 km$^2$, resulting in an extension of 560 km$^2$, which is quite appreciable in such a space.

During the first period, the shrub group lost 2,438 km$^2$ of its surface area, of which 748.5 km$^2$ declined into low vegetation group (scrub and brush) and 1,689.7 km$^2$ into bare soil due to repeated fires. In contrary direction, 1,271.4 km$^2$ of forest and dense shrub and 2128.3 km$^2$ of

Table 2. Evolution of forest area

| Classes | Area in 1984 | | Area in 2000 | | Area in 2011 | |
|---|---|---|---|---|---|---|
| Forests and dense scrub | 2 661.70 km$^2$ | 7.00% | 2 062.00 km$^2$ | 5.48% | 3 777.80 km$^2$ | 10.00% |
| Shrub | 5 430.60 km$^2$ | 14.45% | 6 392.20 km$^2$ | 17.00% | 6 951.80 km$^2$ | 18.50% |
| Bare soils | 29 477.70 km$^2$ | 78.46% | 29 115.80 km$^2$ | 77.50% | 26 840.40 km$^2$ | 72.50% |

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bare soil have been transformed into low and clear vegetation (scrubland and brush).

The areas occupied by forest land (forests and scrubland) underwent a significant decline during the period 1984−2000, of which 600 km$^2$ was lost in 16 years. The intensive impact of the anthropogenic action on these areas included clearing, overexploitation, overgrazing, an extension of cultivated fields (M. Benchetrit 1966), and very intense fires during the period 1995−2000 (DGF 2013).

On the other hand, eleven years later, between 2000 and 2011, the situation was reversed, these areas recovered these losses and with additional gains estimated at 1,715.7 km$^2$ or 45%.

The reforestation effort includes the national reforestation programme, together with mild precipitation that stimulates the natural regenerative power of plant groups.

Figures 5, 6 and 7 offer a highly significant insight into the spatial dynamics of forest plants over a period of 27 years, these changes being translated into the gains and losses in the area of each type of plant group.

The areas occupied by shrubs and brushwood represent the two stages of degradation of the Mediterranean forest. There was a significant decline between 1984 and 2000 in some regions, which lost 748.5 km$^2$ mainly due to fires, clearing and exploitation as a rangeland for herds. These spaces are considered to be excellent pasture areas because they are easy to penetrate, very accessible all year round and offer a green biomass of palatable herbaceous plants even during dry periods (K. Benabdeli 1996).

During the second period, the surface of these areas increased remarkably, i.e. 961.6 km$^2$ of gain and 560 km$^2$ between 2000 and 2011. This increase is reflected in the degradation of the forest and the decrease in the use of these areas in this period by the population because

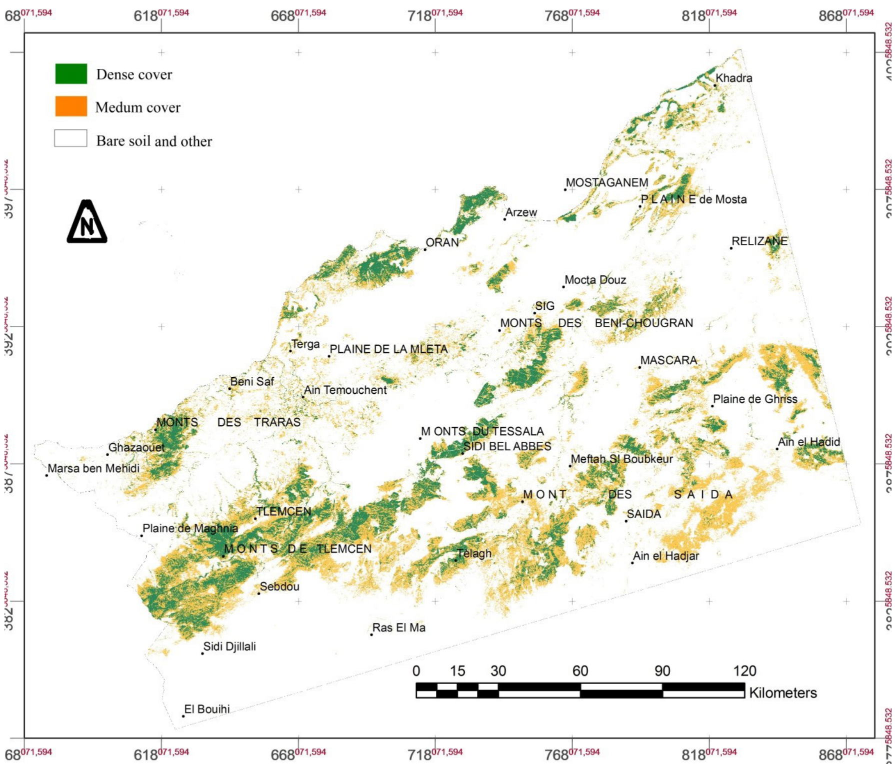


Fig. 5. Vegetation cover, 1984

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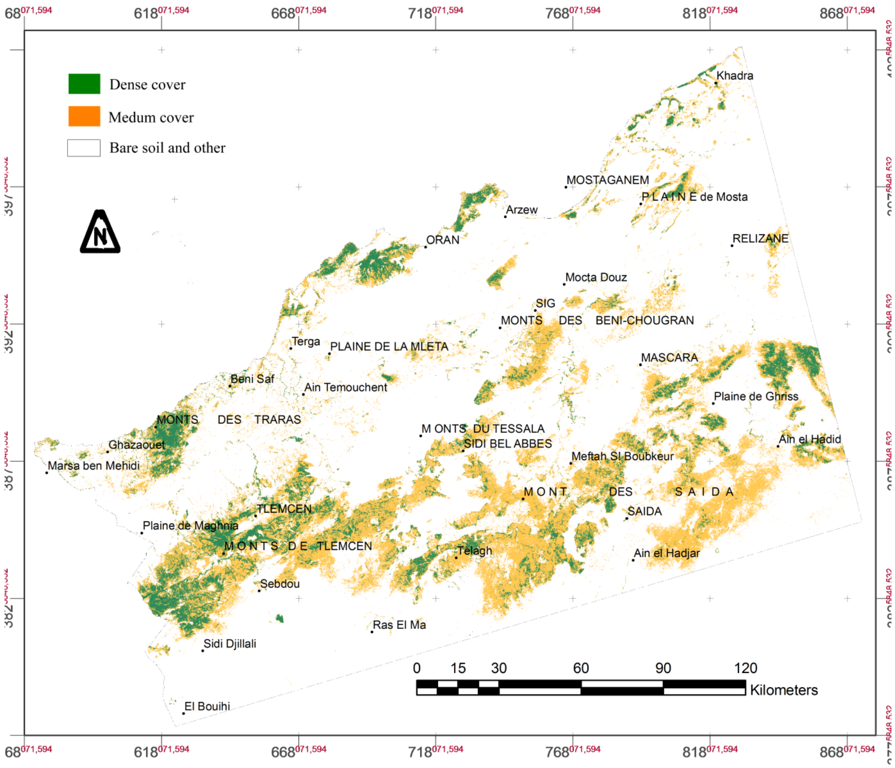


Fig. 6. Vegetation cover, 2000

of the security problems, where the brushwood occupied the land abandoned by the farmers (T. Sitayeb and K. Benabdeli 2008).

### 4.2. Disturbance factors

The degradation factors of forest cover in the western region of Algeria affecting their dynamics are fires, clearing, poorly managed forestry, short-lived agriculture and overgrazing.

*Clearing*

Clearing is still a major degradation of vegetation cover, especially in fragile environments and near villages and agricultural land. Oranie is undergoing continuous clearing, the rural population uses the natural area to establish these agricultural activities, notably cereal crops and vegetable crops and livestock activities, where the inadequately protected natural area is considered as an exploitable resources free of charge (M. Benchetrit 1966). These activities have contributed to the acceleration of the degree of the degradation process, especially clear and easily penetrable formations and near urban areas.

*Forestry work*

The inadequacy of the work carried out with the types of vegetation cover and the ecological conditions of the environment are at the origin of the high failure rates of the restoration programmes and the absence of natural regeneration induced by unsuitable forestry works. The techniques used resulted in a disturbance of natural vegetation, making it more vulnerable to fires and herd pressure (trampling, cutting, flammability) (M. Benabdeli 1996).

*Agriculture and grazing*

This is the main activity in the region. The agricultural area is dominated by cereal farming,

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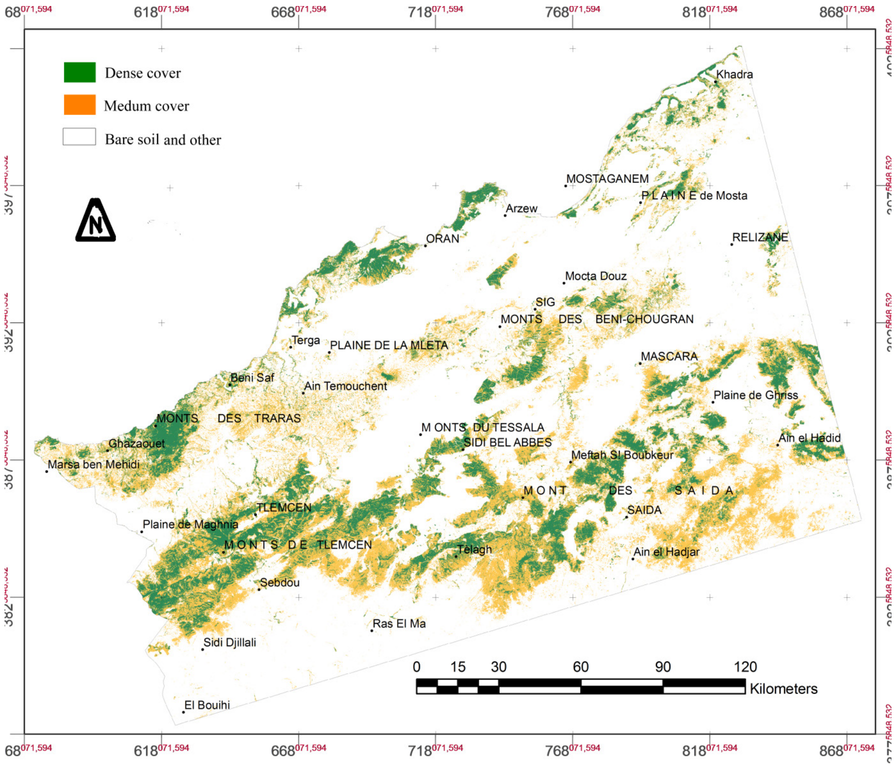


Fig. 7. Vegetation cover, 2011

fallow and rangeland. Agricultural extensions into forest land have contributed greatly to the regression and the area of forest formations and their degradation. Overgrazing in an environment weakened by pressure, poor management and climate with its vagaries (long periods of drought) constitute a major wound of degradation and disturbance of all natural vegetation.

All the studies undertaken in the region underscore the disastrous impact of the forest path through overgrazing, which results in the eradication of young palatable woody species. Trampling and grazing of discards are a permanent threat to the future of forestry. According to K. Benabdeli (1996), the actual pastoral charge is evaluated at 6.5 sheep equivalents per hectare, whereas the possibilities of plant formations are only 2 at most.

*Fires*

Forest fire statistics from the Directorate General for Forestry (2013) confirm the figure of 204,290.68 ha of forests damaged between 1996 and 2005 at the national level. The lack of adequate forest management and effective control of the spread of fires leaves the forest formations facing the risk of repeated fires.

## 5. Conclusions

The utility of remote sensing in the study of the dynamics of natural ecosystems can no longer be dismantled in light of the rapid results obtained on a regional scale. The post-classification, comparison approach of the vegetation index (NDVI) was used to detect changes in forest types in Oranie over a period of 27 years.

The Landsat satellite data allowed for evaluating the spatial dynamics of forest vegetation over time and both detect and quantify significant changes over a long period divided into two tranches in order to better understand the origin of the dynamics for each period.

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The present analysis shows that all forms of natural woody vegetation are subjected to a strong regression imposed by fires and over-exploitation (human and animal). Forest cover in Oranie loses, over a period of 14 years amount to 600 $km^2$ or about 43 $km^2$ per year, over a total area of 2,660 $km^2$ or 22.5%.

An intensive regression of the natural woody vegetation imposed by fires and the human impact on natural resources. This suggests immediate action for a policy based on priorities for the preservation, protection, presentation and rational use of land space.

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