CHARACTERISING OF PLANT COVER EVOLUTION IN THE AURÈS REGION (EASTERN ALGERIA): USING LANDSAT IMAGERY

KARAKTERIZACIJA RAZVOJA BILJNOGA POKROVA U REGIJI AURÈS (ISTOČNI ALŽIR) UPORABOM LANDSATOVIH SNIMKI

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DOI: 10.15291/geoadria.3203
UDK: 551.583:[504:581.9(23)]=111
Original scientific paper / *Izvorni znanstveni rad*
Received / *Primljeno*: 6-1-2021
Accepted / *Prihvaćeno*: 25-10-2021

A better understanding of the evolution of vegetation cover is a major concern for countries where mountain ecosystems are undergoing severe degradation. Mediterranean woodland ecosystems in general and those of Algeria in particular, are suffering from numerous types of degradation, be they climatic or anthropogenic. For this reason, and to have a better understanding of this issue and how to deal with it, we decided to carry out a study in the Aurès Mountains (eastern Algeria), where the phenomenon of degradation has a direct impact on natural resources. The evolution of the vegetation cover in the region was analysed, using remote sensing data (Landsat-type satellite images) over a 33-year period (1984-2017). A notably pronounced regressive evolution of the plant cover was attributed both to the phenomena of climate change and dieback (which particularly affected the cedar groves) and to the anthropogenic pressure exerted on the vegetation as a whole. Data sets from Landsat imagery show an decrease of dense and open forest area, -9,272.52 ha, and -12,953.30 ha respectively. It will therefore become more than necessary to take measures to protect and preserve the region's rich ecological heritage.
KEY WORDS: regression, mountain ecosystems, climate change, anthropogenic pressure

Bolje razumijevanje evolucije vegetacijskog pokrova glavna je briga zemljama u kojima su planinski ekosustavi značajno degradirani. Mediteranski šumski ekosustavi općenito, a posebno oni u Alžiru, ugrožavaju mnogobrojni tipovi degradacija, klimatski ili antropogeni. Radi boljeg razumijevanja ove problematike i nošenja s njom, provedeno je istraživanje u planinama Aurès (istočni Alžir), gdje fenomen degradacije ima izravan utjecaj na prirodne resurse. Analiziran je razvoj vegetacijskog pokrivača u regiji s pomoću podataka daljinskog istraživanja (satelitskih snimaka tipa Landsat) u razdoblju od trideset tri godine (1984. – 2017.). Izrazito izražena regresija biljnog pokrivača pripisuje se klimatskim promjenama i odumiranju (što je posebno zahvatilo nasade cedra) te antropogenom pritisku na vegetaciju u cjelini. Skupovi podataka s Landsat snimaka pokazuju smanjenje guste i otvorene šumske površine za 9.272,52 ha odnosno 12.953,30 ha. Stoga je prijeko potrebno poduzeti mjere za zaštitu i očuvanje bogate ekološke baštine regije.
KLJUČNE RIJEČI: regresija, planinski ekosustavi, klimatske promjene, antropogeni pritisak

INTRODUCTION

Forests are the source of many ecological goods and services for humanity. They are the foundation for biodiversity conservation and condition the presence of animal and plant species (Taboada, Huynh, 2009; Tankoano, 2017). Natural resources are of great importance in the development of societies and their preservation is a real challenge. Indeed, they are elements of the physical environment that people use directly or indirectly to satisfy their monetary and domestic food needs (Mercoiret, 1994). These natural resources are almost permanently subject to human and animal menace, to which vegetation is no longer able to respond and maintain itself. These activities lead to dysfunctions in terrestrial ecosystems and loss of biodiversity (Roche, 1998).

These changes in the ecosystem have direct repercussions on land use and landscape configuration. In particular, Mediterranean forests, which include Algerian forests, are continuously undergoing various and repeated pressures considerably reducing its plant, water and edaphic potentialities. Among the factors of degradation the following should be noted; anthropogenic activity in the form of irresponsible exploitation of pastures, tree felling and land clearing, the high and intense frequency of burning fires, soil erosion, etc. In addition, the Algerian forest is also affected by drought: the case of the Atlas Cedar (*Cedrus atlantica*) (Allen, 2009).

As is the case with all Algerian forests, those in the Aurès and Belezma mountains retain a remarkable biodiversity but unfortunately are experiencing a decline, affecting to a greater or lesser extent cedar and pine forests and the holm oak matorrals, which constitute the first woody cover to fight desertification (Berkane, Yahiaou, 2007).

In order to quantify and understand the phenomenon of degradation better, remote sensing has now become a particularly powerful tool as it provides quantitative spatial information for monitoring changes in land cover. In the field of vegetation mapping, the most commonly applied sensor is Landsat (mainly TM and ETM+). Landsat might have the longest history and widest use for monitoring the earth from space. It is very helpful to map long-term vegetation cover and study the spatiotemporal vegetation changes (Schroeder et al., 2006).

In this respect, numerous studies have been carried out in the Aurès region with the main aim of analysing the spatiotemporal dynamics of the vegetation cover using Landsat imagery (Benmessaoud et al., 2009; Beghami, 2013; Bouzekri, Benmessouad 2014; Garah et al., 2016). Unfortunately, these studies were carried out over a period on a sector-by-sector basis, which partially explains the difficulty in understanding the evolution of vegetation cover across the entire region.

The objective of this study is to analyse the evolution of land use in the Aurès region over a 33-year period. Therefore, satellite images were used to map the vegetation cover, which allows us to trace the dynamics of the vegetation cover from 1984 to 2017.

STUDY AREA

Lying between 34°90` and 35°60` north latitude, and 5°10` and 7°10` east longitude, the Aurès constitute the highest mountain range in eastern Algeria (of which the highest peak, Mount Chélia, rises to 2326 m). Mount Chélia is the second highest mountain peak in the country after Mount Tahat in the Hoggar. The massif of Aurès is located in the Eastern part of the Saharan Atlas and is a bulwark for the protection of the high plains of Constantine against the influence of the desert. It is characterized by its north-eastern, south-western structure orientation (Laffitte, 1939). According to the same author, the study area is part of the lower and upper Cretaceous and Quaternary formations presenting sandstone, limestone clay, flysch and dolomitic facies.

The climate is Mediterranean, with average annual rainfall ranging from 300 mm in the low altitude stations to 800 mm in the highest stations (Seltzer, 1946; Schoenenberger, 1971; Beghami, 2013). The effect of altitude is very pronounced and the spatial variability of precipi-

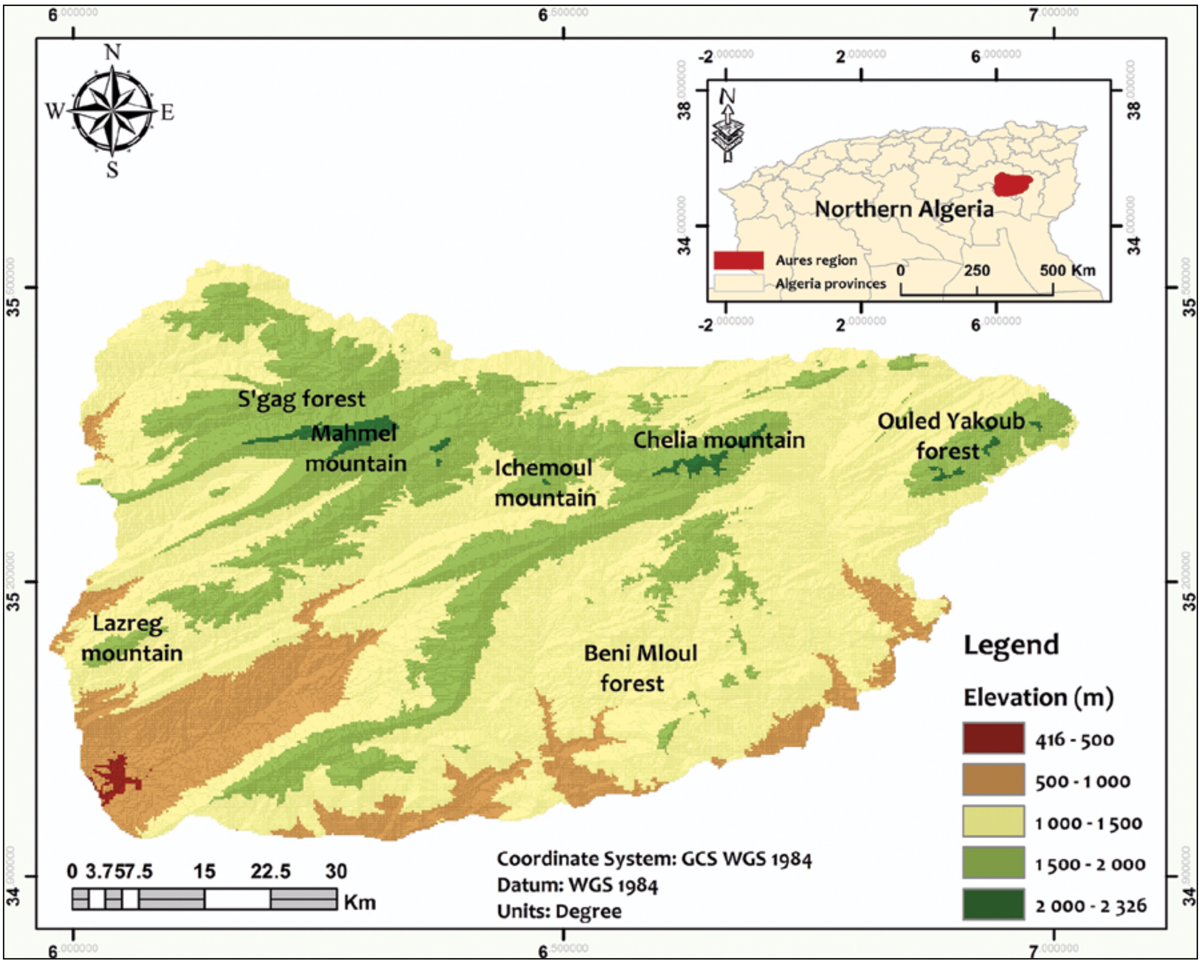

Figure 1 *Location map of the Aurès region*

tation is clearly noticeable. According to Emberger's synthetic classification, this vast area straddles the bioclimatic stages from semi-arid to sub-humid in cold winters (Emberger, 1945).

In this environment, where the most notable forest formations are to be found, the cedars and pine forests form veritable forests combined with several species, particularly the holm oak (*Quercus ilex* subsp. *ballota* (Desf.) Samp), the only Algerian thuriferous stands (*Juniperus thurifera* subsp. *aurasiaca* (Véla, Schäfer, 2013) and a stand of small-leaved Zen oak (*Quercus faginea* subsp. *faginea*) (Aissi et al., 2020). The rest of the vegetation is more or less arboreal matorrals (Abdessemed, 1981).

WORK METHODOLOGY

Materials and methods

The methodology used in this study is based on satellite data, as well as measurements and observations made in the field. In order to study the evolution of the forest cover in the Aurès massif, we analysed three pre-processed (atmospherically correct) satellite images LANDSAT_8; date: 22/09/2017, LANDSAT 5_TM; date 14/07/2003 and L5_TM; date: 07/06/1984, with a spatial resolution of 30 m. They were all acquired during the dry season, in order to make a clearer distinction between different existing biogeographic formations. The images used were obtained free of charge from the U.S. Geological Survey website (2017) (URL 1).

The pre-processing carried out concerned only the atmospheric and radiometric corrections. The aim of these pre-processing operations is to correct the geometric and radiometric deformations of the platforms and specific sensors in order to improve the readability of the images by eliminating all atmospheric effects (Jofack Sokeng, 2016).

The mapping was carried out using QGIS software version 2.18.11 (Quantum GIS Develop-

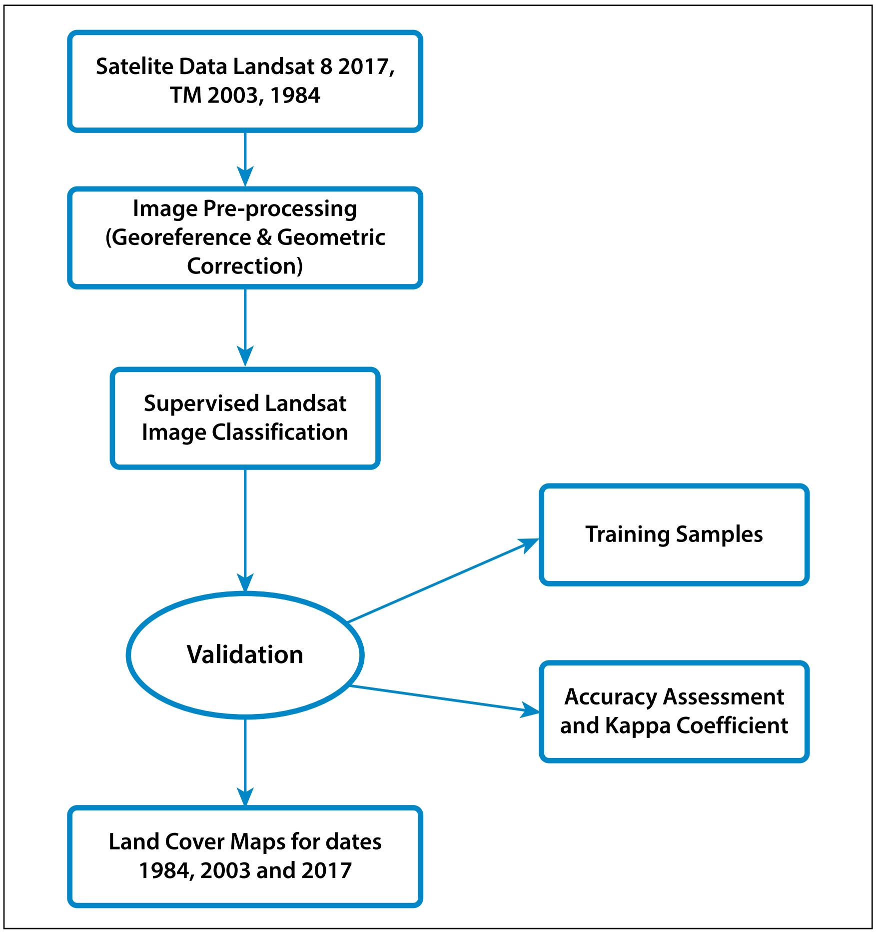

Figure 2 *Location map of the Aurès region*

ment Team, 2016). The land cover maps for the three dates were produced using the supervised 'maximum likelihood algorithm' classification which is a method that calculates the probability of a pixel belonging to a given class rather than another. Pixels will be assigned to the class for which the probability is highest. However, if this probability does not reach the expected threshold, the pixel is classified as 'unknown'.

In order to carry out a supervised classification, it is necessary to have a good knowledge of the terrain to allow the most relevant selection of field samples. Our fieldwork consists of identifying 145 training plots described by their geographical location (with GPS coordinates), and by a summary description of the use of the site. All these data are indispensable and are the most objective to launch a supervised classification on the Landsat images of study area (figure 2).

The quality of the classification obtained was assessed using the parameters calculated by the confusion matrix, overall accuracy and the Kappa coefficient. The confusion matrix displays the statistics of the classification accuracy of an image, including the degree of misclassification among various classes. It is calculated with values expressed in pixels and in percentage (Congalton, 1991). The results of the classification allowed us to highlight five types of land cover, namely dense forest: open forest, matorrals, herbaceous vegetation and bare soil.

The areas of the land cover units and the percentages representing the changes in regression and progression of the different units for the period 1984-2017 are shown in Table 1.

RESULTS

Classification validation and mapping results

The classification of Landsat satellite images produced acceptable overall accuracy. Indeed, the results provide Kappa values of 81%, 87% and 92% for the 1984, 2003 and 2017 images respectively. The results obtained from this classification should nevertheless be used with care

(Pontius, 2000).

Land cover from 1984 to 2017

The maximum likelihood-based classification performed on Landsat images (2017, 2003 and 1984) identified the five land use classes (Fig. 3, 4, 5):

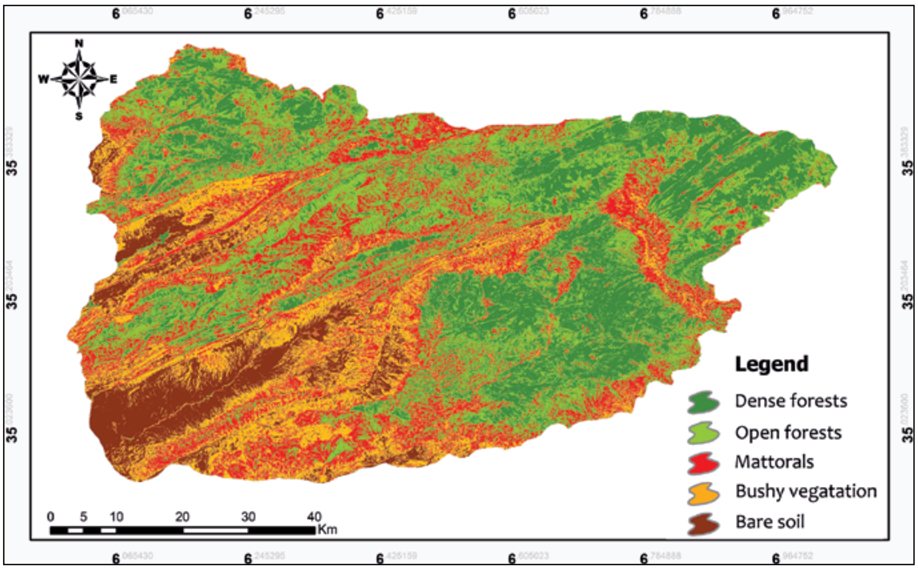

Figure 3 *Land cover map for the year 1984*

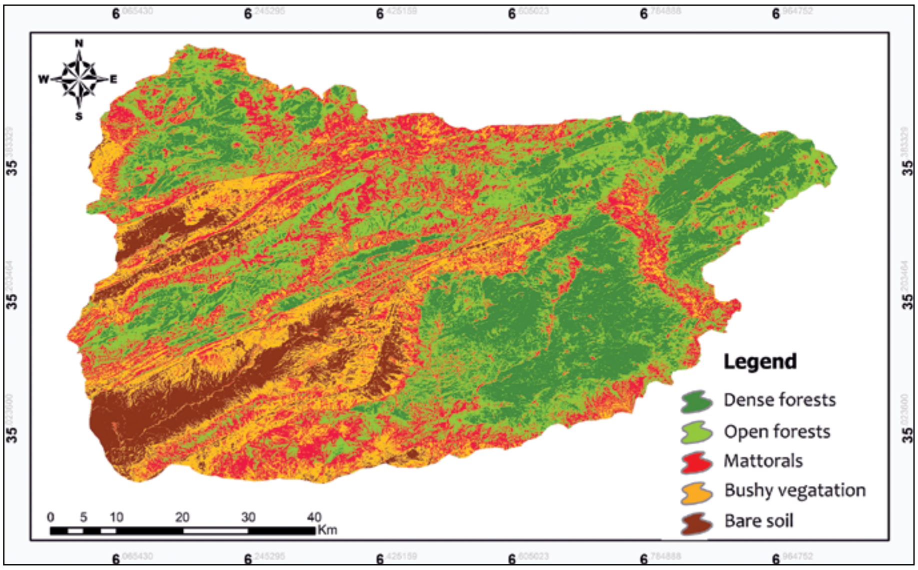

Figure 4 *Land cover map for the year 2003*

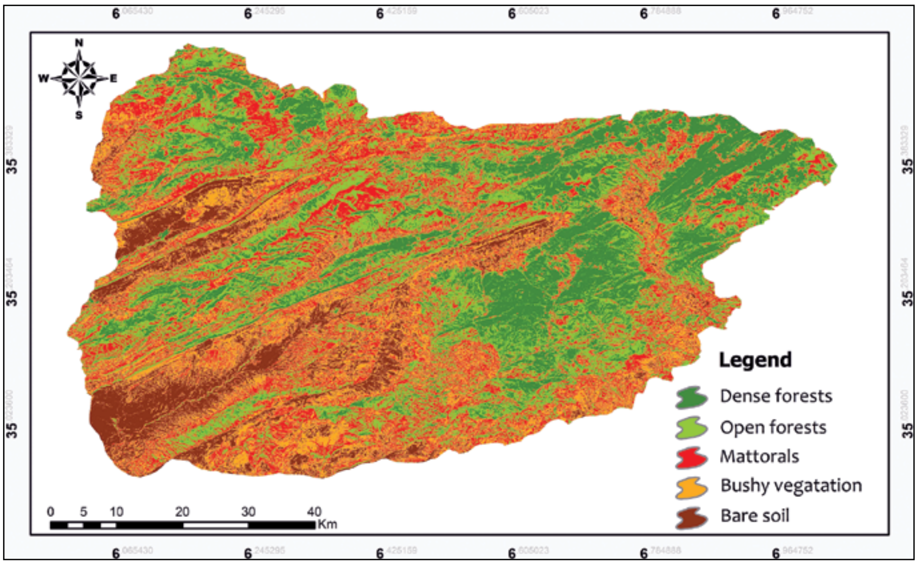

Figure 5 *Land cover map for the year 2017*

Table 1 *Area and dynamics of land cover units between 1984, 2003 and 2017*

	1984		2003		2017		dynamic 1984-2003		dynamic 2003-2017		dynamic 1984-2017	
	ha	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Dense forest	9,7036.29	23.24	95,293.80	22.82	86,021.28	20.61	-1,742.49	-0.42	-9,272.52	-2.22	-9,272.52	- 2.64
Open forest	114,524.30	27.43	112,918.10	27.05	99,964.80	23.95	-1,606.20	-0.38	-12,953.30	-3.10	-12,953.30	- 3.49
Matorral	99,624.33	23.86	106,081.50	25.41	109,126.3	26.15	6,457.17	1.55	3,044.80	0.73	3,044.80	2.28
Bushy vegetation	67,129.83	16.08	65,448.15	15.68	78,682.77	18.86	-1,681.68	-0.40	13,337.61	3.19	13,337.61	2.79
Bare soil	39,195.54	9.39	37,768.74	9.05	43,509.15	10.43	-1,426.80	-0.34	5,843.40	1.40	5,843.40	1.06
Total	417,510.29	100	417,510.29	100	417,304.3	100						

The category of dense forests is comprised of essentially high-altitude pure cedar forests, notably those of Chélia and Ouled Yakoub, as well as the pine forest of Beni-Meloul. Cedar-dominated formations (*Cedrus atlantica* (Endl.) Carrière) show a high cover rate in the northern regions yet very little in the south-western and extreme north-eastern parts of the study area (Abdessemed, 1984).

This class is found in areas of medium and high altitude (above 1400 m), mainly in the north and north-east of the study area, and regresses as we move southwards. The forests become increasingly lighter, gradually giving way, first of all, to holm oak matorrals (*Quercus ilex* subsp. *ballota* (Desf.) Samp), dimorphic ash (*Fraxinus dimporha* Coss. & Durieu) and Phoenician juniper (*Juniperus phoenicea* L.). These matorrals can be found over the entire surface of the study area, spreading from 800 to almost 1400 m, particularly on the southern slopes. The majority of the stands are much degraded and almost always occur in the form of coppices.

Bushy vegetation is found between 1900 and over 2100 m above sea level, and thus mainly occurs in the highest peaks of the Aurès, Chélia and Mahmel. At the extreme south-western end of the study area, the soils are generally bare or covered by prairies. The land-use status for the years 1984, 2003 and 2017 are summarised in Table 1.

Maps examination (Fig. 3, 4 and 5) and Table 1 associated with these figures shows a significant change in land cover in the Aurès massif between 1984 and 2017. Land cover in 1984 reveals a predominance in use of open forests (representing 27.43% of the total area), which generally occur on all exposures and encircle dense forests. Similarly, for the year 2003, open woodlands remain the most dominated. However, an increase in the area of shrubland to the detriment of other classes, notably dense open woodlands and bushy vegetation, can be observed. Indeed, in 2017, matorrals were the pre-eminent (26.61% of total area) with an increase in the spread of bushy vegetation and bare ground (18.86% and 10.43% respectively).

Assessment of land use dynamics from 1984 to 2017

Land cover changes over 33 years are quantified and spatialized in Figure 6 and Table 2. The matrix generated by cross-referencing the 1987 and 2017 land cover maps shows the evolution of land cover.

Comparing (Fig. 6 to 3 and 5) and Table 2 we find that switching from one type of vegetation to another can occur in all the formations. During the study period, dense and open forests tend to regress towards matorrals (29.24 and 37.84% respectively). The main observable causes include illegal cutting, forest fires and the dieback of Atlas cedar stands in particular.

Similarly for matorrals; a moderately high percentage (33.29%) has turned into bushy vegetation, probably due to the intense activity by local people to meet their needs for firewood and to feed their herds. Almost half (49.54%) of the bushy vegetation surface became bare soil. This unfortunately is representative of the final stage of vegetation cover degradation due to xeric environmental conditions associated with heavy land clearing. Nevertheless, this does not rule out a low incidence of transformation to other categories of vegetation.

Figure 7 shows that among the five selected land use classes, two witnessed a relatively sig-

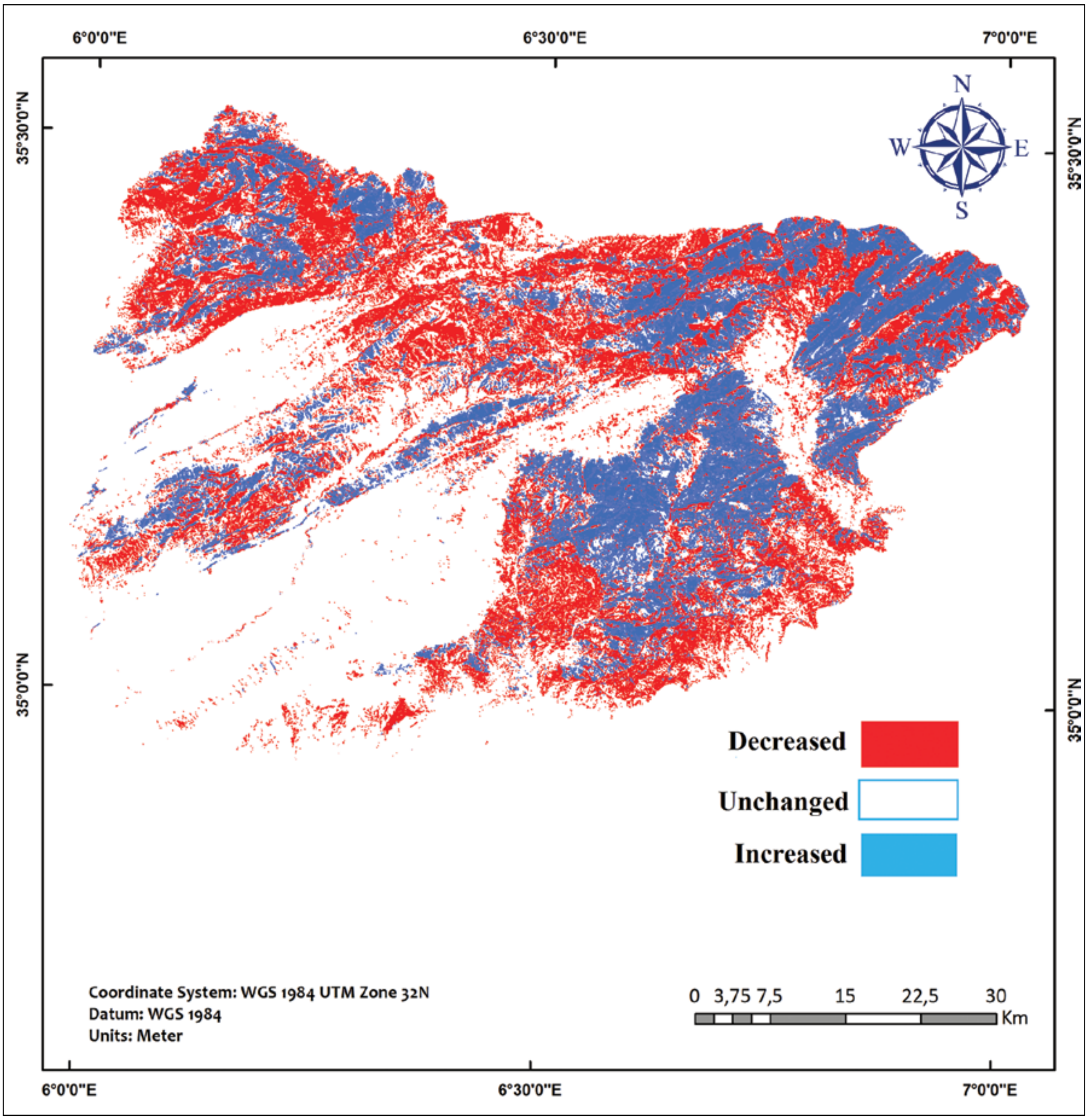

Figure 6 *Map of changes for the period 1984–2017*

Table 2 *Transition matrix of land use classes in the Aurès region between 1984/2017*

	1		2		3		4		5	
	ha	Changes %	ha	Changes %	ha	Changes %	ha	Changes %	ha	Changes %
1	53,053.30	40.25	35.46	0.05	473.74	0.41	199.31	0.70	50.95	0.06
2	28,423.44	21.56	28,202.09	42.35	624.63	0.54	30.29	0.11	41.78	0.05
3	38,539.86	29.24	25,201.07	37.84	49,136.13	42.40	1,977.89	6.99	155.30	0.17
4	639.41	0.49	11,301.54	16.97	38,582.54	33.29	12,077.87	42.66	645.07	0.70
5	11,169.76	8.47	1,858.26	2.79	27,073.51	23.36	14,026.91	49.54	90,890.16	99.03
Total	131,825.78	100.00	66,598.43	100.00	115,890.55	100.00	28,312.27	100.00	91,783.27	100.00

1: class of dense forests; 2: open forests; 3: matorrals; 4: bushy vegetation; 5: bare soil

nificant decline. These classes are represented by dense and open forests, showing a decline of 11,015.01 and 14,559.50 hectares, respectively. On the other hand, the other three land use classes, i.e. matorrals, bushy vegetation and bare soil, were in significant increase. The most notable progress is that of the matorrals class with a surface area of 11,655.93 hectares.

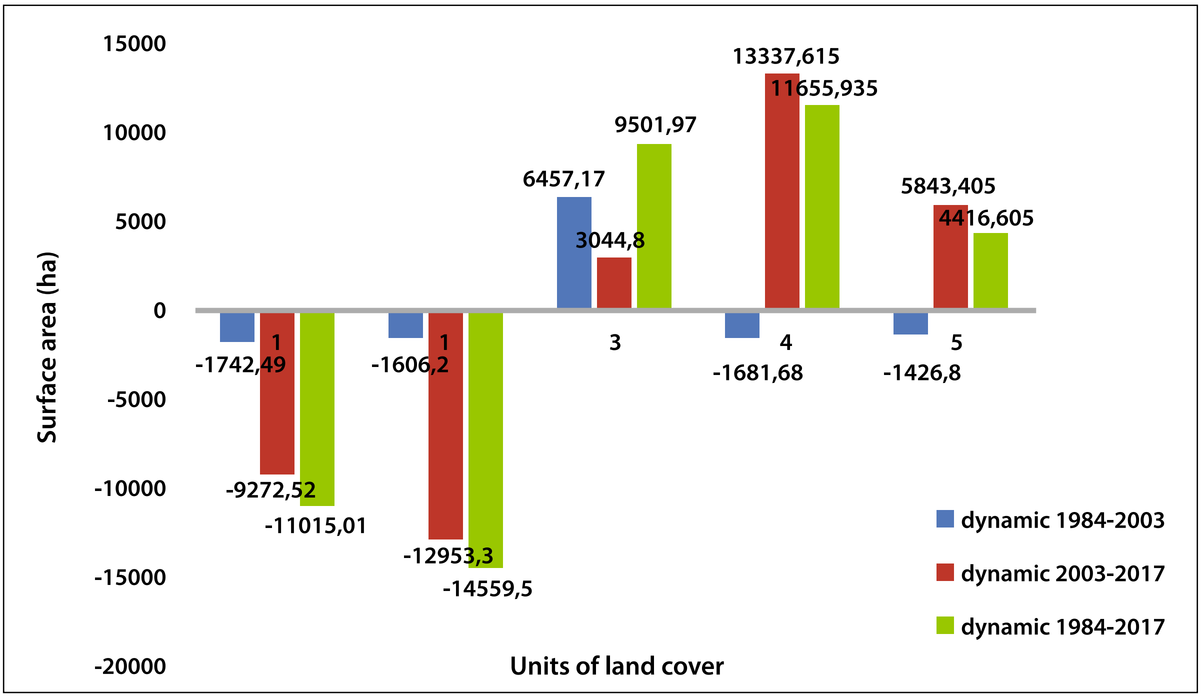

Figure 7 *Final assessment of the evolution of land cover in the Aurès*
1: class of dense forests; 2: open forests; 3: matorrals; 4: bushy vegetation; 5: bare soi

DISCUSSION

The spatio-temporal analysis of land cover shows a regressive dynamic of the natural environment in the Aurès region, particularly with regard to the study period (1984-2003-2017). While the classes of matorrals, bushy vegetation and bare soil reveal a visible increase in terms of surface area, dense and open forests were and still are undergoing accentuated decrease. The

Figure 8 *Atlas cedar dieback in Chélia on 2017* (photo: H. Bezzih)

Figure 9 *Atlas cedar dieback in Ouled Yakoub on 2017* (photo: H. Bezzih)

decline of the dense forest, the causes of which are multiple and remain uncertain, manifests itself in a very striking and alarming manner, particularly with regards to the cedars of Chélia, Ouled Yakoub and Sgag (Fig. 8 and 9). This more or less accelerated degradation of the stands and the progressive diminishing of the arborescent strata are causing the cedar forest to evolve towards a vegetation structure of the pre-forest and matorral type (Quézel, 1998).

According to A. Bentouati (2008), the cedar dieback in the Aurès is probably linked to climatic conditions (drought, hydric stress, Saharan influences), anthropogenic action, overgrazing and uncontrolled logging.

A sharp decline in the Aurès cedar forests was widely reported around 1982. A. Bentouati and M. Bariteau (2006) mentioned that the surface area of the latter had decreased considerably, i.e. by around 400 ha per year (Abdessemed, 1984). National Office for Rural Development Studies (*Study and expertise on the decline of the cedar forest of Ouled Yagoub and Chelia - Wilaya of Khenchela*, 2010) also reported that healthy stands of Atlas cedar occupy only 1713 ha in Ouled Yakoub. M. S. Khanfouci (2005) noted that the surface areas of the Aurès and Belezma cedar forests have declined enormously, from 20,000 to 12,000 ha and from 8,000 to 4,250 ha respectively.

According to certain authors, unfavourable climatic conditions are most probably the main factor in the decline. Indeed, A. Belloula and Y. Beghami (2017) report that the large percentage decrease in the surface area of Atlas cedar in Mount Chélia and Ouled Yakoub, recorded during the period 1999 to 2016 coincided with a period of drought (1999 to 2002), which had been the driest since 1845, according to the study conducted by D. Kherchouche (2013). Similarly, H. Smaihi and M. Kalla (2017) consider that climate change was the triggering factor for cedar dieback in Belezma National Park (the north-western boundary of the Aurès).

When analysing the south-western and eastern Aurès respectively, Benmessaoud et al.

(2009) and A. Bouzekri and H. Benmessaoud (2014) also indicated a regression in vegetation cover essentially due to a geographical location subject to Saharan influences. The cedars in the southern Aurès show a very open distribution, possibly resulting from increased anthropogenic action combined with environmental constraints (Kherchouche, 2013). Garah et al. (2016) noted a 3% decrease in the surface area occupied by Atlas cedars in the Ouled Yakoub massif, i.e. 1506 ha, due in part to the ecological requirements of the species, which no longer allow it to colonise low and medium altitudes of the southern slope in particular. Y. Beghami et al. (2012) noted that dense forest formations, particularly cedar groves, are receding, and are most often replaced by scrublands and herbaceous formations, resulting in a clear canopy that is vulnerable to all kinds of degradation.

Because of this regression, it is important to note that there has been a remarkable progress of holm oak and dimorphic ash, particularly in areas of decline, in the form of matorrals (Chafai, 2016). In spite of its adaptive characteristics to environmental in disturbances (hydric and thermal stress, types of substrate), holm oak forests have experienced a very marked degradation in the Aurès region (Abdessemed, 1984). The open and degraded holm oak formations are probably the result of anthropogenic activity, which is observable in over-grazing and needless excess cutting, thus jeopardising the durability of these oaks and the biodiversity they shelter (Aissi, 2019).

The Aleppo pine (*Pinus halepensis* Mill.) is also showing a decline, particularly in Beni Meloul pine forest, which, with a surface area of around 70,000 hectares (DGF 2010) represents the largest Aleppo pine stand in Algeria. This decrease is mainly due to fires, which are the major and most frequent factor in the degradation of the Aleppo pine forest. Indeed, this region has suffered multiple fires of varying intensity. In 2012, an area of around 6,000 ha of the pine forest was seriously affected by fire (Garah et al., 2016).

The way of life of the local populations, which is closely tied to their need for natural resources, accelerates the phenomenon of degradation of the forest cover itself, thus leading to the onset of more or less degraded formations (matorral and bushy vegetation), and this, to the detriment of dense and clear forests. The potential impact of this degradation in its advanced phases manifests itself in the form of bare soil, the result of an intense and repeated practice of land clearing associated with the phenomenon of desertification.

CONCLUSION

This study addresses the need to update the status of the forest ecosystem in Aurès region and to highlight the impact of poor management of spaces in this region. The use of multispectral satellite imagery show that the land cover has declined manly in the class of dense and open forests by approximately 9300 ha and 1300 ha in 33 years, for fields, mattoral and bare soil. The combined effects of anthropic actions and climatic factors could explain the observed changes. It must be admitted that the conservation of the forest heritage is above all a socio-economic problem, while remaining technical. On this subject, it appears that the preservation of natural environments can only be achieved through consultation and the participation of local communities.

Future research work should focus on integrating GIS and satellite remote sensing with high spectral, spatial and temporal resolution at the local scale to allow achieving high accuracy in classification and mapping. In addition, research work should draw attention to land cover modeling and techniques integrating socio-economic data and GIS tools for predicting future pattern of change in order to achieve sustainable development.

ACKNOWLEDGMENTS

We would like to express our special thanks to the members of Directorate of Forest in Khenchela particularly, the officers of the forest district of the Daira of Bouhmama for their assistance and technical support.

AUTHOR CONTRIBUTION

Houda Bezzih conceived the research goal, analysed the data, authored and reviewed drafts of the paper, and approved the final draft.

Abdeldjalil Aissi reviewed drafts of the paper, and approved the final draft.

Hamana Malki conceived the original papers' idea and research goal, approved the final draft.

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