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Diachronic study of changes in vegetal cover in a mountainous ecosystem by spatial remote sensing: Aures region (Algeria)

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Abstract. Since the 1970s, arid and semi-arid zones, as one of the most vulnerable ecosystems, have attracted considerable attention. The the study of the influences of climate variations and human activities in this zone have become, and being the hot topics in the field of ecological environment research.

A better understanding of the evolution of land use patterns and plant cover is a major concern for countries whose ecosystems are undergoing severe degradation. Indeed, land use dynamics have direct implications on the availability of natural resources. spatial remote sensing provides an extremely effective tool for locating problems and monitoring developments, our study carried out on the Aures Mountains in eastern Algeria, using the normalized difference vegetation index (NDVI), highlights the extent of changes in vegetation cover between 2000 and 2023, 80815,25 ha of the vegetal cover witnessed a regression between 2000 and 2023, or the area lost 3513,706 ha of vegetation the per year.

A pronounced regressive evolution of the plant cover is observed in the southwest and northeast of the Aures mountains, particularly in the "forest of Beni Oudjana, Beni Melloul and Ouled Yaakoub", in the municipalities of Chelia, Bouhmama and M'sara. The main factors contributing to the decline in plant cover are: deforestation, overgrazing, forest fires and the resulting water erosion.

Keywords. vegetal cover, regression, remote sensing, NDVI, Aures mountains.

1. Introduction

Since the 1970s, arid and semi-arid zones, as one of the most vulnerable ecosystems, have attracted considerable attention. The discussion, and even the controversy, on the study of the influences of climate variations and human activities in arid zones have become, in recent decades, hot topics in the field of ecological environment research (Bagnouls & Gaussen, 1957) and (Ballais J., 1978). The common feature of arid and semi-arid environments is aridity, low rainfall, erosion and their vulnerability to degradation. These characteristics are present in all arid and semi-arid environments (Halitim, 1975), (Pouget, Cornet, & Kamal, 1989) and (Le Houerou, 2005).

The Aures region is part of the semi-arid and arid regions of the Mediterranean shore. Due to the climate and the very fragile nature of the soil, the plant cover is constantly faced with problems of degradation.

The phenomenon of degradation has increased over time due to socio-economic transformations and changes in production systems. Indeed, the conjunction of several factors has broken the balance:

demographic growth and the increase in the needs of the population, clearing of the forest for the benefit of cereal crops, increase in livestock and uncontrolled management of natural resources. This situation has been aggravated in recent years by the decrease in rainfall, the irregularity of precipitation and the increase in the probability of periods of drought (Cote, 2003), (Abdessemed, 1985), (Anser, 2002), (Bensaid, 2006), and (Berkane & Yahiaou, 2007).

According to several authors (Laffitte, 1939), (Ballais, 1975, 1981), (Abdessemed K., 1981, 1984), (Anser, 2002) and (Berkane & Yahiaou, 2007) who have worked on this area it is indeed a progressive degradation of which the human being is the 'solely responsible because of poor management and use of fragile lands in the ecosystem. Likewise, in his study on the development of pastures (LeHouerou. H, 1981) states: "… if the management methods are not adapted, we risk in certain cases seeing the appearance, in a few decades, of deserts of anthropic origin whose evolution will be difficult to reverse. It is important to note that this phenomenon has experienced an alarming progression since the 1980s, but in reality, it began to manifest itself since the 1970s (Benmessaoud, 2008).

A regressive evolution is observed in certain forest ecosystems: the dieback of the Aures cedar groves which are experiencing a major decline in their original areas or the recurring fires in the pine forests which have ravaged 35,025 hectares of total forested area per year in Algeria during the period 1985-2010 (Meddour & Derridj, 2012). This dynamic, probably primarily linked to climatic changes, is also accentuated by harmful and repeated anthropogenic actions such as land clearing, excess grazing, tree topping; it has led to a shift in the bioclimatic areas of species (Vennetier, Liang, Ripert, Vila, & Guibal, 2005) and variation in the structure and composition of ecosystems. Among spatial observation techniques, land use mapping occupies a central place. The interest in using remote sensing in the study of pathways was very early demonstrated by G. De Wispelaere and G. Waksman (1977), (Courel, Cuq, & Tounsi, 1988).

More recently, numerous studies based on the diachronic analysis of land use (Sarr. M, 2009), (Souley Yero, 2012) and (Marega, 2016), but also in more humid regions (Andrieu, 2018), (Solly, Dieye, Mballo, SY, & Sane, 2020), confirm this contribution of remote sensing.

From this diachronic perspective, old aerial photographs from the 1950s and 1960s have very often been compared to medium or high-resolution satellite images, such as Landsat MSS, Landsat TM, ETM+, HRV from Spot, with the aim of having a greater historical depth in the study of land use (Hountondji, 2008). Furthermore, several studies have demonstrated that NDVI time series are very effective for estimating vegetation productivity as well as the phenological rhythms of different terrestrial biomes (Tucker & Sellers, 1986), (Bannari, Morin, & Bonn, 1995), (Dardel, Kergoat, Hiernaux, & Mougin, 2014), (Andrieu J., 2017), (San Emeterio, 2018). This index is very widely used by the scientific community, due to its reproducibility and its effectiveness in detecting chlorophyll activity.

This study aims to map and quantify by remote sensing the processes of progression or regression of vegetation cover between 2000, 2013 and 2023 respectively. This involves diachronic mapping of plant cover through the analysis of medium-resolution multispectral images using an approach based on NDVI time series.

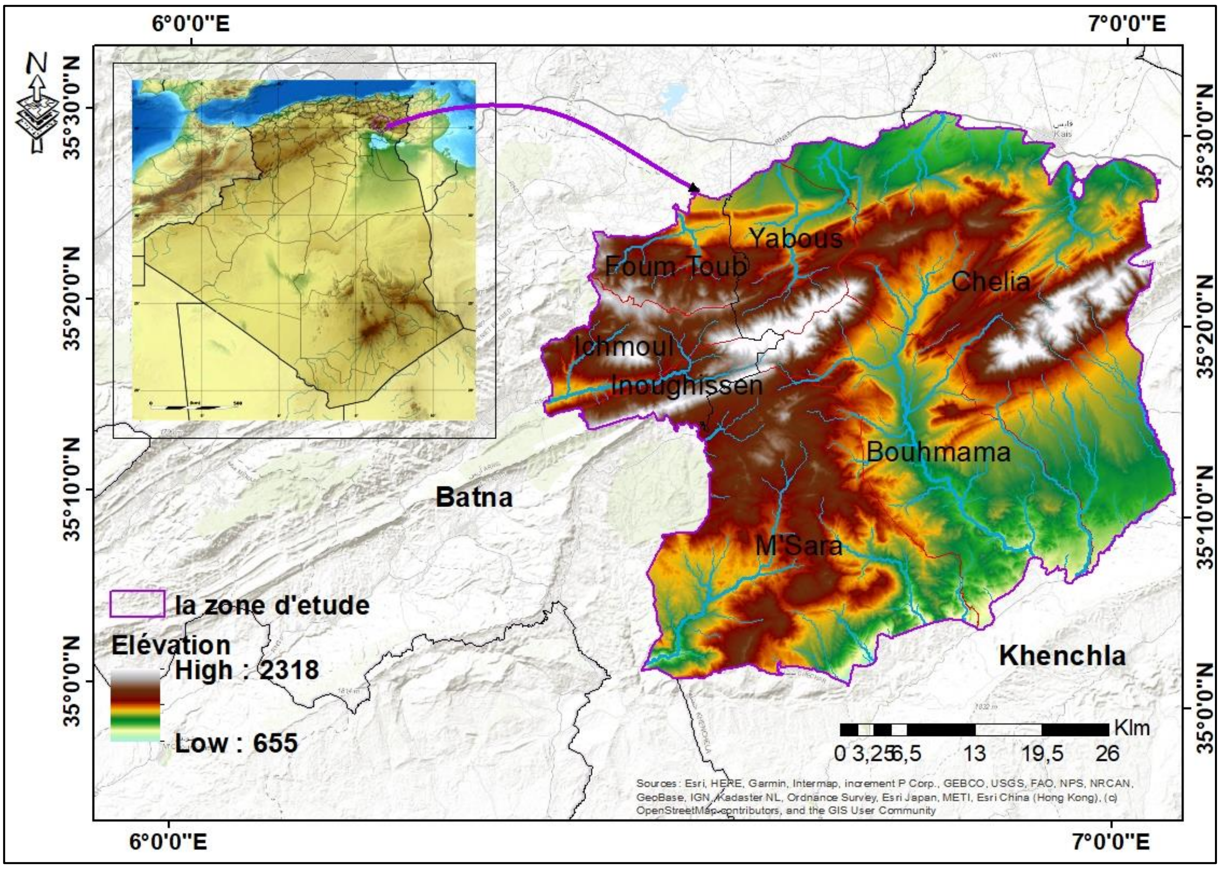
2. Materials and methods

2.1. Study area

The study region is located in the northeast of Algeria. It is located approximately within the range of the following geographic coordinates: 6°22.5 - 7°3.7 East and latitudes 35°30.00 -35°2.31 North (figure 1), with an area of 2264.80 Km2, it is a vast mountainous region of the Eastern part of the Saharan Atlas which separates the high plains of Constantine from the Sahara, it is raised massively above the Quaternary plain of Biskra (Cote, 2003).

The altitudes, between 800 and more than 2000 m, are part of a rather rugged terrain. Climatically, the study area is subject, as a whole, to semi-arid conditions under Saharan influence. The area has been the subject of several vegetation studies, but none have used remote sensing to confirm, visualize and quantify canopy shrinkage. However, this method has largely proven itself for the analysis of the evolution of natural spaces.

Figure 1. Geographic localization and the land use of the study area
(Treated by arc gis 10.8 proj: UTM84 zone 32)



The Aures region is part of the northern ecosystems of northern Algeria, vegetation cover is strongly linked to soils and climate, the vegetation of the study area presents characteristics similar to that of the physical environment (Boudy, 1955), (Schoenenberger, 1971), (Abdessemed K., 1984), (Anser, 2002).

Forest formations: The various species that populate them are (figure 2): Juniperus communis, Juniperus phoenicea, Juniperus oxycedrus, Quercus ilex, fraxinus, Pinus halepensis, Cedrus atlantica, Taxus baccata. Cedrus atlantica begins to appear at the height of 1,400 m on the sheltered slopes of the Siroco, but we do not see it at any altitude on the slopes exposed to the breath of the desert. The pine is, after the cedar, the natural ornament of the Aures and forms beautiful forests in certain centers, but cedar and pine do not resist the Chehili, the terrible southwest wind. Only holm oaks and junipers are robust enough for this. The first seem to occupy the place of cedars and the second those of pines. On the contrary, on the north side not only in the shelter of the high peaks but even behind the lowest ridges the vegetation develops vigorously. Cedrus atlantica then mix with Pinus halepensis and especially with the Quercus ilex which are the most beautiful that can be seen. Juniperus in the south compete with the taller trees. In some places the forests are inextricable.

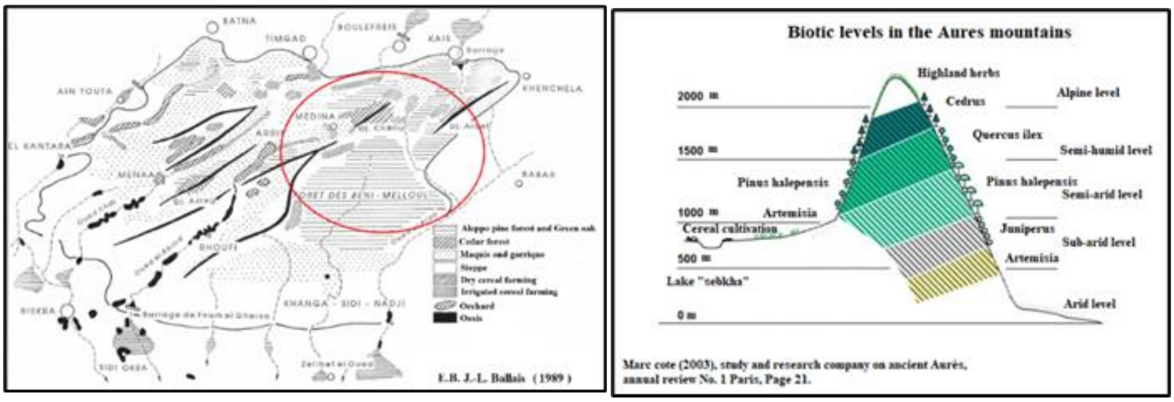
Para-forestry formations: Occupy a large area in the form of discontinuous islands based mainly on holm oak. The maquis are in a very advanced state of aging and are degraded. They are intended for environmental protection.

Rangelands: This unit is widely distributed in the southern region. After forests and scrubland, it remains the most important. It generally presents in the form of very degraded vegetation, where non-potable species predominate due to the overload of sheep numbers. It includes all areas with herbaceous cover, sometimes even low woody cover. The very light, low and very degraded scrubland, which showed very clear signs of overgrazing, was also considered as rangeland given its current use. From a phytoecological point of view, the dominant vegetation is that of the steppe (sheets of esparto, white mugwort, etc.), The steppe formations of this zone are rangelands (medium areas of low vegetation) very often degraded.

Agriculture: The agricultural environment of the area is characterized by subsistence mountain agriculture focused essentially on the combination of livestock breeding in association with cereal growing, market gardening and fruit growing. On the other hand, it is worth noting the practice of small breeding which is in full expansion after the implementation of the PNDA program.

Despite this very degraded situation, plant resources, the region offers very beautiful climax plant formations, botanical curiosities and especially endemic populations in danger of disappearing, such as Juniperus thurifera and Fraxinus dimorpha or Aures Fraxinus which there is to save.

Figure 2. Land use map of the Aures Mountains in 1989



2.2. Data processing

To study the evolution of the plant cover of the Aures mountains, three Landsat satellite images were chosen, both taken in August:

-Landsat TM image 30/08/2000 with geometric correction.

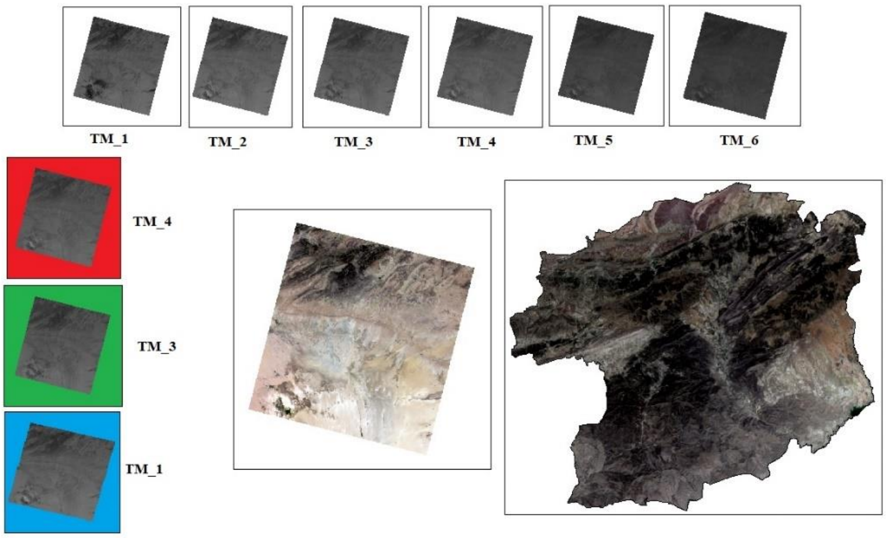
-Landsat ETM+ image 07/08/2013 with geometric correction.

-Landsat ETM+ image 06/08/2023 with geometric correction.

Landsat TM imagery (thematic mapper) covers a wider portion of the electromagnetic spectrum. The TM sensor records reflectance in the visible (TM1, TM2, TM3), in the mid-infrared (TM5 and TM7) and in the near-infrared (TM4). It is recognized that taking into account at least one band from each of these three spectrum zones allows good general discrimination of land use.

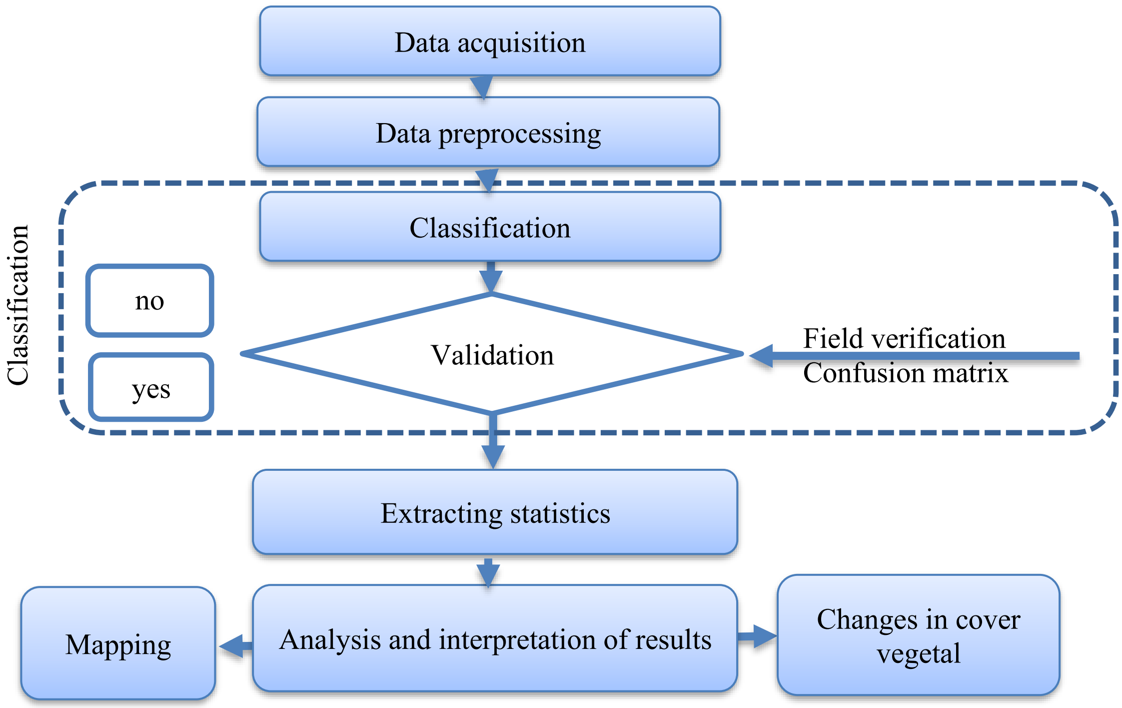
It is also generally accepted that the use of a large number of spectral bands provides little more discrimination between objects on the ground than that of a few judiciously chosen bands (Beaudoin, Cavayas, & Marois, 1995). Each thematic target being characterized by a spectral signature and not reacting in the same way in the different channels (Bensaïd, 1997), the analysis of the average reflectance's of the different individualized themes in each of the channels allows the choice of appropriate spectral bands. for soil mapping (Escadafal, 1989). Our colored composition was obtained from the superposition of three channels, by assigning to each one of the three fundamental colors (red, green, blue) (figure 3) according to their wavelength (respectively near infrared, red and blue).

Figure 3. Creation of the colored composition
(Treated by arc gis 10.8 proj: UTM84 zone 32)



The detection and identification of changes in land use in the Aures mountains between 2000 and 2023 are based on the use of the three reference images obtained. The method used to identify changes in plant cover (figure 4). The images have undergone atmospheric correction using the method applied by (Durrieu, 1994).

Figure 4. Working methodology



The detection and identification of changes in land use in the Aures mountains between 2000 and 2023 are based on the use of the three reference images obtained. The method used to identify changes in plant cover (figure 4). The images have undergone atmospheric correction using the method applied by (Durrieu, 1994). To carry out our analysis, we chose the NDVI (Normalized Difference Vegetation Index), which is relatively insensitive to observation conditions, the average error due to atmospheric effects being 15%. For other indices, if the average error is also 15% for the STAVI (Transformed Soil Adjusted Vegetation Index), it reaches 17 to 20% for the GEMI (Global Environment Monitoring Index) and even 26% for the MSAVI (Modified Soil Adjusted Vegetation Index).

The normalized vegetation index (NDVI) is established by subtracting from the infrared channel (where vegetation cover has strong reflectance) the red channel (where mineral surfaces have strong reflectance). The resulting neo-channel exhibits an increasing gradient of plant activity from black (absence of cover) to white (very high chlorophyll activity). The result of an NDVI takes the form of a new image, the value of each pixel being between 0 (bare ground) and 1 (maximum vegetation cover). It is the analysis of the range of nuances extending between these extreme values (very infrequent) which informs the observer about the density of the plant cover and the quantity of green biomass. To rule out the hypothesis that the general evolution of the vegetation could be masked by particular climatic conditions preceding the shots, we examined the precipitation and temperatures over the period from 2000 to 2023.

3. Results

3.1. *Classification validation*

The resulting thematic maps are illustrated in figure 6, they correspond respectively to the years 2000, 2013 and 2023. The confusion matrices generated for these three maps showed a satisfactory level of precision, both for the overall precision and the precision of the classes (table1). The Kappa index (Khat) thus showed an acceptable level of precision with values 0.81, 0.89 and 0.90 for the years 2000, 2013 and 2023 respectively.

Table 1. Classification accuracy of the three images 2000, 2013 and 2023.

Type of assessment	2000	2013	2023
Overall accuracy (%)	91,01	95,18	94,87
“Vegetation” class accuracy (%)	96,00	92,30	98,10
Khat Index	0,81	0,89	0,90

Source: Author calculation

3.2. *Mapping* change

In this study, the calculation of dominant vegetation classification of the study area by using the supervised classification (maximum likelihood) tool in Arc GIS 10.8 software, and the change of vegetation is estimated from the vegetation index normalized difference (NDVI) using raster calculator tool in ArcGIS. The NDVI is defined as the difference between the red and near infrared (NIR) reflectance divided by their sum (Tucker, 1979), and it is calculated from these individual measurements as follows:

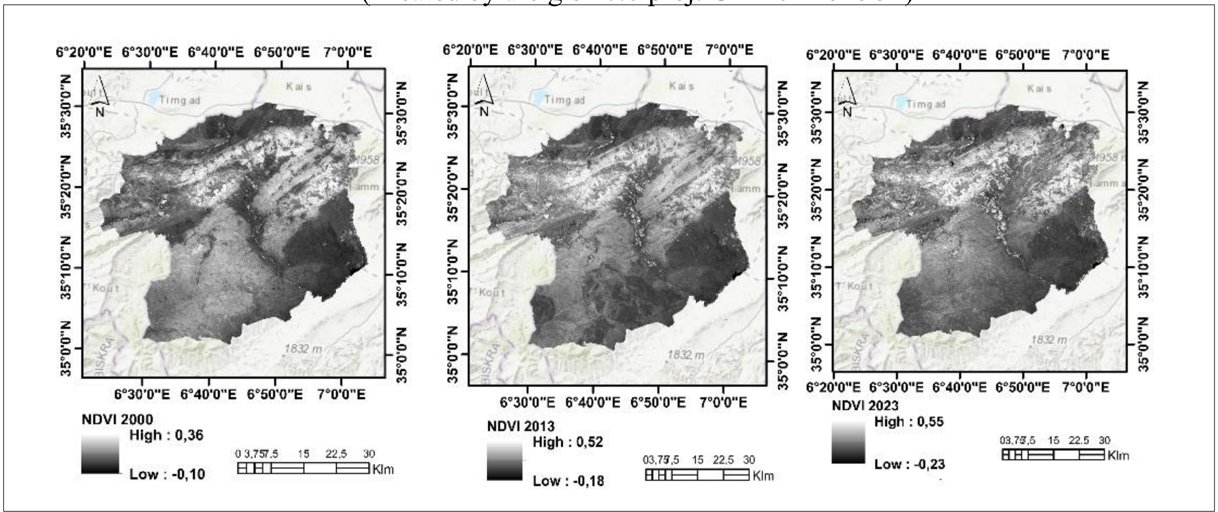
$$NDVI = (NIR - R) / (NIR + R) \qquad (1)$$

In Landsat 4-7, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3).

In Landsat 8-9, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4).

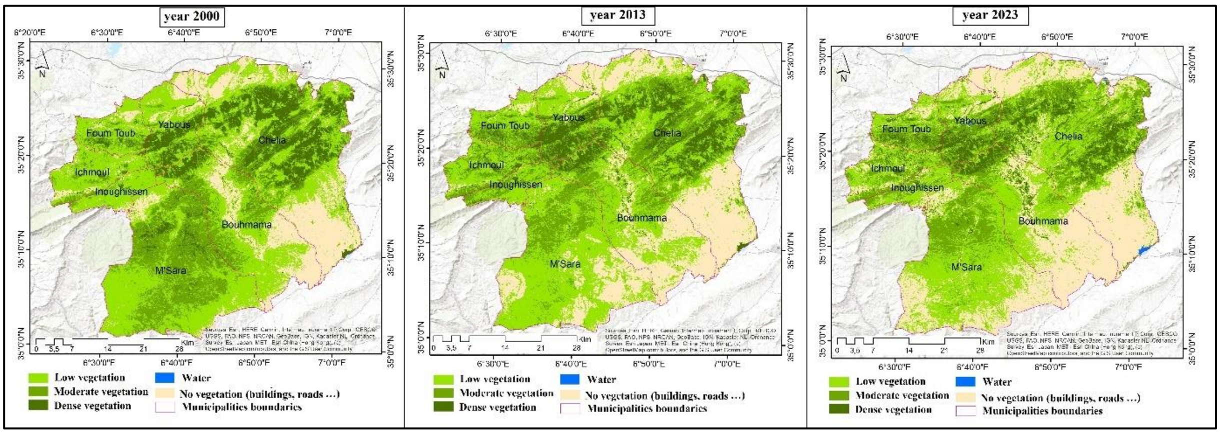
This step of calculation used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health (figure 5). was done from three satellite images taken from the satellite LANDSAT, acquired in the dry season, where one can distinguish the various types of land cover.

Figure 5. Spatiotemporal evolution of vegetation classes (2000 - 2013 - 2023)
(Treated by arc gis 10.8 proj: UTM84 zone 32)



Clouds, water and snow have a higher reflectance in the visible than in the near infrared, so these surfaces have a low NDVI. Rocks and bare soil also have reflection indices close to zero (É. NGUESSAN et al., 2003). In areas with vegetation, the NDVI is higher and varies on average between 0.8 and 1. Higher values are associated with a high density of plant foliage. The white color, which represents vegetation in the NDVI, is less apparent on the TM 2000 image than on the ETM+ 2013 image, which is indicative of a regression in vegetation cover between the two dates. Finally, black and shades of gray, colors representing surfaces where plant cover is absent, are more pronounced in the NDVI on the ETM+ 2013 and 2023 image than in the NDVI on the TM 2000 image. This approach therefore highlights a regression in plant cover (figure 6), particularly in the Northern-Est part of the municipality of Chelia and in the municipality of Bouhmama and M'sara.

Figure 6. Evolution of vegetation cover (2000 - 2013 - 2023)
(Treated by arc gis 10.8 proj: UTM84 zone 32)



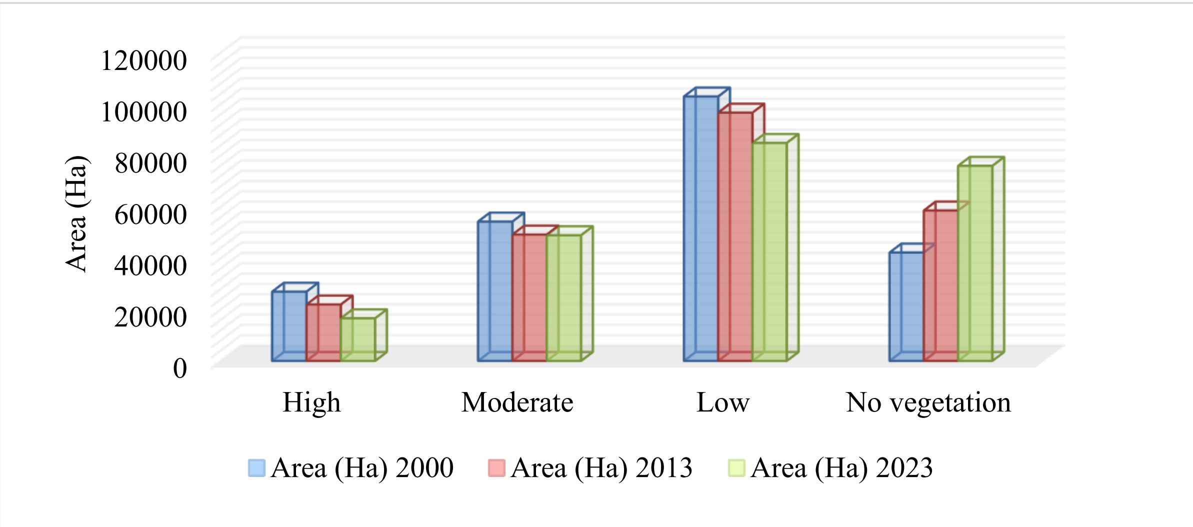
In vegetated areas, the NDVI is higher and varies on average between 0.8 and 1. Higher values are associated with a high density of plant foliage. The white color, which represents vegetation in the NDVI, is less apparent on the TM 2000 image than on the ETM+ 2013 image, which indicates a regression in vegetation cover between the two dates. Finally, black and shades of gray, colors representing surfaces where plant cover is absent, are more pronounced in the NDVI on the ETM+ 2013 and 2022 image than in the NDVI on the TM 2000 image. This approach therefore highlights evidence a regression in plant cover (figure 7), particularly in the northern part of the municipality of Bouhmama and the eastern part of the municipality of Chelia. The dominance of the green color in Figure 8 (result of the superposition of the three satellite scenes studied) reflects an increase in chlorophyll activity between 2000, 2013 and 2023 in the north of the Chelia mountains (municipalities of Chelia, Yabous and of M'sara), as well as on their northeastern spillovers (municipality of Bouhmama).

Table 2. Surface evolution of land occupation and use classes

Class	Area (Ha)			2000-2013	2013-2023
	2000	2013	2023	+/- (Ha)	+/- (Ha)
High vegetation	26987,312	21972,285	16613,988	-5015,027	-5358,297
Moderate vegetation	54272,406	49197,616	48957,714	-5074,789	-239,903
Low vegetation	102982,941	96706,265	84909,957	-6276,676	-11796,308
No vegetation (buildings, roads,…)	42213,551	58580,065	75972,361	16366,513	17392,296
Total		226456,2119		/	/

Source: Author calculation

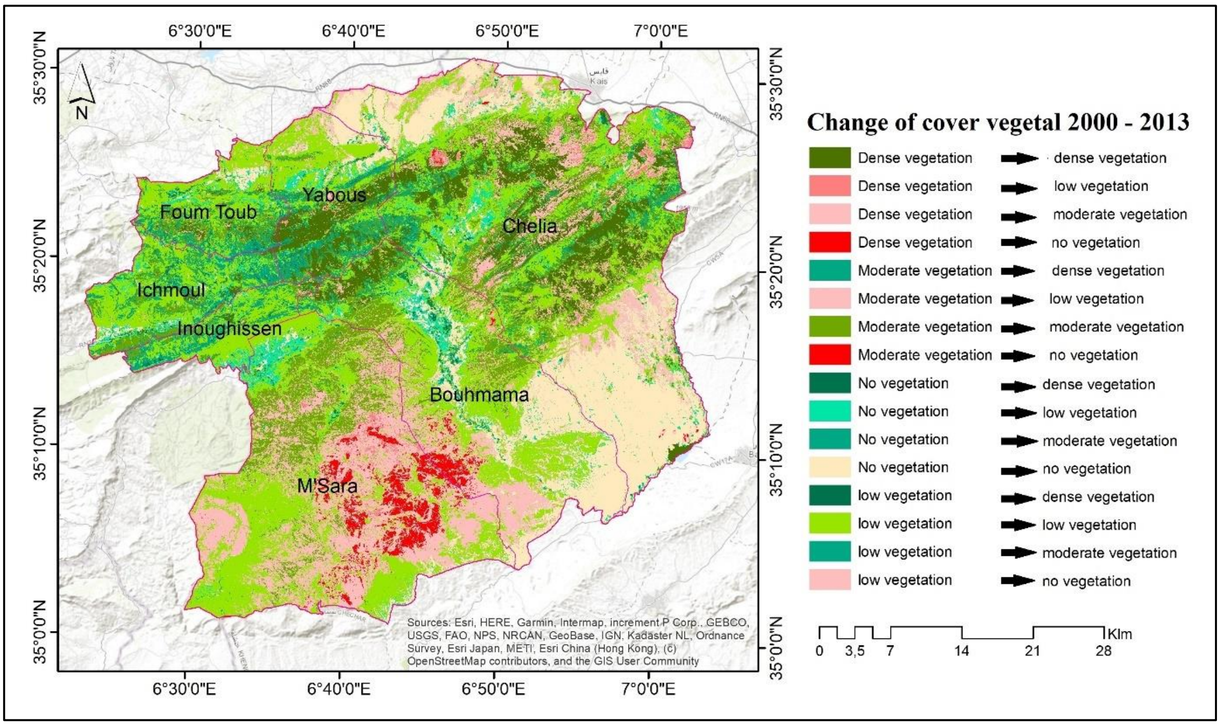
Figure 7. Evolution of surface portions of land use classes (2000 - 2013 - 2023)



The study highlights the extent of the decline in the forest vegetation cover of the Aures (graph 1). It reveals a variation in the rate of decline between the two periods (2000/2013) and (2013/2023). During the first period, the vegetation cover underwent a regression or degradation process (figure 8). the area of dense vegetation decreased from 26987.31 ha in 2000 to 21972.28 ha in 2013 with a loss of 5015.02

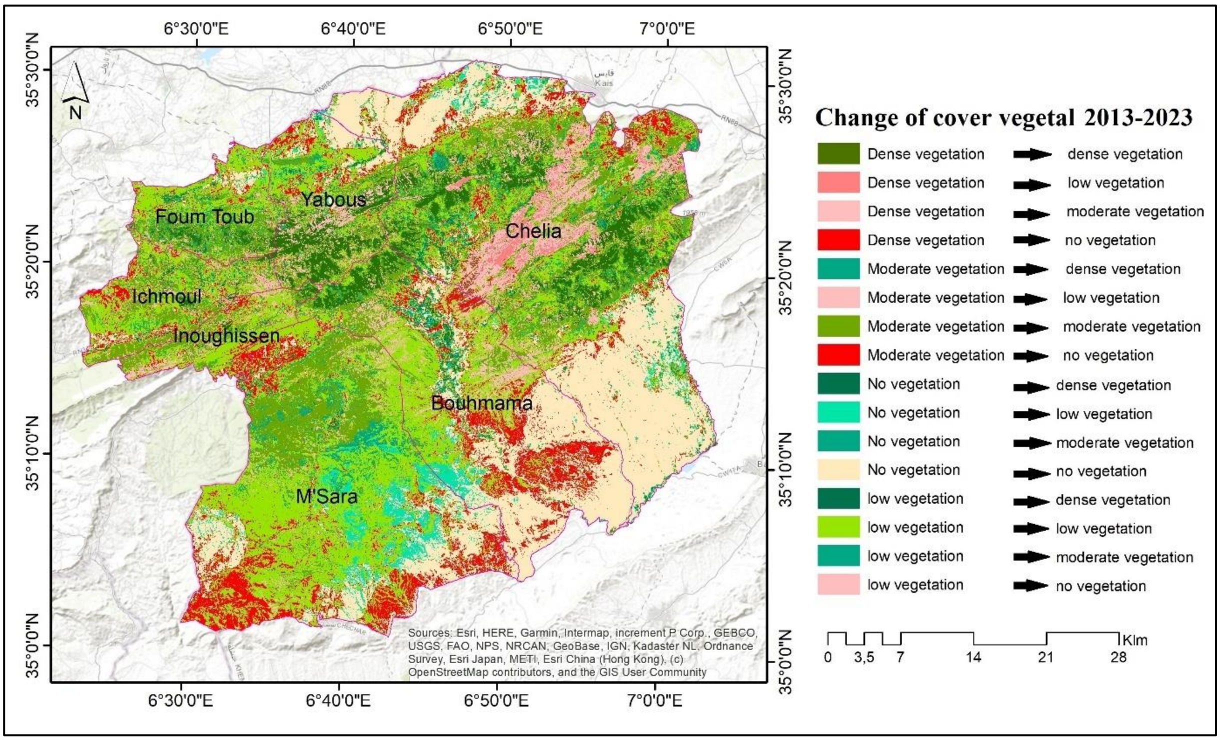
ha, or 385,77 ha of annual loss. The area of moderate vegetation decreased from 54272.406 ha in 2000 to 49197.616 ha in 2013 with a loss of 5074.789 ha, or 507.479 ha of annual loss. The area of low vegetation decreased from 102982.941 ha in 2000 to 96706.265 ha in 2013 with a loss of 6276.675 ha, or 482.821 ha of annual loss. On the other hand, the no vegetation class (buildings, roads and rocky terrain, etc.) recorded an increase in its surface area. It increased from 42213.551 ha in 2000 to reach 58580.064 ha in 2013 with an increase of 16366.513 ha, an annual change estimated at 1258.962 ha converted from other classes (table 2).

Figure 8. Map of changes in vegetation cover in the Aures mountains (2000 - 2013)



During the second period (2013–2023), the degradation and the regression of vegetation cover continues (figure 9), but with a variation in magnitude and spatial distribution. vegetation continued to lose surface area, but at a faster rate. The area of dense vegetation decreased from 21972.28 ha in 2013 to 16613.988 ha in 2023 with a loss of 5358.297 ha, or 535,928 ha of annual loss. The area of moderate vegetation decreased from 49197.616 ha in 2013 to 48957.713 ha in 2023 with a loss of 239.903 ha, or 23.990 ha of annual loss. The area of low vegetation decreased from 96706.265 ha in 2013 to 84909.957 ha in 2023 with a loss of 11796.308 ha, or 1179.630 ha of annual loss. On the other hand, the no vegetation class (buildings, roads and rocky terrain, etc.) recorded an increase in its surface area. It increased from 58580.064 ha in 2013 to reach 75972.3612 ha in 2023 with an increase of 17392.296 ha, an annual change estimated at 1739.229 ha converted from other classes (table 2).

Figure 9. Map of changes in vegetation cover in the Aures mountains (2000 - 2013)



The area degraded during this period is estimated at 48701,256 ha (compared to 54470,67823 ha between 2000 and 2013), i.e. a degradation of 4870.125 ha per year. In contrast, the no vegetation class (buildings, roads and rocky terrain, etc.) marked a more accelerated evolution compared to the first period. It has integrated more than 17392,29629 ha to reach 75972.361ha of area in 2023, an annual increase of around 7597.236 ha (compared to 1258,962 ha/year during the period 2000–2013).

4. Discussion

Around of 20% (the equivalent of 48280,861 ha) in the east and south of study area marked by a degradation of the plant cover, thus, the light forest of Pinus Halepensis and Quercus ilex has greatly declined, often giving way to low formations. The matorral located to the south-east of the Beni Melloul Forest, has also been affected, in particular by a strong decline in Quercus ilex thickets.

4.1. Natural factors

The Aures massif is in a very sensitive geographical position, it is subject to southern influences which are, climatically, often unfavorable, its bedrock is an element which, as a whole, promotes this degradation:

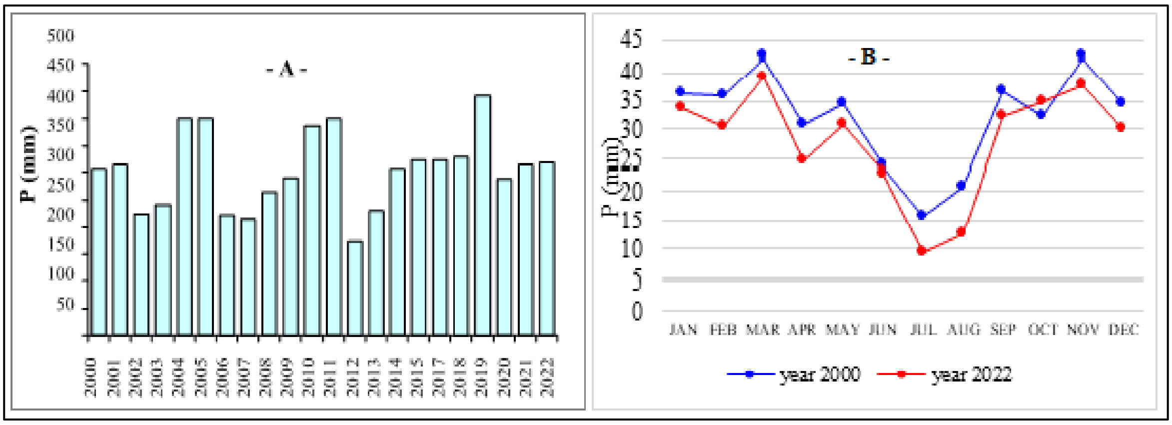
4.1.1. An easily erodible lithology:

Limestone-marl formations predominate in Aures massif, the high areas are covered by relatively hard materials (Sandstone and limestone), the low altitude areas are the domain of fine materials in the North and coarse materials in the South, the dominance of easily erodible materials is an element which accentuates the degradation of the plant cover. This vulnerability is accentuated by steep slopes in the north and medium slopes in the center and south (Laffitte, 1939).

4.1.2. Climate Change (a bioclimate in clear decline):

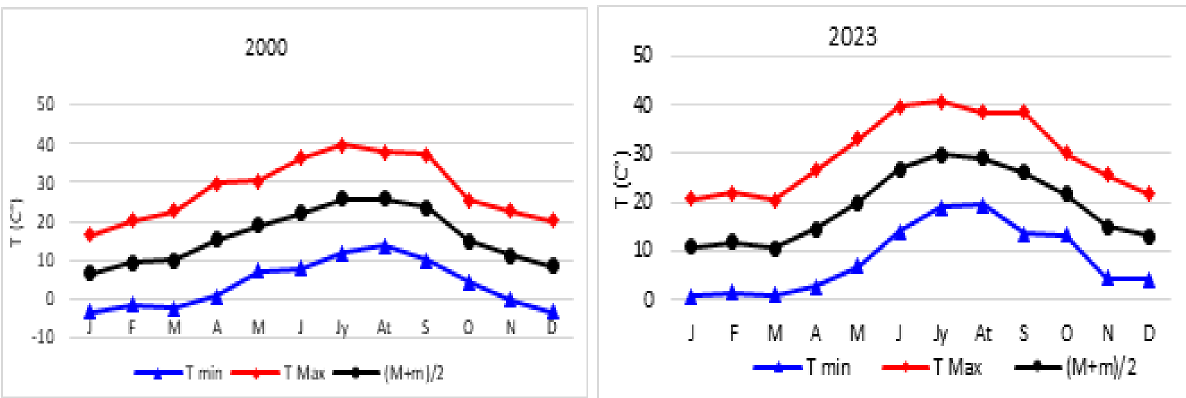
the climate of the Aures, like that of the world, is undergoing changes. Indeed, temperatures are increasing (Tabeaud, 1998), while rainfall is clearly decreasing (Anser A, 1998). The divergence of these two elements inevitably leads to bioclimatic changes which result in a degradation of the cover vegetal. A decrease in rainfall, the rain decreases from north to south and non-rainy sequences are more important than rainy sequences, The precipitation recorded at the Bouhmama station during the years preceding the taking of the images shows significant differences (figure 10). Annual precipitation reached 300 mm in 2000 and 200 mm in 2013.

Figure 10. (A) Annual precipitation from 2000 to 2022 at Bouhmama station
(B) monthly precipitation in 2000 and 2022 at Bouhmama station



Rising temperatures, the degradation of the vegetation cover reveals a trend of increasing temperatures, some researchers have proven that temperatures have been increasing since 1975 (Tabeaud, 1998) The comparison of maps relating to vegetation and climatic data clearly shows that the southern foothills are the most affected, the open forest is advancing at the expense of the dense forest (obvious signs of degradation of the plant cover), The temperature data show significant differences between the two years (figure 11).

Figure 11. Monthly average temperatures at the Bouhmama station in 2000 and 2023



Water Erosion: The exposure of soils by clearing, fires and overgrazing, as well as their degradation by the trampling of herds, encourage erosion phenomena. The slopes, very steep, 5415.57 HA exceed 25% Leading to very active water erosion. Limestone-marl formations predominate in the massif. The high areas are covered by relatively hard materials (sandstone and limestone). The low altitude areas are the domain of fine materials in the north and coarse materials in the south. The dominance of easily erodible materials is an element which accentuates the degradation of the plant cover. This vulnerability is accentuated by steep slopes in the north and medium slopes in the center and south (figure 12), To stop the degradation processes and safeguard the plant heritage and soils, several attempts have been undertaken without convincing results in the Aures mountains. Attempts to extend the vegetation, the only one capable of retaining the soil, have not been successful. the expected results (due to planting on unsuitable soils or due to a lack of monitoring and maintenance).

Figure 12. Water erosion by gullying on the south-eastern slope.

4.2. Anthropogenic interventions

The decline in plant cover is, also, taking place under the effect of increasing human pressure, indeed, the population of the study area increased from 49,912 inhabitants in 2008 to 65,249 inhabitants in 2023, to reach a density of 30 inhabitants/km2 (DPSB, 2022), The impact of population growth is manifested through several induced factors, man's relationship with his environment, in Aures, often turns to the latter's detriment, in fact, most anthropogenic actions are harmful to it.

4.2.1. Deforestation:

Excessive cutting: Cutting generally takes two forms, either under management or illegally by local residents. If the first form is often carried out according to scientific parameters, then it does not harm forestry potential. The second, on the other hand, is very harmful to the forest. The peddler only seeks personal gain. Ecological balance is relegated to the background. Between 1980 and 1984, crimes were frequent, 1108 related to illegal logging and 1629 to peddling (Anser A. , 1987). Algeria inherited a whole arsenal of laws from the colonial era. Indeed, if in French law individual forest property is both clearly defined and easily transferable, but Muslim law considers the forest as dead land and therefore, as such, as property belonging to the entire community. Faced with this situation, the Senatus Consult of April 22, 1863 awarded the Arab tribes' ownership of the lands they occupied. But the law of July 26, 1873 repealed the Senatus Consult, thus putting an end to collective enjoyment, the management of the forest being entrusted to the State.

Despite this legal development, ancestral practices have not stopped. The general forest regime was therefore redefined by Law No. 84-12 of June 23, 1984, article 32 of which grants certain rights to citizens established within or near the forest, in return for their acceptance of requirements to protect forest heritage. This law was unfortunately little applied during the 1990s, marked by a very troubled situation in Algeria. Over the period 2000-2022, the average annual number of logging offenses punishable by a fine in accordance with article 72 of the general forest regime law of 1984 – amounts to 26. The fraudulent logging thus identified affected in particular Quercus ilex, Quercus coccifera and Pinus halepensis .

4.2.2. Overgrazing:

Intensive grazing: Grazing is one of the actions which, if organized, is considered to purify the forest. If it is not, there is a risk of harm to the forest. The Aures is a sector which experiences continuous transhumance. This movement is concentrated on the fringes of the Aures, where the plant cover is the most fragile. The rural population, which demographic growth has made numerous, has fallen back on goat and sheep farming as its main source of income. However, the forest offers it its undergrowth and the possibility of stubble grazing after the harvest on the firebreaks given to farmers. The temptation is therefore great to enter the national forest. From 2000 to 2023, more than 420 grazing offenses (according to the 1984 law, articles 66 and 81) were recorded in the Aures massif (18/year on average). But many infractions escape forest guards.

The pastoral load is significant, it is of the order of 2.02 ha/sheep equivalent, the livestock (cattle, sheep, goats) comprises more than three hundred thousand head. Sheep are the most numerous, but goats, although much less represented, are the most devastating, due to the fact that they can feed on tree branches. It is in summer that the forest is most threatened by grazing. As the usual rangelands no longer provide enough food, it is tempting to direct the herds towards the undergrowth. Animals consume young shoots, which prevents regeneration, but also the foliage of trees, thus encouraging attacks by wood-eating insects.

The composition of the undergrowth is also modified, with palatable species disappearing in favor of non-palatable species, such as asphodel (Asphodelus microcarpus). Overgrazing in undergrowth should be avoided due to its harmful effects. On the other hand, controlled, regulated and supported grazing would be able to enhance the diversity of resources offered by the forest: herbs, foliage and fruits.

4.2.3. Forest fires:

devastating fires: The spread and intensity of forest fires are related to climatic, topo-morphological conditions, the type of vegetation and anthropogenic factors (Faleh, Lakhouaja, Sadiki, & Chaaouan, 2012). The forests suffer fires due to pastoral fires, the fact is that degraded to the stage of scrub or wasteland, it could be downgraded and transferred to municipal property. Only cultivation, when recognized as a fait accompli, gave the land a private character, which was ratified by the law of 1984. Since that date, the forest has been better protected. However, certain residents can benefit from a right of use (passage, wood collection, route, etc.) on the destroyed parts adjoining the forest, without however being the owners. The Monts des Aures is very affected by this scourge. The consequences are multiple, Weakening of forest potential, acceleration of erosion and ecological imbalance. 335 ha between 1980 and 1985 (Anser A., 1987) The causes of these fires are often unknown.

In July 2021 alone, fires ravaged more than 1500 ha of forest cover (figure 13), it consists mainly of Aleppo pines. In the forests of Ain Mimoun, Tamza and Bouhamama, over the period 2000-2023, more than 1000 ha garrigue and matorral were burned each year on average. However, the shrub cover is slowly rebuilding. Fires are therefore an important factor in the degradation of the plant cover, which is very difficult to control (Benabdeli, 1998). Repeated fires expose the soil to water erosion and make it more and more problematic. regeneration of forest cover.

Figure 13. Water erosion by gullying on the south-eastern slope.

4.2.4. Facilities with a limited role:

Through their interventions, reforestation, development and protection, the authorities try to restore balance to the forest. However, these constructive actions do not have the magnitude of destructive actions. Reforestation did not have the expected results. The low level of reforested areas only represents 10% of the total area. The lack of maintenance and the non-participation of local residents are the essential reasons for this failure.

Between 2013 and 2023, a slight evolution in plant cover is noted in certain sites in the communes of Bouhamama, Chelia and Echmoul. In fact, these municipalities have benefited from several development programs. These interventions have resulted in reforestation of fruit tree plantations, especially apple growing, and in soil restoration operations (making benches, gabionage, creation of hill reservoirs). …). Note that the PNDA has enabled the development of numerous farms in the municipality of Bouhmama. These farms are divided between private properties, collective farms (EAC) and individual farms (EAI).

No less than 70 farmers from the daïra Bouhmama wilaya of Khenchela benefited during the year 2019 from various aid and support operations aimed at the development of the agricultural sector in the region, we learned Thursday from management local agricultural services. these actions in particular help farmers to establish themselves sustainably on their land, 21 professionals from the municipality of Bouhmama, 23 from Chélia, 19 from M'sara and 7 others from Yabous, were also able to acquire equipment irrigation and create artesian wells and water retention basins in agricultural operations. To do this, and after studying the files submitted to the daïra of Bouhmama, a financial envelope of more than 160 million dinars was mobilized during the year 2019 to realize these agricultural support operations. The DSA of Khenchela province reaffirmed its desire to support farmers attached to the sub-directorate of agriculture in Bouhmama through this type of action, in light of the “positive results” obtained over the last two years by the fruit tree growing sector. more than 130 farmers from the daïra of Bouhmama had benefited during the year 2018 from the various support operations put in place by the supervisory ministry as part of the program for the development of the sector and the reduction of the import bill.

To preserve this region, the actions undertaken or planned must place this environment in its socio-economic context:

- The multiplication of jobs relating to the vegetation, the pastoral organization, the establishment of industrial units for the transformation of wood are actions which can create a mobilization of forest production factors.
- Respect for the productive role of the cover vegetal.
- Solve problems relating to regeneration.
- Respect for the specificity of the work (specialized forestry workers, breeders, horticulturists, arboriculturists, forestry managers, etc.)
- Development of development plans which must take charge of the exploitation of the vegetation, fight against fires and land clearing.
- Encourage reforestation which must be based on the choice of species as well as the participation of local residents.
- Raise awareness among populations about the importance of the cover vegetal.

This work could be carried out by municipal awareness committees (C.C.S). These different axes will have the objective of establishing new relationships between the natural environment and man. These must take into consideration the socio-economic reality of this environment. They must restore this massif to its ecological balance. Since the end of October 2022, the Forestry Governorate has begun the implementation of a planting program of more than a million shrubs, through which it is taking up the challenge of renewing what was damaged by the fires that broke out in forests during the summer of 2021, which destroyed at least 400 hectares of forest vegetation in the region of 4 municipalities. The period extending between June 1 and October 20 of 2021 was marked by the outbreak of 36 fires in the two forest blocks of Ouled Yaakoub and Beni Oudjana, causing the destruction of 6.7 percent of the total area of vegetation. To restore greenery to forest areas affected by the fires, the forestry governorate will continue its program to plant 1 million 26 thousand shrubs.

4. Conclusion

The Algerian mountains, both terrestrial and Mediterranean, have become places of ecological ruptures which, if not contained, initiate chain processes of destruction. It is an extremely difficult situation following excessive clearing and the abandonment of traditional agricultural arrangements, which results in denudation and weakening of the soil. Mountain agro-ecosystems are almost all in an advanced state of degradation, due to human pressure: deforestation, unsuitable plowing on steep slopes, overgrazing, overexploitation of groundwater (Benabdeli , 1998). The Aures mountains are not spared from this development. The area of forests has decreased and at the same time the composition of the plant cover has evolved, with negative consequences on fauna and in terms of soil erosion.

The Aures area risks losing its plant cover. Natural conditions (unfavorable climate and substratum) and anthropogenic interventions (often negative) combine to harm this massif. The present study shows that between 2000 and 2023, thanks to the method of comparing classifications, the detection and quantification of a decline in the Aurasian Forest heritage, shows a degradation which would be due to natural hazards linked essentially to the geographical position and bioclimatic of the area. Added to this are anthropogenic actions (clearing and cutting for agricultural or construction purposes, etc.). Finally, the climate changes experienced by the Mediterranean region are also responsible for the current situation of these fragile forest ecosystems in the semi-arid region.

It is urgent to look into the fate of this forest. Without harming this environment or the interests of local residents, we believe that new relationships must be established between the natural environment and man. Taking into account historical considerations and socio-economic particularities, an integrated development plan would contribute to safeguarding this environment and restoring its ecological and economic role.

The implementation of such a plan would imply taking charge of the Aures mountains by the Algerian State (by application of Law No. 84-12 of June 23, 1984 on the general regime of forests, article 38), and the evaluation of results based on a scientific approach. On this point, spatial remote sensing provides an extremely effective tool for locating problems and monitoring developments.

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