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A STUDY OF VEGETATION COVER DYNAMICS USING LANDSAT IMAGES: CASE OF THE BENI HAROUN WATERSHED (ALGERIA)

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Summary

Conducting a diachronic study of vegetation cover helps to assess its transformations over a period of time, allowing for a comprehensive assessment of the factors influencing these transformations. The purpose of this research is to analyze the vegetation cover spatio-temporal changes within Beni Haroun watershed, located in the northeast region of Algeria. Based on remote sensing data, two satellite images for the years 2009 and 2020 from Landsat 7 ETM+ and Landsat 8 OLI/TIRS were downloaded. The Normalized Difference Vegetation Index was employed to remotely detect and monitor the changes of the vegetation cover. It was calculated for both chosen dates, and the results were classified into four classes (no vegetation, sparse vegetation, moderate vegetation, dense vegetation), each representing a different vegetation density. The obtained maps showed a regression of the vegetation cover. The NDVI values have decreased from 0.77 in 2009 to 0.58 in 2020. Spatial patterns in the classified NDVI maps illustrated reduced vegetation cover demonstrated by an expansion of the no vegetation class: 35,3479 ha in 2009 and 56,7916 ha in 2020. The final map of the change detection depicted a predominance of the negative change throughout Beni Haroun watershed, in consequence of various controlling factors, including climate and human interventions.

Keywords

Beni Haroun watershed • change detection • NDVI • remote sensing • Vegetation cover

1. Introduction

The nutritional requirements of a population increase with its growth, and this leads to an expansion of human activities which adversely affect the environment. [Farhan and Nawaiseh 2015]. These activities are the source of anthropogenic factors affecting the soil. Soils can be affected by two types of factors: natural or anthropogenic. The vegetation cover plays an important role in evaluating soil's sensitivity to erosion as a natural factor [Igwe et al. 2017], due to its significant interactions with the environment impacting surface water, energy and carbon cycles, etc., in earth systems [Chen et al. 2018]. A diachronic study of vegetation cover helps in understanding land cover modifications

[Alpha and Derse 2013] on the basis of remote sensing as a tool to track and map transformations on the earth surface [Sapucci et al. 2021]. This enables to assess and observe the factors influencing these changes. Analyzing vegetation cover based on satellite images is a useful technique to predict natural disasters and to assess its damage [Gandhi et al. 2015], enabling decision makers to take appropriate interventions to protect the environment. The Normalized Difference Vegetation Index (NDVI) is one of several indexes that have been used to remotely detect the vegetation cover spatio-temporal changes for microregions on the earth surface [Agone and Bhamare 2012, Gandhi et al. 2015], as an index of floras to identify different vegetation cover classes [Shimu et al. 2019].

In this paper, we aim to detect, identify and map the vegetation cover changes in the Beni Haroun watershed over the past 11 years, applying the Normalized Difference Vegetation Index (NDVI) to classify the density of the vegetation cover and to understand its metamorphosis in the study area, using the satellite images provided by earthexplorer.usgs.gov coupled with Geographic Information Systems (GIS) to calculate this index. The objective of this research is to assess and analyze the extent of the changes in the vegetation cover within Beni Haroun, the watershed of Algeria's largest dam, which is already experiencing siltation resulting from erosion-induced sediments in its watershed. This research aims to provide insight that aids in erosion study and prevention strategies.

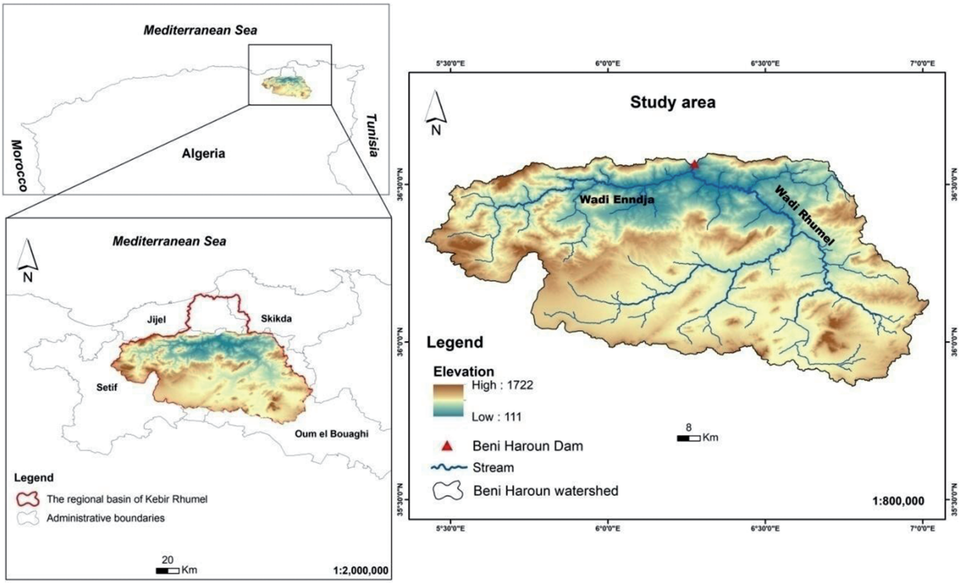
2. Material and methods

2.1. Study area

Beni Haroun watershed is located in the north-east of Algeria. It is included in the regional basin 10 of Kebir Rhumel. The watershed expands over a vast area estimated at 7544 km^2, in contrast to the north under a Mediterranean influence and the south under a continental influence (Fig. 1). The climate changes from sub-humid in the north to semi-arid in the south with an average annual precipitation and temperature of 662.8 mm/year and 19.33°C, respectively [Koussa and Bouziane 2018]. The precipitations decrease from the north to the south while the temperatures increase; for instance, the National Agency of Hydraulic Resources (NAHR) precipitation data of 1965/66–1994/95 shows a decline in precipitation from 800 mm in the north to 300 mm in the south.

Beni Haroun watershed includes two sub-basins from two major rivers; the Wadi Rhumel sub-basin from the south to northeast region with low-altitude and the Wadi Ennadja sub-basin in the western region with high-altitude. The watershed exhibits a distinct topography represented by a mountainous region in the north and a region of high plains in the south. Both, the topography and the climate play a role in controlling population distribution and its activities, which directly affects the vegetation cover in the area.

The analysis of the National Institute of Soils, Irrigation and Drainage (INSID) land use map showed three principal zones in the Beni Haroun watershed based on the vegetation cover. First, forest zones located in the north. Second, bare zones, where the limestone massifs of the semi-arid margins expand. Third, the agricultural zones that dominate most of the watershed area [Lakache 2022]. It is characterized by a reduced vegetation cover that significantly encourages soil erosion [Koussa and Bouziane 2018].



Source: Authors' own studies

Fig. 1. Geographic situation of the study area

2.2. Methodology

Several formulas were employed for the calculation of the Normalized Difference Vegetation Index and of the accuracy assessment as described below.

2.2.1. Comparative analysis of the NDVI

In order to create a change detection map, Landsat 7 and Landsat 8 scenes were used at a timescale of 11 years. For this purpose, we needed two images, the first one from 2009 and the second one from 2020. The images were captured during the dry season to ignore the negative impacts caused by rain and easily differentiate the land units as explained by [Khallef and Zennir 2021, Pantho et al. 2022]. It required two scenes for each image to cover the whole study area; hence, four scenes were downloaded from earthexplorer.usgs.gov and processed in ArcGis to create a mosaic raster for the two images. The satellite data characteristics are shown in Table 1.

Table 1. Satellite data

Satellite	Sensor	Path / Row	Resolution	Acquisition date
Landsat 8	OLI/TIRS	194/35	30M	6/17/2020
Landsat 7	ETM+	194/35	30M	6/27/2009

The Normalized Difference Vegetation Index is used for the estimation of greenness on the earth surface. The NDVI is the ratio between the visible and the near infra-red bands with values ranging between +1 and -1. The NDVI index is calculated following this formula:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})} \tag{1}$$

Both satellites have eight bands, three of which are red bands and four are the near infra-red bands on Landsat 7. On Landsat 8, the number of red bands is four and number of the near infra-red bands is five. Due to chlorophyll, green plants absorb the red bands of the visible spectrum and reflect the near infra-red bands. Green plants are observed dark in the visible light but relatively brighter in the near infra-red spectra [Pantho et al. 2022], the NDVI values are higher, close to +1.

The Normalized Difference Vegetation Index results obtained by using the formula above were classified into four classes: no vegetation; sparse vegetation; moderate vegetation; and dense vegetation.

2.2.2. Supervised classification

Depending on the parametric algorithm (non-statistical algorithm) process of the supervised classification in ArcGis, we have developed a spectral signature of the NDVI classes out of training samples of each class. This method permits to estimate a multivariate normal form of data out of training data [Ansar 2017].

Initially, multiple training samples were created for each vegetation class of the reclassified NDVI images to define the Areas of Interest (AOI). Subsequently, we have created a spectral signature for these samples. Derived from the previous step, each pixel will be designated for the vegetation class that it is most similar to.

2.2.3. Accuracy assessment

To determine the accuracy of the classified results we have employed several equations in order to compute various statistics that are related to the classification accuracy, using Google Earth Pro as a reference dataset [Jaman et al. 2022, Khallef et al. 2023].

The accuracy Assessment formulas:

$$\text{Users Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category (the row total)}} \cdot 100 \tag{2}$$

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of reference pixels in that category (the column total)}} \cdot 100 \tag{3}$$

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels}}{\text{Total number of reference pixels}} \cdot 100 \tag{4}$$

$$\text{Kappa Coefficient} = \frac{(TS \cdot TCS) - \sum(\text{column total} \cdot \text{row total})}{TS^2 - \sum(\text{column total} - \text{row total})} \cdot 100 \tag{5}$$

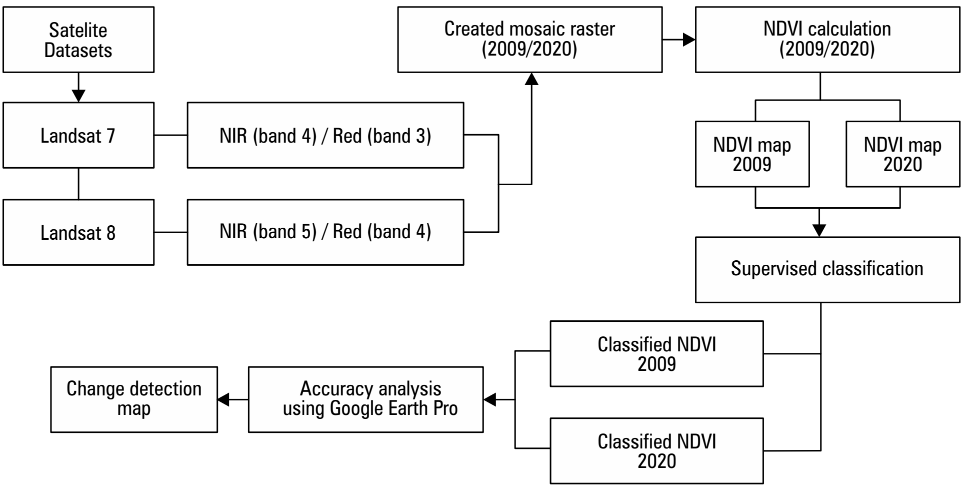
TS: Total Sample
TCS: Total corrected Sample

2.2.4. Change detection

With the aim of identifying the change between the two NDVI results we have used the following formula to calculate the change detection using the ArcGis toolbox:

$$\Delta NDVI_{2009/2020} = NDVI_{2020} - NDVI_{2009} \tag{6}$$

The methodology flowchart is shown in (Fig. 2).



Source: Authors' own studies

Fig. 2. The flowchart of this research

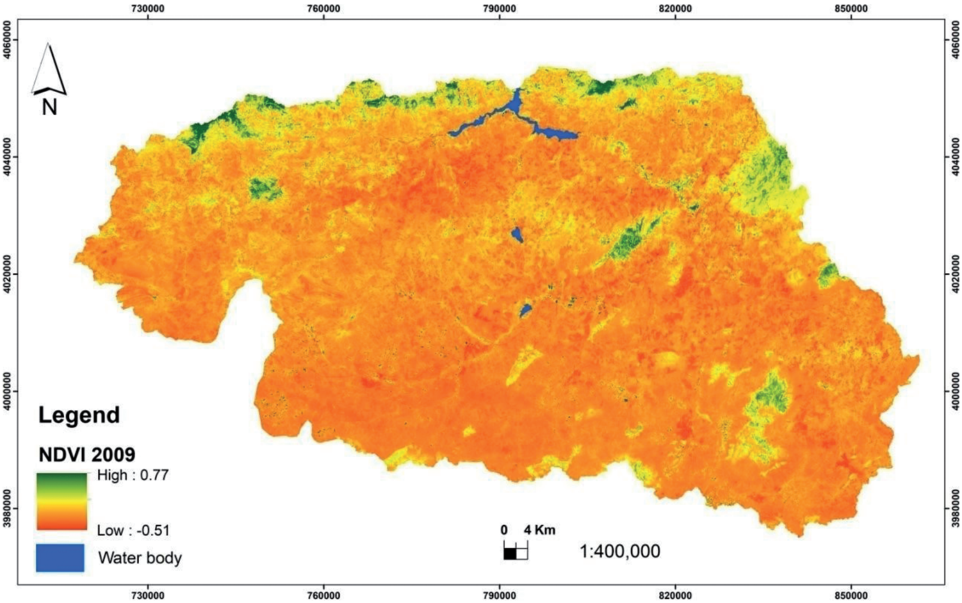
3. Results and discussion

3.1. Results

3.1.1. NDVI analysis

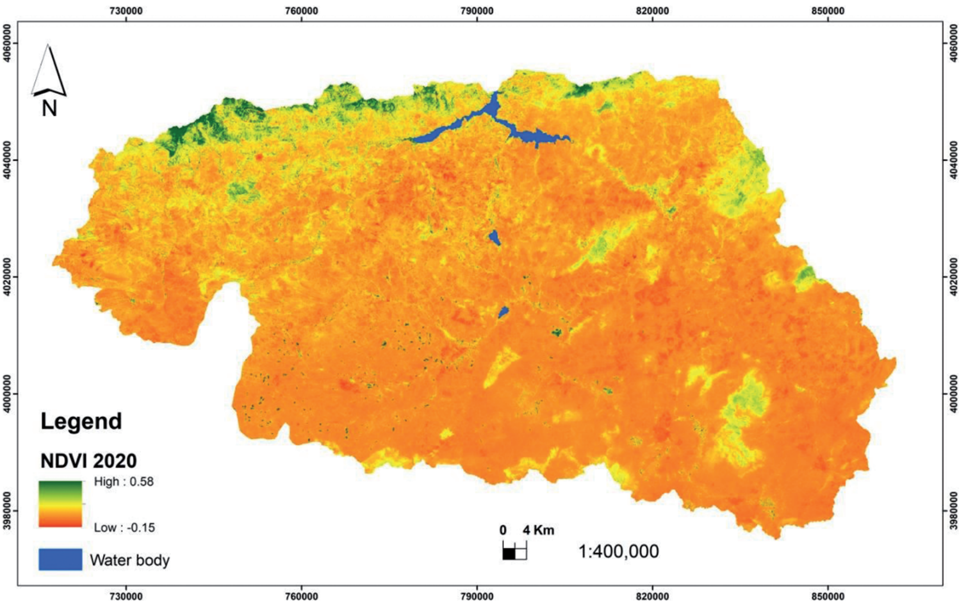
The NDVI results for the Beni Haroun watershed obtained by applying formula (1) to both images are revealed in (Fig. 3 and 4).

According to the Normalized Vegetation Index map of 2009, NDVI values range from −0.51 (low value) to 0.77 (high value). Regarding the Normalized Difference Vegetation Index map of 2020, NDVI values vary from −0.15 (low value) to 0.58 (high value). High NDVI values depict dense and healthier vegetation due to dense chlorophyll, while low NDVI values indicate low, weak and no vegetation. From the initial observation, it is clear that the NDVI values have declined by 0.19 during a timescale of 11 years, which demonstrates a reduction of the vegetation cover. The spatial distribution of the four NDVI classes is illustrated in (Fig. 5 and 6).



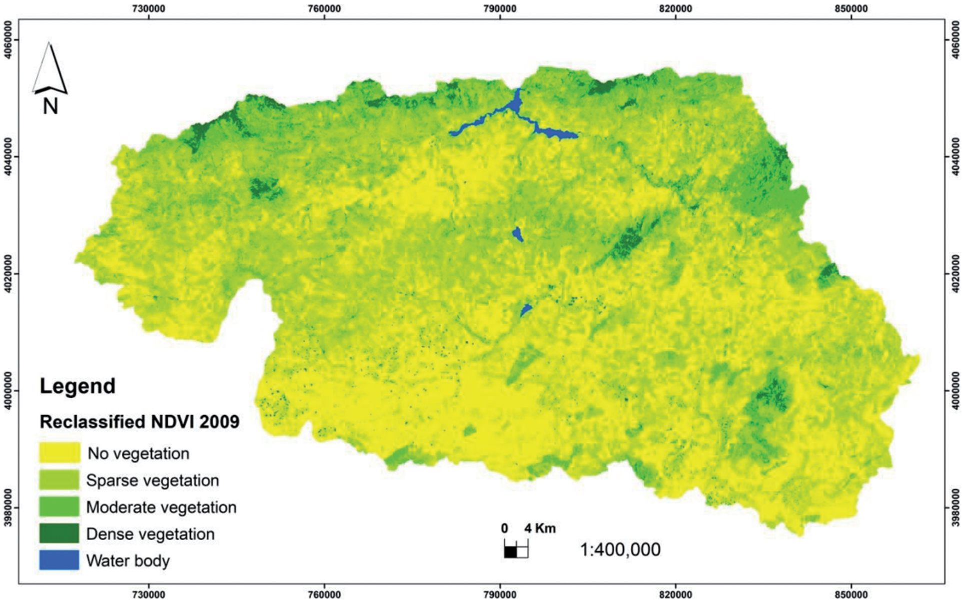
Source: Authors' own studies

Fig. 3. Normalized Difference Vegetation Index of 2009



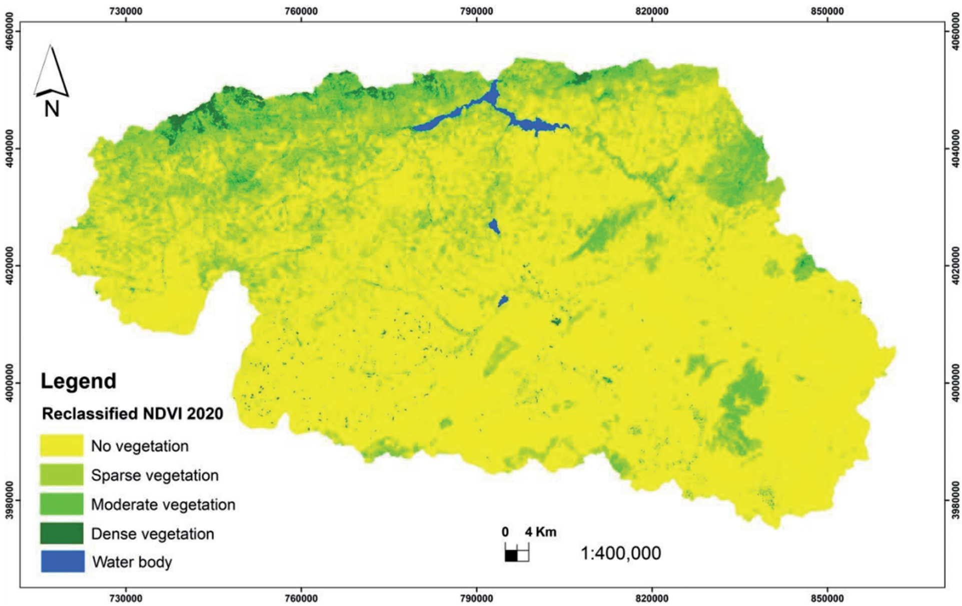
Source: Authors' own studies

Fig. 4. Normalized Difference Vegetation Index of 2020



Source: Authors' own studies

Fig. 5. The reclassified NDVI of 2009



Source: Authors' own studies

Fig. 6. The reclassified NDVI of 2020

As depicted in Figure 4, the Beni Haroun watershed was dominated by no vegetation class accounting for 46.86%. However, there was a presence of sparse vegetation class covering the entire region, comprising 39.02% of the landscape. Additionally, moderate vegetation class occupied 11.38% of the watershed, while dense vegetation class was mainly concentrated in the northern part of the study area and few zones dispersed across the sub-basin of Wadi Rhumel, totaling 2.74%. In the reclassified NDVI map of 2020, a noteworthy observation is the expansion of the no vegetation class, which covers a larger portion of the watershed amounting to 75.28%. The expansion coincides with a reduction in the other vegetation classes; sparse vegetation 16.09%, moderate vegetation 6.95% and dense vegetation 1.68%. Interestingly, the last two classes were found predominantly in areas at higher altitudes, particularly in the northern part of the watershed and scattered locations in the eastern side of Beni Haroun.

Table 2. Distribution of the vegetation cover classes area in percentage and hectares

	2009		2020	
Vegetation classes	**Area [ha]**	**[%]**	**Area [ha]**	**[%]**
No vegetation	35,3479	46.86	567,916	75.28
Sparse vegetation	29,4387	39.02	121,407	16.09
Moderate vegetation	85,870	11.38	52,400	6.95
Dense vegetation	20,674	2.74	12,687	1.68
Total	754,410	100	754,410	100

3.1.2. Accuracy statistics

In remote sensing data processing, it is a crucial step to determine the informational worth of a resulting data to a user, by assessing its accuracy [Rwanga and Ndambuki 2017]. The preceding accuracy assessment formulas (2), (3), (4) and (5) have been applied for a total of 85 samples of the four vegetation classes and yielded the following results: user accuracy ranged from 77.27% to 95% in 2009 and from 80% to 94.74% in 2020. Furthermore, producer accuracy values varied between 81.82% and 90.48 in 2009 and from 77.27% to 94.74% in 2020.

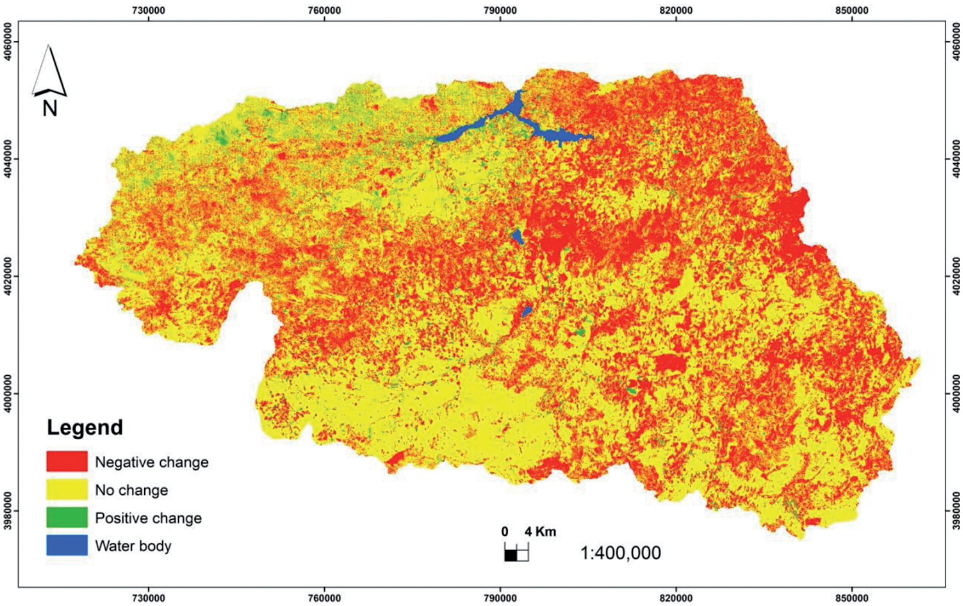
Table 3. Overall Accuracy and Kappa Coefficient results

Year	2009	2020
Overall Accuracy [%]	87.05	85.05
Kappa Coefficient [%]	82.74	80.03

Taking into account that an overall accuracy of 100% reflects ideal classification, and that a kappa coefficient closer to +1 indicates a better classification compared to random [Pantho et al. 2022], the values revealed in Table 3 indicate good results for our study.

3.1.3. Change detection

The change detection map resulting out of the application of the sixth equation shows the spatial patterns of the vegetation changes in the study area throughout the duration of 11 years (Fig. 7).



Source: Authors' own studies

Fig. 7. The vegetation change detection map

The vegetation cover changes were categorized into three categories, illustrating its metamorphosis. These categories include: negative change indicating a regression of the vegetation cover, no change indicating stability, and positive change indicating a progression of the vegetation cover.

Based on the visual representation of the spatial distribution of the change categories, we observe that the no change category predominantly occupied the majority of the Beni Haroun area, mainly located in the northwestern and southern parts, indicating that the vegetation cover in these areas remained unchanged over an 11-year period. The portions occupied by this category are estimated at 446,145 ha. The negative change category covers 277,473 ha of the watershed particularly its eastern and central-western parts. Regarding the positive change category, it is barely shown in the study area, occupying 30,792 ha of the watershed, this category mainly situated in the north-western region of Beni Haroun. The distribution of the change categories in hectares is tabulated in Table 4, while Table 5 presents the results of the change detection calculations of each vegetation class between 2009 and 2020.

Table 4. Change categories areas in hectares

Change category	Change area [ha]
Negative change	277,473
No change	446,145
Positive change	30,792

Table 5. Vegetation cover change detection areas between 2009 and 2020

Class	Change detection between 2009 and 2020	
	[ha]	[%]
No vegetation	214,437	28.42
Sparse vegetation	−172,980	−22.93
Moderate vegetation	−33,470	−4.43
Dense vegetation	−7,987	−1.06
Total	0	0

3.2. Discussion

The diachronic study denotes a degradation in the vegetation cover within the Beni Haroun watershed, which is affected by various controlling factors impacting its state and distribution. Precipitation and temperature are the most influential climatic factors driving changes in the vegetation cover, and they considerably impact the states of plant species [Faramarzi et al. 2017, Khellaf et al. 2021]. The MENA region (Middle East and North Africa) is experiencing one of the most rapid population growth rates globally, resulting in considerable urban expansion [Lange 2019]. Thus, the expansion of the agricultural activities and zones is a response to the growing population's nutritional needs. The combination of these activities, along with clearing, overgrazing and urban expansion is the source of anthropogenic factors that affect the vegetation cover. Generally, human interventions have a detrimental impact on the environment, resulting in significant damages. Moreover, Algeria has the highest percentage of land area affected by forest fires among the countries in the MENA region [Belgherbi et al. 2018].

The Beni Haroun watershed includes several major agglomerations and cities, which are a crucial human resource. The population growth led to an urban extension throughout the region; e.g., the new cities of Ali Mendjeli in Constantine and Ferdoua in Mila. Population's main occupations revolve around agriculture and industry. Overall, the watershed primarily represents an agricultural region with a notable domination of the cereal cultivation [Tourki 2019, Lakach 2022]. The presence of gentle slopes in the southern region facilitates agriculture and urban expansion, contributing to the negative change; Tables 7 and 8 show several examples of human interventions that have negatively impacted vegetation cover in our study area. In contrast, the mountainous northwestern region with steep slopes impedes agricultural and urban expansion, leading to positive changes. Furthermore, this area experiences positive human interventions including anti-erosive activities like fruit plantation, reforestation, revegetalization, opuntia, etc. These activities were programmed by the National Bureau of Forest Studies in 1990 and the Canadian study of TECSULT in 2006. The realization of these activities covered 13813 ha of the watershed in Mila between 1999 and 2019, as detailed in Table 6.

Table 6. Distribution of different plantation areas in hectares between 1999 and 2019

Plantation type	Area [ha]
Revegetalization	150
Reforestation	5,959
Fruit plantation	7,604
Opentia	100
Total	13,813

Source: Forest Conservation of Mila

Table 7. Distribution of different illicit activities areas in hectares between 2012 and 2020

<table>
<tr><th rowspan="2">Year</th><th colspan="3">Type of illicit activities (number and hectares)</th></tr>
<tr><th>Construction</th><th>Tree cutting</th><th>Clearing</th></tr>
<tr><td rowspan="2">2012</td><td>45</td><td>9</td><td>61</td></tr>
<tr><td>0.65</td><td>250 trees</td><td>29.17</td></tr>
<tr><td rowspan="2">2013</td><td>41</td><td>12</td><td>39</td></tr>
<tr><td>2.11</td><td>429 trees</td><td>34.7</td></tr>
<tr><td rowspan="2">2014</td><td>29</td><td>3</td><td>19</td></tr>
<tr><td>1.86</td><td>135 trees</td><td>23.69</td></tr>
<tr><td rowspan="2">2015</td><td>36</td><td>5</td><td>20</td></tr>
<tr><td>0.69</td><td>55 trees</td><td>7.5</td></tr>
</table>

Table 7. cont.

Year	Type of illicit activities (number and hectares)		
	Construction	Tree cutting	Clearing
2016	33	6	15
	1.02	158 trees	7.09
2017	18	4	19
	3.9	20 trees	4.61
2018	21	9	40
	3,5	274 trees	19.75
2019	37	13	38
	2	217 trees	39.83
2020	11	10	16
	3.5	100 trees	3.01
Total	19.23 ha	1,638 trees	169.35 ha

Source: Forest Conservation of Mila

Table 8. Distribution of forest fires areas between 2011 and 2020

Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Number of households	11	37	8	16	4	15	17	16	16	16	156
Area [ha]	121	151	17	98.5	207.7	56.5	180	56.25	564	480	1932

Source: Forest Conservation of Mila

Data limitations

We would like to draw attention to the difficulties we faced in this research concerning the validation of our NDVI results. Due to the extensive study area we had to change the observation period multiple times to adequately cover the area.

4. Conclusions

Based on remote sensing data, which is an effective tool for monitoring the earth's surface, we have used the Normalized Difference Vegetation Index to study the vegetation cover dynamics over an 11-year period. The results obtained showed that Beni Haroun watershed is undergoing significant degradation in its vegetation cover, with barren lands encompassing 75.28% of the area, while 1.68% is covered with dense vegetation. The accuracy statistics reflect the classification to be on a good level, with an overall accuracy estimated at 87.05% in 2009 and 85.05% in 2020. The change detection results denoted a regression of the vegetation cover accounted at 277 473 ha of negative change. Which is represented by an expansion of the no vegetation class estimated at 28.42% and a reduction of the sparse, moderate and dense vegetation estimated at -22.93%, -4.43%, -1.06% respectively. These findings aid in monitoring changes of vegetation cover. The maps facilitate spatial detection of these changes, enabling the identification of factors influencing transformations within our study area. This research serves as an illustrative example for studying vegetation cover dynamics in the northeast watersheds of Algeria. It helps decision makers to implement suitable interventions for environmental protection and damage prevention. Furthermore, it can offer insights for other studies concerning erosion in this area.

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