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Forest cover change detection using Normalized Difference Vegetation Index in the Oued Bouhamdane watershed, Algeria – A case study

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Abstract: The Algeria forest, particularly in the northeastern region, has undergone profound changes in recent years. The Oued Bouhamdane watershed has a great forest potential, which is threatened by several factors of natural and human origin, resulting in a decrease in forest cover. It requires adequate forest monitoring to support the sustainable forest management of this watershed, which is possible thanks to satellite imagery. The objective of this research is to study the spatiotemporal dynamics of the vegetation cover of the Oued Bouhamdane watershed between 2013 and 2022 using remote sensing data. This study is based on the use of Landsat 8 and 9 images for two dates in 2013 and 2022, and the calculation of the Normalized Difference Vegetation Index (*NDVI*) to identify changes in vegetation cover between 2013 and 2022. The calculation of *NDVI* and the realization of the vegetation change map showed a regression of the forest cover between 2013 and 2022 with a rate of –5.53% of the total of the study area with a general negative change of 28.62% of the study area. This regression is essentially linked to natural and anthropogenic factors. This work can be a valuable tool for sustainable management of the forest of this watershed; moreover, the method is also adaptable to other watersheds of the northeastern region of Algeria.

Keywords: remote sensing; GIS; indices; degradation; Landsat

The global forest cover is a major indicator of the health of our planet. A natural, non-degradable forest provides many services, including nutrient recycling, climate regulation, soil stabilization, waste recycling and the creation of natural habitats, not to mention a wide range of recreational activities and outdoors (Larsen 2003). The global forest is shrinking. From year to year, it loses area. Even today, it still covers some 40 million km^2 (Mayer 2022). The forest cover in Algeria is spread over an area of 1.3 million ha of real natural forests (Barbache 2021). These forests have experienced an almost exponential regression in recent years, and are today in an appalling state (El Zerey 2014). Poorly managed Algerian forest biodiversity is deteriorating due to the loss of natural resources (Haichour et al. 2022). The forest cover of the Oued Bouhamdane watershed presents a concrete illustrative example of intense degradation in an area where climatic factors and human activities are combined, contrary to the idea of sustainable management and development of the forest area. In this watershed, which is characterised by an important forest heritage and hydrographic network, the forest cov-

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er is today facing illegal cutting, overgrazing, clearing, agricultural extension and devastating fires. A better understanding of the evolution of forest cover is a major concern for countries whose forest cover is undergoing severe degradation. Indeed, the dynamics of this forest cover has direct implications on the availability of natural resources (Bouidjra et al. 2011). The use of remote sensing to study forest cover is a major asset with high spatial resolution satellite data (Hansen et al. 2008). In Algeria and more specifically in the Batna Province, the study and diachronic analysis of changes in the forest cover of Belezma were carried out by Barbache et al. (2019) using vegetation indices. However, vegetation indices are very useful for assessing forest cover performance (Morton et al. 2006). One of the most widely used indices for monitoring forest cover is the Normalized Difference Vegetation Index (*NDVI*) (Nath et al. 2013). According to Ghebrezgabher et al. (2016), *NDVI* is the most widely used factor in vegetation studies. To calculate *NDVI*, we use the reflectance of the red (R) and near infrared (NIR) bands measured in the visible band by sensors on board drones or satellites (Alexandre 2020). In theory, *NDVI* values for vegetation tend towards 1 while those in no vegetation areas tend towards –1. Thus, the more the proportion of vegetation decreases, the more the red reflectance values tend to decrease linearly, so that the relationship between plant cover in percentage and *NDVI* values is linear (Beck et al. 2006). The objective of this study is the detection of forest cover changes, based on *NDVI* using Landsat program images acquired in different years. This approach is part of the protection and preservation of the forest cover of this watershed, and this of course to protect it from the phenomenon of soil erosion.

MATERIAL AND METHODS

Study area. The Oued Bouhamdane watershed is one of the major tributaries of the Seybouse with an area of 1 108 km² (Khallef et al. 2020). It is located in the northeast of Algeria, it is part of the Seybouse watershed and results from the junction of three major rivers: Oued Sabath, Oued Zenati and Oued Sakkoum (Bouguerra 2018). Under the Seybouse watershed, its limits are part of the territory of three wilayas; these are the southwestern part of the Guelma wilaya, the eastern part of the Constantine wilaya, and the southern part of the Skikda wilaya. It is limited to the north by the coast Constantinois watershed, to the south and southeast by the Oued Cherf watershed, to the east by the middle Seybouse watershed and to the west by the Kebir Rhumel watershed (Figure 1).

It has an elongated shape; it is drained by Oued Bouhamdane and its tributaries. The relief of this watershed is characterised by a significant altitudinal variance, ranging from 997 m to 1 237 m at Djbel Oum Settas. The lithology encompasses a multitude of lithological formations composed mainly of Numidian sandstones, clays, marls, limestones, marl-limestones, shales, conglomerates and superficial formations. These facies, ranging from the Quaternary to the Triassic, present variations in facies resistance ranging from the hardest rocks represented by limestone and sandstone rocks to the softer clayey rocks (Bouguerra 2018). The climate of the study area is of the Mediterranean type characterised by a cold, rainy winter and a dry and hot summer. The average annual rainfall varies from 644 mm to 932 mm. The rainiest months are January, February and March, totalling 237.63 mm, with a maximum rainfall that reaches the value of 81.92 mm recorded during the month of February for the period 2009–2022. The average temperature is 18 °C, the average minimum temperature is 4.68 °C in February, while the average maximum is 36.81 °C for the month of July. The vegetation cover of the study area consists mainly of a rugged mountain forest. A forest system is balanced when consisting of three strata, namely tree, shrub and herbaceous stratum of various age groups. The inspection of the field shows that there is a dominance of the tree and shrub training formations found in the form of forest and maquis, which are generally represented by *Quercus coccifera, Quercus suber, Erica arborea, Calycotome spinosa, Phillyrea angustifolia, Olea oleaster, Pistacia lentiscus, Cistus monspeliensis, Ceratonia siliqua*, and *Crataegus monogyna.* However, the herbaceous stratum is represented by lawns and brush, followed by shrub vegetation in the form of maquis and the understorey of the forest. On the along with Oued Bouhamdane, there are ripisylves dominated by *Nerium oleander*, *Tamarix gallica*, and *Mentha aquatica*.

Methodology. The methodology followed in this study is based on the use of *NDVI* to detect changes in forest cover at the scale of the Oued Bouhamdane watershed for a period of 9 years (2013–2022). This

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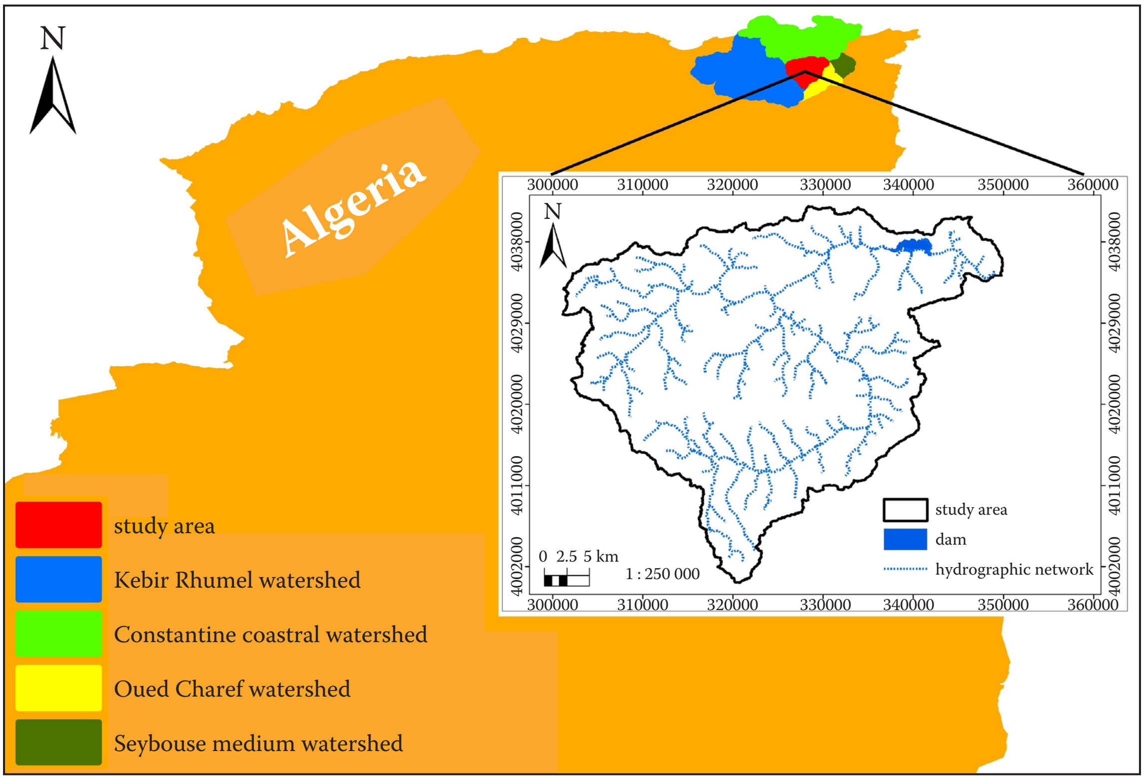

Figure 1. Location of the study area

methodological approach comprises three phases, summarised and developed below (Figure 2).

Data collection. This study is based on two medium-resolution (30 m) satellite images from the Landsat program during the period of 2013 and 2022, downloaded from the US Geological National Center (USGC). Landsat 8 OLI was acquired on July 25, 2013 and Landsat 9 OLI-2

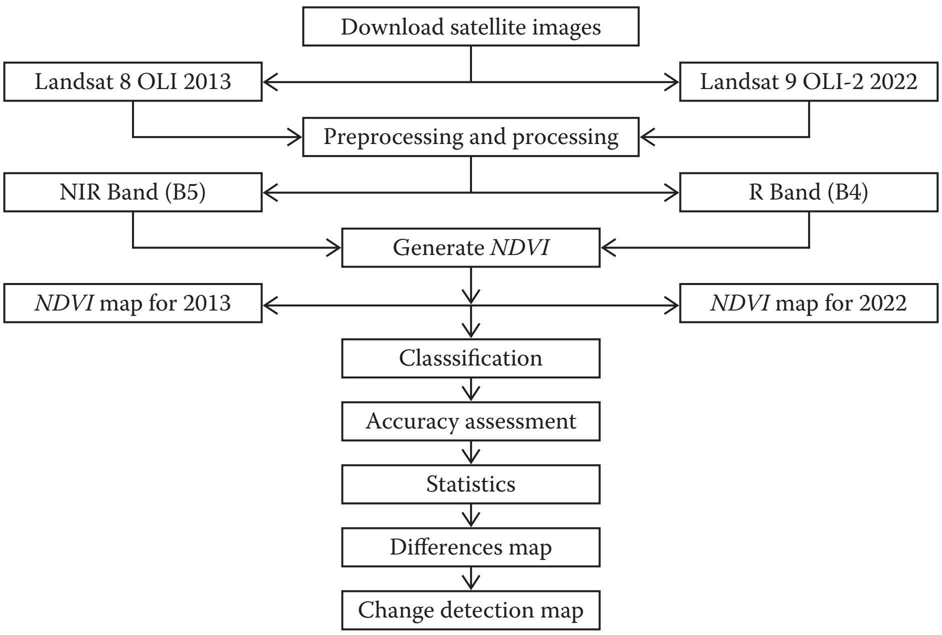

Figure 2. Flowchart for change detection in forest cover between 2013 and 2022

NIR – near infrared; R – red; *NDVI* – Normalized Difference Vegetation Index

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on July 26, 2022 (Table 1). The basic satellite images of this work were all acquired during the dry season, the period of maximum differentiation of forest cover compared to other elements of land use. The preprocessing and image processing were carried out using ENVI (Version 5.1, 2015) and ArcGis (Version 10.6.1, 2015) software. The spatial resolution is 30 m and the projection system applied to all our data is Transverse Mercator zone 32 north.

Image processing. The *NDVI* values vary from –1 to 1. The low values of *NDVI* correspond to the sterile areas of rock, sand, snow, clouds. Moderate values represent shrubs and meadows, while high values indicate a dense vegetation cover. The bare soil is represented with *NDVI* values which are closest to 0 and the water bodies are represented with negative *NDVI* values (Xie et al. 2010). The *NDVI* is a vegetation index used to estimate the quantity, quality and development of vegetation, from the measurement of the radiation intensity of certain bands of the electromagnetic spectrum that the vegetation emits or reflects (Rouse et al. 1973). The *NDVI* is calculated by the following formula:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} \quad (1)$$

where:

NIR – near infrared (Band 5 for Landsat 8 and Landsat 9);

R – red (Band 4 for Landsat 8 and Landsat 9).

For the two chosen observation dates, each calculated Normalized Difference Vegetation Index is classified into ranges. The *NDVI* values for areas of barren rock, sand or snow generally have very low values corresponding to classes (no vegetation). The low values that represent shrubs and grasslands are the sparsely vegetated classes while senescent crops can result in moderate values – these are the moderately vegetated classes. High to very high *NDVI* values correspond to high and dense vegetation, respectively (USGS 2018).

Class determination. The overlay of thematic maps, in particular, the vegetation map drawn up by the BNEF (National Bureau of Forest Studies) on the one hand, and the information acquired during field surveys on the other hand, made it possible to determine five classes which are: (*i*) no vegetation – this class looks like what is bare soil, ploughland, rocks, urban, barren land and body of water where the vegetation is totally nil; (*ii*) sparse vegetation represents shrubs and meadows; (*iii*) moderate vegetation stands for rangelands and senescent crops; (*iv*) high forest is Mediterranean-type maquis composed mainly of Cistus, heather, lentisk, thorny Calycotome, wild olive, *Phillyrea latifolia* and other species; (*v*) dense forest – this class represents the state forests of Taya and Beni Medjaled. The forest cover of this class is characterised mainly by cork oak, zeen oak and reforestation of eucalyptus and other species.

***NDVI* classification.** According to the value of *NDVI*, the image can be classified by means of the method adopted for the study, which is the supervised classification, with the 'Maximum likelihood' algorithm used as an approach leading to the identification of homogeneous samples in images representative of both types of surfaces (vegetation and no vegetation) (Congalton 1991). These samples then form a set of test data (Soudani 2006). The choice of test data is based not only on the surface types identified in the images but also on the knowledge of the terrain. The intensive visual analysis of our images, the use of Google Earth support, the information acquired during the field surveys and the visual interpretation of the satellite image provided a general idea of the components of the study area (Khallef et al. 2021).

Accuracy assessment of classification. The classification of an image is not complete until its accuracy is assessed. To determine the accuracy of the classification, a sample of test pixels must be selected in the classified images and their class identity to compare it with the reference data (ground reality). Overall accuracy is a standard criterion used to assess the accuracy of classifications. Overall accuracy is defined as the total number of correctly classified pixels divided by the total number of reference pixels (Rogan et al. 2002). To assess the ac-

Table 1. Dates and characteristics of Landsat images used

Sensor	Acquisition date	Path/Row	Resolution (m)	Bands used
Landsat 8 OLI	July 25, 2013	193/035	30	B5, B4
Landsat 9 OLI-2	July 26, 2022	193/035		

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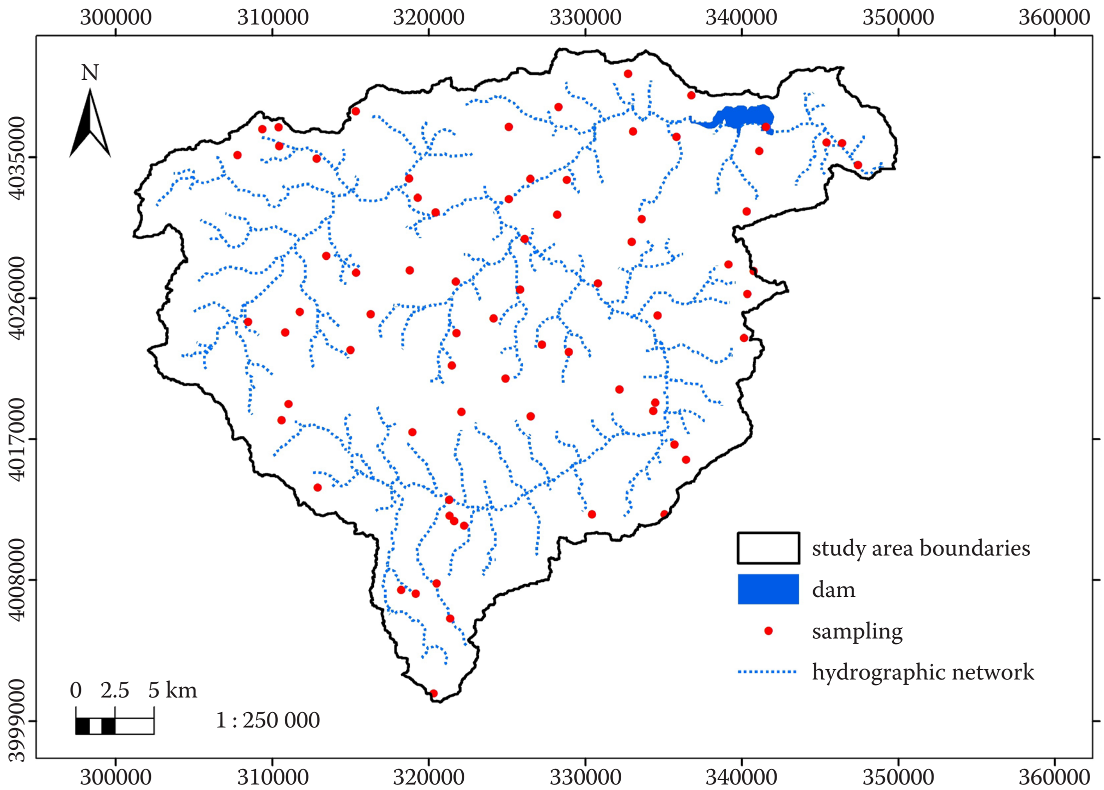

Figure 3. Reference points

curacy of the *NDVI* supervised classification result of 2013 and 2022, a comparison is made with high-resolution images from Google Earth for the two observation dates (2013, 2022). 72 reference points are randomly selected using the Create Accuracy Assessment toolbox (Version 7, 2011) for the two classified *NDVI*. Then the 72 points created for each classified *NDVI* are displayed in Google Earth to compare the result obtained by supervised classification with reality (Figure 3). The level of precision is calculated on the basis of reference data using Google Earth images for the two reference dates followed by a verification of the ground.

Change detection. Change detection evaluates and identifies any difference change between two images in the same study area on different dates (Hegazy et al. 2015). In this study, image differentiation is used by subtracting the recent image from the old one to find out the extent of the change. Change detection was calculated using post-classification change techniques or map-to-map change detection; it is a process of overlaying coincident thematic maps of different time periods to identify changes between them. The distinct advantage of this technique is that the basic classification and change transitions are explicitly known. Direct comparison of satellite-derived land cover maps is one of the most established and widely used change detection methods applicable to Landsat-class imagery (Tewkesbury et al. 2015). This change detection is calculated as follows:

$$\Delta NDVI_{2013/2022} = NDVI(\text{classified})_{2022} - NDVI(\text{classified})_{2013} \quad (2)$$

RESULTS

The *NDVI* has been widely used to study the relationship between spectral variation and changes in the vegetation growth rate. It is also useful for determining green production as well as detecting vegetation changes (Perminder 2021). In the case of the vegetation cover of the Oued Bouhamdane watershed, the result of the calculation of the *NDVI* of the two dates chosen is represented in Figures 4 and 5.

The range of *NDVI* values in the 2013 image varies from –0.08629 to 0.5107 and in the 2022 image from –0.1220 to 0.4941. A high *NDVI* value indicates high vegetation density while a lower *NDVI* value indicates low vegetation density. According to Figures 4 and 5, the *NDVI* values for the year 2013 are

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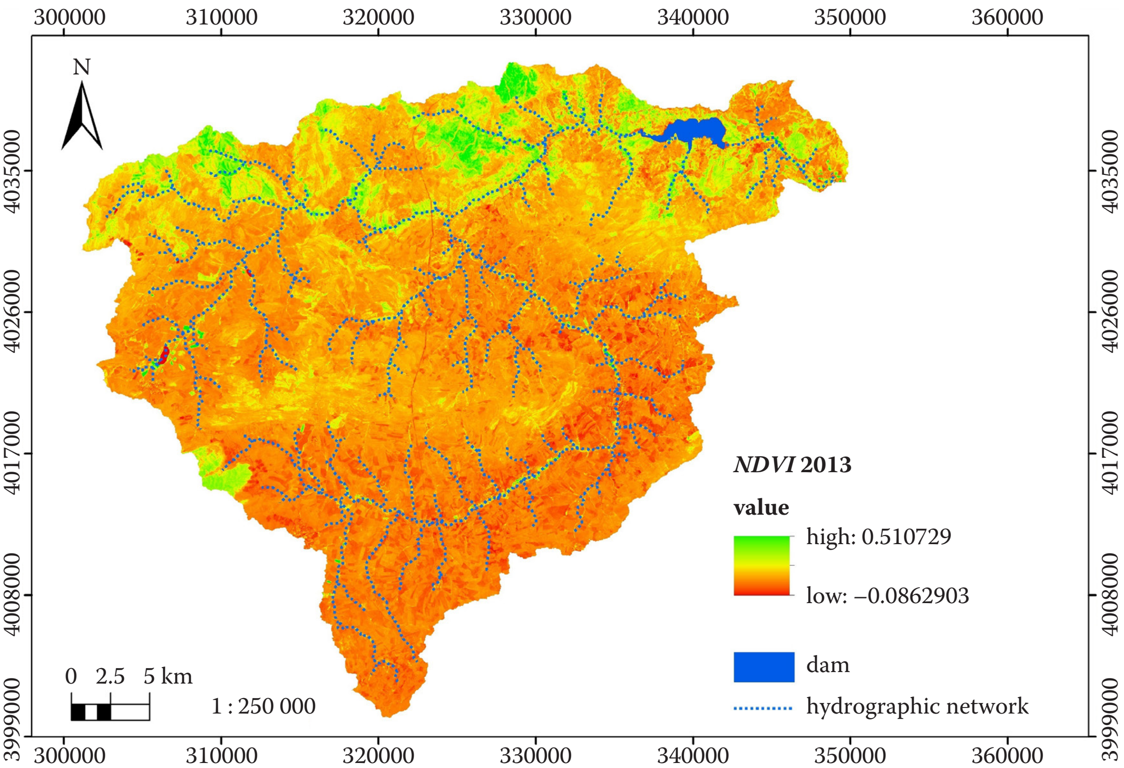

Figure 4. *NDVI* map of the study area in 2013

NDVI – Normalized Difference Vegetation Index

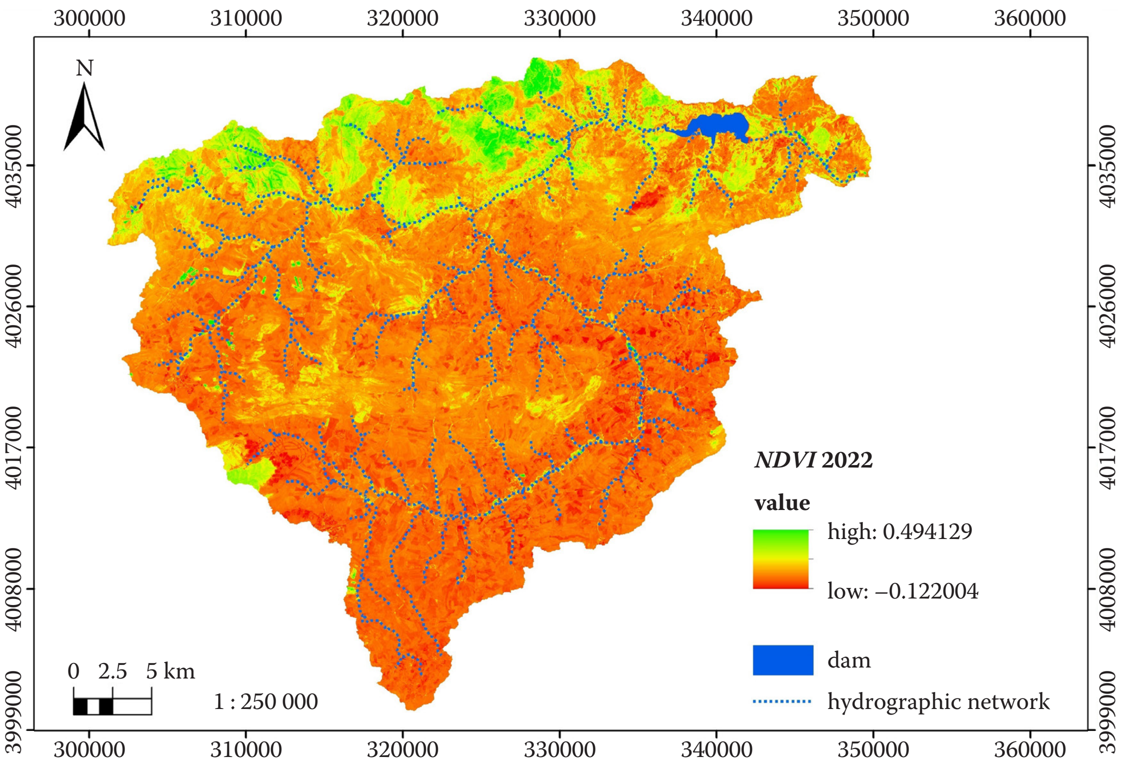

Figure 5. *NDVI* map of the study area in 2022

NDVI – Normalized Difference Vegetation Index

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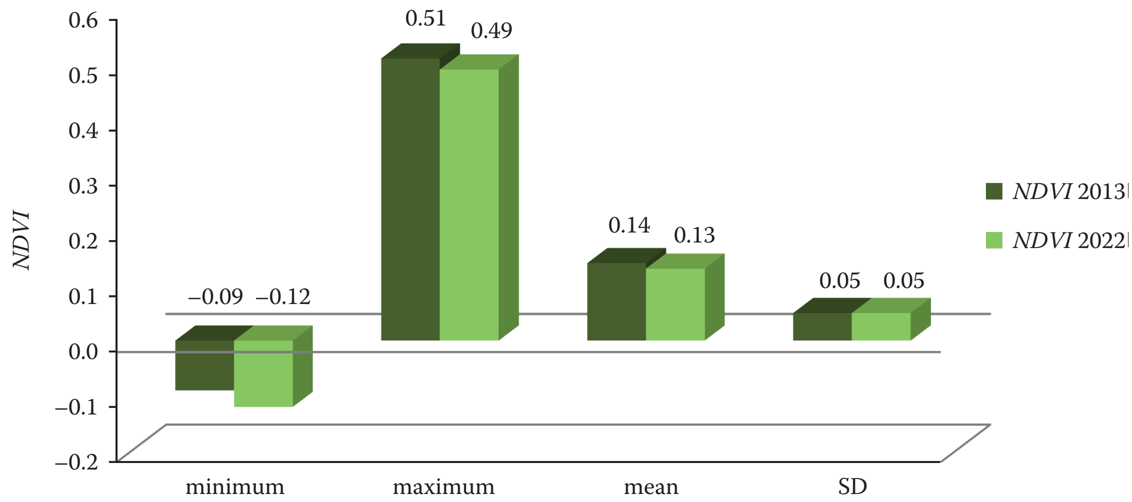

Figure 6. *NDVI* values for the years 2013 and 2022

NDVI – Normalized Difference Vegetation Index

higher than those of the year 2022, and the maximum value of the *NDVI* decreases by 0.02, which provides information on the decrease in vegetation cover during this observation period. Figure 6 shows that the *NDVI* values of 2013 are significantly higher than the *NDVI* values of 2022. The average *NDVI* value for 2013 is estimated at 0.14 while the average *NDVI* value for 2022 is 0.13.

The result of the *NDVI* supervised classification of the Landsat images from 2013 and 2022 made it possible to observe and quantify the state of the evolution of the forest cover in the Oued Bouhamdane watershed, and to highlight its different changes occurring during 9 years, thus obtaining good quality maps (Figure 7 and 8). On the one hand, this is due to the date on which the satellite

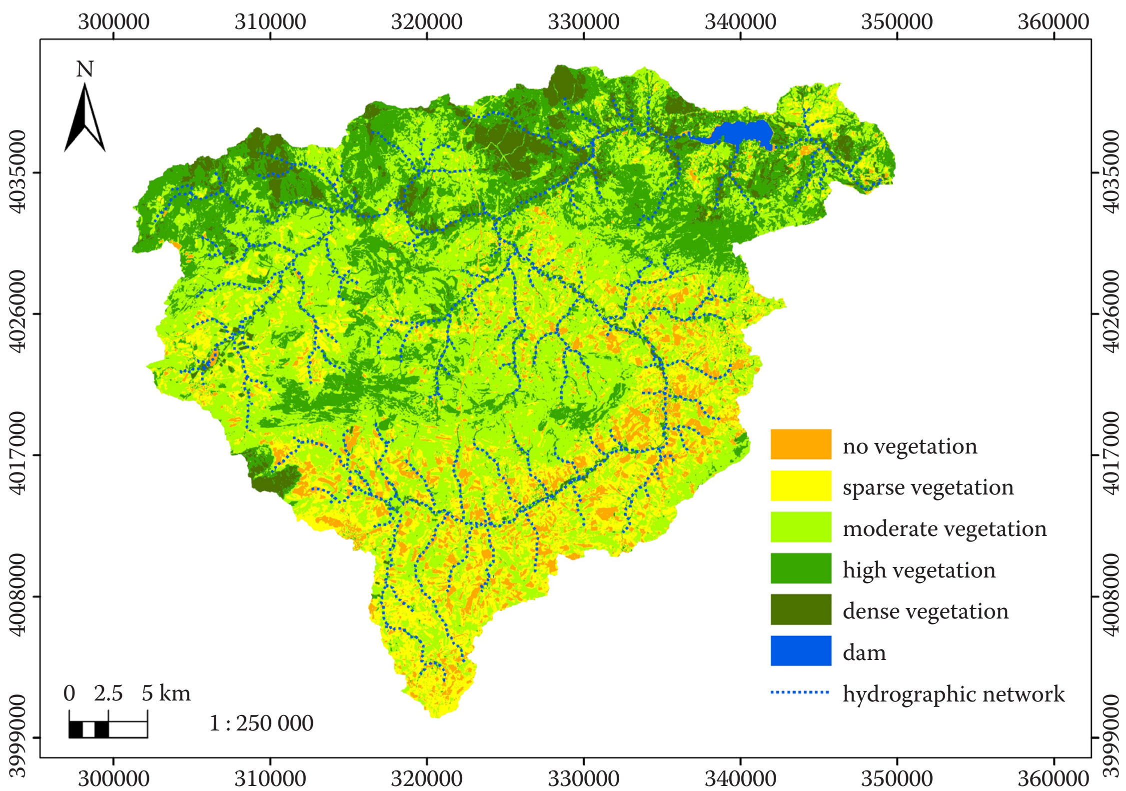

Figure 7. Map of classification of vegetation classes for the year 2013

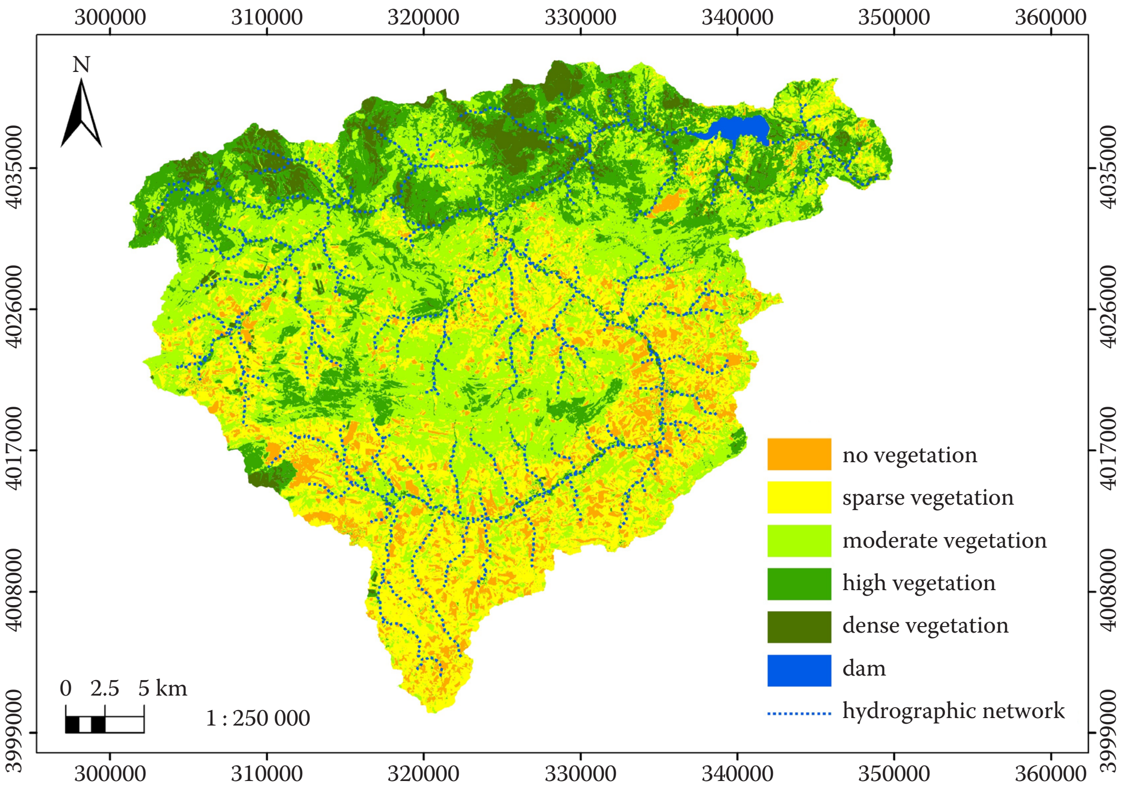

Figure 8. Map of classification of vegetation classes for the year 2022

images were taken in the dry season and on the other hand to field verification.

The level of accuracy of the results obtained for the classified *NDVI* retained for the year 2013 is 87.5%, the Kappa coefficient is 83.76%, whereas the level of accuracy calculated for the classified *NDVI* retained for the year 2022 is around 83.33% with the Kappa coefficient estimated at 78.48% (Tables 2 and 3).

Dynamics of forest cover between 2013 and 2022. The resulting *NDVI* map from the 2013 classification reveals that forest cover (high vegetation and dense vegetation) occupied 30.85% or 34 178.40 ha of the total study area. For the classified *NDVI* map used for the year 2022, the forest cover accounts for an area of 28 054.89 ha, or for 25.31% of the total study area (Table 4).

Table 4 shows that the classes of high vegetation decreased from 27 833.49 ha in 2013 to 22 285.89 ha in 2022; the same applies to the classes of dense vegetation which were estimated at 6 344.91 ha in 2013 but reached only 5 769 ha in 2022. These two classes (high vegetation, dense vegetation) really represent the forest cover in the Oued Bouhamdane watershed, unlike the classes which have no cover or have low veg-

Table 2. Statistics of assessment accuracy of the *NDVI* (2013)

Class	No vegetation	Sparse vegetation	Moderate vegetation	High vegetation	Dense vegetation	Total user	User accuracy	Producer accuracy
No vegetation	9	1	0	0	0	10	90.00	100.00
Sparse vegetation	0	11	0	0	0	11	100.00	61.11
Moderate vegetation	0	3	23	0	0	26	88.46	92.00
High vegetation	0	2	2	11	–	15	73.33	100.00
Dense vegetation	–	1	–	–	9	10	90.00	100.00
Total	9	18	25	11	9	72	441.79	453.11

NDVI – Normalized Difference Vegetation Index

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Table 3. Statistics of assessment accuracy of the *NDVI* (2022)

Class	No vegetation	Sparse vegetation	Moderate vegetation	High vegetation	Dense vegetation	Total user	User accuracy	Producer accuracy
No Vegetation	8	2	0	0	0	10	80.00	61.54
Sparse vegetation	2	16	0	0	0	17	94.12	76.19
Moderate vegetation	2	3	18	0	0	23	78.26	85.71
High vegetation	0	0	3	9	0	12	75.00	100.00
Dense vegetation	1	0	0	0	9	10	90.00	100.00
Total	13	21	21	9	9	72	417.38	423.44

NDVI – Normalized Difference Vegetation Index

Table 4. *NDVI* classification statistics for the year 2013 and 2022

Class	*NDVI* 2013		*NDVI* 2022	
	area (ha)	area (%)	area (ha)	area (%)
No vegetation	8 471.88	7.64	10 363.59	9.36
Sparse vegetation	20 583.81	18.58	30 687.93	27.70
Moderate vegetation	47 569.68	42.93	41 697.36	37.63
High vegetation	27 833.49	25.12	22 285.89	20.11
Dense vegetation	6 344.91	5.73	5 769.00	5.20
Total	110 803.77	100.00	110 803.77	100.00

NDVI – Normalized Difference Vegetation Index

etation (no Vegetation, sparse vegetation) which represent an area of 2 905 569 ha in 2013 against 41 051.52 ha in 2022. However, the moderate vegetation classes are not considered forest cover; the area of these classes varies from 47 569.68 ha in 2013 to 41 697.36 ha in 2022.

Change detection. The calculation of Δ*NDVI* by applying Equation (2) reveals changes in forest cover within the Oued Bouhamdane watershed during the period considered (Table 5).

Table 5 shows different evolutions (progression or regression) of the vegetation cover during 9 years of observation. No vegetation classes increased from 8 471.88 ha in 2013 to 10 363.59 ha in 2022, showing a growth of 1.71% – this is mainly due to the increase in urban and agricultural areas. The sparse vegetation classes vary from 20 583.81 ha in 2013 to 30 687.93 ha in 2022, thus showing an upward trend of 9.12%, indicating deforestation in these areas. However, the classes of moderate vegetation estimated at 47 569.68 ha in 2013 reached 41 697.36 ha in 2022, which represents a regression of –5.30% compared to the year 2013. The classes that actually represent the forest cover (high vegetation and dense vegetation) go from 34 178.4 ha in 2013 to 28 054.89 ha in 2022, which generates

Table 5. Area changes of vegetation classes during the observation period (2013–2022)

Class	Change detection between 2013 and 2022		Average rate (ha·year^{-1})
	area (ha)	area (%)	
No vegetation	+1 891.71	+1.71	+210.19
Sparse vegetation	+10 104.12	+9.12	+1 122.68
Moderate vegetation	–5 872.32	–5.30	–652.48
High vegetation	–5 547.60	–5.01	–616.40
Dense vegetation	–575.91	–0.52	–63.99
Total	0.00	0.00	0.00

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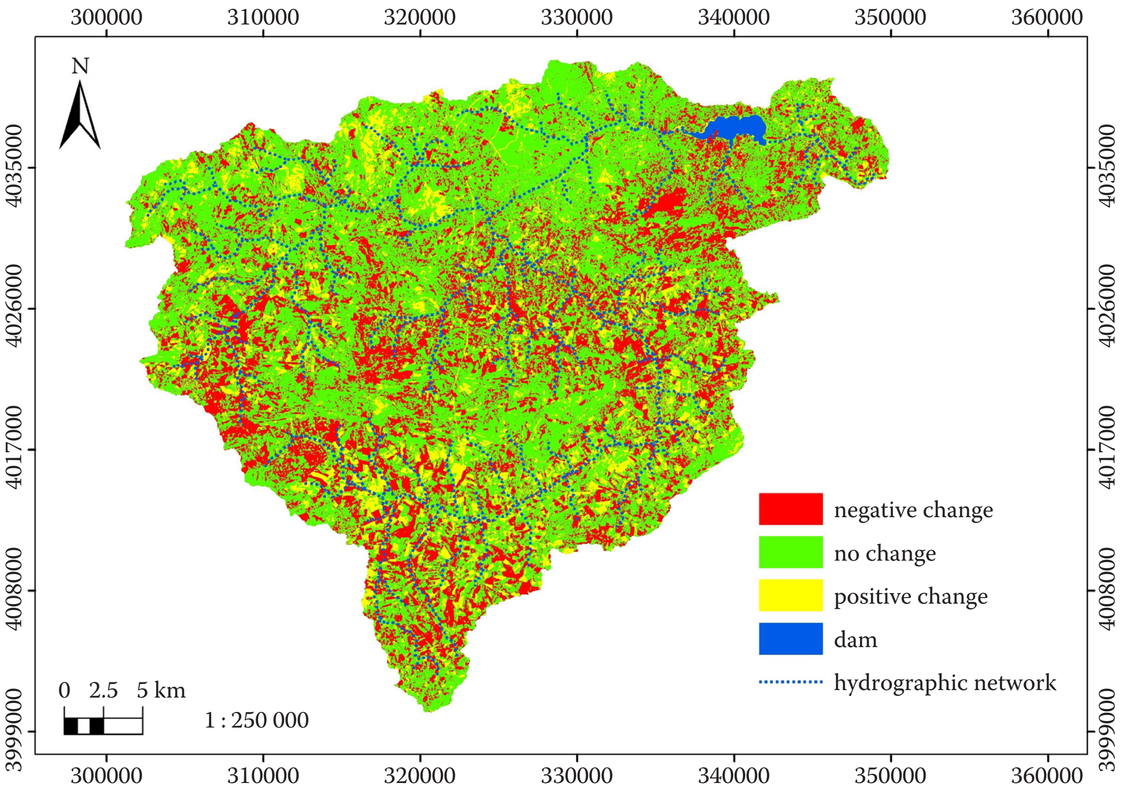

Figure 9. Map of vegetation changes between 2013 and 2022

a negative change of –5.53%. According to Table 5, the Oued Bouhamdane watershed loses 680.39 ha of its forest cover annually for the 2013–2022 observation periods, which explains the increase in the area of no vegetation and sparse vegetation classes. This regression is mainly due to natural and anthropogenic factors (repeated fires, drought, clearing, illegal cutting, overgrazing). The established change map spatially and quantitatively illustrates significant changes in the vegetation cover that occurred in the Oued Bouhamdane watershed over a 9-year period (2013–2022). These changes in vegetation are represented by three classes which are: (*i*) the class of positive changes for the zones where the vegetation has progressed, (*ii*) the class of negative changes for the zones where the vegetation has undergone a regression, and (*iii*) the class of zero changes for the zones of stability (Figure 9).

Table 6. Vegetation changes between 2013 and 2022

Type of change	Area (ha)	Area (%)
Positive	13 440.51	12.13
Negative	31 709.07	28.62
No change	65 654.19	59.25
Total	110 803.77	100.00

Figure 9 shows that the regression zones (negative changes) are mainly located in the central, northeastern, southern and southwestern part, with the rate of 28.62% or 31 709.07 ha of the total area of the perimeter of the study. However, the areas of positive changes have increased to 13 440.51 ha, i.e. a rate of 12.13% of the total study area. This progression is concentrated mainly in the southern, central and northern part, while the stability zones cover almost the entire territory of the watershed, covering 59.25% with an area of 65 654.19 ha (Table 6).

DISCUSSION

In general, the carried out diachronic study makes it possible to judge that the forest cover of the Oued Bouhamdane watershed is subject to an upheaval which leads to its regression. This regression is reflected in the decrease in the maximum *NDVI* value of 0.51 in 2013 to 0.49 in 2022. The rate of changes that was found by the verification of the ground and that reached 28.62% of the total surface of the watershed confirms that the situation of the vegetation cover of this area is alarming. We point out that the rate of vegetation regeneration is always dependent on the sanitary state of the vegetation

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cover, the regression factor and the climatic conditions of the region. The baring of the soil by the factors of clearing, fires, overgrazing and urbanization promotes the phenomenon of erosion. The repetitive passage of fires exposes the soil to water erosion and makes the regeneration of the vegetation cover more and more problematic. The missions organised during the field inspection show that human impacts are present and visible. These human attacks undoubtedly remain the determining factor in the regressive evolution of the vegetation cover in this watershed. The populations close to the forest exercise practices on the forest which still persist such as clearing, overgrazing, browsing, illegal cutting, especially on the cork oak and the zeen oak. All these actions were at the origin of the regression of the forest cover of the state forest of Beni Medjaled and Taya. Between 2013 and 2022, the burned forest area (cork oak, zeen oak, reforestation and maquis) on the scale of this watershed amounted to 1 200 ha, i.e. an average of 133.33 ha·year^{-1}. The methodological approach based on the use of *NDVI* to detect changes between 2013 and 2022 on the scale of the Oued Bouhamdane watershed shows an effective close to reality on the ground, if we compare the result obtained in this research with that obtained by other researchers in Algeria, such as Barbache et al. (2019) and others.

CONCLUSION

The monitoring of vegetation change in the Oued Bouhamdane watershed was conducted by the *NDVI* differentiation method applied using Landsat images taken in 2013 and 2022. This monitoring made it possible to highlight the major changes in the study area. The calculation of *NDVI* for the two chosen reference dates shows that the maximum values of the *NDVI* for the year 2013 are higher than those of the *NDVI* for 2022. The supervised classification of the *NDVI* from the years 2013 and 2022 made it possible to quantify the vegetation cover of the Oued Bouhamdane watershed. This quantification shows that the classes (High vegetation, Dense vegetation) which really represent the forest cover of this zone have undergone a regression which reaches –5.53% of the total area of the watershed. This regression is linked to multiple factors of aggression, mainly anthropogenic (overgrazing, deforestation, fires), which is currently destabilizing the ecological balance of this forest ecosystem. To protect this forest wealth, and in this region in particular, it is urgent to set up a management plan, and a monitoring and surveillance program in order to ensure better protection of this forest wealth in line with the current situation.

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