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Monitoring vegetation cover trends in the steppe region of western Algeria using MODIS imagery

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ABSTRACT

The steppe region of Chehaima (Tiaret Province, northwestern Algeria) covers an area of 2,202 km², representing 10.94% of the total area of Tiaret. This study identified the ecological state of the area using a spatial theme from a 24-year synchronized moderate-resolution imaging spectroradiometer (MODIS) satellite image campaign (2000–2023). The adopted method consists of analyzing spectral indices (normalized difference vegetative index, low surface temperature (LST), and soil moisture index) from MODIS sensors (MOD13Q1), making it possible to evaluate the spatiotemporal dynamics of the vegetation in the study area and to identify regions degraded by several biotic and abiotic factors. The results show a vegetation cover rate of intense fluctuations in unfavorable conditions over 24 years. The percentage of plant growth recorded does not exceed 32%. The abundance of LST vegetation decreases when the LST exceeds 35°C, with a soil that has a water deficit. The De Martonne aridity index (*I*) classifies the study area as a lower semiarid bioclimatic zone. These indicators made it possible to determine the spatiotemporal dynamics of vegetation, which modifies the plant cover, leading to the loss of native species such as alfa *Stipa tenacissima* L. Defensive measures are necessary over large areas of the study area to allow successful protection of steppe rangelands through a sustainable conservation strategy, preserving endemic species, stabilizing dunes, and adopting the steppe rotation system.

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1. INTRODUCTION

Degradation of vegetation cover is a fundamental aspect of the desert landscape and is included in the study of the environment and natural phenomena such as desertification, which designates the accentuated degradation of soils and the vegetation cover in the arid, semiarid, and dry subhumid zones (Slimani & Aidoud, 2018). It is one of the most worrying environmental problems of the 21st century due to climatic variations and human activities, which can lead to vegetation deterioration, soil erosion, and population migration (Dalila & Slimane, 2008).

The phenomenon of desertification affects the steppe zones in Algeria. In this study, we focus on the steppe of the Tiaret region, which indicates an arid ecosystem marked by a rich landscape diversity with a high variability of ecological factors (Haddouche & Zennouche, 2018), promoting the installation of different forms of desertification at various stages (installation of sand accumulations of different shapes and sizes and degradation of vegetation cover (Aidoud & Jean, 1996). The study of vegetation dynamics highlighting the reality of vegetation cover evolution requires temporal monitoring at multiple spatial scales to identify the risks and effects resulting from this problem (Meriem et al., 2018) and highlight the factors favoring but also the effective means of control, implying new techniques such as remote sensing and geographic information system (Boudjemline & Semar, 2018).

The daily and composite time series of several vegetation indices from moderate-resolution imaging spectroradiometer (MODIS) data have been widely used in scientific works for phenological studies (Testa et al., 2018). Currently, the major limitation is that imagery that can be used operationally and economically over large areas with high temporal frequency has a coarse spatial resolution. Deus and Gloaguen (2013) also showed that the remote sensing approach is a cost-effective and accurate method to study the dynamics of water resources in semiarid areas. Several authors have studied the phenomenon of desertification and the degradation of steppe rangelands through remote sensing and monitoring of the dynamics of plant ecosystems using calculations of spectral indices such as NDVI, LST, and SMI from MODIS imaging (Debaine & Jaubert, 2006; Escadafal & Bégni, 2016). These studies noted the regressive evolution of steppe vegetation. The Chehaima region (Tiaret Province, west Algeria) is one of these cases.

Indeed, this region is considered as a gateway rise of the desert towards the North Algeria. It was constituted as part of the green dam project to renew the Algerian forest heritage endangered particularly by desertification. At the current state, given the failure of this agroecological project, the need to seek other solutions becomes a significant concern for the afforestation of the Algerian steppe, which started with an inventory study via methods of mapping and remote sensing of the Chehaima area.

The study area, with its steppe character, shows a high tendency to degradation, which results in the reduction of biological potential and the rupture of ecological and socioeconomic balances (Amrouni et al., 2022), a consequence of the abusive exploitation of resources, including overgrazing (Chermat et al., 2016). Hence, to what extent did changing plant coverage contribute to the degradation of the natural environment and its basic components?

The objective of this study is to determine indicators that make it possible to monitor the spatiotemporal dynamics of vegetation in the study area through spectral indices from MODIS sensors (MOD13Q1), indicating the most vulnerable sites for the phenomenon of desertification and subsequently define the defensive measures necessary for successful protection of the Algerian steppe rangelands.

2. MATERIALS AND METHODS

2.1. Study area

The Chehaima region, located in 34°53′57″N and 1°18′24″E (in the northwest of Algeria), belongs to the Algerian steppe area and is located south of the Tiaret region. It extends over an area of 2,200.64 km² (Figure 1). It has significant agropastoral potential, presenting a homogeneous landscape morphology, with vast areas of land occupied mainly by alfa *Stipa tenacissima* L. tablecloth in its southern part and agricultural perimeters in the northern and central parts. The regional soils are typical of steppe courses dominated by calcareous soils (Figure 1). The regional climate is characterized by long periods of drought and irregular rainfall ranging from 150 to 200 mm/year (Islem et al., 2018).

The methodology adopted consists of analyzing spectral indices (NDVI, LST, and SMI) from MODIS sensors (MOD13Q1) synchronized over 24 years (2000–2023) to put forward a method for monitoring the evolution of the plant cover in the study area through a spatiotemporal analysis of data sources on vegetation and degradation factors of steppe rangelands in the study region.

2.2. MODIS data

The images of the MODIS sensors (MOD13Q1) are used for regular monitoring from 2000 to 2023, with a spatial resolution of 250 m. We used these data because they allow monitoring over long observation periods and large areas. Hence, we used the following:

- Land-use map: This map is extracted from the ESRI 2020 database, which represents land-use data derived from sentinel-2 images at 10-m resolution, of which seven classes are retained. Map data are extracted from a site (https://livingatlas.arcgis.com/landcover/ [link Consulted in 2023).
- Climate data: Climate data include the 2000–2023 precipitation, evapotranspiration, and temperature data, which are available as a point layer loaded from a platform (https://power.larc.nasa.gov/data-access-viewer).
- Spectral indices and vegetation monitoring: The methodology is organized around the time series analysis obtained from the MODIS images used. These indices are excellent monitoring indicators and enable the identification of the different evolutionary phases of vegetation in its environment.
- Vegetation index: This index is known as NDVI [1], and it detects and monitors vegetation using remote sensing techniques and is calculated according to Equation 1.

  $$NDVI = NIR - \frac{RED}{NIR} + RED \quad ....[1]$$

  where *NIR* is the reflection of the near-infrared spectrum and RED is the reflection of the infrared spectrum.
- LST: The surface temperature is obtained from the MODIS-Terra images at 1 km resolution. The gloss or surface temperature can be a good indicator of the absence of vegetation; a dense vegetation cover manifests with attenuations of the surface temperature, and bare soil has high values.
- SMI: This index is an important factor in modeling environmental risks. Equation 2 reflects the relationship between surface temperature and vegetation cover.

  $$SMI = (LST\max - LST)/(LST\max - LST\min) \quad .... [2]$$

  where *SMI* is the soil moisture index, and *LST* is the low surface temperature.

2.3. Index of aridity *I* of the Chehaima region

Aridity expresses the restrictive character of certain plant formations; it is a quantitative indicator of the degree of lack of water present at a given location, which is calculated using Equation 3 (de Martonne, 1926).

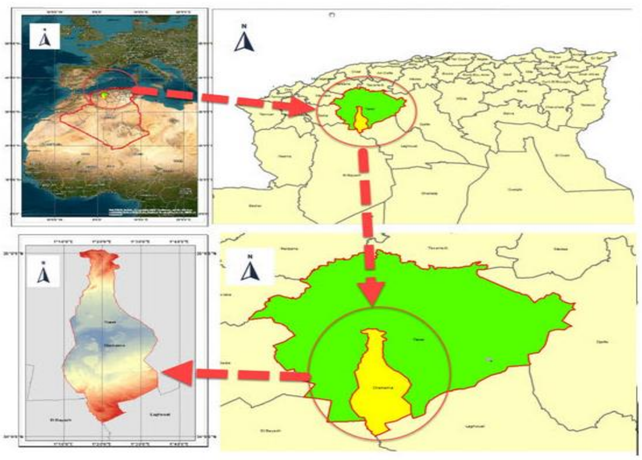


Figure 1. Chehaima area situation map

$$I = P/(T + 10) \text{ .... } [3]$$

where P is the average annual precipitation (mm) and T is the average annual temperature (°C).

2.4. Canonical correlation analysis (CCA)

CCA allows you to compare two groups of quantitative variables, both applied to the same individuals. It compares these two groups of variables to determine whether they describe the same phenomenon, in which case we can do without one of the two groups of variables.

To study the different relationships between the biotope (NDVI and rate and surface of the vegetative cover) and physical parameters of the steppe environment, such as precipitation (*P*, *T*, LST, and SMI) of the study area, we performed CCA, and Figure 6 shows the CCA results.

The CCA (Figure 6) showed that Axes F1 and F2 are likely to be interpreted, representing 93.29% of the information. F1 and F2 explain 73.67% and 19.63% of the information, respectively.

The initial variables correlated strongly with the canonical variables:

- On the F1 axis, on the positive side, the variables *P* (mm) and *NDVI*max are correlated positively. (The higher the *P* (mm), the higher the *NDVI*max increases.)
- On the F2 axis, we observe that this axis is correlated negatively with the two-recovery rate and *SMI*max variables (projection on the positive side). The redundancy coefficients show that the canonical variables predicted a small portion of the variability of the initial variables.

3. RESULTS

3.1. Vegetation dynamics of the Chehaima region from 2000 to 2023

The obtained results (Fig. 2 and Fig. 3), which indicate the vegetation recovery rate in the Chehaima area, show that the vegetation cover rate in the region is characterized by intense adverse fluctuations over 24 years, where the growth percentage does not exceed 32%. The lowest recovery rate during the study period was 4% in May 2023.

3.2. Monitoring indicators and evolution of vegetation cover

3.2.1. Low surface temperature

LST allows an assessment of the water conditions of soil, including the availability of water necessary for the sustainability of the vegetation (Figure 4). The obtained results show that the abundance of vegetation decreases when the LST exceeds 35°C. The soil loses its moisture through evaporation (Lucot et al., 1995).

3.2.2. Soil moisture index

SMI makes it possible to assess the humidity state of the soil for optimal storage (available storage). The soil is wet and saturated if the SMI is close to 1 and >1, respectively. Conversely, soil water deficit did if its SMI tends toward 0 (Figure 5).

3.2.3 Aridity of the Chehaima region (*I*)

The calculation of the aridity index in the Tiaret region over a series of 24 years (2000–2023) reveals that *I* = 15.65, with *P* = 400.8 mm and *T*avg = 15.6°C.

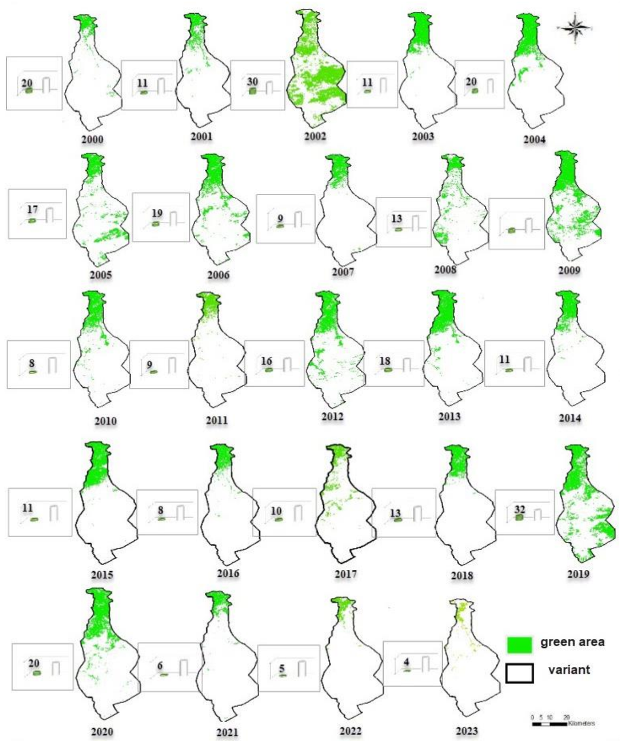


Figure 2. Vegetation recovery rate in the Chehaima area

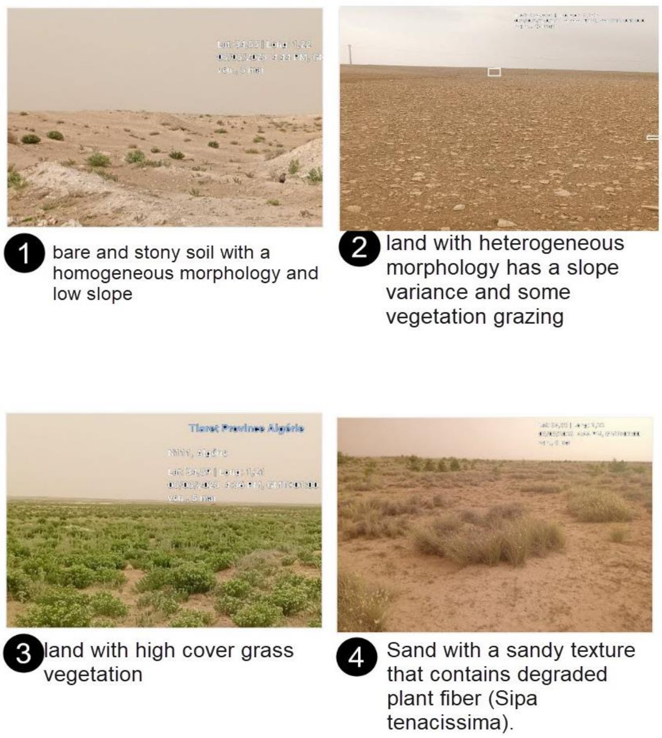


Figure 3. Photographs of the study area

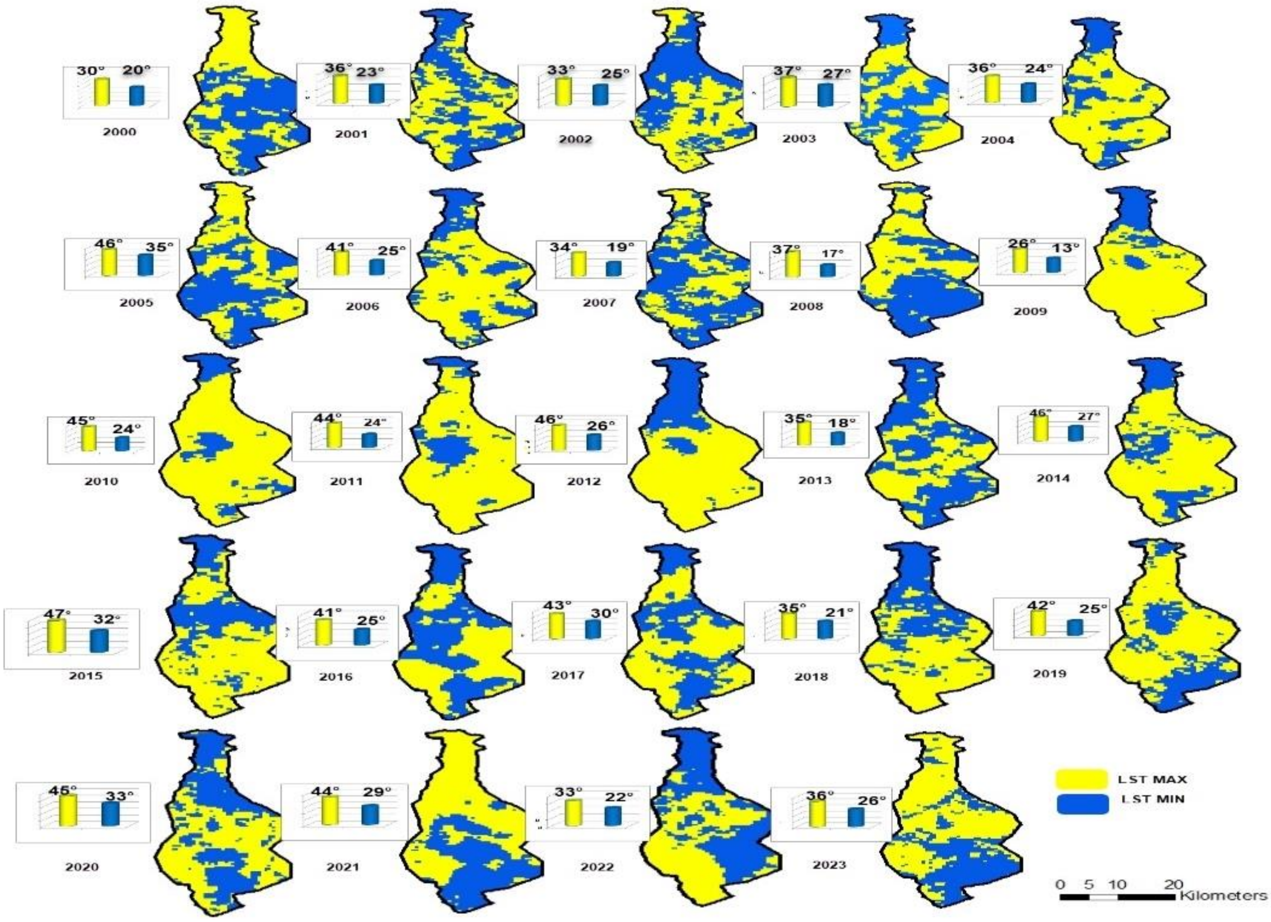


Figure 4. Distribution of surface temperature (*LST*max and *LST*min) in the Chehaima area. (LST, low surface temperature)

4. DISCUSSION

In this study, we demonstrated the vulnerability and resilience of the steppe rangelands of Chehaima (northwestern Algeria), where this region is strongly affected by the degradation process, to identify the ecological state of the area using a spatial theme from a 24-year synchronized MODIS satellite image campaign (2000–2023).

Figures 2 and 3 show that the vegetation cover reached its maximum in May 2011 with a rate of 32%; the values vary between 5% and 30% for the other years. Cultivated vegetation only exists around sites in the north of the region. Almost 70% of the study area represents an agropastoral system with a bare landscape dotted with random vegetative distribution. Indeed, the region typically has steppe vegetation with *Stipa tenacissima* L. and *Artemisia herba* L., but in scattered groups, halophytic vegetation dominated by *Atriplex halimus* L. and *Salsola vermiculata* L. is also present. The value of *LST*max was 47.77°C in May 2015 as the maximum, whereas the minimum value of *LST*max was 32.25°C recorded in May 2022. In this context, Nguyen et al. (2022) confirmed that the highest temperatures correspond to the driest surfaces; this may express the absence of vegetation cover due to the increase in surface temperature, favoring the aridity of the surface of the study region (Figure 4). Land-use dynamics have direct implications on the availability of natural plant resources.

The obtained SMI results indicate that the soils of the study area experienced prolonged drought throughout the observation period. This drought affected all the steppe rangelands of Algeria for over 30 years, but this situation had a negative influence on the endemic vegetation of the region. Zoungrana et al. (2018) found significant downward trends in NDVI ($p < 0.05$), indicating negative changes in natural vegetation (period 2000–2011 in the savannah of Burkina Faso) occurring along protected area boundaries and in fragmented landscapes characterized by disruption of the continuity of natural vegetation.

Soils exposed to high surface temperatures favor this rapid drying, and therefore, combined with low vegetation cover, evapotranspiration rates are high, making the region vulnerable to degradation processes and experiencing phases of regressive evolution (Figure 5). The study area belongs to classes of semiarid or semidesert climates, characterized by insufficient precipitation in certain years to maintain crops, where evaporation often exceeds precipitation (Gherraz et al., 2020).

Roose et al. (2010) monitored land degradation, soil erosion, and desertification in a French Mediterranean region and demonstrated excellent accuracy in identifying levels of land degradation using spectroscopy airborne imagery (AVIRIS) and Landsat TM data.

The CCA (Figure 6) shows the following findings:

- The precipitation variable *P* and *NDVI*max are positively correlated (the higher the precipitation, the more the NDVImax increases). Steppe vegetation was favored by high precipitation values, showing the sensitivity of steppe vegetation to external disturbances, particularly climatic and edaphic factors (Islem et al., 2018).

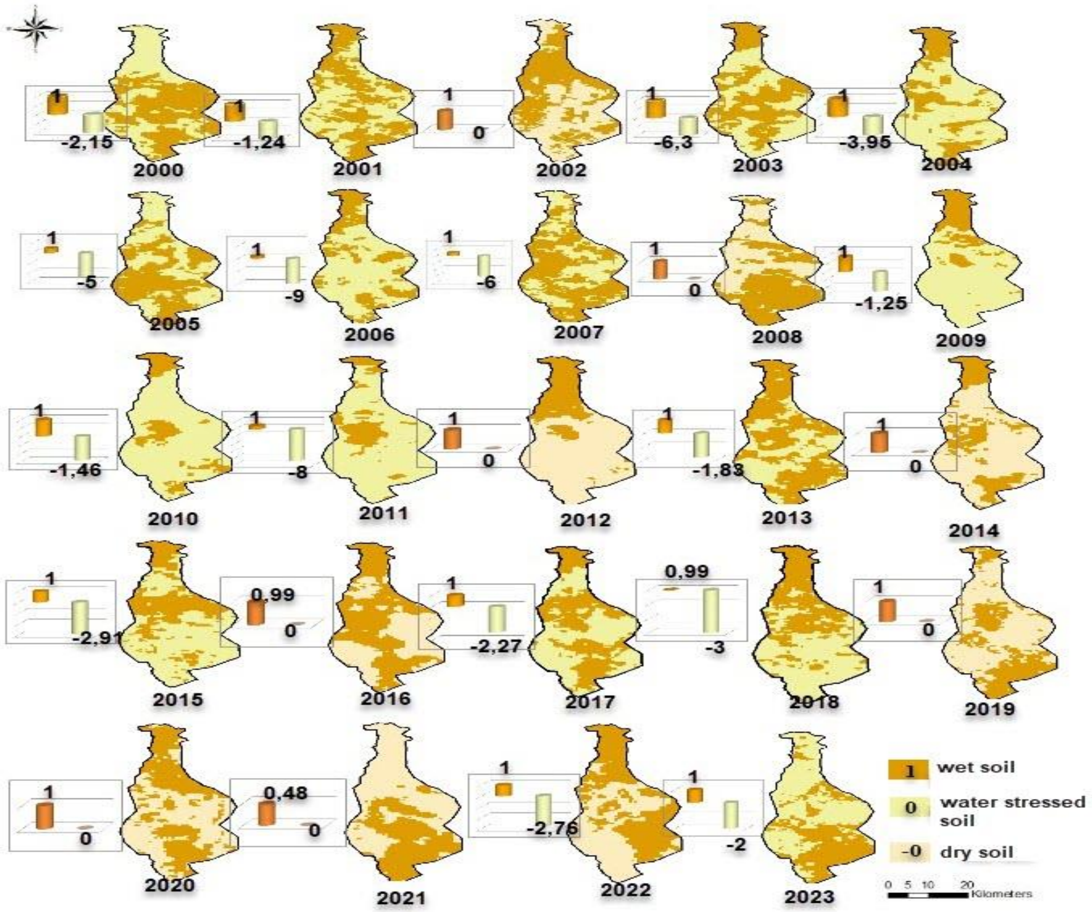
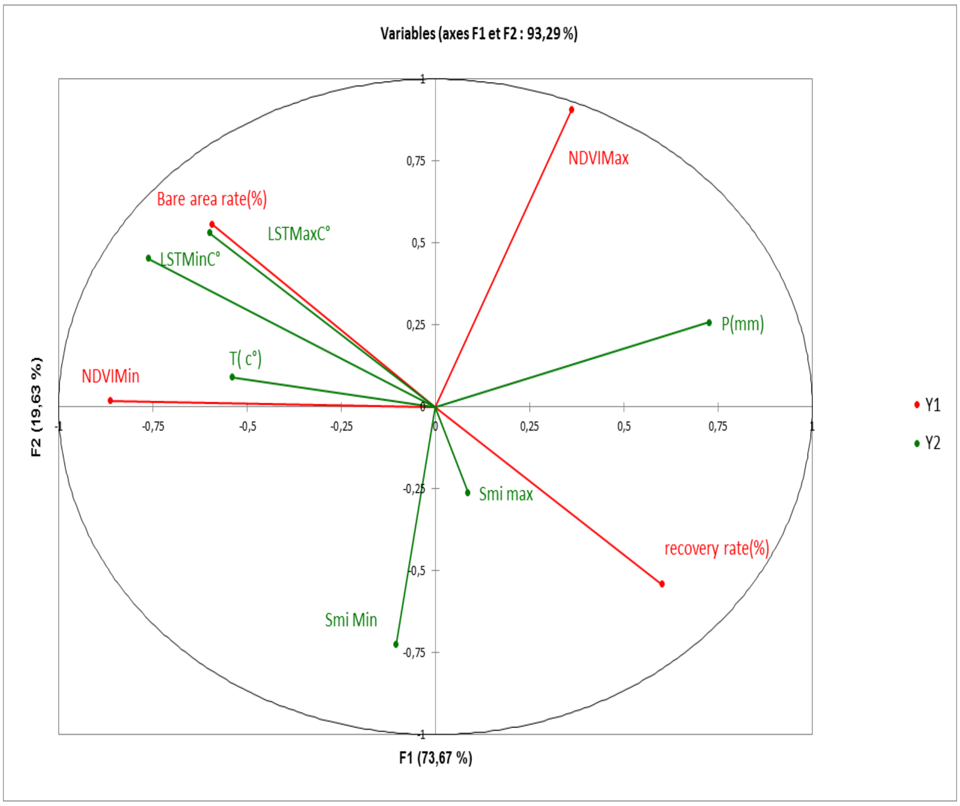


Figure 5. Distribution of the soil moisture index on the surface of the Chehaima zone



Legend:
Y1: Biotope parameters
Y2: Abiotic parameters

Figure 6. Canonical correlation analysis for biotic and abiotic parameters in the Chehaima zone. NDVI, normalized difference vegetative index; SMI, soil moisture index; LST, low surface temperature

- The variables LST, *T*, and bare area rate (%) are correlated negatively. High temperature has a negative effect on the minimum NDVI and bare area rate. Indeed, the climate of the Algerian steppe is an aggravating factor compared with the situation in countries in the Sahel region, where drought is an essential factor of degradation. The growing human pressure on the steppe ecosystem has amplified and accelerated the degradation process of the plant cover (El Zerey et al., 2009). Vegetation indices, such as LST and evapotranspiration factors, can also be indicators of vegetation stress and available soil water capacity for plants during dry periods(Deus & Gloaguen, 2013).
- *NDVI*max and recovery rate (%) are not correlated with *SMI*min and LST, respectively, where they exhibit opposite correlation values (Traoré et al., 2017).

Dubovyk et al. (2015) studied vegetation dynamics with medium-resolution MODIS-EVI time series at a subregional scale in southern Africa and concluded that the decline in vegetation observed in the study area was linked to factors of human origin. However, the information obtained from this study is helpful for land rehabilitation interventions and serves as input for a range of land surface models.

5. CONCLUSIONS

This study analyzes some spectral indices from MODIS sensors (MOD13Q1) to evaluate the spatiotemporal dynamics of vegetation in the steppe zone of Chehaima (northwestern Algeria). The study results showed spatial and temporal fluctuations of plant cover, the principal biological indicator of the dynamics of steppe ecosystems, with a recovery rate not exceeding 30%. Because of natural factors, such as low precipitation and high temperatures demonstrated by the De Martonne aridity index, the study area has changed plant cover, leading to the loss of native species and the predominance of bare landscapes. Promoting vegetation sustainability is considered a necessary defensive measure over large areas and at regular intervals to enable successful protection of steppe rangelands through a sustainable agricultural strategy. Adopting a prevention plan through the grazing rotation system in the steppe will preserve endemic plants and stabilize the dunes.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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