ARID RANGELAND DEGRADATION AND ITS DRIVING FORCES IN SOUTHERN HODNA, ALGERIA

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ABSTRACT

The Algerian steppes frequently experience droughts and significant anthropogenic activities than harm its natural resources, endangering the fragile arid ecosystem's balance. Hence, an analysis of steppe degradation can be instrumental in initiating remedial measures in the region. This study aims to assess the level of rangeland degradation in the southern Hodna region, a crucial component of the steppe landscape, and analyse the factors driving this degradation. The methodology employed a supervised classification technique, using multi-temporal remote sensing imagery from 1987 to 2016 to analyse land cover distribution. Furthermore, land cover dynamics were combined with carefully selected climatic and anthropogenic data, which were then subjected to canonical correspondece analysis to identify the primary drivers of rangeland degradation. The results reveal a sustained change in land cover dynamics, with a notable 48.65 % reduction in the rangeland class. Simultaneously, there has been a continuous expansion in sand dunes, rangeland degradation, and agriculture classes. It is worth noting that canonical correspondence analysis reveals stronger associations between rangeland degradation and anthropogenic factors than climatic factors. Finally, the study offers crucial insights into rangeland degradation in southern Hodna, aiding policymakers and land managers in developing sustainable development strategies for the region.

Keywords: Rangeland degradation; Driving forces; Landsat images; Canonical correspondence analysis; Hodna; Algeria

INTRODUCTION

The degradation of rangelands manifests a situation of concern for a large area around the world (Bedunah & Angerer, 2012), and it affects biotic sustainability and limits the variety of future usage of rangeland ecosystems (Kauffman *et al*., 1997). In the arid steppe rangelands of Northern Africa, pastoral production has experienced a substantial decrease over the last forty years, with arguments suggesting that this region has been reduced and often severely degraded (Aidoud *et al*., 2006). Several studies have shown that the Algerian steppe rangelands are exposed to recurring droughts (Belala *et al*., 2018; MARA, 1974; Nedjraoui & Bedrani, 2008;), and they are exclusively used for grazing and pastoral livestock farming, which is the most significant economic and cultural practice (Bencherif, 2018). As a result, the steppe undergoes degradation at a rapidly accentuated rate and severity, leading to a decline in biological potential and a disruption in ecological and socio-economic balances (Aidoud & Touffet, 1996; Nedjraoui & Bedrani, 2008; Hourizi *et al*., 2017).

The continuous assessment of rangeland cover at spatio-temporal scales would provide the necessary clarity to reduce degradation and guide adaptive management in a fast-changing world (Jones *et al.,* 2018). In this context, remote sensing offers the benefit of covering large geographical areas with varying spatial, spectral, and temporal resolutions. It provides opportunities to observe, monitor, predict, and classify sensitive areas at risk of rangeland degradation (Al-bukhari *et al*., 2018). Land cover information can be easily and inexpensively collected from remotely sensed data to effectively study changes in rangeland area (Mas, 1999). Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Various methods in change detection techniques have been reported in the literature (Mas, 1999; Lu *et al*., 2004). Post-classification comparison is an effective method widely used to identify various changes (Haque & Basak, 2017). In recent years, this approach has also been employed to estimate the loss of rangelands through land cover change (Sahnouni & Abdesselam, 2018, Sawalhah *et al*., 2018).

Recently, the monitoring of rangeland degradation has shifted towards a more holistic approach, analyzing driving forces, including their interactions with land use (Geist & Lambin, 2004). Many authors have attempted to discuss the relationship between changes in land cover and their driving factors through statistical analysis. Opršal *et al*. (2013) examined the link between landscape change and climatic factors CCA (Canonical Correspondence Analysis) and found that socioeconomic factors are the main forces affecting landscape character and change. In the western steppe of Algeria, Bouacha *et al*. (2018) employed canonical correspondence analysis to identify a structure behind the evolution of steppe vegetation. Their results revealed associations between steppe vegetation cover and precipitation and salinity parameters, demonstrating a strong sensitivity of steppe vegetation to external hazards.

This paper focuses on the South Hodna region, which serves as a suitable example of the degraded arid steppe in Algeria. This region has undergone significant changes in water and soil resource utilization due to agricultural policies adopted in recent decades (Sebhi, 1987; Mimoune, 1995; Abdesselam, 2013; Sahnouni & Abdesselam, 2018). The agricultural area has expanded significantly at the expense of rangelands following the development of irrigation, which began in the early 1970s. The rapid evolution of land use and the various pressures exerted on the environment (both climatic and anthropogenic) necessitate an assessment and an evaluation of the environmental changes. However, very few studies have been conducted in this region to evaluate rangeland degradation.

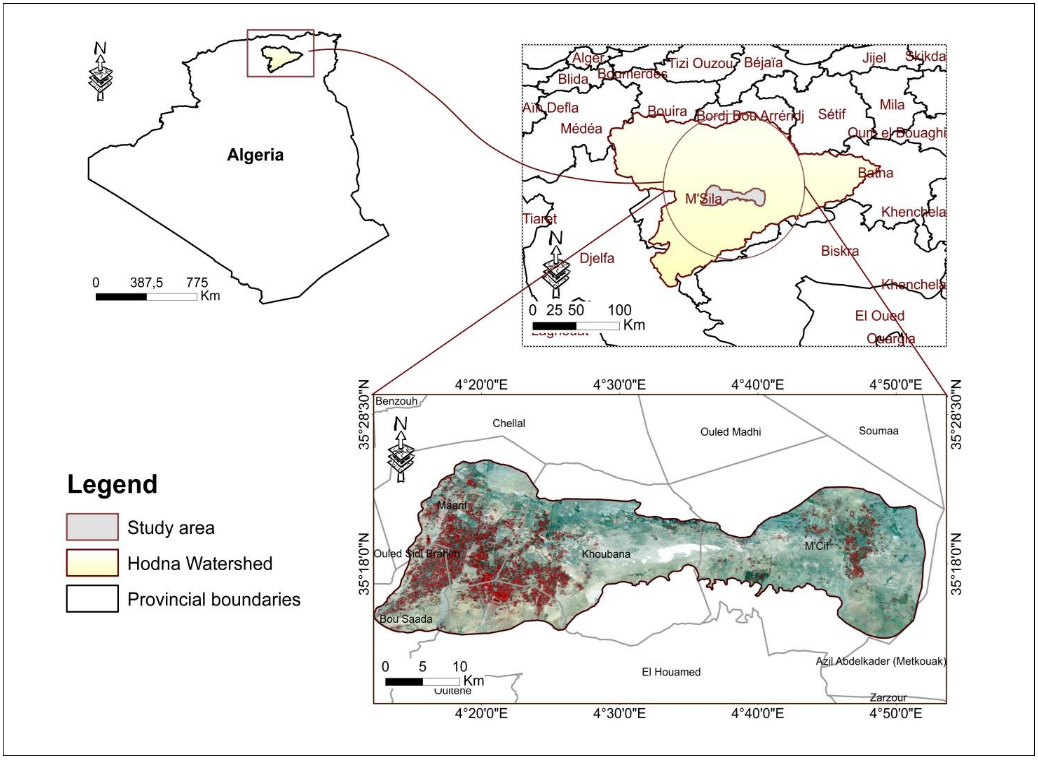
Therefore, the main objectives of this study were: (i) to examine the distribution of land cover in southern Hodna between 1987 and 2016, (ii) to apply post-classification change detection techniques to assess rangeland degradation by examining detailed information on land cover changes, (iii) to understand the relationship between land cover dynamics and driving forces using CCA.

MATERIAL AND METHODS

Study area

Southern Hodna is a highly fragile environment located in the center of Algeria. It extends from 4°12'12" to 4°52'6" North and from 35°12'47" to 35°25'18" East, covering an approximate area of 800 km² (Fig. 1). The region experiences an arid climate with an annual average precipitation of 172 mm, a temperature of 19.4°C, and an evapotranspiration rate of 1,330 mm/year. Southern Hodna is primarily a pastoral region that has undergone significant anthropogenic changes due to agricultural policies implemented in recent decades (Sebhi, 1987; Mimoune, 1995; Abdesselam, 2013; Sahnouni & Abdesselam, 2018).

Fig. 1: Geographical location of the study area



Data collection

To achieve the objective of this analysis, six Landsat multispectral satellite images have been freely downloaded from the USGS. Table 1 shows the selected satellite data. Some ancillary data have also been collected to better support the image analysis. These included ground truth details and photographs taken during various field surveys, topographic maps, and Google Earth pictures. Climatic data from 1987 to 2016, including average monthly temperature and precipitation, were obtained from the Ain Diss Weather Station. Additionally, socio-economic data, such as population and over-grazing, were extracted from the statistics provided by the Agricultural Services Directorate (DAS) for the study duration.

Table 1: Satellite sensor specification

Acquisition date	Sensor	Path/row	Pixel size
13-05-1987	Landsat TM	195/35	30m
19-05-1995	Landsat TM	195/35	30m
22-04-2000	Landsat ETM	195/35	30m
14-05-2005	Landsat TM	195/35	30m
13-04-2011	Landsat TM	195/35	30m
25-03-2016	Landsat OLI	195/35	30m

Data analysis

Land cover was analyzed using the six Landsat images mentioned above. During the pre-processing stage, the images were georeferenced in ENVI 5.3 using the WGS84 system with the Universal Transverse Mercator (UTM) projection zone 31 north. Additionally, atmospheric correction was performed using the calibration tool and FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes). The satellite images were subsetted by selecting the study region based on a georeferenced outline boundary of Southern Hodna. For Landsat OLI, a false-color composite image was created using bands 5-4-3 (R-G-B), while for Landsat TM and Landsat ETM, bands 4-3-2 (R-G-B) were used. This composite image provided the best identification of major land cover classes in the study area.

Supervised classification was conducted on each satellite image using the Maximum Likelihood Algorithm. Training areas were defined for each land cover category to capture their spectral reflectance patterns. Pixels with similar spectral patterns were assigned to specific categories based on the classifier's signatures (Ozesmi & Bauer, 2002). The training areas for each category were created through visual analysis of the images, using RGB display, and supported by the ancillary data mentioned earlier. The identified land cover classes included Agriculture, Rangeland, Degraded Rangeland, and Sand Dunes.

To assess the accuracy of the land cover maps, a stratified random approach was applied in the ENVI 5.3 program. This involved comparing the land cover maps with ground truth regions of interest (ROIs) based on ground truth points, visual perception, and local area information. The accuracy was evaluated using the Kappa index, which measures the classification's level of accuracy.

To examine the role of climatic and anthropogenic factors in driving land cover change, all the data were standardized as follows:

- For the anthropogenic factors we used grazing intensity and population density.
- Grazing intensity was determined using the following formula, which considers the number of animals per unit area during the grazing season (Archer & Smeins, 1991): Grazing intensity (animals/ha) = Number of grazing animals / grazed area. This equation has been effectively used as a benchmark for determining grazing sustainability and estimating the stocking rate (Kairis *et al.*, 2015).

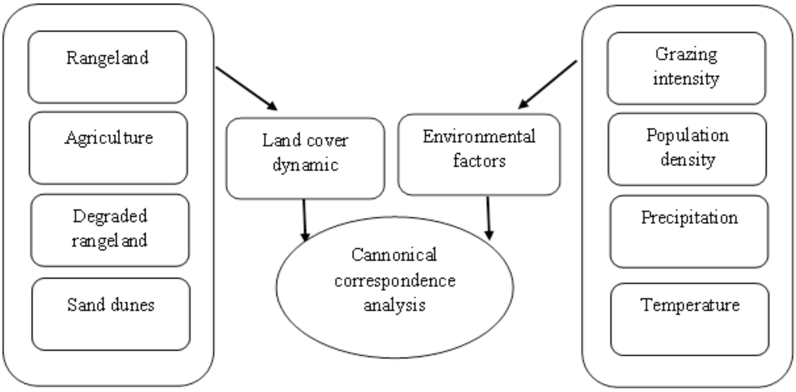
Population density distribution was quantified using the following formula, where the population numbers for the region were divided by the land area for each year:

- Population Density = Number of People / Land Area.

For the climatic factors we used, average annual precipitation and temperature data sets for the six years considered in the study.

To identify the relationship between changes in land cover, rangeland degradation, and the selected environmental variables during the observed time periond, all data were combined an plotted using Canonical correspondence analysis (CCA) in the XLSTAT statistical classifier software.

Fig. 2: Data input for canonical correspondence analysis



RESULTS

Land cover distribution and change

Six land cover maps were created, covering the entire study area for the period 1987-2016 (Fig. 3, 4, 5, 6, 7, 8). The overall accuracies of all six analyzed maps for each year exceeded 90 %, resulting in kappa indices greater than 0.91.

Fig. 3: Land cover map of the year 1987

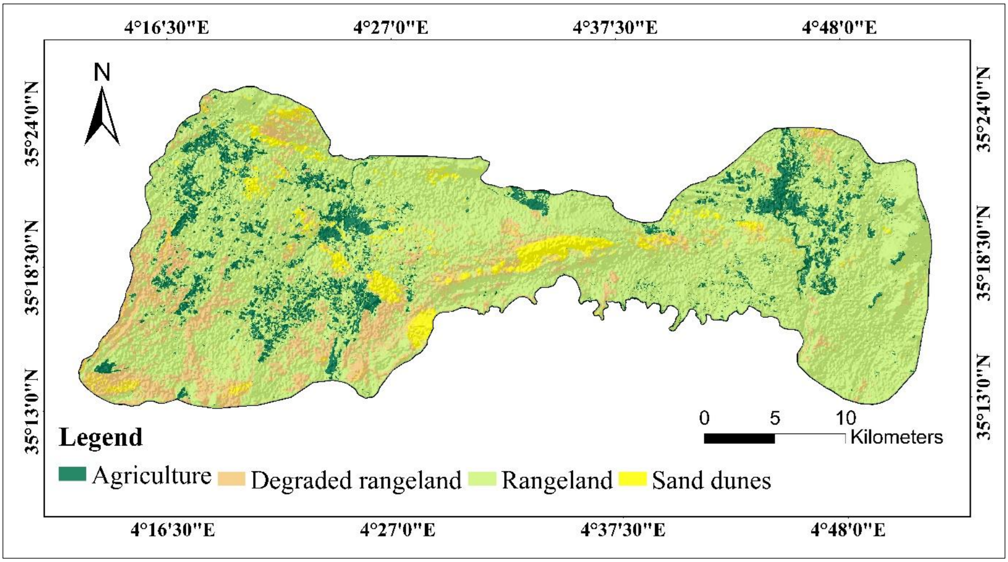


Fig. 4: Land cover map of the year 1995

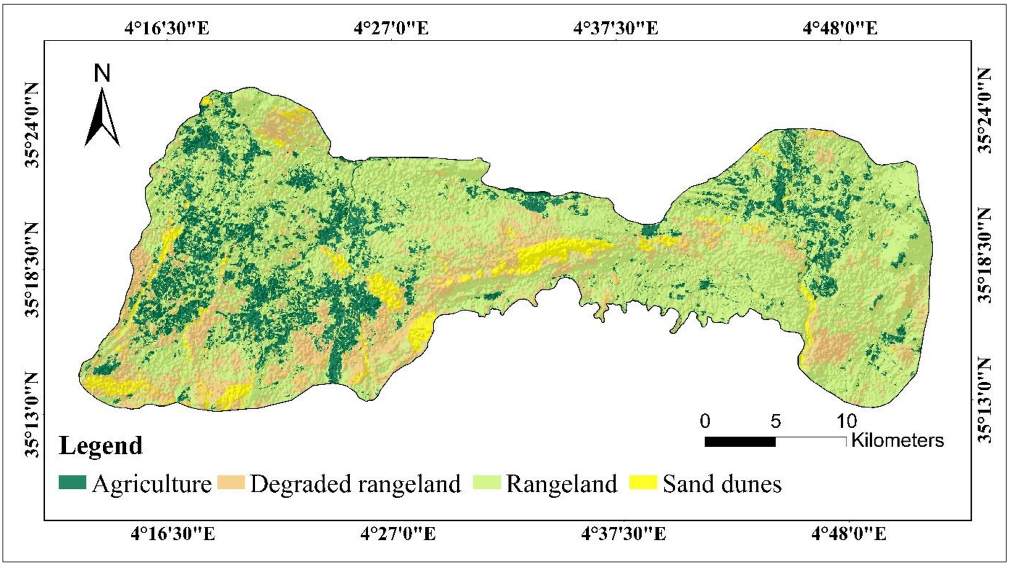


Fig. 5: Land cover map of the year 2000

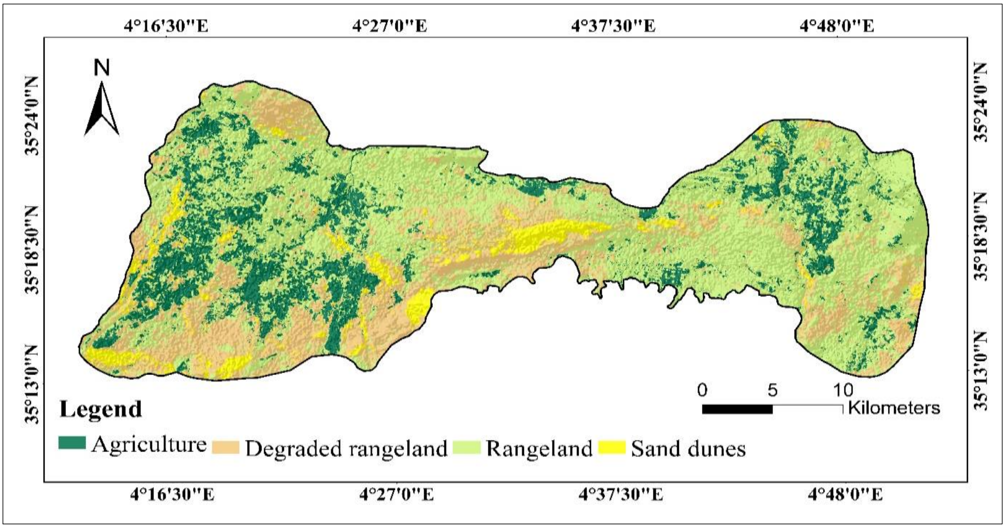


Fig. 6: Land cover map of the year 2005

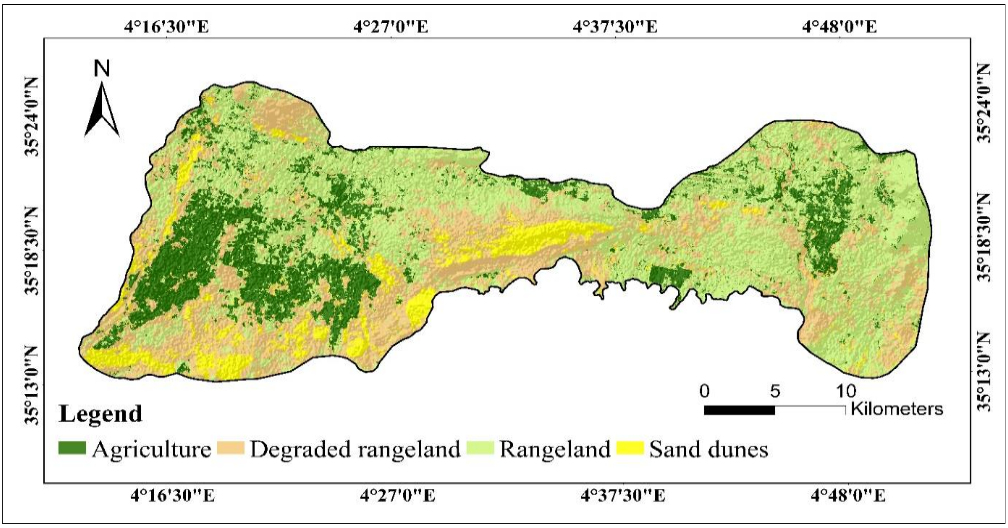


Fig. 7: Land cover map of the year 2011

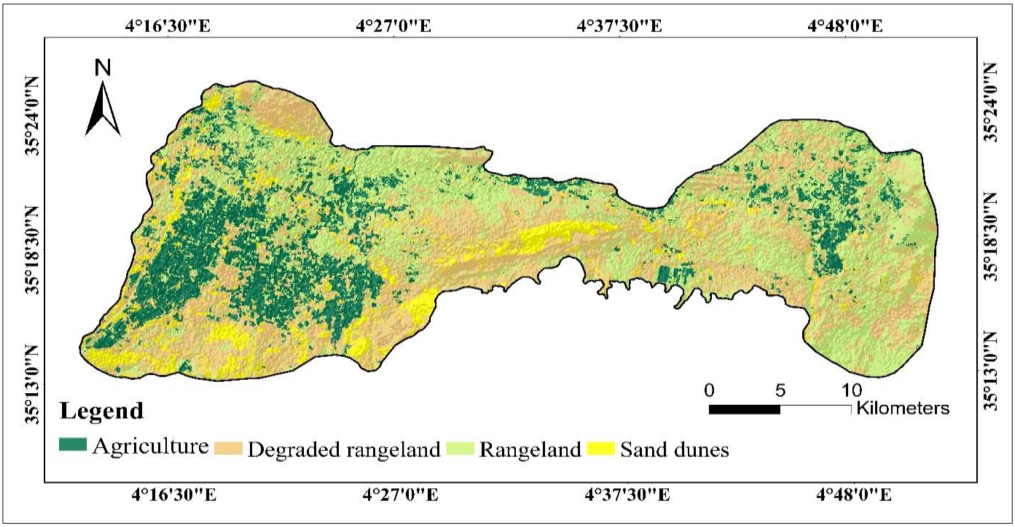
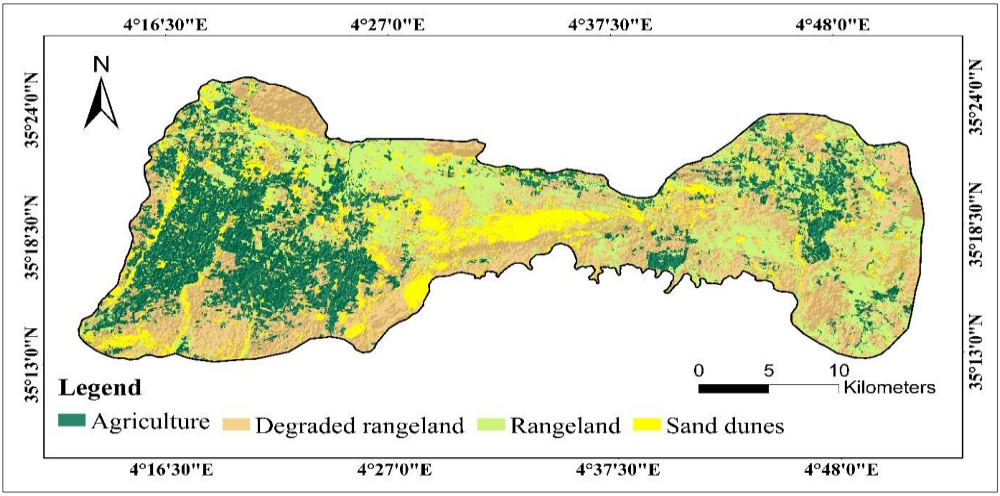


Fig. 8: Land cover map of the year 2016



The statistics derived from the land cover maps (Fig. 9) reveal a consistent decline in rangeland coverage throughout the entire period from 1987 to 2016. However, compared to other land cover classes, rangeland still occupies a significant portion of the study area. In 1987, it covered approximately 71.19 % of the study area, which decreased to 60.92 % in 1995. By 2005, it further decreased to 44.16 %, and in 2011, it reached 37.35 %. The decline continued, and by 2016, rangeland covered only 22.54 %. These findings indicate that more than half of the studied region experienced degradation during this period.

On the other hand, the class of degraded rangeland witnessed an increase from 12.56 % of the whole studied region in 1987 and 16.49 % in 1995, then further increased to 23.85 % 2000. Subsequently, it expanded to 28.76 % in 2005 and further to 34.78 % in 2011, finally reaching 39.68 % in 2016.

The agriculture class exhibited notable growth, with an expansion in surface area, with the following expansions observed: 10.14 % in 1987, 16.63 % in 1995, 17.23 % in 2000, and eventually reaching 24.98 % in 2016.

Throughout the period from 1987 to 2016, there was a continuous increase in the surface area covered by sand dunes. In 1995, the recorded surface area was 4.70 %, which doubled to approximately 8.90 % in 2011. By 2016, the surface area of sand dunes had further expanded to 11.56 %.

Driving forces behind land cover change and rangeland degradation

The analysis of climatic and anthropogenic factors shows:

Over the studied period, the population density increased from 130.90 inhabitants/km^2 in 1987 to 780.83 inhabitants/km^2 in 2016. Concurrently, grazing intensity significantly increased, with the number of sheep growing considerably (Fig. 9). Concerning the agricultural activity in the region, Figure 09 demonstrates a gradual increase in the total agricultural area from 81.14 km^2 in 1987 to 199.8 km^2 in 2016.

Climate variability has had a significant impact on land cover changes in our region, as Figure 10 shows a significant in the average annual temperature during the study period (1987 – 2016), reaching its highest value at 22.7°C in 2014 and its lowest value at 17.9°C. Precipitation displayed fluctuations, with the highest average annual precipitation recorded at 316.2 mm in 2003 and a minimum of 78 mm in 2002. Recent decades have witnessed a substantial decrease in precipitation, often accompanied by several consecutive years of persistent drought. Consequently, annual precipitation levels fall significantly short of supporting vegetation growth.

Fig. 9: Anthropogenic factors in the south of Hodna (1987-2016)

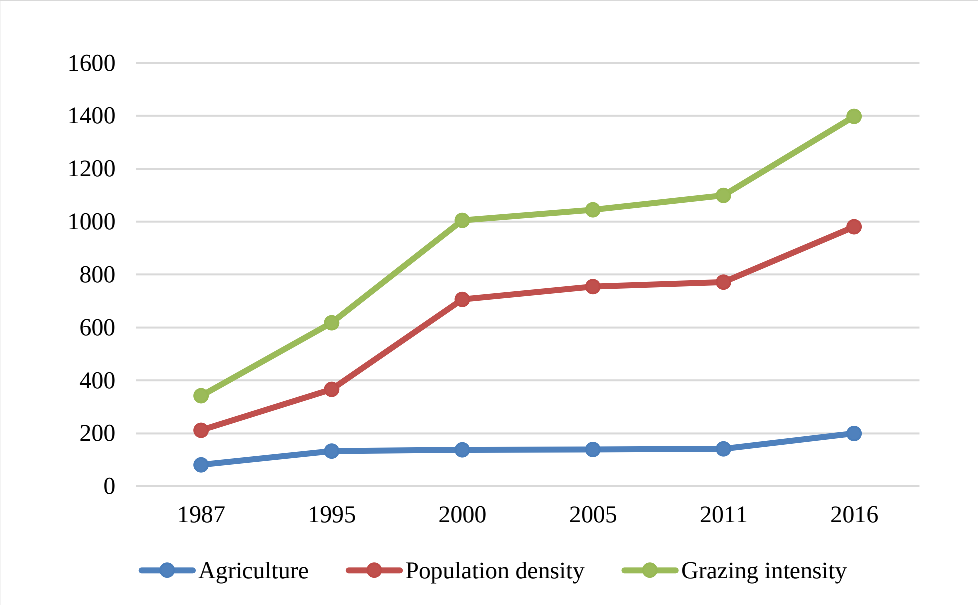
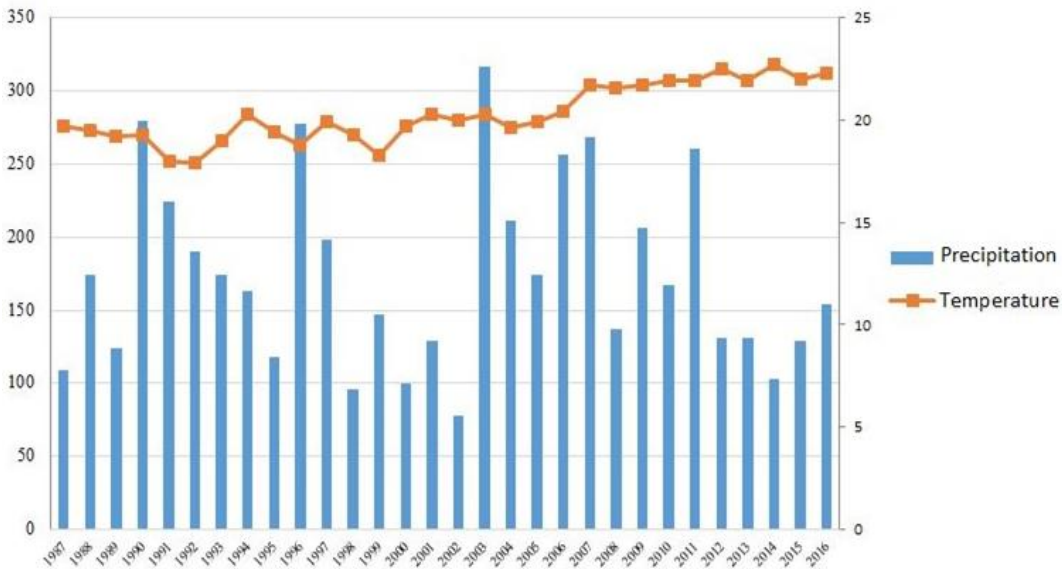


Fig. 10: Climatic factors in the south of Hodna (1987-2016)



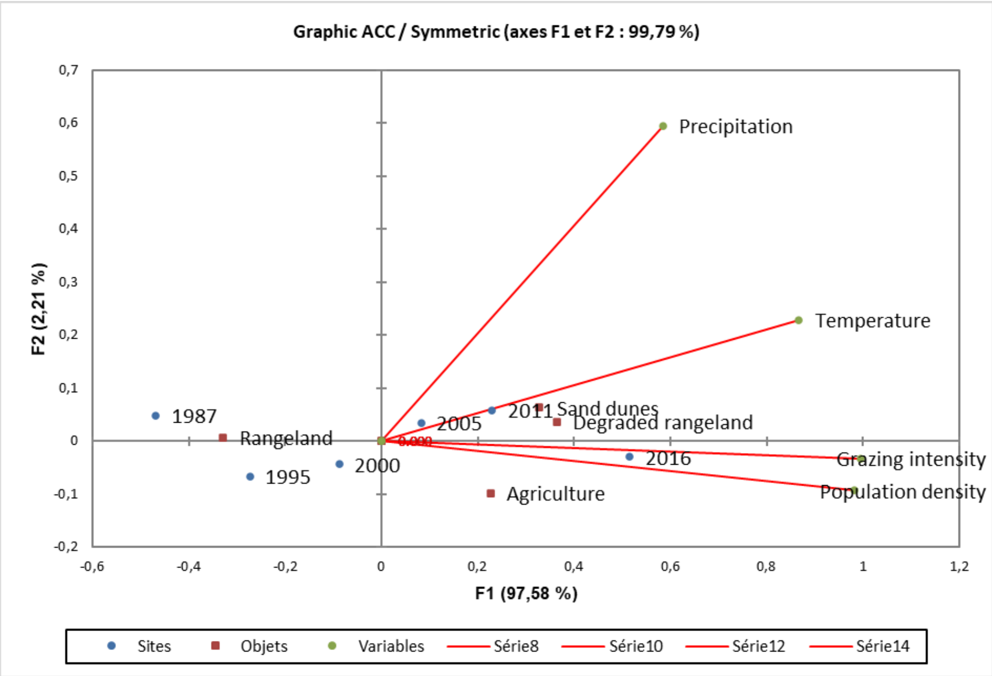
Canonical correspondence analysis of the relationship between land cover changes and their driving forces

The results derived from the CCA method illustrate the spatial evolution of land cover changes along the X-axis (Fig. 11). Over the study period, there has been a decline in the rangeland class, accompanied by an increase in sand dunes, degraded rangeland, and agricultural areas. These changes are notably influenced by anthropogenic factors, which serve as the primary driver (evident along the Y-axis). Conversely, climatic factors, represented by two variables (precipitation and temperature), appear to play a secondary role but still contribute to the dynamics of rangeland degradation (also along the Y-axis).

To appreciate which factors are more affected the rangeland degradation, the results of CCA indicate that:

- The effect of overgrazing seems to be more important in rangeland degradation.
- The population was the second strongest extrinsic factor identified in our study area.
- The agricultural practice ranked third after the overgrazing and population growth.
- The average temperature seems to be an explanatory variable as it has low variability.
- The effect of precipitation is not clearly visible in CCA.

Fig. 11: Canonical analysis of correlations linking land cover, temperature, precipitation, grazing intensity and population density



DISCUSSION

The land cover maps obtained from the supervised classification of the satellite images reveal a significant decline in rangeland. In 1987, it covered approximately 75 % of the total area, but by 2016, this coverage had significantly decreased to 29 %. Simultaneously, there has been a continuous expansion of sand dunes, rangeland degradation, and agricultural land. This was explained by the conversion of a large amount of rangeland to other land classes as demonstrated by a study conducted by Sahnouni & Abdesselam (2018). This complex change in land cover dynamics, particularly the degradation of rangeland, aligns with common trends observed in several studies assessing land cover change in the Algerian steppe (Bouacha *et al*., 2018; Hirche *et al*., 2019; Merdas *et al*., 2019).

The degradation of rangeland in southern Hodna can be attributed to its historical dependence on pastoralism as the primary activity. The Hodna nomads of the region used it as extensive pasture during their seasonal transhumance to the south (Sebhi, 1987). This is despite the fact that the nomadic lifestyle in the Algerian steppes faced major disturbances due to colonial regulations related to pastoral movements (Boukhbaza, 1982) and the implementation of various agricultural policies in southern Hodna before Algeria's independence in 1962 (Sebhi, 1987).

Various factors have been identified by numerous researchers to explain rangeland degradation in different regions of the Algerian steppe (Bedrani, 1999; Nedjraoui et Bedrani, 2008; Slimani *et al*., 2010; Hirche *et al*., 2011; Arabi *et al*., 2015; Martínez-Valderrama *et al*., 2018). These studies highlight the interactive relationship between climate change and anthropogenic activities as the main drivers of rangeland degradation in this region.

Population pressure, especially in arid regions, has been identified as a significant contributor to rangeland degradation in the Algerian steppe (Nedjraoui & Bedrani, 2008). The rapid demographic growth in these arid areas has led to excessive environmnetal exploitation, resulting in the weakening of ecosystems (Morand-Fehr *et al*., 1983). The changing population dynamics in the steppe have led to heightened competition for available space. The traditional nomadic way of life has been replaced by an agro-pastoral system, where sedentary pastoralist families now reside in fixed dwellings within the steppe and occasionally practice transhumance towards the Tell or the Sahara (Bencherif, 2011). In southern Hodna, this population growth from 1987 to 2016 (Fig. 9) has intensified the exploitation of natural resources, disturbing the natural ecological balance in the region.

Overgrazing is considered also the primary and direct cause of rangeland degradation in the Algerian steppe (Aidoud & Touffet, 1996; Slimani et Aidoud, 2004). Furthermore, the survival of the steppe population is heavily reliant on pastoral activities, primarily sheep farming, which has led to an increase in the sheep population. This increase has played a role in changing the composition of plant communities by reducing the abundance of palatable plants and promoting ephemeral plants (Milton & Hoffman, 1994). Additionallly, extensive grazing can result in the reduction of perennial vegetation cover and expose the soil to increased wind and water erosion (Le Houérou, 1986).

In the study area, the rangeland has progressively shrunk and can no longer support the growing number of animals, which has led to overcrowding from 1987 to 2016 (Fig. 9). The persistent overgrazing, driven by this imbalance between the rangeland's natural forage capacity and the livestock's needs, has contributed to the degradation of the rangeland over an extended period. Similar findings have been reported by Merdas *et al*. (2019) and Slimani *et al*. (2010).

Furthermore, Agricultural practices seem to be one of the principal cause of land cover changes in the Algerian steppe, where the conversion of rangelands to agricultural land has accelerated in recent decades (Hirche *et al*., 2011; Abdesselam, 2013). On the other hand the implementation of a National Agricultural Development Plan (PNDA) launched by the government in 2000 plays a significant role in agricultural expansion by stimulating agricultural acitvities and attracting more people to agriculture and rural areas. Consequently, it has contributed to the growth of the agricultural population and the expansion of cultivated land at the expanse of rangeland areas.

Additionally, the climatic conditions affect rangeland degradation (Belala *et al.*, 2018). A large part of Algeria belongs to the Mediterranean basin, which is a „hot spot" of climate change (Sahnoune *et al.*, 2013). The analysis of climate data in norhern Algeria from 1931 to 1990 reveals a rise in temperature of 0,5°C would reach an increase of 1°C by 2020 and 2°C is expected by 2050 (Belala *et al*, 2018). In general, in Algerian steppe, the average annual precipitation is low (between 100 and 400 mm/year) and its distribution is variable in time and spece (MARA, 1974).

Le Houérou (1996) noted that the irregularity of precipitation, increase in temperatures, and the lenght of periods of drought, marking the conditions of the development of plants even more difficult. Nedjraoui & Bedrani (2008), and Fodil (2018) indicate that climatic disturbances are a major cause of the fragility of these already very sensitive environments and cause ecological crises having repercussions on the entire ecosystem.

Lots of case studies pointed out the devastating impact of droughts in rangeland (Aidoud *et al*., 2006; Nedjraoui et Bedrani, 2008; Hammouda *et al*., 2014; Belala *et al*.,.2018; Slimani et Aidoud, 2018).

Indeed, the south of Hodna is a windy region characterized by high temperatures and very significant interannual irregularities in precipitation resulting in very marked periods of drought, which have always played a significant role in rangeland degradation and the evolution of desertification (Sebhi, 1987).

In our study, the application of CCA was invaluable for unraveling complex relationships and idendifying key drivers in the southern Hodna steppe ecosystem. This analysis provided essential insights into how anthropogenic and climatic factors interact over time and space.

The CCA results emphasize that rangeland degradation in southern Hodna is primarily driven by intensified grazing, population growth, and agricultural activities. Additionally, unfavorable conditions, chracterized by higher temperatures and limited, erratic precipitation, further exacerbate the adverse impact on vegetation growth. This comprehensive understanding of the interplay between these factors is crucial for effective ecosystem management and sustainable development in the region.

CONCLUSION

This study used geospatial techniques and Canonical Correspondence Analysis (CCA) to evaluate rangeland degradation and it's determining driving forces in southern Hodna from 1987 to 2016. The examination of land cover dynamics unveiled swift changes, characterized by the growth of agricultural land, degraded rangeland, and sandy areas, leading to degradation in over half of the study area.

This degradation is primarily driven by population growth, which has escalated land resource demands, resulting in increased agricultural expansion and overgrazing, consequently leading to accelerated rangeland degradation. The CCA findings highlight that rangeland degradation in this region is more closely linked to anthopogenic activities than to the deterioration of unfavorable climatic conditions.

This study provides valuable insights into the dynamics of rangeland degradation in southern Hodna, offering essential information for policymakers and land managers to formulate sustainable development strategies for the region.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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