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Article

Monitoring the spatiotemporal evolution of the Green Dam in Djelfa Province, Algeria

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Abstract: Green walls and green dams are increasingly being considered as part of many national and international desertification initiatives. This paper studies the spatiotemporal evolution of the green dam in the Moudjbara region (Djelfa Province, Algeria) from 1972 to 2019 by using Landsat imagery, Land Change Modeler and Open Land package. The future evolution of pine plantations for the year 2029 was also forecasted, based on an anthropogenic scenario (i.e., anthropogenic pressure is the main driver of the green dam destruction). Our findings revealed that the green dam project was successful for a few years, but after that, pine plantations deteriorated significantly due to forest harvesting, livestock overgrazing, and the proliferation of the pine caterpillar processionary, which destroyed most of the reforestation. Land Change Modeler predicted a huge degradation of pine plantations for the year 2029, and if the deforestation continues at the same rate, the green dam will disappear in the Moudjbara region during the next few decades. Aware of this threat, the Algerian authorities are now planning to reforest more than 1.2 million ha under the latest rural renewal policy by introducing new principles related to sustainable development, fighting desertification, and climate change adaptation

Keywords: Green Dam; Green Walls; Desertification; Aleppo pine; Land degradation.

1. Introduction

Land degradation and desertification (LDD) are the main reasons for the rapid changes affecting the majority of the earth's drylands, resulting in an overall loss of habitats and changes in vegetation cover, plant composition, hydrologic conditions and soil properties [1]. Land-use changes, such as crops and urban expansion and global climate change (mainly recurrent droughts) are considered the main drivers of LDD in dryland ecosystems [1–3]. Understanding the dynamics and processes of Land-Use and Land-Cover (LULC) changes has thus become a central objective in research dealing with the dynamic relationships between humans and the environment at all scales, from local to global [4].

The Algerian regions bordering the Sahara desert have undergone rapid LDD during the last few decades [5]. In addition to sandstorms (eolian desertification), the LDD phenomenon is triggered by the expansion of cultivated land in marginal areas, urban expansion and livestock overgrazing [6–8]. Numerous researchers have used remote sensing imagery to study LDD in these sensitive ecosystems [8–12]. For instance, [8,9] have studied desertification in the high plateau of Algeria during the last few decades, together

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with their environmental and social impacts, and have found that most of the studied regions have undergone dramatic land degradation.

Fully aware of the severity of the desertification issue, since independence the Algerian authorities have put into operation several programs to combat LDD [13]. The green dam project was, without any doubt, the most important action implemented within the framework of these programs. The project extends across arid and semi-arid zones between the 300 mm and 200 mm isohyets. It is a 3 Mha band of plantations running from east to west. It is over 1200 km long (from the Algerian–Moroccan border to the Algerian–Tunisian border) and has an average width of about 20 km. Initially, it was intended to stop the advance of the desert towards the north of the country, particularly aiming at conserving natural resources, improving the living conditions of residents and avoiding their exodus to urban areas [7,14–16]. The green dam inspired many African countries to build a "Great Green Wall" to combat land degradation and biodiversity loss, and to reduce climate change impacts and poverty[11,15].

Currently, green walls and green dams are increasingly being considered as part of many national and international desertification initiatives[17,18]. However, while the afforestation programmes carried out in China reduced the amount of degraded land by 12,120 km^2 between 2009 and 2014, and also reduced wind erosion (the average annual occurrence of sandstorms decreased by 20.3% in 2014) [19,17], reforestation programs curried out in the arid Sahel and North Africa were poorly researched and cost a lot of money without producing any real results [20,17]

Many authors have studied the evolution and the current situation of the Algerian green dam [5,21–24] and all of them have emphasized the failure of the green dam to achieve the planned goals, mainly because of the lack of planning, livestock overgrazing and non-involvement of the local population in the project. As a complement to existing knowledge, the main objective of this research is to study the evolution of the green dam project from its establishment in 1972 to the present, as well as a future projection of the green dam status in 2029, by using Landsat imagery and geographic information systems. We also aim to identify the main driving forces of green dam destruction in recent decades. We hypothesize that the total area occupied by pine plantations has been decreasing since their establishment due to human pressure - mainly overgrazing and land use changes (i.e., extensive cereal cultivation in pasture land). We also expect that if LDD continue at the same rates the green dam will disappear during the next few decades.

2. Materials and Methods

2.1 Study area

The **study** area "Moudjbara" is located in the southeastern part of Djelfa province, which in turn is situated in the Saharan Atlas, nearly 300 km south of the capital Algiers (Figure 1). The area is characterized by a slightly rugged flat terrain with relatively homogeneous relief at an altitude ranging between 1200 and 1400m. The soils of the area are dominated by little evolved and shallow rendzine. The climate is semi-arid with cold and harsh winters (the average minimum temperature of the coldest month is 0.1 °C) and hot and dry summers (the average maximum temperature of the warmest month is 33.8 °C), There is, therefore, a sharp thermal contrast between seasons, as winters are cold and summers are warm. Mean rainfall is 300 mm [20] and, since 1972, there has been noted a drying climate trend [19]. It is worth noting that this zone is considered a gateway to the Great Sahara which makes it a region of major importance in fighting against desertification and protecting soil against wind erosion**.** Moudjbara was the first perimeter to be afforested using Aleppo pine (Pinus halepensis) in 1972 within the framework of the green dam project. The plantations were established near the existing natural Aleppo pine forests. In addition to natural and planted Aleppo pine forests the area also includes urban zones (the town of Djelfa and its suburban areas), croplands used mainly for cereal production and degraded steppe pasture land dominated by Stipa tenacissima, Artemisia herba-alba and Lygeum spartum used for livestock grazing.

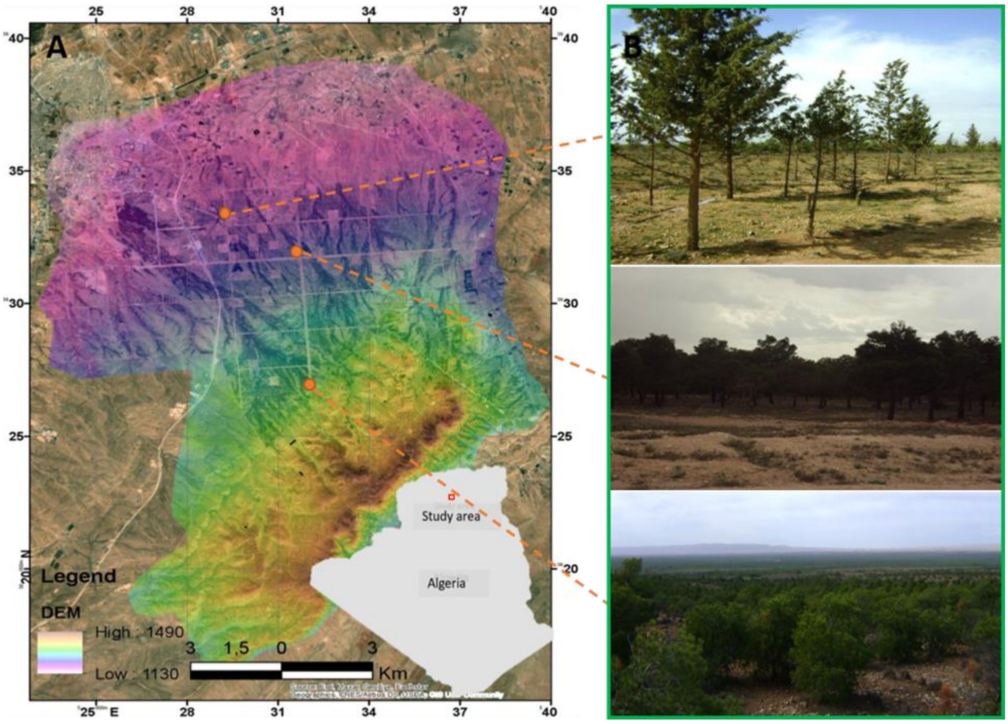

Figure 1 the geographic setting of the study area (A), and three photographs showing the current state of the green dam in different sites over the study area (B).

2.2 Data collection

For monitoring green dam evolution and changes in our study area during the following time intervals: 1972-1989, 1989-1999, 1999-2009, and 2009-2019, we used Landsat images with 30-meter resolution. Five temporal datasets (see Table 1) were acquired from the US Geological Survey (USGS; **http://www.earthexplorer.usgs.gov/**). The Landsat MSS data set has four spectral bands (4–7) with a spatial resolution of 60 m. Landsat TM data set has seven spectral bands with a spatial resolution of 30 meters, and the Landsat 8 OLI data set has nine spectral bands (2–7) with a spatial resolution of 30 m. We used good quality and cloud-free scenes for the realization of LULC maps. Except for the 1972-images, which were taken in September because of the unavailability of cloud-free images in the same season, all Landsat images (1989-, 1999-, 2009-, and 2019-images) were taken in July, which allows the comparison of the resulting LULC maps.

Table 1 Spatial resolution, spectral characteristics and date of acquisition of the Landsat images used in this study

Satellite	Sensor	Resolution	Path/Row	Spectral bands	Wavelength (nm)	Acquisition date
Landsat	MSS	60 m	195/36	Green	500-600	13th September 1972
				Red	600-700	
				Infrared 1	700-800	
				Infrared 2	800-1100	
Landsat	TM	30m	195/36	Blue	450-520	5th July 1989
				Green	520-600	

				Red	630-690	
				Near-Infrared 1	760-900	
				Near-infrared 2	1550-1750	
				Midinfrared	2080-2350	
Landsat	ETM+	30m	195/36	Blue	450-520	9th July 1999
				Green	520-600	
				Red	630-690	
				Near infrared 1	760-900	
				Near infrared 2	1550-1750	
				Midinfrared	2080-2350	
Landsat	TM	30m	195/36	Blue	450-520	28th July 2009
				Green	520-600	
				Red	630-690	
				Near infrared 1	760-900	
				Nearinfrared2	1550-1750	
				Midinfrared	2080-2350	
Landsat	OLI-TIRS	30m	195/36	Coastal aerosol	430-450	24th July 2019
				Blue	450-510	
				Green	530-590	
				Red	640-670	
				Near-infrared	850-880	
				Short wave infrared 1	1570-1650	
					2210-2290	
				Short wave infrared 2	1360-1380	
				Cirrus		

2.3 Image preprocessing and classification

The acquired images were initially subject to radiometric calibration to convert digital numbers to the top of atmosphere radiance (i.e., converting pixels values to spectral radiance and reflectance). By using the FLAASH tool in the ENVI 5.3 we then performed atmospheric correction which consists of the conversion of the top of atmospheric values that were generated from radiometric calibration to the bottom of atmosphere reflectance (surface reflectance) and to remove the atmospheric effects to obtain reflectance of ground images. Finally, all images were clipped out according to the vector of the study area and projected in the GIS environment using the Universal Transverse Mercator (UTM_Zone_31N) as a reference system.

There are various techniques for classifying satellite imagery to generate LULC maps. Among the existing techniques, supervised classification is an image-processing method regularly used to detect changes in land surface features in different multi-spectral global datasets[25,26]. In this study, we applied the supervised classification method using a Maximum Likelihood Classifier (MLC) in ArcGIS 10.8.1 [27] to classify the acquired Landsat images. The MLC technique depends on the likelihood that each pixel fits in a particular class based on a normal distribution of each band's data in the classification [28–30]. The first step in the classification process is to create training samples. In this study, training samples were created from high-resolution Google Earth aerial photographs by digitalizing at least 20 polygons for each one of the five LULC classes considered in this study, which included degraded steppes (degraded steppe pasture land dominated by Stipa tenacissima, Artemisia herba-alba and Lygeum spartum used for livestock grazing), urban areas (the town of Djelfa and its suburban areas), crops (croplands used mainly for cereal production), dense plantations and natural forests (natural forests and dense plantations of Aleppo pine), and open plantations (Aleppo pine plantations planted within the framework of the green dam project). It is worth stating that the separation of natural forests and dense plantations of Aleppo pine was impossible, so these two classes were grouped into one LULC class. The low number of LULC classes included in this study made the classification procedure easy for the green dam monitoring study.

2.4 Accuracy assessment

Accuracy assessment is very useful for individual classification when the resulting data are used for change detection analysis [27]. To assess the classification accuracy of the resulting maps, over 150 random points (validation samples) were created on the study area on each classified map for the five LULC classes using ArcGIS 10.8.1 [23]. The validation data were derived through the interpretation of high-resolution Google Earth aerial photographs close to the date of the acquisition of the images. Kappa coefficient and overall accuracy were computed for the resulting LULC maps based on confusion matrices.

2.5 LULC changes analysis and prediction of the future scenario for the year 2029

Chronological series of LULC maps are required to understand the range, types, and spatial configuration of changes that have occurred to a specific site, and to understand what drives those changes as well as to predict future changes. To identify spatially explicit LULC change in the Moudjbara region, we used the Land Change Modeler (LCM) tool and the OpenLand package in Idrisi TerrSet 18.7 and R 4.0.3, respectively. The LCM is the most widely used spatial model for LULC change analysis and for predicting future scenarios[31], and OpenLand implements a complete intensity analysis, according to Aldwaik and Pontius (2012), including tools for the generation of standardized multilevel output graphics[32]. Change analysis was performed for the following time intervals: 1972–1989, 1989–1999, 1999–2009, and 2009–2019, with the aim of (1) quantifying LULC changes in each time interval, (2) assessing whether the size and annual rate of change differ over time periods by comparing the observed rates to the uniform rate (i.e., the rate that would occur if the annual changes were spread evenly over the entire time extent), and (3) scrutinizing the spatiotemporal evolution of the green dam project in the study area (i.e., quantifying gains, losses, and net changes in pine plantations in each time interval).

The future evolution of pine plantations in the Moudjbara region for the year 2029 was also forecast using LCM, based on the following steps: (1) we grouped all the transitions from pine plantations (i.e., dense cover or low cover pine plantations) to other LULC classes (i.e., degraded steppes, urban areas, and croplands) in one sub-model, assuming that the underlying drivers of these changes are the same (i.e., the anthropogenic pressure); (2) based on their potential in explaining the changes, i.e. pine plantation destruction, the following explanatory variables were used: Digital Elevation Model (DEM), distance from croplands, distance from steppes, distance from roads, and distance from urban areas (we used Cramer's V coefficient to test the significance of each variable); (3) after selecting the suitable set of explanatory variables, transitions were modeled in LCM using an Artificial Neural Network (ANN) approach based on Multi-Layer Perceptron (MLP); (4) change prediction was executed based on the Markov chain and the calibration periods from 1999 and 2009 were used to perform the modeling for 2019; (5) After evaluating the accuracy and skill measure of the modeling, the developed model and the maps for 2009 and 2019 were used to estimate the changes in pine plantations for the year 2029.

Results

3.1 Accuracy assessment and LULC changes

The accuracy assessment of the LULC maps of the five temporal periods is shown in Table 2. Overall accuracy ranged from 75.5% to 94% and Kappa from 64% to 89.9%. The 2019 LULC map had the highest overall accuracy (94%) and Kappa (89.9%), whereas the 1989 LULC map had the lowest overall accuracy (75.5%) and Kappa (64.1%).

Table 2 Assessment of classification accuracy. Overall Accuracies (OA) and Kappa statistics (K) of the five LULC maps

Classes	1972		1989		1999		2009		2019	
	PA (%)	UC (%)	PA (%)	UC (%)	PA (%)	UC (%)	PA (%)	UC (%)	PA (%)	UC (%)
Dense plantations & Natural forest	80	88.8	10	100	80	100	80	100	100	100
Open plantations			78.3	74.6	91.6	89.7	80.4	94.2	100	100
Degraded steppes	90	96.7	70	43.7	91.1	92	90.6	89.8		100
Urban			76.8	100	80	66.6	80	33.3	100	98.9
Crops	70	41	60	26	80	80	100	83.3	100	100
Overall accuracy (OA)	0.88		0.75		0.89		0.87		0.94	
Overall Kappa (K)	0.64		0.64		0.82		0.80		0.89	

PA: Producer's Accuracy; UC: User's Accuracy

The LULC change analysis results clarify the historical change and give us a clear statement about the land use practice in different years and the dynamic change in each cover class. The spatial distribution of the five LULC classes (Degraded steppes, Crops, Urban, Dense plantation & Natural forest, and Open plantation) during the five-time periods 1972, 1989, 1999, 2009, and 2019 are presented in Figure 2 and the statistics (including the changes from one period to another) are shown in Table 3. The results show that both negative and positive changes occurred in the LULC pattern of the Moudjbara region over the last 47 years. In 1972 most of the study area was occupied by degraded steppes and by 1989 a great part of the degraded steppes had converted to open plantations as the result of the afforestation within the framework of the green dam project (Table 3, Figure 3). Open plantations had a massive increase from non-existing in 1972 to 10345 ha in 1989, befor decreasing between 1989 and 1999 and increasing between 1999 and 2009 by -19.9% and 33.6%, respectively (Table 3, Figure 3). Between 2009 and 2019, open plantations showed a massive drop (-43%) from 11074 ha to 6303 ha (Table 3, Figure 3). The area occupied by dense plantations and natural forests increased linearly between 1972 and 1999 from 585 ha to 1615.65 ha, and then decreased linearly to 626.6 ha in 2019 (Table 3, Figure 3). The surface of the urban area grew from 0 ha in 1972 to 117.20 ha in 1989 and 151.7 ha in 1999, accounting for 117% in 1989 and 29.5% in 1999 (Table 3, Figure 3). The urban area kept growing, to reach 776.5 ha (an increase of 412%) ha in 2009 and 910.4 ha (an increase of 17%) in 2019 (Table 3, Figure 3). The area of cropland declined from 157 ha (-15.3%) in 1972 to 133 ha in 1989, then grew linearly to reach 174 ha (31%) in 1999 and 236.3 ha (35.7%) in 2009, before decreasing slightly to 235.5 ha (-0.34%) in 2019 (Table 3, Figure 3). The area of degraded steppes showed a non-linear evolution during the time intervals studied.

During the first time interval (1972-1989) this LULC class shrunk by -44.08 % from 24626.62 ha to 13770.76 ha, then expanded by 9.94% during the second time interval (1989-1999) to reach 15139.31 ha (Table 3, Figure 3). The area of degraded steppes declined by -16.50% between 1999 and 2009 and then increased (+36.81) to reach 17293.83 ha in 2019 (Table 3, Figure 3).

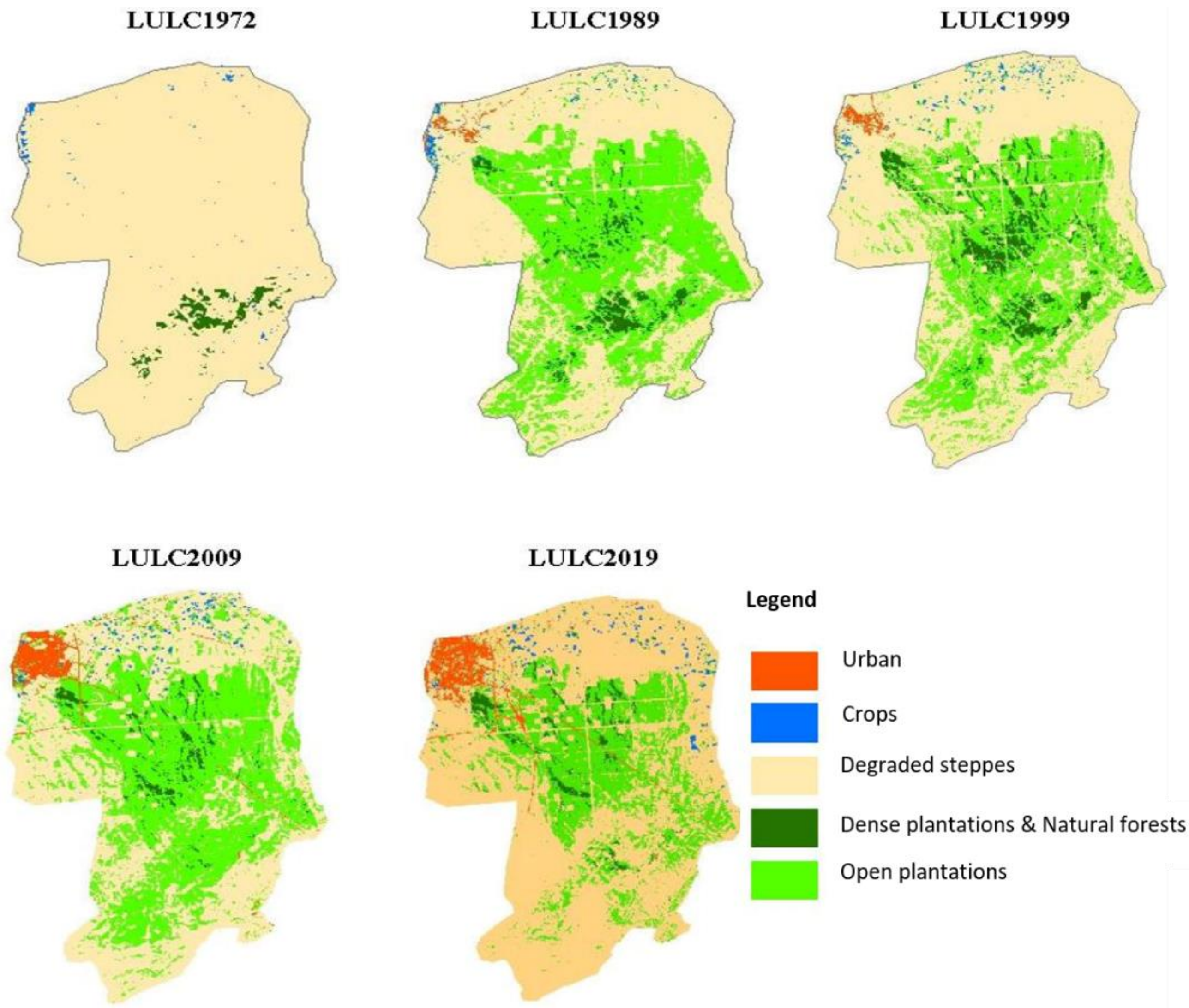

Figure 2 *LULC classified maps of the Moudjbara region for the five studied years (1972, 1989, 1999, 2009, and*

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LULC class	1972	1989		1999		2009		2019	
	Area (ha)	Area (ha)	C (%)	Area (ha)	C (%)	Area (ha)	C (%)	Area (ha)	C (%)
Crops	157.01	132.91	-15.35	174.17	+31.05	236.36	+35.71	235.55	-0.34
Degraded steppes	24626.62	13770.76	-44.08	15139.31	+9.94	12640.89	-16.5	17293.83	+36.81
Dense plantations & Natural forests	585.48	1003.26	+71.36	1615.65	+61.04	641.35	-60.3	626.62	-2.3
Open plantations	0	10344.99	+10344.99	8288.23	-19.88	11073.97	+33.61	6302.66	-43.09
Urban	0	117.2	+117.20	151.75	+29.48	776.54	+411.73	910.46	+17.25

Table3 *LULC changes analysis in the Moudjbara region from 1972 to 2029*

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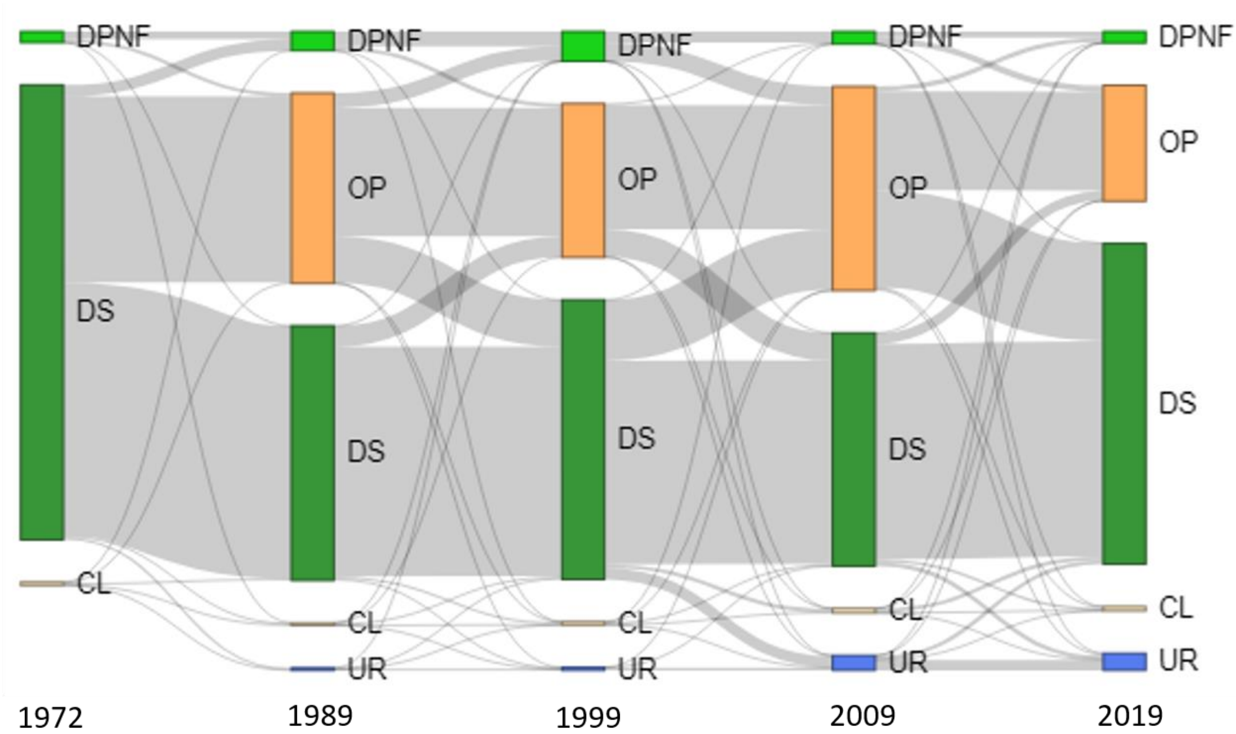

***Figure** 3* Sankey diagram illustrating LULC changes between 1972 and 2019 in the Moudjbara region; all links and nodes are displayed proportionately to absolute hectares. DPNF, Dense plantation & Natural forest; OP, Open plantation; DS, Degraded steppes; CL, Crops; and UR, Urban.

Figure 4 shows that the rate of LULC change is not perfectly stationary during the studied time intervals because the bars on the right do not all equal the uniform line. The left side of Figure 4 shows that the size of the change during the second time interval (1989-1999) is the smallest. However, the size of the change during the first-time interval (1972-1989) is the greatest and its duration is the longest (17 years). The right side of Figure 4 shows that the annual rate of LULC change was slower in the second time interval (1989-1999) compared to the other time intervals, and the rate of LULC change became fast in 1999.

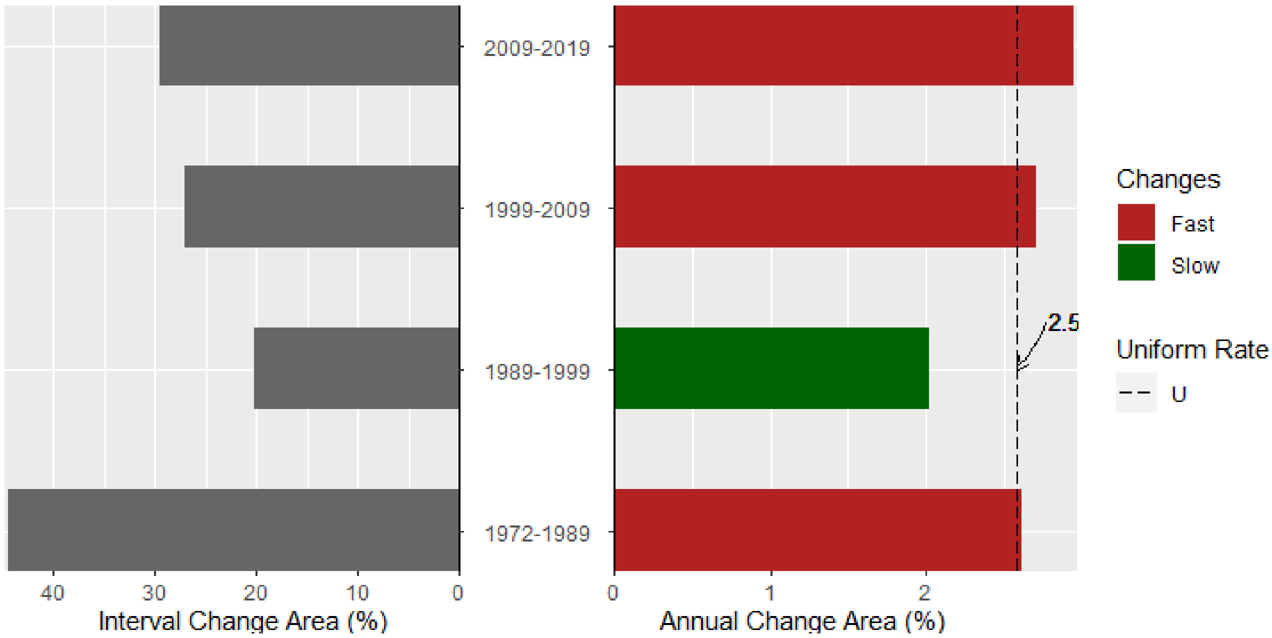

Figure 4. Time-intensity analysis for the four studied time-intervals (1972–1989, 1989–1999, 1999–2009, and 2009–2019) showing how the size and speed of change vary across time intervals. Bars that extend to the left of zero show the area of overall change in each interval, while bars that extend to the right of zero show the intensity of the annual area of change within each time interval. Uniform Rate (U) refers to the rate that would occur if the annual changes were spread evenly over the entire time extent.

3.2 Green Dam evolution during the last 47 years and its future projection by the year 2029

Firstly, we should note that the green dam in the Moudjbara region includes all open plantations and a great portion of dense plantations and natural forests. Results clearly show both losses and gains in these two LULC classes during the studied periods (Figure 5). During the first period, 1972-1989, open plantations gained approximately 10000 ha which had been occupied by degraded steppes; during the same period the transition of dense plantations and natural forests gained 600 ha on the degraded steppes and lost about 200 ha which became open plantations (Figure 6). During the second period, between 1989 and 1999, open plantations lost about 2000 ha which was replaced by degraded steppes and reinforced by dense plantation which had almost 600 ha of net gain during that period (Figure 6). Throughout the third period, 1999-2009, open plantations had almost 2700 ha of net gain; this change was at the expense of degraded steppes and dense plantations which lost practically 900 ha (Figure 6). From 2009 to 2019 open plantations have lost more than 4000 ha, which became degraded steppes (Figure 6). Land change modeler predicted a huge loss of more than 2000 ha in the area of open plantations by 2029 which will be converted to degraded steppes (Figure 6). Figure 7 reveals a nonlinear evolution of the area occupied by open plantations between 1972 and 2019 and the Land Change Modeler predicted a huge degradation of open plantations by the year 2029; if the deforestation continues at the same rate, open plantations will disappear in the Moudjbara region during the next few decades. Whereas the area occupied by dense plantations and natural forests remain almost stable during the studied time intervals.

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Figure 5 Gains and losses in open plantations and dense plantations & natural forests in the Moudjbara region during the studied time intervals, (a) 1972-1989, (b) 1989-1999, (c) 1999-2009, (d) 2009-2019, and (e) 2019-2029. Gains in map (a) represent the transition from degraded steppes to both open plantations and dense plantations & natural forests; those in map (b) correspond to the switching from dense plantations & natural forests to open plantations; those in map (c) embody the transitions from both degraded steppes and dense plantations & natural to open plantations. Losses in map (b) refer to the areas converted from open plantations to degraded steppes; those in map (c) represent the degradation of the dense plantation & natural forest to open plantation, and those in map (c) represent the degradation of open plantation to degraded steppes.

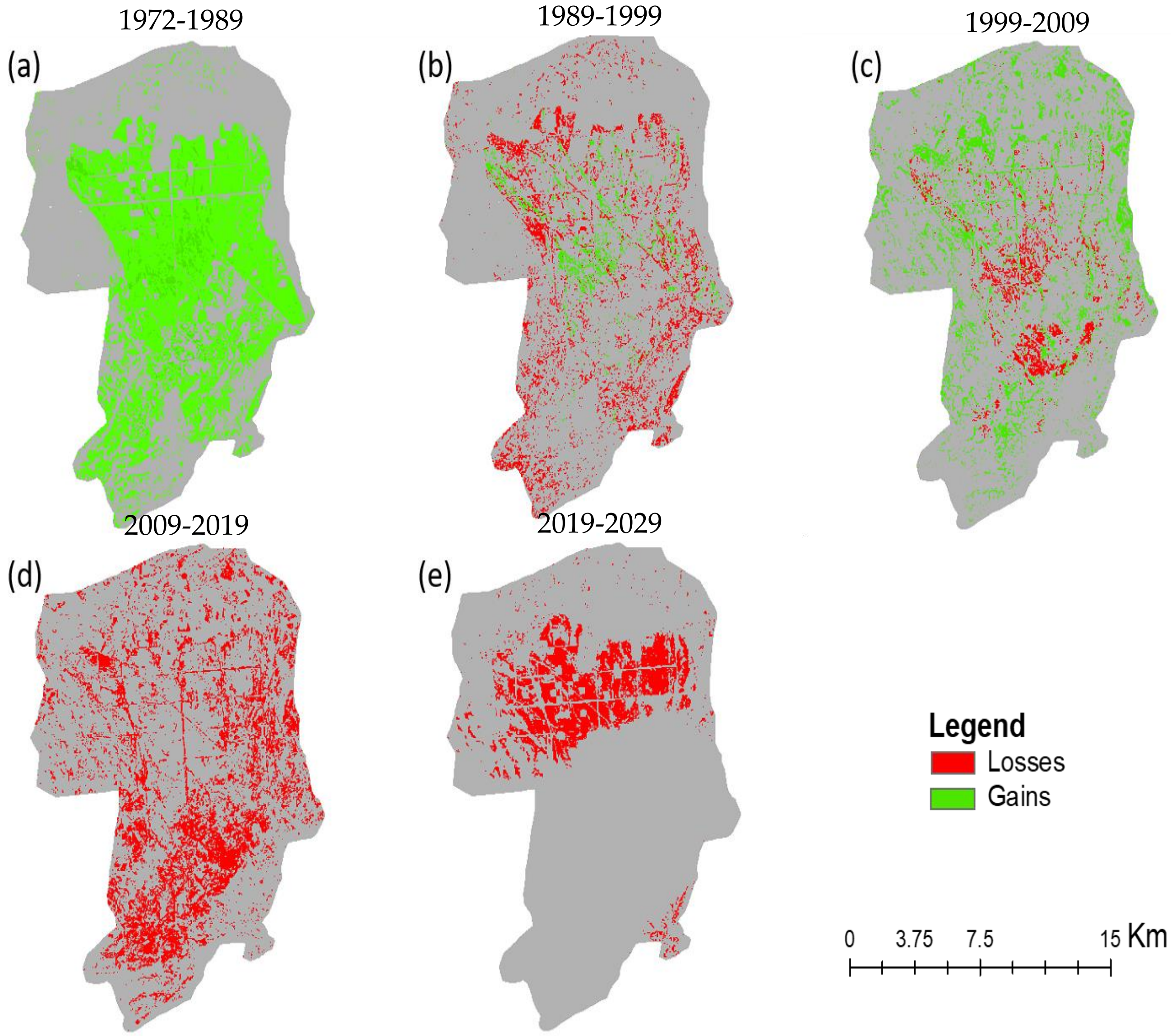
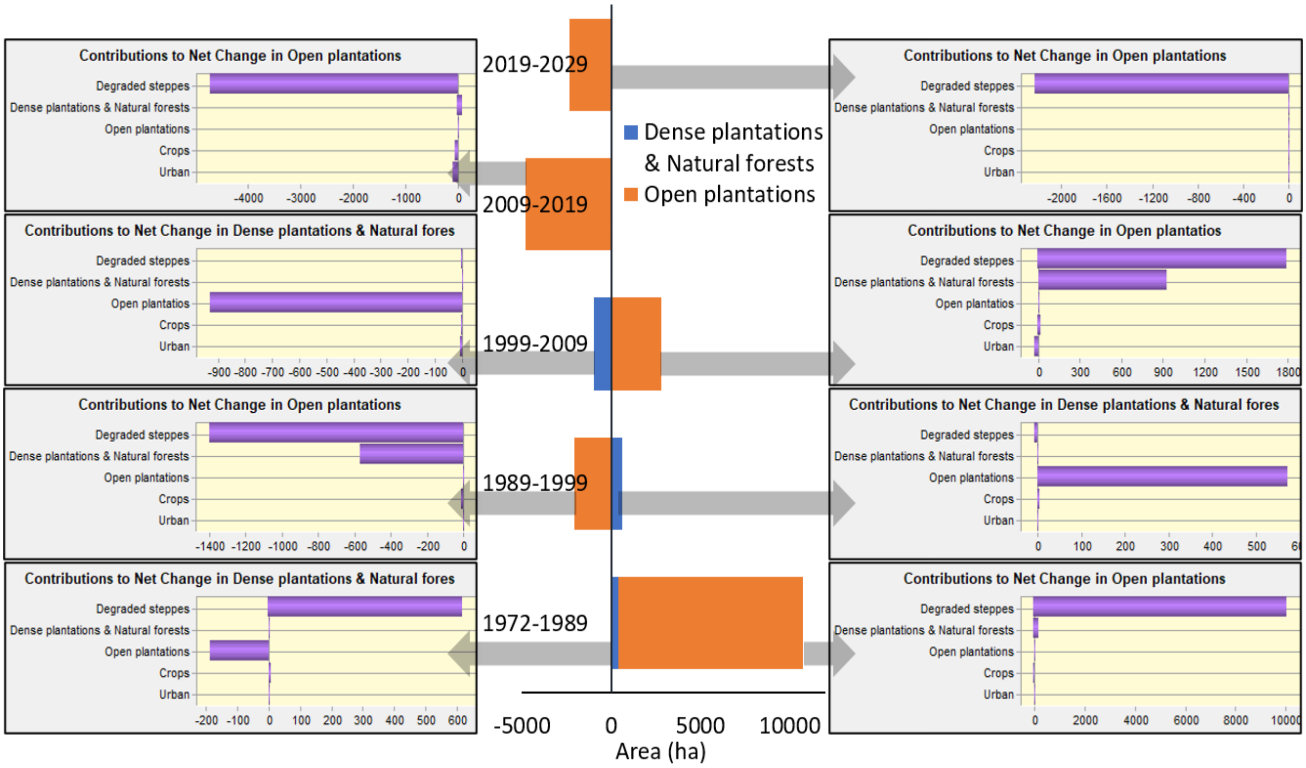


Figure 6 Contribution to net change (gain and loss) in open plantations and dense plantations & natural forests during the five studied time intervals in the Moudjbara region



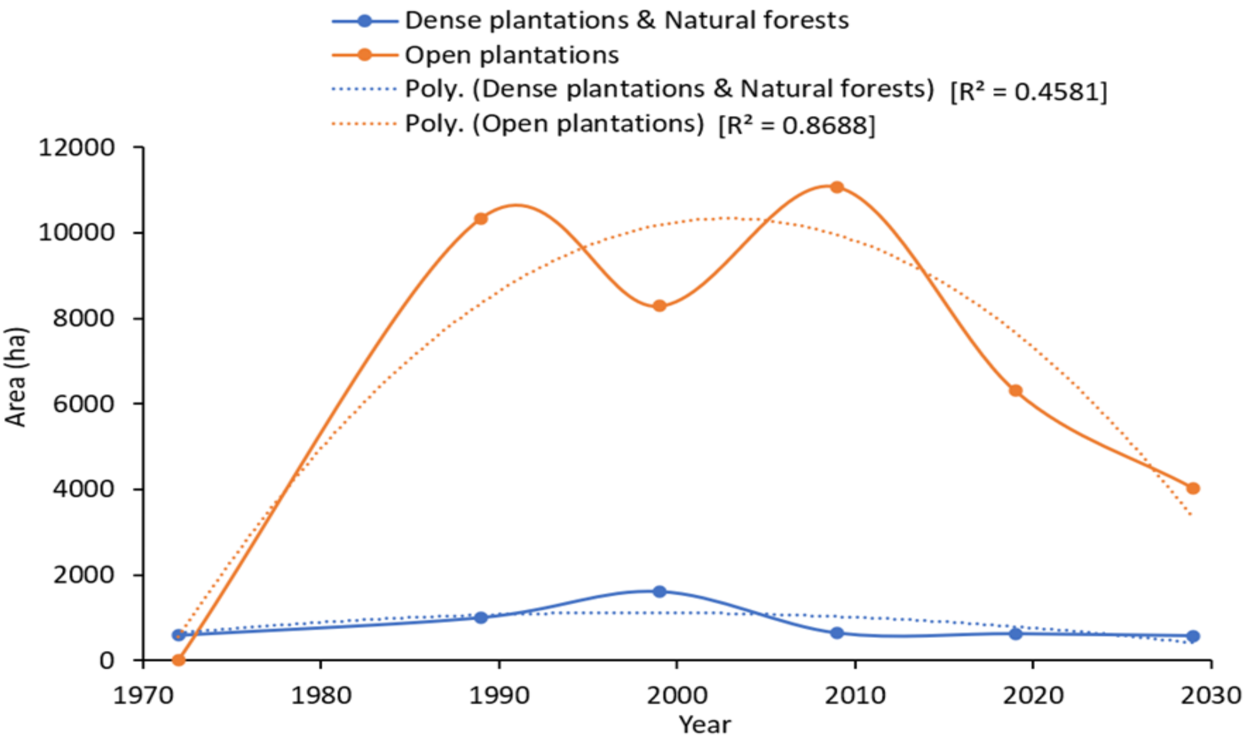


Figure 7 Temporal evolution of the areas occupied by open plantations and dense plantations & natural forests in the Moudjbara region. The two distributions were best fitted by a quadratic polynomial function.

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4. Discussion

The spatiotemporal dynamics of LULC in the Moudjbara region experienced both negative and positive changes during the five time intervals studied. The rate of LULC change was not stationary during the studied time intervals. The intensity of LULC change was slow in the first and second time intervals, and became relatively fast from 1999. Likewise, our results revealed a nonlinear evolution of the area occupied by pine plantations between 1972 and 2019 and predicted a huge degradation of the green dam by the year 2029.

Our findings showed that during the first period of study (1972-1989), the area of the Moudjbara gained a huge extent of pine plantations (the natural forest was the central point for plantations) which replaced the steppe pasture lands. This transformation of the steppe pasture lands where the natural vegetation of Artemisia herba-alba, Lygeum spartum, Stipa tenacissima and many other plants have adapted to the harsh climatic conditions and which constitutes in itself a natural barrier against land degradation and desertification was the big error committed by the Algerian authorities. Another issue was the lack of integration of local populations; the project did not allow the local populations to adopt it as a complementary initiative to their socio-economic way of life, which is based mainly on livestock farming [28,12]. Many pastoralists opposed the establishment of these plantations, which led to the emergence of permanent conflicts that lasted for a long time [7].

Although many efforts were made during the second period (1989-1999) to improve the quality of reforestation and the application of other operations such as dune fixation and track openings [29], the total area of the pine plantations decreased sharply. This degradation was mainly due to the expansion of croplands (pine plantations were harvested at some locations to increase the amount of arable land, especially for the cultivation of cereals), livestock overgrazing and phytophagous attacks [33]. It should be noted that the use of monospecific stands of Aleppo pine has resulted in a proliferation of the pine caterpillar processionary, which has destroyed most of the reforestations [17,34,35]. Furthermore, in many sites, the trees were planted on encrusted soils that impeded the penetrability of their roots, and as a consequence led to the development of dwarf trees.

The third period, between 1999 and 2009, was characterized by a notable increase in the area occupied by open plantations, but also by a decrease in dense plantations due to tree cutting for timber and fuelwood provision or due to their direct use as a sylvo-pastoral system. The expansion of plantations during that period was mainly due to the reforestation program curried out by the General Directorate of Forests (DGF) in 2000 within the framework of the National Reforestation Plan (PNR). PNR was characterized by a diversification of actions, ranging from reforestation to improving steppe pasture lands by regulating livestock farming.

Our findings revealed a massive loss in pine plantations between 2009 and 2019 and most of the lost areas were converted to degraded steppes. To satisfy the need for the increasing number of livestock, pine plantations were completely harvested in some locations to increase the area of pasture. In other locations and as cited above, pine plantations were used as a sylvo-pastoral system with a high livestock grazing pressure. Long term overgrazing coupled with prolonged cyclical droughts[36] has hampered the natural regeneration of these plantations. It is also worth noting that this period in particular was characterized by a widespread occurrence of fires and a huge proliferation of the pine caterpillar processionary, which led to the disappearance of large areas of the green dam.

Based on the anthropogenic scenario, i.e. where anthropogenic pressure is the main driver of the green dam destruction, our model predicted a loss of a huge amount of pine plantations in the Moudjbara region during the next decade. This finding is in line with the study by [28], who found only traces of the green dam, formed by a few bands of puny Aleppo pines scattered over a decertified area.

Aware of the threat of the destruction of the green dam, the General Directorate of Forests (DGF) is currently planning to reforest more than 1.2 million ha in the region under the latest rural renewal policy by introducing new principles related to sustainable development, fighting desertification, and climate change adaptation. Today, DGF has learnt lessons from former programs, and plantations with monospecific stands are barred.

5. Conclusions

This paper has presented a study of LULC changes and their effect on the Moudjbara plantations during the last 47 years (from 1972 to 2019), using freely available data (Landsat Imagery) and geographic information systems. The findings revealed that the green dam project was effective for a few years and after this period, pine plantations underwent a considerable deterioration due to forest clearing, livestock overgrazing, and the proliferation of the pine caterpillar processionary which has destroyed much of the reforestation. Our analysis also predicted that if the degradation continues at the same rate the green dam project will disappear during the next few decades in the analyzed region.

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