



Prospective modeling of agricultural evolution in desert regions using the Land Change Modeler (LCM) - a case study in Menia, Algeria. Modelización prospectiva de la evolución agrícola en regiones desérticas, utilizando el Land Change Modeler (LCM) - un estudio de caso en Menia, Argelia.

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Abstract

The Land Change Modeler (LCM) is crucial for understanding and shaping the future of agriculture in Algeria's Saharan regions. The study used satellite data from 2000, 2010, and 2020 and predicted agricultural growth up to 2030 using the Land Change Modler (LCM) based on the Logistic Regression Model (LRM). Results showed rapid agricultural growth in Menia, with an annual rate of 3.05% between 2000 and 2020. This growth is projected to moderate to 1.85% between 2020 and 2030, indicating a shift in the growth trajectory. This growth contributes to sustainability and food security in the region.

Keywords: Food security. Land use and cover change (LUCC). Remote sensing. Saharan regions. North Africa.

Resumen

Este estudio utilizó tres conjuntos de datos de satélite (2000, 2010 y 2020) clasificados empleando la (CLM). Mediante la integración de cuatro factores influyentes en la agricultura, se predijo el crecimiento agrícola hasta 2030 utilizando el Land Change Modeler (LCM) basado en el Modelo de Regresión Logística (LRM). Los resultados muestran un rápido crecimiento agrícola en Ménia, con una tasa anual del 3,05% entre 2000 y 2020, que se prevé ser del 1,85% entre 2020 y 2030. Este crecimiento indica la rehabilitación de 11,88 km² de tierras baldías, contribuyendo a la sostenibilidad y la seguridad alimentaria en esta región crítica.

Palabras-clave: Seguridad alimentaria. Cambios en el uso de la tierra y en la cobertura del suelo. Teledetección. Regiones saharianas. Norte de África.



Introduction

Desert regions are fragile and often marginalized ecosystems, subject to extreme environmental conditions such as scarce precipitation and high temperatures (EL-BELTAGY and MADKOUR, 2012; WALE and DEJENIE, 2013). Despite these challenges, they play a crucial role in global food security and biodiversity preservation (NOY-MEIR, 1973; GAUR et al., 2018).

In Algeria, the Saharan ecosystem has long been sustained through a delicate harmony between human activities and the extreme environment surrounding them (KOOHAFKAN and ALTIERI, 2011; HAFIDA, 2017). This harmony stems from ancestral human practices, such as traditional qanat irrigation systems and terraced farming techniques, that ensure the sustainability and regeneration of natural resources, primarily through careful water management. However, these territories have undergone profound transformations in recent decades (MULDER and COPPOLILLO, 2005; CHOUAIB and BASER, 2022), with the adoption of new practices often foreign to the traditional way of life of Saharan populations (DARKO et al., 2020; LAL, 2024). This evolution has led to tensions between the imperatives of economic development and environmental preservation, thus exacerbating pressures on the fragile balance of desert ecosystems (BARRETT et al., 2022; ABEGUNDE et al., 2019).

Nevertheless, it is crucial to recognize that these vast desert expanses present untapped potential in terms of food security and economic development for Algeria. For instance, the utilization of innovative drip irrigation technologies can significantly enhance agricultural productivity in arid environments (ABDELHEDI and ZOUARI, 2020; KAOUTHER, 2024). Understanding the dynamics of these changes is essential for developing sustainable and resilient land management strategies that allow for the reconciliation of national food security, natural resource preservation, and local populations' well-being in Algeria's desert regions and beyond (KHADER et al., 2020 and KHADER et al., 2022). The growth of intensive agriculture over vast areas significantly contributes to the local economy by generating employment and reducing unemployment, a chronic issue in this region devoid of other forms of economic activity (MEIJERINK and ROZA, 2007).

To explore this issue, we meticulously analyze current trends in land use and agricultural activity, identifying key influencing factors such as climatic conditions, water availability, soil characteristics, and human interventions, including climatic conditions such as precipitation, maximum, minimum, and average temperatures, as well as water resources (WANG et al., 2009), particularly groundwater.

We also consider edaphic factors such as lithology and soil moisture, expressed by the Topographic Moisture Index. Using the Land Change Modeler (LCM), we develop a prospective scenario based on Markov chains to predict agricultural dynamics in the El Menia region until 2030. Model validation is done using the Area Under Curve (AUC), also known as the Receiver Operating Characteristic (ROC).

The objective of this study is to prospectively model the agricultural expansion and land use dynamics in the Saharan region of El Menia, southern Algeria. This region is particularly unique due to its extremely limited resources and harsh environmental conditions, which makes agricultural development in it highly challenging yet increasingly attractive. In recent years, we have observed significant expansion of agricultural areas in this region. Therefore, the goal of this study is to forecast the future evolution of these agricultural areas through modeling, in order to provide insights for sustainable land management in this fragile and resource-scarce environment.

Material and methods

1. Study area

El Menia's Department, also known locally as El Goléa, is located in southern Algeria. This lovely oasis was built along the banks of the Oued Seggeur. The region has an average altitude of 396 meters and is bordered to the west by the immense Grand Erg Occidental and to the east by the Tademaït plateau. Its geographical coordinates are 30.57° N, 2.87° E. El Menia is located roughly 900 kilometers south of Algiers and serves as an important transit hub for tourists moving towards the Saharan south and Niger (Figure 1). Neighboring oases include In Salah (400 kilometers to the south), Ghardaïa (270 kilometers to the northeast), Timimoune (360 kilometers to the southwest), and Ouargla (410 kilometers to the east).

In 2018, the population of the region was 78691 individuals, with a density of barely 1.24 inhabitants/km² (ONS, 2008), covering a total area of 62215 km². According to the National Spatial Planning Scheme for 2030 (SNAT), El Menia holds tremendous potential in the agricultural, water, energy (AMROUNE et al., 2023), and oil sectors. Geologically, it belongs to the Saharan platform and is characterized by a Precambrian bedrock and sedimentary overlay structured into multiple basins separated by high zones (BENYOUCEF et al., 2023). Climatically, the region suffers from a chronic water deficit and severe temperature changes, with annual temperatures ranging between 13 and 40°C. Despite a relatively low local demographic compared to the Department of Ghardaïa, the region faces constant growth, demanding suitable planning.

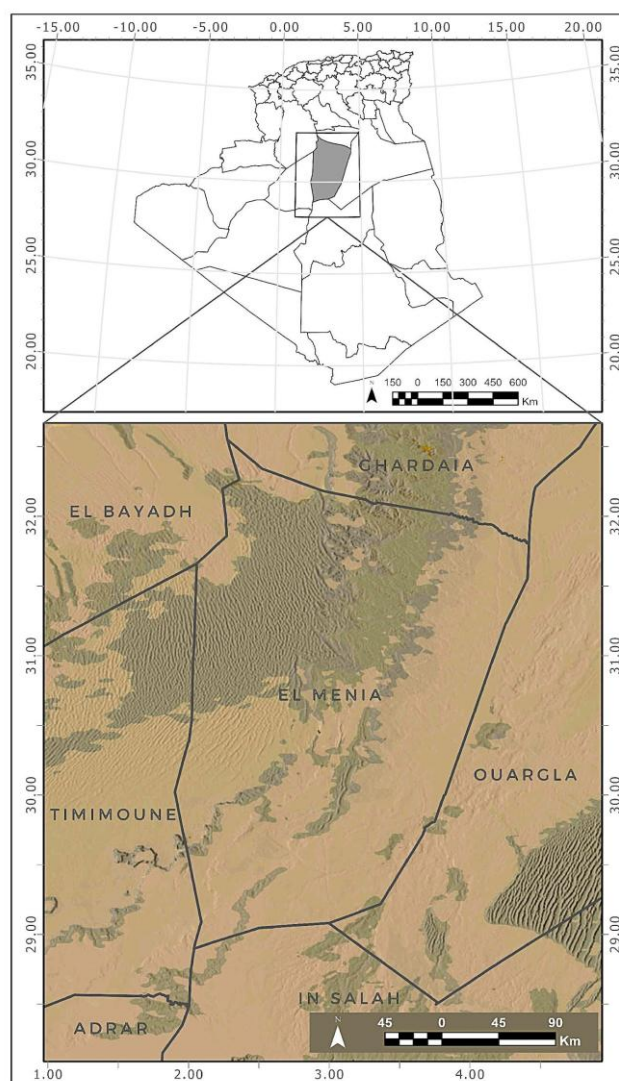


Figure 1 - Location map of the Menia region.

2. Methodology

2.1. Identification of change factors

In order to get a deeper comprehension of the territorial and agricultural dynamics in the El Menia region, we have commenced a participatory approach that entails conducting meetings with domain experts and local stakeholders. The objective of these discussions is to identify and characterize the key elements that have a significant impact on the region. This technique was preferred because the key parameters were not well delineated in academic literature. Domain specialists, with extensive knowledge of the topic, participated in multiple sessions with local stakeholders in El Menia. The primary goals of this participatory process were to determine the reasons that have influenced changes in land use and landscape structures from 2000 to 2020, establish the many dimensions at which these factors manifest (such as farm, production basin, municipality, region, etc.), and predict future trends. This strategy, which involved active participation and careful analysis, addressed the shortcomings in scientific literature by offering a comprehensive and contextual comprehension of the territorial and agricultural dynamics in the El Menia region.

2.2. Inventory of change factors and validation

In order to effectively predict the future of agriculture in dry environments, particularly in the Saharan region where the Menia zone is located, we encountered a distinct obstacle: the absence of prior research pertaining to our study area that may assist us in determining the appropriate variables for agricultural development. As a result, we relied on the knowledge and experience of experts in the field, who identified crucial parameters based on their extensive understanding of agricultural dynamics in these challenging conditions. The specialists highlighted the critical role of specific natural elements, such as lithology (ABDELRAHMAN and ARAFAT, 2020; NWER et al., 2020), climatic parameters (HAMDY et al., 2022; NAIMA et al., 2022), topography, and hydrogeology (CHARIKH et al., 2022; HAMDY et al., 2022), in the region's agricultural advancement.

2.3. Lithology

According to lithological data, the prevalence of lacustrine limestone and sand in Algeria's El Menia region is significant for agriculture, particularly intensive horticulture. The soil qualities mentioned have a significant impact on the region's agricultural feasibility, as they affect soil texture, water retention, and fertility. It is important to mention that the agriculturally acceptable zones are primarily found in the Hamada areas, which lack sandy accumulations, in contrast to the widespread sand dunes that dominate much of the territory. As a result, the lithology map (ANRH, 2013) provides useful insights into possible agricultural sites, emphasizing the need to address them in order to promote ideal conditions for crop growth and ensure sustainable agriculture in the region.

2.4. Climatic parameters

Agricultural planning, especially under harsh conditions, must account for climatic unpredictability. Using climate models to identify suitable irrigation systems is vital, as in this drought-prone location, implementing irrigation practices is necessary for cultivating any crop. Furthermore, extreme weather events such as droughts, floods, and storms can destroy crops and result in significant losses for farmers, increasing the risks associated with agricultural output. For

this reason, we selected the following climatic parameters provided by the World Climate 2.1 database (FICK and HIJMAN, 2017): precipitation, average temperatures, maximum temperatures, and minimum temperatures.

2.5. Topography

Topography is a significant aspect of agricultural management, particularly in arid locations where water conservation is paramount. The Global Digital Elevation (GDEM 003) delivers extensive insights into the topography, providing vital data for locating appropriate agricultural regions. By appreciating these topographical changes, it becomes possible to build irrigation systems that are both efficient and economical. The specified parameters to represent the topographical component include altitude and slope.

2.6. Hydrogeology

Hydrogeological studies play a key role in maintaining sustainable and productive agriculture in El Menia, a region experiencing harsh climatic and geological problems. Such a study is critical for agricultural planning and development, particularly in dry and semi-arid countries where water is a scarce and vital resource. The Albian aquifer, largely located in Algeria and expanding into Libya and Tunisia, represents a subterranean reservoir developed roughly 100 million years ago. This aquifer (TAWADROS, 2011), which contains over 50,000 billion cubic meters of water, is critical for meeting the long-term water needs of the El Menia region (ODEH, 1973). Therefore, educated and sustainable management of this aquifer is vital for the future management of water resources in this area. The integration of the hydrogeological element is highly recommended if we want to model the evolution of agriculture in the El Menia region.

2.7. Land use mapping

This study aims to prospectively model agricultural expansion in El Menia and quantify its progress over time. Initially, the procedure began with the classification of Landsat satellite imaging data. We employed the Maximum Likelihood Classification (MLC) technique (OTUKEI and BLASCHKE, 2010), leveraging preset training areas to assure accuracy. For the analysis, land use maps for the years 2000, 2010, and 2020 were employed. In total, 120 samples were randomly distributed around the study area for each map. A substantial amount, 70%, or 84 samples, was meant for the classification process, while the remaining 30%, corresponding to 36 samples, were reserved for validation reasons. This thorough sampling technique resulted in the construction of three unique Land Use and Land Cover (LULC) maps, finding five key categories: urban areas, aquatic bodies, bare land, agricultural fields, and sand dunes. The validity of the categorization was verified by an error matrix and the Kappa index.

2.8. Modeling agricultural growth factors with the Land Change Modeler

Using precisely labeled LULC maps, the predictive analysis focused on El Menia's agricultural growth using the Land Change Modeler (LCM) built into the TerrSet program. This model is known for being very good at finding and predicting changes (BENKHELIF et al., 2024). It operates on a comparison basis, necessitating two distinct temporal LULC maps to determine patterns of change. The maps of 2000 and 2010 were studied to project future changes, with the 2020 map serving as a reference to validate the model's predictions. The model's focus was primarily on transitions within the agricultural land category, ranging from bare ground, urban areas, aquatic bodies, and sand dunes to cultivated land.

2.9. Integration of agricultural growth factors into the LCM

Factors influencing agricultural growth were included to further strengthen our forecast model. These factors were transformed into raster format with a 30 m resolution to homogenize with the Landsat resolution, and a detailed analysis was performed using the Distance function of the TerrSet software. The Logistic Regression Model (LRM) was then applied to simulate probable transitions to agricultural land (ISLAM et al., 2023). The LRM uses independent variables (factors influencing agricultural expansion) and a dependent variable (showing the shift to agricultural land). This model operates on a binary logic, where '0' signifies no change and '1' reflects a transfer to agricultural land between 2000 and 2010.

2.10. Validation and analysis of predictive accuracy

After making four maps of possible transitions, ROC curve analysis was used to compare how well the models predicted they would work with what actually happened. This stage was critical to assessing the model's capacity to accurately estimate areas of agricultural expansion. The ultimate test of the model's efficacy involves a comparative examination between the predicted 2020 LULC map and the actual 2020 map, with a specific focus on the agricultural class. This comparison extended to assessing the expected changes' quantity and spatial accuracy. The TerrSet software's "Cross Tab" function allowed for a detailed review of the predictions, detecting accurately anticipated changes, unaltered areas, false positives, and misses. The cumulative error, comprising inconsistencies in the number and location of projected changes, was used to assess the overall validity of the model (PONTIUS and SCHNEIDER, 2001; FAN et al., 2006). A low margin of error would demonstrate the model's trustworthiness in anticipating and estimating El Menia's future agricultural expansion, thereby meeting the initial aims of the study.

Results and discussion

This piece of the study attempts to present the results derived from the approach outlined in the preceding part, as well as the statistics used to measure changes in land use over a ten-year period. Next, we will evaluate a forward-looking map of land-occupation changes in the Menia area until 2030, produced by the LCM model. This will provide a visual representation of potential future land use patterns based on the model's predictions. Finally, we will discuss the implications of these findings for sustainable agricultural development in the region.

1. Validation of historical land use maps

The lowest precision value of 0.90 for the year 2000 map is attributed to a slight discrepancy between the urban class and the hamada class. Conversely, in 2010, the thematic groups showed a better division, but there is still some confusion between the bare (hamada) and urban classes. This gives a respectable Kappa index of 0.92. Finally, the ranking for 2020 is even more precise, with a Kappa value greater than 0.93. Despite these minor confusions, these classifications are exceptional and play a crucial role in accurately estimating the evolution of job changes in the field considered.

The confusion between bare soils and urban areas in remote sensing of arid lands arises due to their similar spectral characteristics, making it challenging to differentiate them accurately. Several studies have addressed this issue and suggested solutions to improve the discrimination between these land cover types. Using spectral indices like the Dry Bare-Soil Index (DBSI) and the Normalized Difference Tillage Index (NDTI), for instance, has shown promise in telling the difference between bare lands and built-up areas in dry and semi-dry environments (ZHANG et al., 2015; RASUL et al., 2018).

2. The evolution of land use classes in Menia between 2000 and 2020

Between the years 2000 and 2020, we can observe distinct phases in the evolution of agricultural land use, as shown in the (Table 1). The initial phase, spanning from 2000 to 2010, was characterized by a significant downturn in agricultural activities. This period witnessed a substantial reduction in agricultural land area, diminishing from 3069.69 hectares in 2000 to a mere 2987.12 hectares by 2010, representing a notable decline of 2.69%. The primary factors contributing to this decrease were the prevailing traditional agricultural methods that heavily relied on the personal investments of local farmers and the exorbitant expenses linked to direct groundwater extraction, rendering intensive agricultural practices economically unsustainable (Figure 2).

Table 1 - Areas of land change in Menia between 2000 and 2020

Legend	Urban	Waters	Hamada	Agriculture	Sand dunes
2000	2161.73	3050.13	750039.36	3069.69	312869.71
2010	2541.60	1136.31	639290.22	2987.12	425235.37
2020	2976.46	1311.40	594327.22	4922.73	467652.81

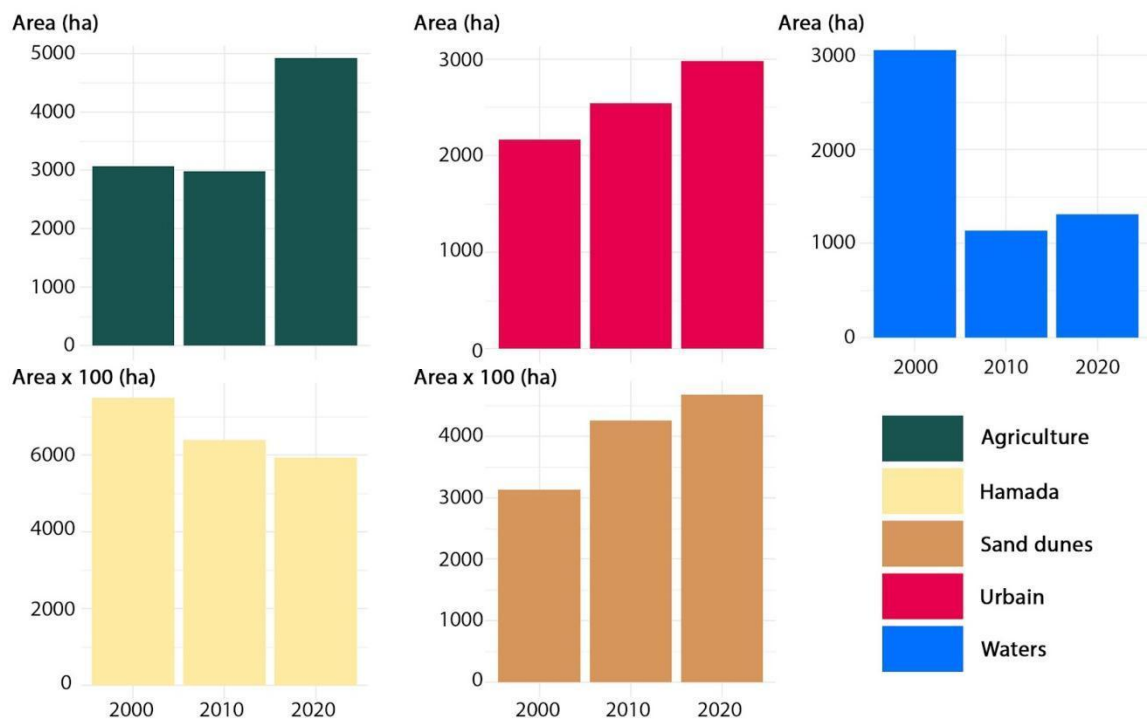


Figure 2 - Evolution of land use classes in Menia between 2000 and 2020.

On the other hand, starting in 2010, a new evolutionary phase is under way, highlighted by tremendous development in agricultural areas. In 2020, they reached 4922.73 hectares, an increase of 164.80% compared to 2010. This trend reversal is a result of extensive land exploitation by local

investors, supported by state funding under the National Program for Agricultural and Rural Development (CHAIB and BAROUDI, 2014) (Figure 3).

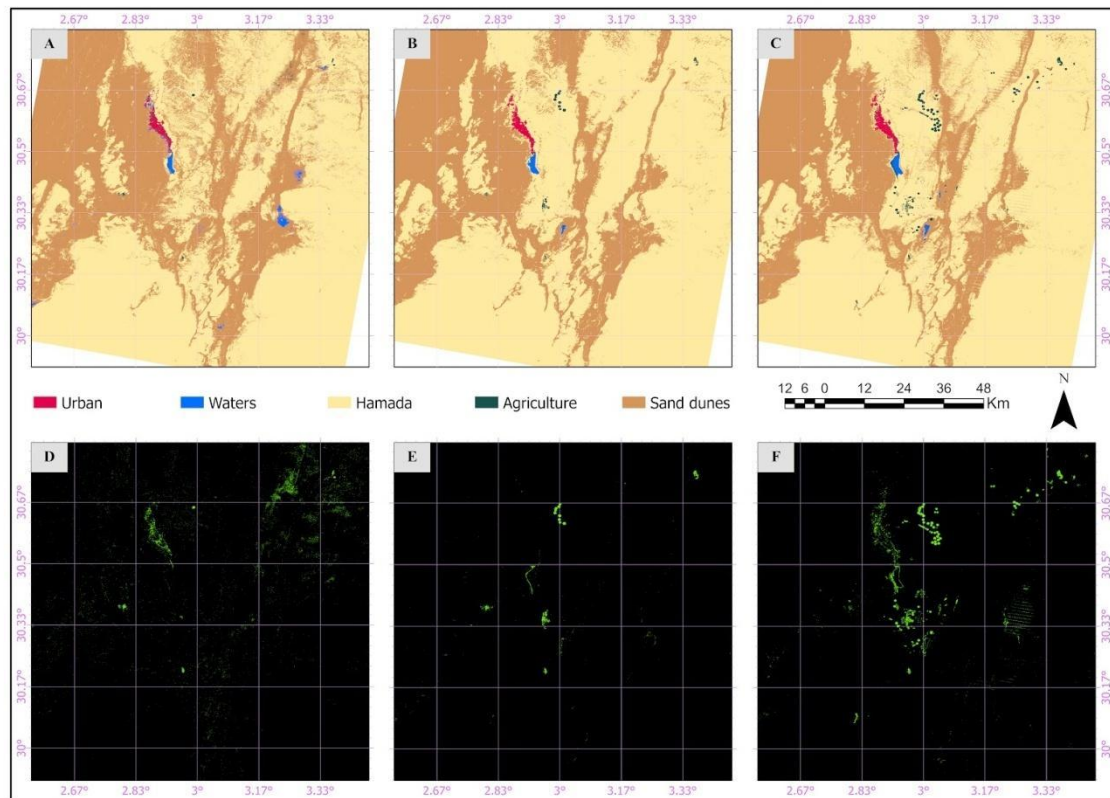


Figure 3 - Land use of the Menia region in (A: 2000, B: 2010 and C: 2020).
Menia region agriculture class in (D: 2000, E: 2010 and F: 2020).

This change was motivated by widespread agricultural development by local investors, supported by public financing through the various agricultural and rural development projects (DJEFLAT, 2020). initiated in 2010, they underscore the government's initiatives to enhance agriculture in vast arid regions (OUILI and ZENNIR, 2022). In addition to the expansion of agricultural areas, the increased investment in irrigation infrastructure played a crucial role in boosting crop yields and diversifying agricultural production (OULMANE and BENMEHALA, 2019). The introduction of modern farming techniques and the adoption of drought-resistant crop varieties further contributed to the sector's growth and resilience in the face of climatic challenges (FOUFOU, 2022). As a result, the region saw a significant improvement in food security and economic stability, benefiting both local communities and the broader economy.

3. Menia region's land use map by 2030

Building forward-looking scenarios involves engaging stakeholders to raise awareness about potential future developments and their impact on landscape changes (RICHTER et al., 2023). This approach emphasizes inclusivity, trustworthiness, and transparency, highlighting the need for a comprehensive strategy to navigate potential hazards and changes effectively. Decision-makers must consider the different features of natural settings, including economic, social, and environmental ambitions beyond the agricultural sector (CRONAN et al., 2022). The study selected a trend scenario built using the CA-Markov model, examining temporal and spatial variations and their impact on agricultural activities in the Saharan region (LACHER et al., 2023). This approach aims to empower decision-makers with a clearer understanding of the future landscape, enabling more informed and sustainable decision-making processes.

4. Prospective land use according to the trend scenario

The Land Change Modeler trend scenario aims to logically project the results of current trends and assumptions while taking into account existing restrictions and maintaining consistency with trends observed in the past (DADASHPOOR and PANAHI, 2021). Using the transition matrix obtained by analyzing the Markov chains between 2010 and 2020, we developed a trend scenario for the Menia region. In this context, we assume that changes in land use patterns will remain consistent without the implementation of additional protection restrictions or significant deterioration of occupied regions until 2030. This scenario aims to reduce potential errors and uncertainties naturally included in the projections. It maintains the period between 2010 and 2020, which was used to calibrate the model, to ensure its reliability and relevance for future decision-making.

The design of tendential and contrasting future scenarios displays their full potential in finding locations with substantial socio-economic stakes. Their ability to quantify and locate future changes in land use provides a solid platform for decision-making processes, particularly when evaluating the implications of socio-economic processes through impact studies on activities, for example (VELDKAMP et al., 2004; VERBURG et al., 2004). This scenario presents a bright prognosis for the region. Future changes in land use by 2030, according to the tendential scenario, reveal major transitions between land use groups. While maintaining their existing surfaces, urban agglomerations will expand at the expense of other groups. Additionally, agriculture will undergo a tremendous increase, with an area of 47,000 hectares, promising major economic activity in the region and even contributing to national economic development. However, sand encroachment remains a major limitation for the development of the Menia region, creating substantial dangers for agricultural investments or infrastructure.

5. Transition matrix of land use classes between 2010 and 2020

The 2010– 2020 transition matrix based on Markovian chains provides crucial information on the future evolution of different land use groups in the Menia region. Projected changes between 2010 and 2020 are used to determine expected changes for 2030 (Table 2). Cross-referenced data for 2010 (columns) and 2020 (rows) is provided in the table above. This matrix presents several notable trends. First, the urban class displays a surplus of 434.86 hectares, fueled mainly by the conversions of Hamada, lake, and agricultural areas, with respectively 325.60 hectares, 96.50 hectares, and 12.76 hectares. Then, the hamadas, these rock formations typical of the desert environment, lose more than 45000 hectares, mainly to the benefit of dunes and agricultural areas, with a significant net drop of 44963 hectares of their initial surface area (Figure 4).

Table 2 - Transition matrix of future changes in land use classes

Legend	Urban	Water	Hamada	Agriculture	Dunes
Urban	2 976.46	0	0	0	0
Water	96.50	1 311.40	162.50	22.74	902.83
Hamada	325.60	894.20	594 327.22	15 651.40	28 743.76

Agriculture	12.76	35.12	44.15	4 922.73	1 4131.50
Sand dunes	0	430.34	445.31	485	467 652.81

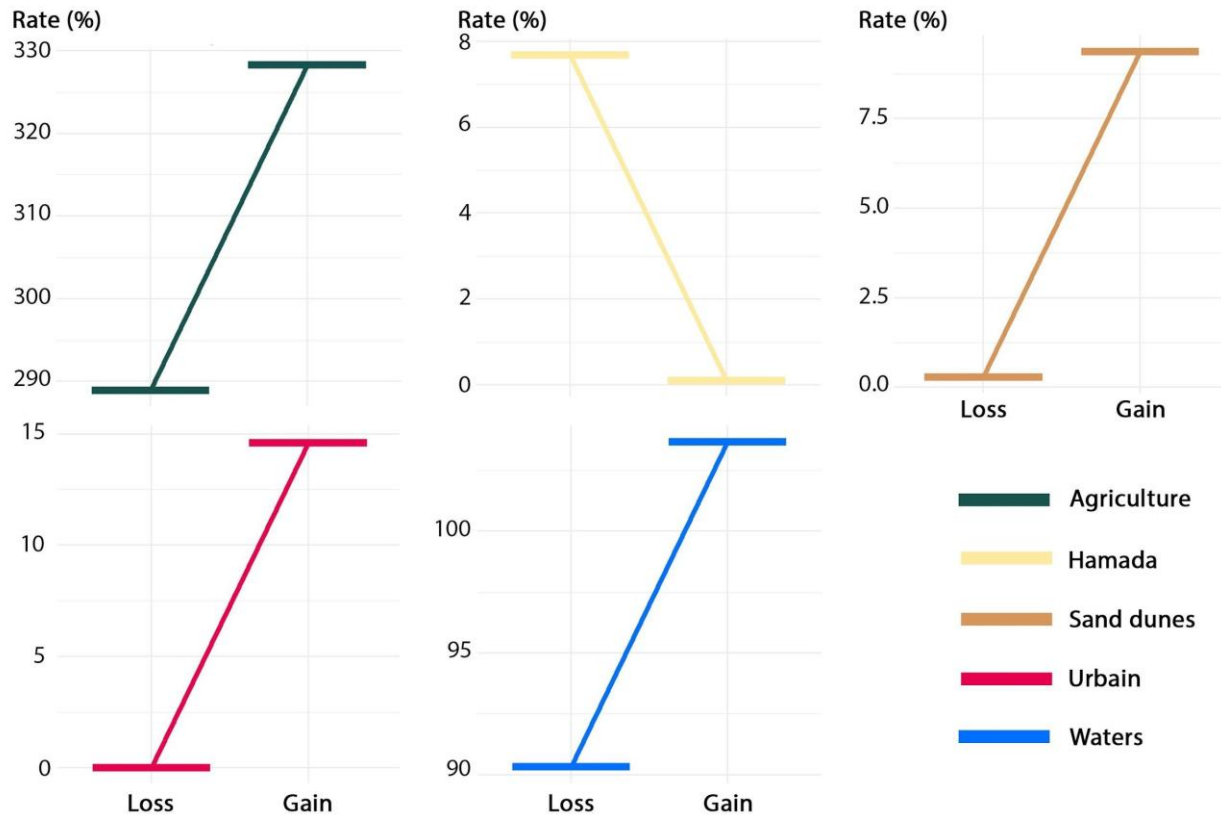


Figure 4 - Loss and gains of land use classes between 2020 and 2030.

The expansion of agricultural land, particularly intensive crops, is impressive despite the difficult conditions of the study area, with a net gain of 1,935.61 hectares. This expansion will mainly be to the detriment of the hamadas with 15651.4 hectares, while the dunes will contribute to the expansion of agriculture by 485 hectares. The dried lakes will also be exploited by agriculture, with an area of 22.74 hectares.

6. Model validation

While the visual assessment provides an initial indication of the forecast's accuracy by comparing the 2020 reference map with the 2020 simulation, this approach does not allow exact localization and quantification of the correctly predicted areas of error that may have escaped the observer's eye. In order to transcend beyond the subjectivity of the modeler (PONTIUS and MILLONES, 2011; OLMEDO et al., 2015) stressed the necessity of a statistical comparison between these maps. The budgeting approach (error or accuracy) will be applied to examine and validate the model.

7. Global budgeting of errors and accuracy

This method enables assessing and pinpointing mistakes and accuracies in changes resulting from the comparison of two reference maps (t1 and t2) with a prediction map (t2). Model validation

occurs in two steps: first, by examining expected and actual changes between 2010 and 2020, and then by comparing land cover classes between the known land cover map and the predicted map. Out of a total of 80% observed constancy between 2010 and 2020, 61% were accurately predicted (N) (Table 3). The stability of Hamadas, which represents 68% of the region's stability compared to other land cover categories, partly explains this conclusion (SEHL, 2018). Errors, which result from observed constancy but are forecasted as change, account for 6.3% (F), while "misses," which reflect the opposite process (M), account for 20%. Finally, the model's observed and accurately predicted changes equal 12% (H) (BENKHELIF et al., 2024).

Table 3 - Comparison between prediction and observation

		Observed Changes 2010 - 2020		
		0	1	Total général
Predicted Changes 2010 - 2020	0	(N) 61.04%	(M) 19.88%	80.92%
	1	(F) 6.30%	(H) 12.78%	19.08%
	Total général	67.34%	32.66%	100%

8. Menia's land use in 2030

The prospective modeling of the land use map for the year 2030 using the LCM model, applying the transition matrix (2010–2020) and suitability maps for each land use class, is provided below. The urban area will encompass 2757.82 hectares (Table 4), representing 0.26% of the total area. Despite being the least popular land use type, it enjoys significant expansion compared to 2020. The hamada will remain the largest category, comprising 667018 hectares, representing substantially over half of the overall study area (62.27%).

The dunes class, which occupies 36.18% of the land, is closely followed. Under the trend scenario, the agricultural class will see substantial expansion, spanning 12,024 hectares, or 1.12% of the overall region's area (Figure 5).

Table 4 - Ground occupation class area projected in 2030

Legend	Urban	Water	Hamada	Agriculture	Sand dunes
Acres	2 757.82	1 877.52	667 018.14	12 024.30	387 512.85
Rate	0.26	0.18	62.27	1.12	36.18

9. Analysis of changes for each land use class (2021–2030)

The primary aim of this data analysis is to accurately measure changes in land occupation and use. Additionally, this study tries to understand the evolutionary processes, specifically detecting transitions between distinct land use classes in terms of losses and benefits. To do this, transition matrices were calculated using the Idrisi program. Utilizing these matrices provides insight into the surface area (in hectares) of each land use class by 2030, as well as the fraction of each class that

remains stable and those moving to other classes. This approach enables us to follow the future trajectory and origins of each land use class. Moreover, these matrices provide a detailed examination of the evolution of each class, defining gains and losses relative to other classes.

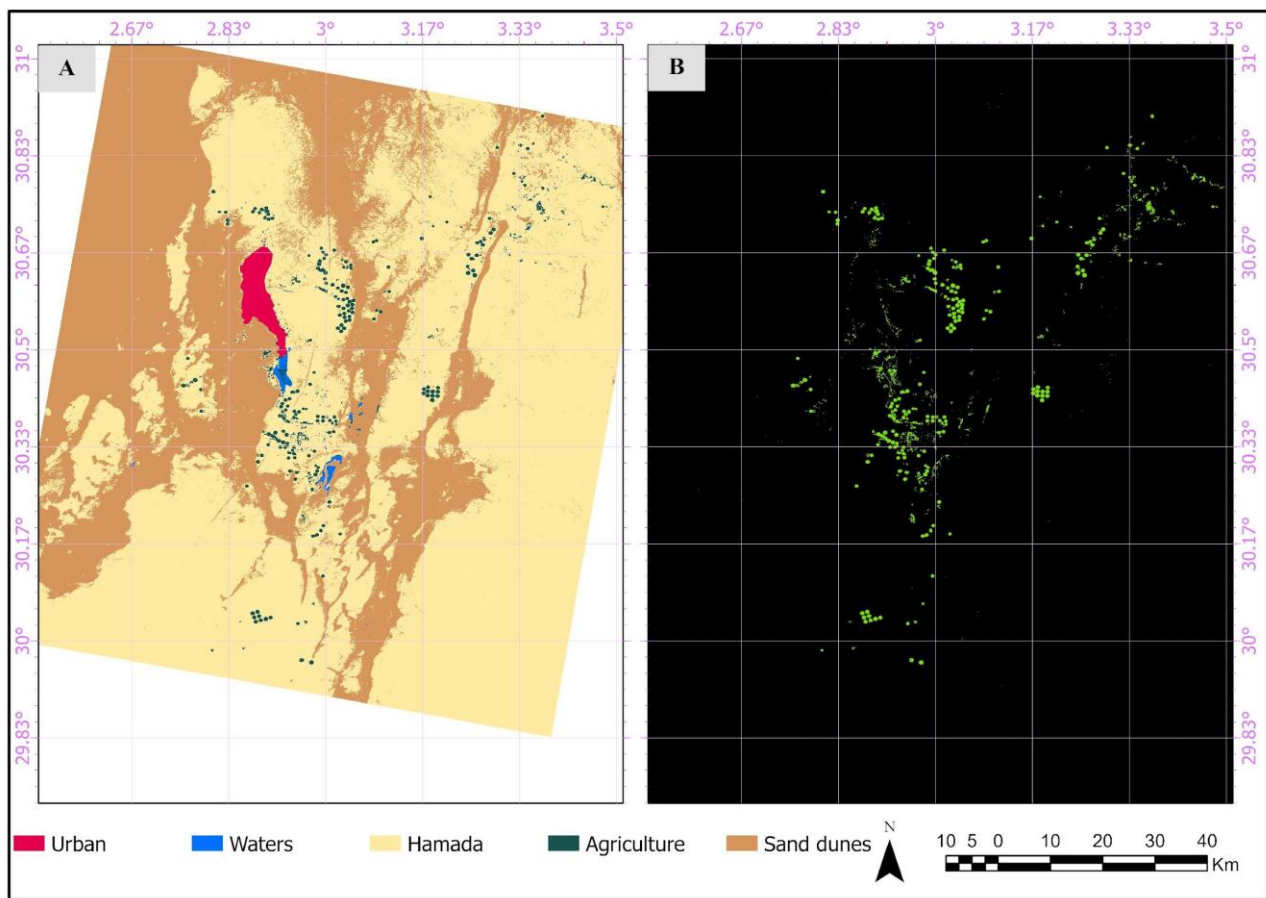


Figure 5 - A: Land use of the Menia region in 2030. B: Menia region agriculture class in 2030.

10. Contribution to net change in agriculture class

The analysis of the agriculture class reveals a large development of this land use at the expense of enormous barren lands existing in the region. This increase is ascribed to the rise of the Albian aquifer in the region, fostered by different agricultural and rural development programs developed by the government. These schemes have permitted the construction of enormous regions of intensively irrigated agriculture (Table 5).

Table 5 - Net contribution of land use classes

Legend	Urban	Water	Hamada	Agriculture	Sand dunes
Net Contribution	473	90	5520	0	612
Rate	7.06	1.34	82.45	0.00	9.14

Spatial research suggests that the majority of agricultural land will be reclaimed to the north along the trajectory of the Albian aquifer, making these places very favorable to agriculture. Additionally, the low-lying portions of the dunes will also be restored as they hold large groundwater resources in the form of free-flowing aquifers, save for places extremely near the chott due to their high saline levels (BOUZEKRI, 2022).

11. Predictive Modeling for 2030

The predictive modeling for 2030, utilizing the LCM model, suggests a consistent expansion of agricultural land by that time. This forecast, based on trends observed between 2010 and 2020 using Markov chains, incorporates lithology, slope, altitude, maximum and minimum temperatures, average temperatures, and soil humidity index. These factors are crucial in understanding the geographical and climatic conditions affecting agricultural land use. The model's anticipation of agricultural expansion underscores the expected impact of ongoing developmental policies and the potential for increased agricultural productivity in the region. Additionally, by incorporating these variables, a more accurate prediction of future land use changes is enabled, which aids in decision-making processes for sustainable development. Considering these factors, policymakers can strategically plan for the challenges, such as resource management, and opportunities, like economic growth, that may arise with the expansion of agricultural land in the future (WANG, 2023).

The projections for 2030 indicate a substantial increase in agricultural land compared to 2020. In the baseline scenario, agricultural land in 2020 encompassed 4,922.73 hectares, while the predictions for 2030 anticipate an expansion to 12,024.30 hectares. This represents a notable 144.23% increase from the 2020 figures, reflecting the persistent growth trend in the agricultural sector within the Menia region. The extension of agricultural land in Menia goes beyond mere expansion; it has significant and multifaceted implications for regional development. Primarily, it lays the groundwork for future enhancements in food security by potentially increasing local food production (KAHLA, 2019; ABDELHEDI and ZOUARI, 2020). This could reduce reliance on food imports and bolster the region's resilience to external market fluctuations (MEIJERINK and ROZA, 2007). Additionally, agricultural expansion can stimulate regional economic growth by generating employment opportunities in agriculture and related sectors like food processing, logistics, and distribution. This could further spur the development of rural infrastructure and support services, thereby enhancing overall living standards in the region. However, this expansion also raises sustainability concerns. Heightened demand for water resources, particularly in arid regions like Menia (SHIN et al., 2022) may strain freshwater supplies and jeopardize future water availability for agriculture and local communities (MOIWO et al., 2022). Moreover, the expansion of agricultural land could contribute to environmental degradation (RASTGOO and HASANFARD, 2022), habitat loss, and ecosystem fragmentation, posing significant risks to biodiversity and vital ecosystem services. Addressing these challenges requires the implementation of sustainable agricultural policies and practices that prioritize natural resource conservation, efficient water management, and ecosystem preservation. It is imperative to engage local communities, farmers, and stakeholders in inclusive decision-making processes to achieve balanced and sustainable agricultural development in Menia. While increased agricultural activity can drive economic growth and enhance food security, it necessitates prudent natural resource management. Mitigating challenges such as water scarcity, soil degradation, and climate change impacts will be critical for sustaining agricultural expansion. Conversely, opportunities lie in adopting sustainable farming practices, enhancing irrigation efficiency, and harnessing technological innovations to boost productivity while minimizing environmental impacts.

Conclusion

This study proposed the modeling and anticipating of agricultural land evolution in the region of Menia in Algeria, using Land Change Modeler (LCM). The results reveal a significant expansion

of agricultural lands between 2000 and 2020, with a projection indicating the continuation of this trend until 2030, while experiencing a reduced rate of growth.

The methodological framework employed illustrates the efficacy of spatial modeling tools in analyzing and predicting agricultural dynamics in complex and fragile environments such as Saharan regions. These results further contribute to the global discourse on food security by proposing strategies to optimize natural resource utilization while mitigating environmental impacts.

According to the tendential scenario, future land use changes by 2030 will involve significant transitions between land use categories. Urban areas will continue to expand, consuming land from other categories, while agricultural areas will see a remarkable increase, growing by 47,000 hectares. This growth has the potential to be a key driver of regional economic activity, with possible contributions to national economic development. However, the threat of sand encroachment remains a significant challenge to the development of the Menia region, posing considerable risks to agricultural investments and infrastructure.

To ensure sustainable development, it is essential to establish politics that promote efficient irrigation systems, the adoption of crop varieties suited to arid conditions, and the rational sustainable management of aquifers. Furthermore, future studies could explore the socioeconomic impacts of agricultural expansion or adapt these models to other arid regions encountering similar challenges.

This study provides a robust scientific foundation to inform decision-making processes in land management within arid contexts, while highlighting the necessity of finding a balance between agricultural development and preservation of Saharan ecosystems.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No financial or personal relationships with other organizations or individuals influenced the work presented in this study.

Authors' contributions

Boudjema Sehl - conceptualization, methodology, data analysis, manuscript writing and review; Mhammed Khader - data collection, fieldwork, model development, and manuscript writing; Kouider Hadjadj - statistical analysis, model calibration, and manuscript editing; Mohamed Lahouel - supervision, project administration, review and editing. All authors read and approved the final manuscript.

References

- ABDELHEDI, I. T.; ZOUARI, S. Z. Agriculture and food security in North Africa: a theoretical and empirical approach. **Journal of the Knowledge Economy**, v. 11, p. 193-210, 2020. <https://doi.org/10.1007/s13132-018-0528-y>
- ABDELRAHMAN, M. A. E.; ARAFAT, S. M. An approach of agricultural courses for soil conservation based on crop soil suitability using geomatics. **Earth Systems and Environment**, v. 4, p. 273-285, 2020. <https://doi.org/10.1007/s41748-020-00145-x>

- ABEGUNDE, V. O.; SIBANDA, M.; OBI, A. The dynamics of climate change adaptation in Sub-Saharan Africa: a review of climate-smart agriculture among small-scale farmers. **Climate**, v. 7, n. 11, p. 1-23, 2019. <https://doi.org/10.3390/cli7110132>
- AMROUNE, A.; MIHOUB, R.; GUASTALDI, E. Groundwater overexploitation of the continental intercalacry aquifer. a case study from Ghardaia, Algeria. **Analele Universității din Oradea, Seria Geografie**, v. 33, n. 1, p. 65-77, 2023. <https://doi.org/10.30892/auog.331106-898>
- ANRH. Agence Nationale des Ressources Hydrauliques. **Lithology map of Algeria (1/500.000)**. Algérie, 2013.
- BARRETT, C. B.; PLACE, F.; ABOUD, A. A.; BROWN, D. R. The challenge of stimulating adoption of improved natural resource management practices in African agriculture. In: BARRETT, C. B.; PLACE, F.; ABOUD, A. A. (Eds.). **Natural resources management in African agriculture: understanding and improving current practices**. 1st ed. UK: CABI Publishing, p. 1-21, 2022. <https://doi.org/10.1079/9780851995847.0001>
- BENKHELIF, A.; SETTI, M.; SEHL, B.; DJEDDAOUI, F.; NAZRUL, I. Predicting urban growth and its impact on fragile environment using Land Change Modeler (LCM): a case study of Djelfa City, Algeria. **GeoJournal**, v. 89, art. 72, 2024. <https://doi.org/10.1007/s10708-024-11078-7>
- BENYOUCEF, M.; SALAMON, M.; FERRÉ, B.; BOUCHEMLA, I.; SLAMI, R.; VESELSKÁ, M. K. Stratigraphy, palaeontology and sedimentology of the Upper Cretaceous of northern Tademaït (Sahara, Algeria). **Cretaceous Research**, v. 149, 2023. <https://doi.org/10.1016/j.cretres.2023.105547>
- BOUZEKRI, A. Diachronic analysis to detect and monitor barchan dune migration in Ain Salah (Algeria). **Geoadria**, v. 27, n. 1, p. 7-15, 2022. <https://doi.org/10.15291/geoadria.3486>
- CHAIB, B.; BAROUDI, N. La stratégie du développement rural en Algérie dans un cadre de renouveau et approche participative. **Revue Algérien de Développement Économique**, v. 1, n. 1, p. 31-46, 2014. <https://asjp.cerist.dz/en/article/13041>
- CHARIKH, M.; SLIMANI, R.; HAMDI-AISSA, B.; BOUADJILA, O.; HASSAINE, A. Evaluation of arid soil landscapes permeability in Algerian Sahara. **Al-Qadisiyah Journal For Agriculture Sciences**, v. 12, n. 2, p. 12-18, 2022. <https://doi.org/10.33794/qjas.2022.134247.1050>
- CHOUAIB, G.; KALYONCUOGLU, B. B. Understanding the cultural landscape value of traditional agrarian landscapes of African Sahara Desert: the case of Timimoun, Algeria. **Journal of Design for Resilience in Architecture and Planning**, v. 3, n. 1, p. 82-95, 2022. <https://doi.org/10.47818/DRArch.2022.v3i1045>
- CRONAN, D.; TRAMMELL, E. J.; KLISKEY, A. Images to evoke decision-making: building compelling representations for stakeholder-driven futures. **Sustainability**, v. 14, n. 5, p. 1-13, 2022. <https://doi.org/10.3390/su14052980>
- DADASHPOOR, H.; PANAHI, H. Exploring an integrated spatially model for land-use scenarios simulation in a metropolitan region. **Environment, Development and Sustainability**, v. 23, p. 13628-13649, 2021. <https://doi.org/10.1007/s10668-021-01231-4>
- DARKO, R. O.; LIU, J.; YUAN, S.; SAM-AMOA, L. K.; YAN, H. Irrigated agriculture for food self-sufficiency in the sub-Saharan African region. **International Journal of Agricultural and Biological Engineering**, v. 13, n. 3, p. 1-12, 2020. <https://doi.org/10.25165/j.ijabe.20201303.4397>
- DJEFLAT, A. Transforming Algeria's rural areas through STI and the knowledge economy: the proximity programme for integrated rural development (PPDRI). **Innovation and Development**, v. 10, n. 2, p. 187-206, 2020. <https://doi.org/10.1080/2157930X.2019.1580941>

- EL-BELTAGY, A.; MADKOUR, M. Impact of climate change on arid lands agriculture. **Agriculture & Food Security**, v. 1, n. 1, p. 1-12, 2012. <https://doi.org/10.1186/2048-7010-1-3>
- FAN, J.; UPADHYE, S.; WORSTER, A. Understanding receiver operating characteristic (ROC) curves. **Canadian Journal of Emergency Medicine**, v. 8, n. 1, p. 19-20, 2006. <https://doi.org/10.1017/S1481803500013336>
- FICK, S. E.; HIJMAN, R. J. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. **International Journal of Climatology**, v. 37, n. 12, p. 4302-4315, 2017. <https://doi.org/10.1002/joc.5086>
- FOUFOU, A. National food safety depends on the modernization and mechanization of agriculture. **International Journal of Sciences and Natural Resources**, v. 1, n. 1, p. 16-20, 2022. <https://doi.org/10.58205/ijsnr.v1i1.198>
- GAUR, M. K.; SQUIRES, V. R. Geographic extent and characteristics of the world's arid zones and their peoples. In: GAUR, M. K.; SQUIRES, V. R. (Eds.). **Climate Variability Impacts on Land Use and Livelihoods in Drylands**. Cham: Springer International Publishing, p. 3-20, 2018. https://doi.org/10.1007/978-3-319-56681-8_1
- HAFIDA, R.-B. Climate change, biodiversity and agro-biodiversity: global view and particular case of Algeria. **American Journal of Agricultural Research**, v. 2, n. 3, p. 1-16, 2017. https://www.researchgate.net/publication/322686599_Climate_change_biodiversity_and_agrobiodiversity_global_view_and_particular_case_of_Algeria
- HAMDY, M.; TAMMA, A. A.; PÉTER, S.; KOVÁCS, A. Hydrogeochemical evaluation of groundwater and its suitability for drinking and irrigation using water quality index, statistical and geochemical modelling, debila and El-Oued regions, Algeria. **Research Square**, 2022. PREPRINT (Version 1). <https://doi.org/10.21203/rs.3.rs-1855927/v1>
- ISLAM, M. Y.; NASHER, N. M. R.; KARIM, K. H. R.; RASHID, K. J. Quantifying forest land-use changes using remote-sensing and CA-ANN model of Madhupur Sal Forests, Bangladesh. **Heliyon**, v. 9, n. 5, e15617, 2023. <https://doi.org/10.1016/j.heliyon.2023.e15617>
- KAHLA, K. B. **From food security to food sovereignty in Tunisia main challenges and obstacles**. 2019. https://www.researchgate.net/publication/359258532_From_food_security_to_food_sovereignty_in_Tunisia_Main_challenges_and_obstacles_Report_to_the_Arab_NGO_Network_for_Development_1_ANND
- KAOUTHER, T. The development of desert agriculture as a method of achieving food security in Algeria. **Journal of Contemporary Business and Economic Studies**, v. 7, n. 1, p. 133-148 2024. https://www.researchgate.net/publication/377523582_The_Development_Of_Desert_Agriculture_As_A_Method_Of_Achieving_Food_Security_In_Algeria
- KHADER, M.; MOUISSA, H.; BOUFHADI, D.; MEKHLLOUFI, B.; SAHEL, B. Inventory and mapping of the flora of Zahrez El Gharbi Djelfa Algeria using geomatics. **Mitteilungen Klosterneuburg**, v. 70, n. 10 p. 32-41, 2020. https://www.researchgate.net/publication/356493799_Inventory_and_mapping_of_the_flora_of_Zahrez_El_Gharbi_Djelfa_Algeria_using_geomatics
- KHADER, M.; MOUISSA, H.; HADJADJ, K.; SAHEL, B. Use of remote sensing for monitoring of the deforestation in semi-arid region case of the Djelfa forests (Algeria). **Current Trends in Natural Sciences**, v. 11, n. 21, p. 322-331, 2022. <https://doi.org/10.47068/ctns.2022.v11i21.035>
- KOOHAFKAN, P.; ALTIERI, M. A. **Globally important agricultural heritage systems: a legacy for the future**. Food and Agriculture Organization of the United Nations Rome, 2011. https://www.researchgate.net/publication/265536935_Globally_Important_Agricultural_Heritage_Systems_A_Legacy_for_the_Future

- LACHER, I.; FERGUS, C.; MCSHEA, W. J.; PLISINSKI, J.; MORREALE, L.; AKRE, T. S. Modeling alternative future scenarios for direct application in land use and conservation planning. **Conservation Science and Practice**, v. 5, n. 7, p. 1-17, 2023. <https://doi.org/10.1111/csp2.12940>
- LAL, R. (Ed.). **Managing Soil Drought**. 1st edition. Boca Raton, FL: CRC Press, 2024, 440p. <https://doi.org/10.1201/b23132>
- MEIJERINK, G.; ROZA, P. **The role of agriculture in development. Markets, Chains and Sustainable Development Strategy and Policy Paper**. Stichting DLO: Wageningen, n. 5, 2007. <http://www.boci.wur.nl/UK/Publications/>
- MOIWO, J. P.; KAWA, Y. K.; CONTEH, A. M. H. Sustainability of water resources and agricultural production in Semi-arid regions. In: LIMA, M. R. **Research Aspects in Biological Science**. West Bengal, India: B P International, v. 6, p. 44-80, 2022. <https://doi.org/10.9734/bpi/rabs/v6/2251C>
- MULDER, M. B.; COPPOLILLO, P. **Conservation: Linking Ecology, Economics, and Culture**. Princeton, N. J: Princeton University Press, 2005. <https://doi.org/10.2307/j.ctv301g4w>
- NAIMA, K.; HELIMI, S.; MIHOUB, A.; MOKHTARI, S.; KHERRAZE, M. E.; AOUISSI, H. A. Developing a land suitability model for cereals in the Algerian Sahara using GIS and hierarchical multicriteria analysis. **International Journal of Agriculture and Natural Resources**, v. 49, n. 1, p. 36-50, 2022. <https://doi.org/10.7764/ijanr.v49i1.2323>
- NOY-MEIR, I. Desert ecosystems: environment and producers. **Annual Review of Ecology, Evolution and Systematics**, v. 4, p. 25-51, 1973. <https://doi.org/10.1146/annurev.es.04.110173.000325>
- NWER, B. A.; WHAIDA, A. M.; GRAB, F. M. Development of soil suitability ratings index for crops in the North - East of Libya using geographic information system. **Journal of Misurata University for Agricultural Sciences**, v. 2, p. 19-29, 2020. <https://doi.org/10.36602/jmuas.2020.v02.01.02>
- ODEH, A. Stratigraphy of lower triassic sandstone of northwest Algerian Sahara, Algeria. **Bulletin**, v. 57, n. 3, p. 528-540, 1973. <https://doi.org/10.1306/819A4300-16C5-11D7-8645000102C1865D>
- OLMEDO, M. T. C.; PONTIUS, R. G.; PAEGELOW, M.; MAS, J. -F. Comparison of simulation models in terms of quantity and allocation of land change. **Environmental Modelling & Software**, v. 69, p. 214-221, 2015. <https://doi.org/10.1016/j.envsoft.2015.03.003>
- ONS. Office National des Statistiques. 2008. <https://www.ons.dz/spip.php?rubrique33>
- OTUKEI, J. R.; BLASCHKE, T. Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. **International Journal of Applied Earth Observation and Geoinformation**, v. 12, supp. 1, p. 27-31, 2010. <https://doi.org/10.1016/j.jag.2009.11.002>
- OUILI, D. S.; ZENNIR, R. The role of local authorities in the development of rural areas in Algeria within the framework of the rural renewal policy implementation. Case study: municipalities of Mila. **International Journal of Innovative Studies in Sociology and Humanities**, v. 7, n. 8, p. 163-174, 2022. <https://doi.org/10.20431/2456-4931.070816>
- OULMANE, A.; BENMEHALA, A. M. Effects of irrigation technology adoption on farms performance in algeria: a stochastic frontier production function approach. **Review of Agricultural and Applied Economics**, v. 22, n. 2, p. 81-87, 2019. <https://doi.org/10.22004/ag.econ.293661>
- PONTIUS, R. G.; MILLONES, M. Death to Kappa: birth of quantity disagreement and allocation disagreement for accuracy assessment. **International Journal of Remote Sensing**, v. 32, n. 15, p. 4407-4429, 2011. <https://doi.org/10.1080/01431161.2011.552923>
- PONTIUS, R. G.; SCHNEIDER, L. C. Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. **Agriculture, Ecosystems & Environment**, v. 85, n. 1-3, p. 239-248, 2001. [https://doi.org/10.1016/S0167-8809\(01\)00187-6](https://doi.org/10.1016/S0167-8809(01)00187-6)

- RASTGOO, M.; HASANFARD, A. Desertification in agricultural lands: approaches to Mitigation. In: ZHU, Y.; LUO, Q.; LIU, Y. **Deserts and Desertification**. IntechOpen, 2022. <https://doi.org/10.5772/intechopen.98795>
- RASUL, A.; BALZTER, H.; IBRAHIM, G. R. F.; HAMEED, H. M.; WHEELER, J.; ADAMU, B.; IBRAHIM, S.; NAJMADDIN, P. M. Applying built-up and bare-soil indices from landsat 8 to cities in dry climates. **Land**, v. 7, n. 3, p. 1-13, 2018. <https://doi.org/10.3390/land7030081>
- RICHTER, I.; GABE-THOMAS, E.; QUEIRÓS, A. M.; SHEPPARD, S. R. J.; PAHL, S. Advancing the potential impact of future scenarios by integrating psychological principles. **Environmental Science & Policy**, v. 140, p. 68-79, 2023. <https://doi.org/10.1016/j.envsci.2022.11.015>
- SEHL, B. **Modélisation prospective de l'occupation du sol et leurs impacts sur l'activité socio-économique application sur les hautes plaines steppiques Sud algérois**. 2018.
- SHIN, S.; AZIZ, D.; EL-SAYED, M. E. A.; HAZMAN, M.; ALMAS, L.; MCFARLAND, M.; DIN, A. S. E.; BURIAN, S. J. Systems thinking for planning sustainable desert agriculture systems with saline groundwater irrigation: a review. **Water**, v. 14, n. 20, p. 1-25, 2022. <https://doi.org/10.3390/w14203343>
- TAWADROS, E. **Geology of North Africa**. 1st edition. London: CRC Press, 2011, 930p. <https://doi.org/10.1201/b11419>
- VERBURG, P. H.; SCHOT, P. P.; DIJST, M. J.; VELDKAMP, A. Land use change modelling: current practice and research priorities. **GeoJournal**, v. 61, p. 309-324, 2004. <https://doi.org/10.1007/s10708-004-4946-y>
- WALE, A. H.; DEJENIE, T. Dryland ecosystems: Their features, constraints, potentials and managements. **Research Journal of Agricultural and Environmental Management**, v. 2, n. 10, p. 277-288, 2013. <https://www.apexjournal.org/rjaem/archive/2013/Oct/abstract/Wale%20and%20Dejenie.htm>
- WANG, Y.-M.; TRAORE, S.; NAMAONA, W.; KERH, T. Agricultural productivity potential assessment by using rainfall contribution index in Sub-Sahara Africa. **WSEAS Transactions on Information Science and Applications**, v. 6, n. 5, p. 839-848, 2009. <http://www.wseas.us/e-library/transactions/information/2009/29-193.pdf>
- WANG, Z. Land use policy recommendations - based on empirical analysis of the effect of agricultural land expansion on greenhouse gas emission. **Highlights in Science, Engineering and Technology**, v. 59, p. 158-164, 2023. <https://doi.org/10.54097/hset.v59i.10075>
- ZHANG, C.; CHEN, Y.; LU, D. Mapping the land-cover distribution in arid and semiarid urban landscapes with Landsat Thematic Mapper imagery. **International Journal of Remote Sensing**, v. 36, n. 17, p. 4483-4500, 2015. <https://doi.org/10.1080/01431161.2015.1084552>

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