GeoPlanning
Journal of Geomatics and Planning

Geoplanning: Journal of Geomatics and Planning, Vol. 12, No. 1, 2025, 123 - 138

e-ISSN: 2355-6544

Received: 25 September 2024;
Revised: 08 May 2025;
Accepted: 16 May 2025;
Available Online: 16 May 2025;
Published: 28 May 2025.

Keywords:
Spatial Growth, Palm Grove, Oasis Ecosystem, Satellite Image, Landscape Metrics

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Original Research Open access

The Ecological Impact of Urban Expansion in Oasis Environments: A combined Cartographic and Landscape Analysis

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DOI: 10.14710/geoplanning.12.1.123-138

Abstract

Current patterns of urban expansion are mostly considered as impulsive, leading to numerous negative consequences for our biosphere. This disturbing fact has not gone unnoticed in the sprawling oasis cities of the Algerian Sahara, where palm groves are the primary victim. Furthermore, any approach taken to preserve oasis ecosystems requires considering ecological variables. In this perspective, the present study seeks to highlight the spatial growth process of the Laghouat oasis in southern Algeria, during the period 1986 - 2019. The methodology employed is based on the supervised classification of four Landsat satellite images to initiate a cartographic analysis and a landscape quantification of the land use evolution. The analysis is focused on two LUC classes: built-up areas and palm groves. The results of the cartographic analysis highlighted two completely opposite spatiotemporal trends: a significant growth of built-up areas, against a considerable decline in palm groves. The monitoring of the landscape metrics also revealed two different behaviours: growth by densification and elongation of the urban fabric, versus progressive morcellation and fragmentation of the palm groves. These findings pointed to the negative impact of uncontrolled extensions on both the palm groves and the overall oasis ecosystem. This research highlighted the importance of landscape metrics in assessing various forms of spatial urban growth and may support urban planners in choosing the optimal solutions for oasis sustainability.

1. Introduction

The unbridled growth of urban centres is currently one of the major facts characterising human development (UN-Habitat, 2020). The environmental repercussions have been proven to be negative, continuing to adversely affect both local and global ecosystems. The irresponsible expansion of cities significantly contributes to the aggravation of environmental issues that increasingly threaten the equilibrium of our biosphere: depletion of natural resources, greenhouse gases emissions, climate change, and biodiversity loss (UN Environment, 2019). The biodiversity is considered to be the first casualty of the uncontrolled urban growth, a phenomenon that is particularly pronounced in developing countries (McDonald et al., 2013). The oases of the Algerian Sahara are not exempt from this situation. Urban settlements are continuously encroaching upon these sensitive areas, harming the palm groves that constitute the essential biotope of the oasis ecosystem (Kouzmine, 2012). The ecological homogeneity that has distinguished these human settlements since their genesis is currently threatened by the excessive expansion of built-up areas (Côte, 2012; Jouve & Jouve, 2012).

Eco-responsible management of oasis resources essentially requires an understanding of the oasis urbanisation phenomenon and the transformations it generates (Jia et al., 2004; C. Liu et al., 2021; Y. Liu et al., 2019). Nevertheless, the scale of these kinds of transformations is not appropriately addressed in urban planning documents. These documents have primarily been developed to quantitatively respond to the demands imposed by urbanisation. As a result, many researchers and practitioners have raised concerns about their effectiveness, particularly in terms of controlling the impacts on local environmental potential (Gherbi, 2015; Boumedine, 2013).

The application of urban landscape ecology methodologies enables an enhanced comprehension of the environmental challenges currently facing vulnerable regions, including oasis areas (Jia et al., 2004; Y. Liu et al., 2019). Urban landscape ecology is a discipline that emerged from the integration of landscape ecology and urban ecology. This association allows for the study of the structures and forms of urban landscapes while also facilitating an understanding of the conditions necessary for the flourishing of biodiversity and for the equilibrium of ecosystems (Norton et al., 2016; Wu, 2013). Therefore, this discipline provides a conceptual and methodological framework for spatial analysis and evaluation of landscape transformations that impact ecological processes and ecosystem stability, particularly those related to ecological continuity and connectivity (Breuste et al., 2008; Mörtberg et al., 2007; Wu, 2013). Uncontrolled urbanisation is widely recognised as one of the primary exogenous factors disrupting the continuity of ecological processes, by the colonisation of natural and semi-natural areas, and the fragmentation of ecological entities and corridors that host and ensure the sustainability of biodiversity (Haddad et al., 2015; Theodorou, 2022).

To understand the impacts of uncontrolled urbanisation on oasis ecosystems, the present study consists of an analysis of the spatial evolution of Laghouat oasis in southern Algeria, during the period 1986 - 2019. The starting hypothesis posits that an ecological approach can lead to the estimation of landscape transformations associated with the city's spatial growth. The methodology requires the creation of diachronic cartography to track urban evolution and the quantification of the spatial changes characterising each study stage. This approach is based on the use of satellite images and the application of landscape metrics. The research is organised into four distinct sections. The first section addresses the theoretical foundation of the study, while the second section explores the subject area and the methods employed. The third section presents and discusses the collected data, and the final section summarises our findings and includes the conclusion.

Diachronic cartography to identify landscape Transformations, the study of spatiotemporal dynamics characterising landscapes can be conducted by highlighting the diachronic change in biophysical land use. This allows the identification of converted soils and the quantification of their extent (Herold et al., 2002; Lausch et al., 2015; Norton et al., 2016; Wilson et al., 2003). This kind of research is practically based on change mapping using satellite imagery and Geographic Information Systems GIS (Buyantuyev & Wu, 2007; Lechner et al., 2012; Southworth et al., 2002). The level of analysis is that of the urban scale, which covers the whole urban perimeter and offers a synoptic view of the phenomenon studied. At this level of analysis, the landscape is perceptible to the local community and constitutes a major concern for researchers and actors engaged in spatial planning and ecosystemic sustainability (Forman & Forman, 1995; Norton et al., 2016; Turner & Gardner, 2015a).

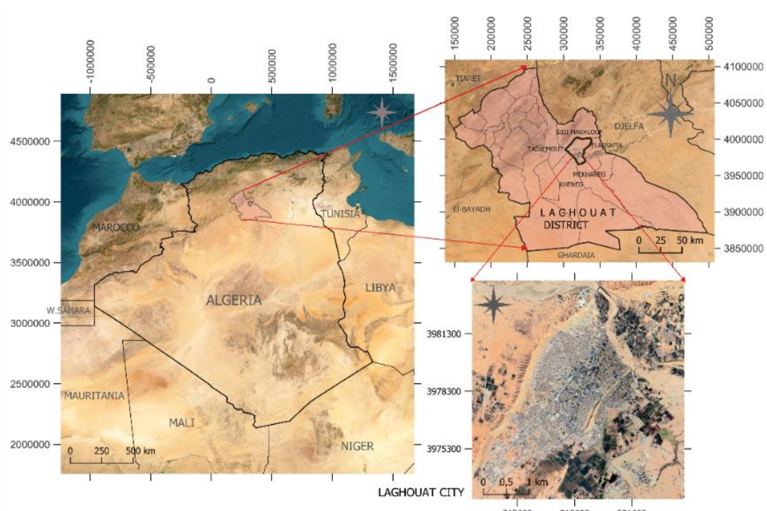
From an ecological point of view, understanding the spatial dynamics that characterise territories necessitates quantitative approaches developed in landscape ecology (Lausch et al., 2015; Turner & Gardner, 1991). Regarding urbanised territories, they are characterised by their heterogeneity and the complexity of their landscape compositions (Leitão & Ahern, 2002; Young et al., 2009). The use of landscape metrics offers the possibility of describing urban landscapes and measuring the changes affecting them over time (Breuste et al., 2008; Huang et al., 2007). These metrics were developed and applied from the 1980s onwards to describe natural landscapes and were later generalised to a variety of study fields (Aguilera et al., 2011; Turner & Gardner, 1991). Two aspects can be analysed: landscape composition, which highlights the diversity and abundance of the fragments constituting the landscape; and spatial configuration, which focuses on the shape and spatial arrangement of these different fragments. Three scales of analysis can be considered: the fragment scale (patch scale), the landscape class scale, and the overall landscape scale (Turner & Gardner, 2015b). These metrics are calculated essentially by the classification of satellite images and the use of GIS. Satellite images are employed as input support; GIS makes the mapping process, calculating these indices, and visualising the findings (McGarigal et al., 2012; O'Neill et al., 1988).

Numerous studies have demonstrated the utility of landscape metrics in monitoring the sprawl of urbanised areas and estimating the associated landscape transformations (Cai et al., 2024; Cyriac & Firoz C., 2022; Herold et al., 2002; Trinder & Liu, 2020; Wahyudi et al., 2019; Wang et al., 2018). As for oases areas, studies using this approach are also numerous. Studies have revealed the detrimental effects of human activity on the fragmentation of oases (Amaya et al., 2024; Ming et al., 2008; Xie et al., 2016; Zhang et al., 2010), while others have sought to assess spatiotemporal changes affecting oases on a broader scale (Chen et al., 2023; Jia et al., 2004; Khebour Allouche et al., 2021; Li et al., 2001; Sun & Zhou, 2016; Xie et al., 2014). However, analysis that based solely on monitoring landscape index behaviour may encounter interpretative limitations, particularly in terms of locating areas affected by the change (Cyriac & Firoz C., 2022; García-Pardo et al., 2022; Herold et al., 2005; Lausch et al., 2015; Ramachandra et al., 2012). A cartographic analysis could complement this analysis, providing a more comprehensive understanding of the landscape under investigation. This study aims to address this gap by integrating cartographic and quantitative methods to identify and quantify the changes affecting the landscape. In the context of Algerian oases, this combined methodology may offer valuable insights into the current state of the land. This research underscores the importance of landscape metrics for eco-responsible spatial planning.

2. Data and Methods

2.1. Study Area

The city of Laghouat is situated 420 km south of the capital Algiers, at a Longitude of 2° 56' East, and a Latitude of 33° 46' North, with an average altitude of 767 meters. It lies in the southern foothills of the Saharan Atlas, a mountain range separating the vast desert from northern Algeria. Laghouat is an ancient oasis and chief town of the wilaya (district) that bears its name. The old city is located on the western bank of the Oued M'zi, a dry riverbed. It is surrounded to the south by the Oued Messaad mountain, as well as to the west and northwest by the Djebel Lahmar mountain, which forms part of the Saharan Atlas' Djebels Ammour mountain range Figure 1. Laghouat climate is an arid environment with very hot and dry summers and chilly and reasonably mild winters.



Source: Authorship from Google satellite Map imagery, 2024

Figure 1. The study area (Authorship from Google satellite Map imagery)

The discovery of large hydrocarbon deposits and the designation of Laghouat city as a chief town of the wilaya in 1974 significantly enhanced the city's economic and administrative status. Laghouat has experienced a remarkable demographic boom, with its population increasing from nearly 26 000 inhabitants in 1966 to over 210 000 in 2019, a more than 8-fold increase over half a century. This demographic boom has not been matched by adequate urban infrastructure, leading to numerous challenges, particularly in the protection of the palm grove and the safeguarding of the unique local oasis landscape. These issues are central to ongoing scientific and professional discussions regarding the sustainability of this ancestral oasis (Benarfa et al., 2018; Benkouider et al., 2013; Rezzoug, 2013).

2.2. Data Used

To initiate the cartographic and landscape analysis, we explored the USGS (United States Geological Survey) free archive. Four Landsat satellite images were acquired corresponding to the following dates: 1986 (8 April, TM5 sensor), 1997 (21 March, TM5 sensor), 2008 (20 April, ETM+ sensor), and 2019 (18 March, OLI-TIRS sensor). The spatial resolution of these images is of the order of 30 m, with spectral richness covering the visible and near-infrared bands. Auxiliary documents are also used as reference maps. These include parcel plans from 1986, 1998, 2006, and 2018, and historical images provided by the USGS that correspond to the same acquisition dates as the selected images. It is essential to highlight that the spatial resolution of the images employed at this level of study, which pertains to the overall macro-form of the oasis, is potentially useful. However, for studies at finer scales, such as neighbourhoods, this spatial quality may not be relevant due to the "mixel" effect that can distort the quality of the desired thematic maps (Lu & Weng, 2007; Phiri & Morgenroth, 2017; Wahyudi et al., 2019; Wulder et al., 2012). The free software QGIS (Congedo, 2021) and FRAGSTAT (McGarigal et al., 2012) were utilised during this research to perform the classification procedure and calculate landscape metrics for each study interval.

2.3. Methodology

The monitoring and evaluation of spatiotemporal transformations characterising Laghouat Oasis from 1986 to 2019 require the creation of thematic maps for the years 1986, 1997, 2008, and 2019. In the first step, these maps will undergo a diachronic analysis of the land use evolution, in order to then proceed to the calculation and evaluation of landscape metrics for each evolutionary stage. An image classification process is performed with the objective to create thematic maps. This procedure was carried out through the following steps:

2.3.1. Pre-processing and Normalisation of Acquired Images

This step consists of a geometric correction and radiometric calibration of the raw images to homogenise their radiometry and ensure a better superposition of the different scenes collected. The study area is defined and extracted using a polygonal cut-out window that encompasses the entire oasis and its surrounding environment. The area of interest is situated between longitudes 2°48′50″ and 2°53′55″ East, and latitudes 33°45′41″ and 33°50′14″ North, based on the WGS 84 datum, zone 31 North. A false colour composition was subsequently selected Figure 2, utilising the band combinations (4-3-2) for the TM and ETM+ images and (5-4-3) for the OLI-TIRS (Congedo, 2021).

2.3.2. Classification, Enhancement, and Validation of Classification

This operation consists of generating a thematic map that represents the state of land cover at a specific date, by assigning to each pixel its corresponding biophysical land cover (Richards & Jia, 2006). Given our field expertise alongside the nature of the reference maps utilised, the supervised classification approach is adopted in the present study (Du et al., 2014; Weng, 2007). Four thematic classes have been predefined using the FAO nomenclature (FAO, 2016): (1) Urbanised areas (built and developed areas); (2) Palm grove (phoeniculture); (3) Bare soil (Unbuilt and uncultivated soils); (4) Peripheral vegetation (of farms outside the urban perimeter). It is important to note that this region is crossed by two dry wadis: the Wadi of M'zi to the east, and the Wadi of Messaad to the south of the city. These wadis are considered as bare soils. The training areas samples were

DOI: 10.14710/geoplanning.12.1.123-138

constructed by digitizing representative polygons of different classes using the "Region Growing" algorithm. The supervised classification is performed using the Maximum Likelihood algorithm (Congedo, 2021; Phiri & Morgenroth, 2017). Subsequently, a post-classification enhancement is applied to the maps generated by the classification to make them homogeneous and comparable. This enhancement involves correcting the confusion induced by the classification and the elimination of isolated pixels by applying a thresholding of 3x3 pixels (Manandhar et al., 2009).

The resulting maps undergo an accuracy assessment to ensure they are suitable for analysis. The confusion matrix and Kappa index (K) are calculated. These two indicators provide information on the classification quality obtained. The classification is statistically accepted when K value is greater than or equal to 0,8. To validate the classification, 200 control points were randomly generated on the thematic maps and matched with the reference documents (Congalton, 1991).

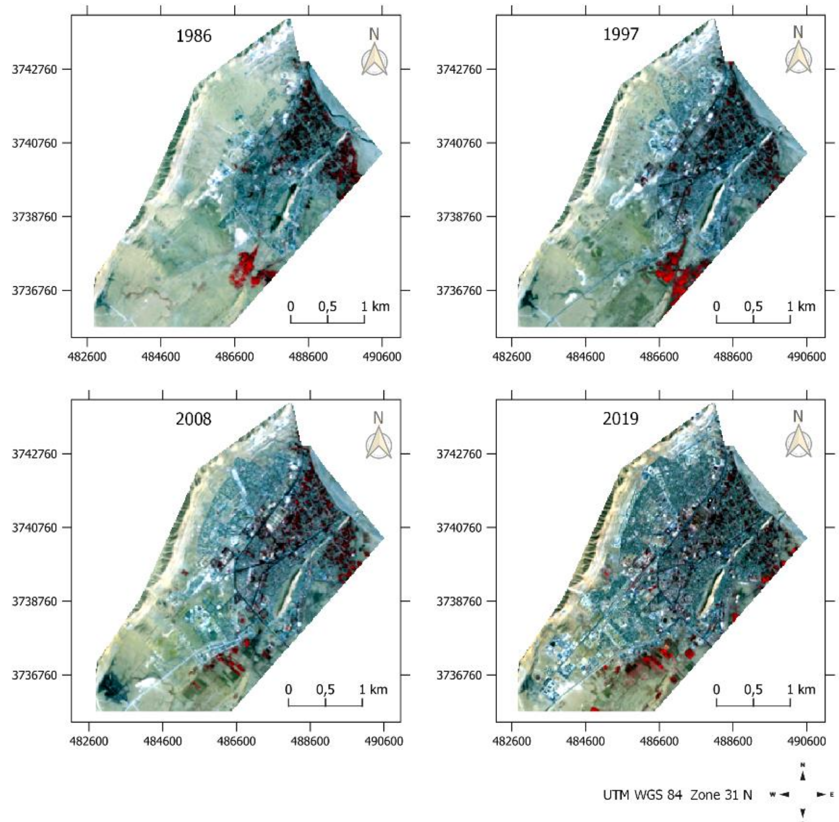
2.3.3. Calculation and Monitoring of Landscape Metrics

Considering that the current study focuses the development of land use classes, the analysis is restricted to the class level. To characterise the spatiotemporal dynamics of the Laghouat oasis, six landscape metrics were used. These metrics include the Class Area (CA), the Percentage in the Landscape (PLAN), the Number of Patches (NP), the Mean patch area (AREA_MN), the Aggregation Index (AI), and the normalised Landscape Shape Index (nLSI). The first four indices are compositional metrics, while the last two serve as spatial configuration indicators. A detailed description of these indices and their interpretations is provided in Table 1 (McGarigal et al., 2012; O'Neill et al., 1988).

Table 1. Description of Selected Metrics

Metric	Description	Interpretation
CA **(ha)**	$$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10.000}\right)$$ a_{ij}: area (m^2) of patch *ij*.	CA ≥ 1 CA is a surface indicator of composition. It indicates the spatial extent of a class in the landscape. Monitoring this index allows to reveal spatial trends (growth/decrease).
PLAND **(%)**	$$PLAND = Pi = \frac{\sum_{j=1}^{n} a_{ij}}{A} (100)$$ P_i: proportion of the landscape occupied by the class *i*. a_{ij}: area (m^2) of patch *ij*. A: total landscape area (m^2).	0 < PLAND ≤ 100 PLAND is an indicator of dominance in the studied landscape.
NP **(Units)**	$$NP = n_I$$ n_i: number of patches constituting the class *i*.	NP ≥ 1 NI reveals the abundance/rarity of fragments belonging to the same landscape class. The evolution of NI indicates the growth or decrease of the patches constituting the landscape
AREA_MN **(ha)**	$$AREA\_MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$$ x_{ij}: total class area (m^2) of patch *ij*. n_i: Number of patches constituting the class *i*.	AREA_MN ≥ 0 AREA_MN combined with NP indicates the spatial trend: growth/decrease, densification/disaggregation.
AI **(%)**	$$AI = \left[\frac{g_{ii}}{mas^{\rightarrow} g_{ii}}\right](100)$$ g_{ii}: number of like adjacencies between pixels of patch type (class) *i*. max-gii: maximum number of like adjacencies between pixels of patch type (class) *i*.	0 < AI ≤ 100 A synthetic index indicating the landscape configuration: compactness/fragmentation. AI increases: compactness of fragments increases, and vice versa.
nLSI **(Without unit)**	$$nLSI = \frac{e_i - \min e_i}{\max e_i - \min e_i}$$ e: total length of the edge of class *i*. min e: minimum total length of the edge of class *i*. max e: maximum total length of the edge of class *i*.	0 ≤ nLSI ≤ 100 nLSI decreases: compactness increases and fragments are tending towards aggregation; nLSI increases: the studied class is tending towards landscape fragmentation.

It is important to note that each of these metrics may have limitations in terms of interpretation when considered in isolation, without reference to other indices. Correlating these metrics may be necessary for meaningful spatial analysis (Feng et al., 2018; McGarigal et al., 2012; O'Neill et al., 1988).



Source: Authorship from Landsat imagery, 2024

Figure 2. Images used in false colour compositing of Landsat imagery, Combination of bands (4-3-2) for the 1986, 1997 and 2008 images, and the bands (5-4-3) for the 2019 image

3. Results and Discussion

3.1. Validation of the classification

The supervised classification has resulted in four thematic maps corresponding to the years 1986, 1997, 2008 and 2019 Figure 3. The accuracy assessment results are shown in Table 2.

Table 2. Classification Accuracy of the Resulting Thematic Maps

Type of assessment	1986	1997	2008	2019
Overall accuracy (%)	94.10	91.38	89.66	92.54
Accuracy of 'urbanised area' class (%)	95.22	92.51	89.19	92.48
Accuracy of the 'palm grove' class (%)	91.15	88.62	91.52	90.66
Kappa index (K)	0.93	0.91	0.89	0.92

The calculation of the confusion matrix for the four maps obtained has demonstrated a satisfactory level of accuracy, both for the overall accuracy (94.10, 91.38, 89.66, 92.48 respectively) and for the accuracy of the classes targeted in this study. Notably, the accuracy for the urbanised areas was 95.22, 92.51, 89.19, and 92.48 respectively, while the accuracy for palm grove was 91.15, 88.62, 91.52, and 90.66 respectively. The Kappa index

(K) also indicated an acceptable level of accuracy; with values of 0.93, 0.91, 0.89, and 0.92 for the years 1986, 1997, 2008, and 2019 respectively. This level of performance has been achieved through post-processing enhancements consisting of the correction of some classification confusions between the built-up area class and the bare soil class, mostly located outside the urban area.

3.2. Land Use Evolution Cartography: Two Opposite Trends

Four thematic maps were generated from the satellite image classification presented above Figure 3. These maps illustrate the spatiotemporal land use evolution characterising Laghouat Oasis during the period from 1986 to 2019.

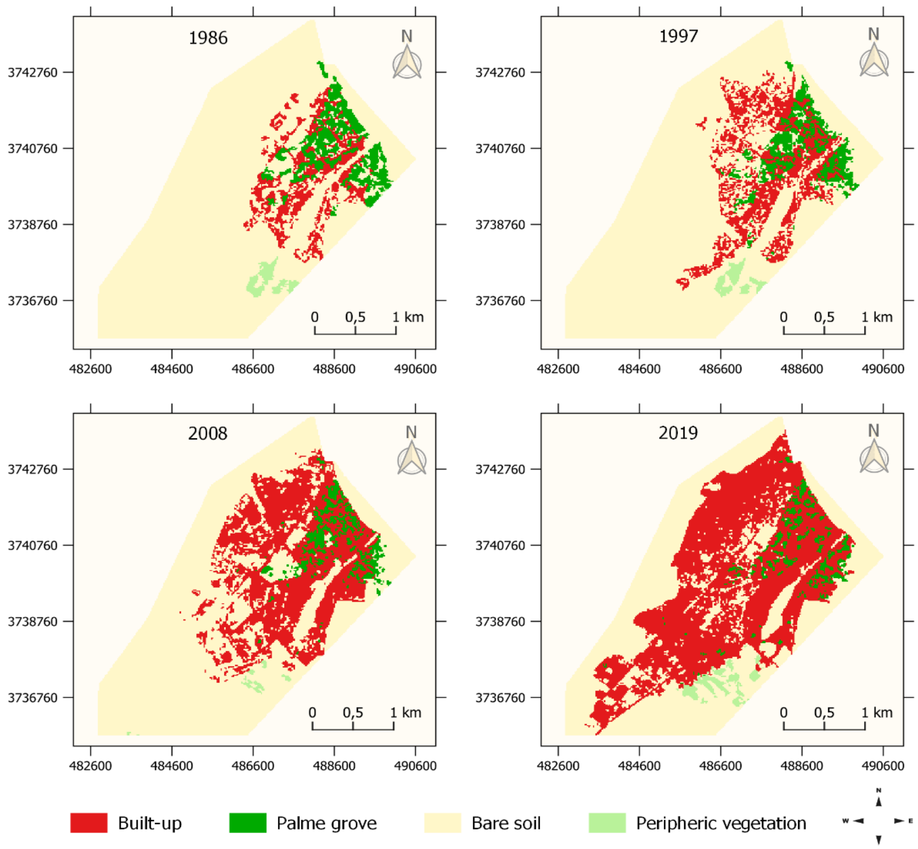


Figure 3. Spatiotemporal Evolution of Land Use Classes between 1986 and 2019

The diachronic interpretation of these maps reveals a notable growth of the urban fabric, characterized by variations in both form and direction, alongside a consistent reduction in the palm groves area. Several landscape forms can be distinguished. The 1986 map shows a balanced landscape between the two spatial components, the city, and the palm grove. The latter occupies the eastern part of the oasis and has a relatively compact form. The built and agricultural spaces appear to be distinct, with only a few small fragments located within the palm grove, in close proximity to the urban fabric. The eastern strip of the palm grove is largely devoid of buildings, presenting itself as a homogeneous and continuous spatial entity. This state of spatial compactness has been maintained to this date due to the regulations in effect during this period, specifically the 1984 regulation that prohibited construction within this green zone.

During this first period, the urban fabric is situated in close proximity to the palm grove, representing the original form of oasis morphology. However, the presence of several urban fragments detached from the central city is evident. These fragments constitute the newly urbanized areas, which are typically located to the north of the northern palm grove and to the east of the city, extending from the old fabric along the National Road NR° 01.

The 1997 map illustrates the beginning of sprawl of the urbanized area class. This sprawl is oriented in two main directions: north-westward from the city, and south-eastward in continuity with the old urban fabric. It is also noticeable that the inner parts of the palm grove have started to be encroached upon by the built-up class, affecting both the northern and southern palm groves. This marks the onset of a conversion process of agricultural land, initiated by the repeal of the 1984 local regulations designed to protect the palm grove. Furthermore, the spatial growth form of the city is increasingly leaning towards morphological fragmentation, as evidenced by the emergence of newly built fragments on the outskirts of the city. This fragmentation impacts the compactness of the urban macroform, leading to a gradual elongation of the urban perimeter.

The newly urbanized areas, especially those in the northwest and south of the city, are shown to be expanding according to the 2008 map. The new districts of the northwest have recorded dynamics of spatial densification due to the realization of the housing and important infrastructure programs launched during this same period (the first five-year program 1999 - 2004, and the second program 2005 - 2010). The growth of informal residential neighborhoods, which spread particularly in the southern and western peripheral regions, has also contributed to the sprawl of the urban class during this third period of evolution. The vegetation has continued to lose surface area, particularly along the northern and southern borders of the two palm groves.

The latest map of 2019 clearly shows a significant expansion of the urban patch, with a larger scale than in previous periods. The built-up areas have reached the natural boundaries of the oasis: the "Djebel Lahmar" to the northwest and the peripheral farms to the south. Reaching these natural limits has led to the densification until saturation of the urban fabric in these parts of the city. A new spatial growth process is also noticed in the southern zone, marked by the appearance of new built-up areas that have evolved along the "District Road CW230", extending beyond the territorial limits of Laghouat municipality. Following this urbanization axis has imparted a more elongated form to the urban macroform. Conversely, we also notice the disappearance of several green fragments in the hearts of the two palm groves. The green urban fabric has clearly become fragmented due to the encroachment of built-up areas.

Overall, the changing cartography illustrated in Figure 3 reveals a clear expansion of urbanized areas against a significant decline in the palm grove. The sprawl of the built-up class has followed three main directions: northwest reaching the physical limit constituted by the mountain of Djebel Lahmar; southwest along the CW230 road axis; and into the palm grove itself. This sprawl has become more pronounced during the last period (2008 - 2019), resulting in a more elongated urban macroform. In contrast, a decrease in the land area has characterised the palm grove class. The loss of agricultural land began first (between 1986 and 1997) with the construction of plots bordering the built-up areas, followed by an axial penetration into the palm grove from the old urban fabric. This conversion process of agricultural land continued steadily until urbanisation of the palm grove heart and the disappearance of large green plots.

3.3. Landscape Quantification of Land Use Change

This part of the analysis seeks to describe the landscape forms characterising the Laghouat oasis over the period 1986 - 2019, by monitoring landscape composition indicators (CA, PLAND, NP and AREA_MN), followed by synthetic configuration indicators (AI and nLSI). The aim is to measure the surface portion occupied by each LUC class on the one hand, and the level of compactness or spatial fragmentation of the studied LUC classes on the other

3.3.1. Landscape Composition Evolution: CA and PLAND.

The temporal evolutions of land use classes and the corresponding changes in their spatial extent are analysed across three interval 1986 - 1997, 1997 – 2008, and 2008 - 2019. The analysis will then focus solely on the two classes targeted in the present study (Built-up areas and Palm groves).The results of the evolution of land use class areas are illustrated in Table 3 and Figure 4. Table 3 shows the area quantification of the land use classes calculated from the thematic cartography presented in Figure 3. Figure 4 specifically highlights the evolution of the two classes targeted in this study: the built-up area and the palm grove.

Continuous growth has been observed in the built-up area class. The area expanded from 300.33 hectares in 1986 to 1647.09 ha in 2019, with intermediate values of 518.67 ha in 1997 and 1002.51 ha in 2008. The surface area gains were 218.34 ha from 1987 to 1997, 483.84 ha from 1997 to 2008, and 644.58 ha from 2008 to 2019. These gains correspond to annual surface area consumption estimates of +19.85 ha, +43.99 ha, and +58.60 ha for the periods 1986 to 1997, 1997 to 2008, and 2008 to 2019, correspondingly. An increasing rate of annual evolution is noticed for this class of buildings. In contrast, the palm grove class has been marked by a continuous decrease in its surface area. It decreased from 243.81 ha in 1986 to 122.94 ha in 2019, passing through 213.75 ha in 1997 and 155.34 ha in 2008. The losses in area for this class are as follows: -30.06 ha during the period (1986 - 1997), -58.41 ha during the second period (1997 - 2008), and -32.40 ha during the last period (2008 - 2019). The rates of annual loss vary across these periods, with recorded annual losses of -2.73 ha/year, -5.31 ha/year and -2.95 ha/year for the periods 1986 - 1997, 1997 – 2008, and 2008 - 2019 respectively. The most accelerated rate of loss corresponds to the second period between 1997 and 2008, with an estimated annual loss of 5.31 ha/year. The third class, peripheral vegetation, has recorded the following values: 45.45 ha, 41.76 ha, 15.48 ha, and 62.19 ha for the years 1986, 1997, 2008 and 2019, respectively. This green class has recovered in the last period (2008 - 2019) after experiencing a decline in the first two study periods. The area of the bare soil class has steadily decreased in favour of the other classes, with the following decreasing values: 2932.02 ha in 1986, 2747.43 ha in 1997, 2347.92 ha in 2008, and 1689.39 ha in 2019. In Figure 4 shows the spatial evolution dynamics of the two classes examined in this study: the built-up areas and the palm grove.

Table 3. Evolution of the Class Areas (CA) between 1986 and 2019

Land use class	Class Area (ha)				Annual Evolution (ha/year)		
	1986	1997	2008	2019	1986 - 1997	1997 - 2008	2008 - 2019
Built-up area	300.33	518.67	1002.51	1647.09	+19.85	+43.99	+58.60
Palm grove	243.81	213.75	155.34	122.94	- 2.73	- 5.31	- 2.95
Peripheral vegetation	45.45	41.76	15.48	62.19	- 0.34	- 2.39	+4.25
Bare soil	2932.02	2747.43	2347.92	1689.39	-16.78	-36.32	-59,87

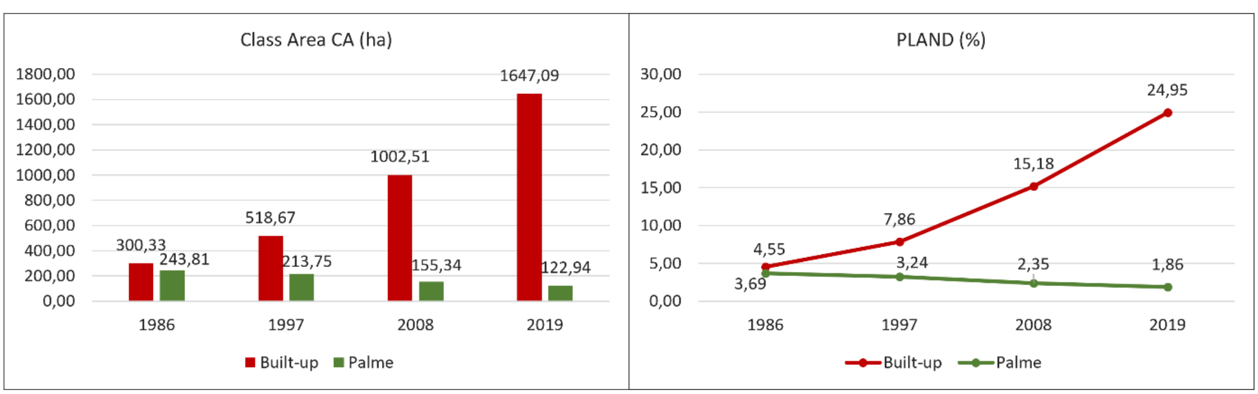


Figure 4. Spatiotemporal Evolution of CA and PLAND Indices between 1986 and 2019

In terms of land area, the proportion occupied by urbanised areas has recorded a remarkable gain. The recorded percentages are as follows: 4.55 % in 1986, 7.86 % in 1997, 15.18 % in 2008, and 24.95 % in 2019, i.e., a global gain estimated at 448.43 % and a multiplication of surface area exceeding 5 times (5.48) compared to the

DOI: 10.14710/geoplanning.12.1.123-138

surface area measured in 1986. Conversely, the palm grove has seen a decline in its surface share, with the following decreasing percentages: 3.69 % in 1986, 3.24 % in 1997, 2.35 % in 2008, and 1.86 % in 2019. Approximately 49.57 % of the agricultural area disappeared between 1986 and 2019, decreasing from 243.81 ha in 1986 to 122.94 ha in 2019. Returning to the thematic cartography, it can be seen that the lost agricultural areas are mostly converted into built-up area or have become uncultivated plots suitable to be built on in the future.

3.3.2. NP and AREA_MN Indices

The spatiotemporal evolution of the last two indicators of oasis landscape composition NP (Number of Fragments) and AREA_MN (Mean patch Area) is illustrated in Figure 5. The correlation of these two indices reveals the spatial trend characterising each of the two classes studied within the urban perimeter.

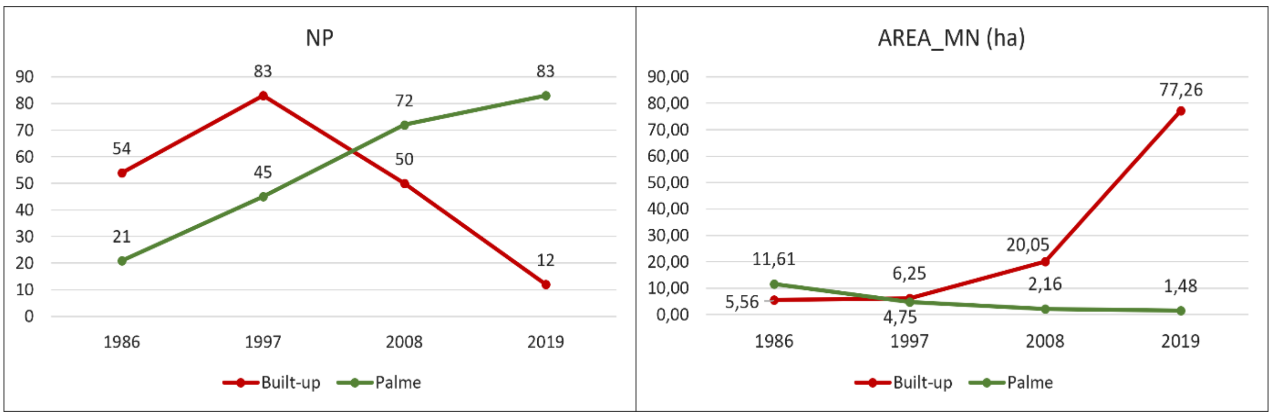


Figure 5. Spatiotemporal Evolution of NP and AREA_MN Between 1986 and 2019

The number of urbanised fragments recorded by NP has exhibited a fluctuating trend: an increase from 54 to 83 fragments between 1986 and 1997, followed by a steady decline during the subsequent study periods (with 50 fragments in 2008 compared to 12 fragments in 2019). Concurrently, the mean size of these built fragments (AREA_MN) has shown a consistent increase over the entire study period, but with a less pronounced rhythm distinguishing the first period (1986 - 1997). The values obtained are as follows: 5.56 ha in 1986, 6.25 ha in 1997, 20.05 ha in 2008, and 77.26 ha in 2019. This growth is characterised by an amplification of the pace, which is more pronounced in the last period (2008 - 2019).

The increase in the number of built-up fragments accompanied by a slight increase in the mean size of these fragments means the emergence of new, smaller, and less dense urbanised areas in the peripheral zones (new town). Conversely, the decrease of NP during the last two study intervals (1997 - 2008 and 2008 - 2019) coupled with a clear increase of the AREA_MN index indicates a merging process of certain urban fragments to form larger entities. The new urbanised areas have undergone a process of densification and spatial continuous growth to join the neighbouring fragments and to form a cohesive built entity. As for the palm grove class, the number of agricultural fragments has increased throughout the entire study period. The number of fragments NP rose from 21 in 1986 to a total of 83 in 2019, with intermediate values of 45 in 1997 and 72 in 2008. However, the rate of growth for NP has relatively decreased during the last period (2008 - 2019) compared to previous periods. Additionally, the mean size of agricultural fragments AREA_MN has continuously declined. The measured values are as follows: 11.61 ha, 6.25 ha, 2.16 ha, and 1.48 ha for the years 1986, 1997, 2008, and 2019 respectively.

An increase in the NP index accompanied with a decrease in the AREA_MN index over the entire study period is noted. This finding indicates that the palm grove class is being decomposed into smaller fragments with significant losses in the profile of the built-up class. The pace of this conversion trend in agricultural areas began to slow down from 2008.

3.3.3. The Spatial Configuration Indices AI and nLSI

In order to better describe the spatiotemporal dynamics of landscape classes evolution, it is important to complete the analysis by monitoring the synthetic configuration indices. The results of the calculation for the AI and nLSI indicators are shown in Figure 6; illustrates the varied behaviour of the indices monitored for the two classes targeted in this study. For the first class, that of built-up areas, the aggregation index AI exhibited relative stagnation during the initial study period, with closely aligned values of 73.57 % in 1986 and 73.74 % in 1997. However, from the second study period onwards, AI starts to register rising values: 85.48 % in 2008 and 90.89 % in 2019. Concurrently, the nLSI index of the same class has also recorded stagnation during the first period, maintaining a value of 0.26 for the two years 1986 and 1997, and then began to have decrease values for the following periods, reaching 0.15 in 2008 and 0.09 in 2019. The stagnation of the compactness indices for the built-up area class means that the spatial growth has followed a balanced pattern, characterised by both continuous extensions of the existing urban fabric and discontinuous extensions into new peripheral areas, a result supported by the increase in the number of fragments outlined above. The rise in AI values, coupled with the decrease in nLSI values during the second and final study periods indicates that the compact mode is more characteristic. The urban extensions took place either by densification of vacant pockets or by spatial continuity with existing areas. From 1997 onwards, the urban fabric began to have more compact forms.

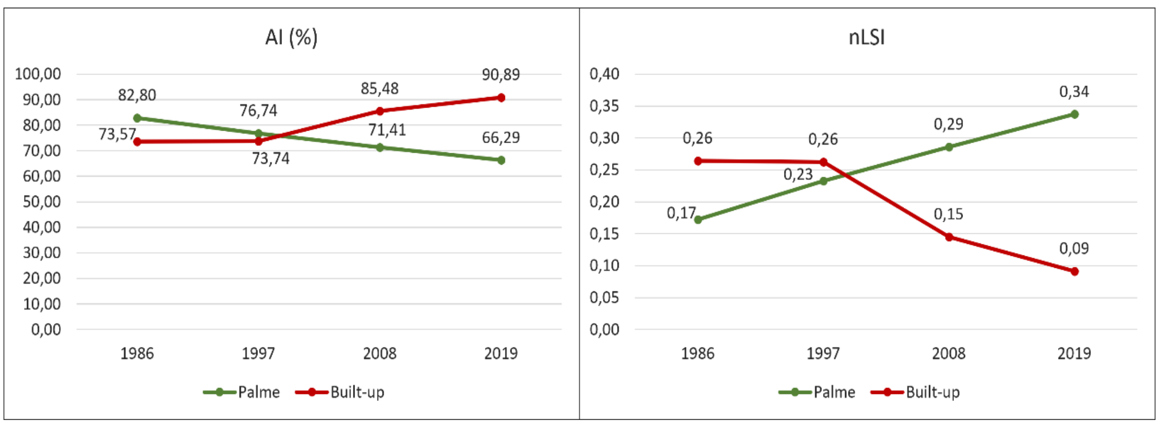


Figure 6. Evolution of Configuration Indices AI and nLSI Between 1986 and 2019

In contrast to this development, the palm grove class has experienced a steady decrease in its AI index, with values of 82.80 %, 76.74 %, 71.42 %, and 66.29 % recorded in the years 1986, 1997, 2008 and 2019 successively. The nLSI index has also been marked by a constant growth during the same study periods, with measured values of 0.17, 0.23, 0.29, and 0.34 in 1986, 1997, 2008 and 2019 respectively. The consistent decrease of AI values, coupled with the continuous increase in nLSI index indicates that the vegetation class has progressively lost its compactness, leading to more fragmented configurations of the green space. The rise in nLSI also means that the shapes of the green fragments tend to have more complex geometric forms, as the edge lengths increase. This evolution indicates that the green fragments have been subject to a nibbling process at their edges, a consequence of the encroachment of built-up areas.

The results of the present study align with previous research that applies landscape metrics in oasis contexts. The decline in urban vegetation within urban perimeters has also been documented in other Algerian cities (Dechaicha & Djamel, 2021; Gherraz et al., 2020; Teqwa Bechaa et al., 2024). In the Arab and North African context, the detrimental effects of urbanisation have been corroborated by several studies (Dechaicha et al., 2021; Gad, 2015; Khebour Allouche et al., 2021; Riad et al., 2020). Additionally, the landscape fragmentation of oases resulting from accelerated urbanisation has been demonstrated in studies conducted on a global scale (Amaya et al., 2024; Chen et al., 2023; Liu et al., 2021; Tang et al., 2019; Xue et al., 2022).

Compared to previous studies, the spatial decline and landscape fragmentation of the palm groves in our case study are more pronounced, with a loss of 49.57% of the surface area and an almost 20% increase in landscape fragmentation. This deterioration is attributed to insufficient control over urban development in the vicinity of the historic palm grove.

4. Conclusion

The goal of the current study was to draw attention to the landscape changes that have characterized the growth of Laghouat oasis from 1986 to 2019. Two methods were employed: a cartographic analysis of land use change and a quantitative analysis based on the measurement of landscape metrics at each stage of evolution.

The results of the cartographic analysis have revealed an important sprawl of the urban fabric, against progressive retreat of the urban vegetation represented by the palm groves. Three main directions have oriented the spatial growth of the urbanised areas: first, from the National Road RN 01 towards the Northwest, reaching the physical limits defined by Djebel Lahmar mountain; second, towards the Southeast, along the CW 230 road axis, until crossing the territorial boundaries of the city, resulting in a more elongated urban macroform due to these extended developments; and third, encroachments into the palm groves, starting with the conversion of the border plots to later invade the core areas of the palm groves. The results of the landscape quantification have highlighted two distinctly contrasting spatial processes: a significant growth of built-up areas, which increased during the last period (2008 - 2019), in contrast to the gradual decline of agricultural areas which were more pronounced during the second study period (1997 - 2008).

The results of the landscape metrics have also shown two distinct spatial trends: a morphological compactification trend of urbanised areas versus a continuous process of fragmentation and landscape desegregation of agricultural areas. The built-up class has experienced two successive modes of spatial growth: an initial period of spatial discontinuous growth, materialised by the appearance of new urbanised areas detached from the existing fabric, followed by a period of continuous growth materialised by the densification of new areas and the filling of unbuilt gaps. This is reflected in the increase in the average sizes of urban fragments. This growth pattern is corroborated by the results of the landscape configuration indices AI and nLSI.

The urban sprawl is characterised by two growth modes: a relatively disaggregated form, followed by a densification process in continuity with the existing neighbourhoods. In contrast, the urban vegetation has undergone a reverse process: continuous loss of surface area and compactness. The palm grove has undergone a landscape fragmentation process over the course of the research period, due to the uncontrolled growth of built-up areas. Between 1986 and 2019, the Laghouat landscape underwent a full transformation. It went from a relatively balanced form between the urban fabric and the palm grove, to an unbalanced form characterized by the predominance of the urbanised areas class over that of green areas. The latter has undergone a twofold spatial process: nibbling of the bordering areas which are in close contact with the built-up areas, and the conversion of the plots located in the heart of the northern and southern palm groves, which has led to the loss of the original form of the oasis.

The negative ecological impact of urban dynamics on oases has also been highlighted in other studies concerned with monitoring oasis spatial dynamics. The extent of this impact is more noticeable in Saharan oases, where urban expansion is less controlled. The research conducted has highlighted the value of using landscape metrics as a tool to analyse the spatial forms brought about by the expansion of urban areas and assess how these forms affect the oasis potential. These measures can be useful tools to aid in optimizing spatial design decisions for an oasis sustainability standpoint.

5. References

Aguilera, F., Valenzuela, L. M., & Botequilha-Leitão, A. (2011). Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish metropolitan area. *Landscape and Urban Planning*, *99* (3–4), 226–238. [Crossref]

Amaya, P., Vega, V., Esenarro, D., Cuya, O., & Raymundo, V. (2024). Evaluation of the Functional Connectivity between the Mangomarca Fog Oasis and the Adjacent Urban Area Using Landscape Graphs. In *Forests* (Vol. 15, Issue 6). [Crossref]

Benarfa, K., Khalfallah, B., & Alkama, D. (2018). Rôle de la règlementation urbaine dans la préservation de l'Oasis de Laghouat (The role of urban regulation in the preservation of the Oasis of Laghouat). *Courrier Du Savoir*, *26*, 175–186. http://revues.univ-biskra.dz/index.php/cds/article/download/3931/3554

Benkouider, F., Abdellaoui, A., Hamami, L., & Elaihar, M. (2013). Spatio Temporal Analysis of Vegetation by Vegetation Indices from Multi-dates Satellite Images: Application to a Semi Arid Area in Algeria. *Energy Procedia*, *36*, 667–675. [Crossref]

Boumedine, R. S. (2013). *L'urbanisme en Algérie, échec des instruments ou instruments de l'échec (Urban planning in Algeria, failure of instruments or instruments of failure)*. Les alternatives urbaines.

Breuste, J., Niemelä, J., & Snep, R. P. H. (2008). Applying landscape ecological principles in urban environments. *Landscape Ecology*, *23*(10), 1139–1142. [Crossref]

Buyantuyev, A., & Wu, J. (2007). Effects of thematic resolution on landscape pattern analysis. *Landscape Ecology*, *22*(1), 7–13. [Crossref]

Cai, Y., Wu, J., Yimiti, T., Li, Z., Yang, X., & Dong, S. (2024). The landscape altered the interaction between vegetation and climate in the desert oasis of Hotan River Basin, Xinjiang, China. *Ecological Modelling*, *491*, 110687. [Crossref]

Chen, D., Zhang, F., Jim, C. Y., & Bahtebay, J. (2023). Spatio-temporal evolution of landscape patterns in an oasis city. *Environmental Science and Pollution Research*, *30*(2), 3872–3886. [Crossref]

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, *37*(1), 35–46. [Crossref]

Congedo, L. (2021). Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. *Journal of Open Source Software*, *6*(64), 3172. [Crossref]

Côte, M. (2012). *Signatures sahariennes: terroirs & territoires vus du ciel (Saharan signatures: terroirs & territories seen from the sky)*. Presses universitaires de Provence.

Cyriac, S., & Firoz C., M. (2022). A Bibliometric Review of Publication Trends in the Application of Landscape Metrics in Urban and Regional Planning. *Papers in Applied Geography*, *8*(3). [Crossref]

Dechaicha, A., Daikh, A., & Alkama, D. (2021). Monitoring and Landscape Quantification of Uncontrolled Urbanisation in Oasis Regions: The Case of Adrar City in Algeria. *Journal of Contemporary Urban Affairs*, *5*(2 SE-Original Researches), 209–219. [Crossref]

Dechaicha, A., & Djamel, A. (2021). Suivi et quantification de l'urbanisation incontrôlée: une approche basée sur l'analyse multitemporelle des images satellitaires LANDSAT. Cas de la ville de Bou-Saada (Algérie). *Revue Française de Photogrammétrie et de Télédétection*, *223*(SE-Numéro spécial Afrique), 159–172. [Crossref]

Du, P., Liu, P., Xia, J., Feng, L., Liu, S., Tan, K., & Cheng, L. (2014). Remote Sensing Image Interpretation for Urban Environment Analysis: Methods, System and Examples. *Remote Sensing*, *6*(10), 9458–9474. [Crossref]

FAO. (2016). *Land Cover Classification System - Classification concepts.* http://www.fao.org/publications/card/en/c/93c7a130-2f12-4f7a-a317-011eef91c5af

Feng, Y., Liu, Y., & Tong, X. (2018). Spatiotemporal variation of landscape patterns and their spatial determinants in Shanghai, China. *Ecological Indicators*, *87*, 22–32. [Crossref]

Forman, R. T., & Forman, R. T. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press.

Gad, A.-A. (2015). Land capability classification of some western desert Oases, Egypt, using remote sensing and GIS. *The Egyptian Journal of Remote Sensing and Space Science*, *18*(1, Supplement 1), S9–S18. [Crossref]

García-Pardo, K. A., Moreno-Rangel, D., Domínguez-Amarillo, S., & García-Chávez, J. R. (2022). Remote sensing for the assessment of ecosystem services provided by urban vegetation: A review of the methods applied. *Urban Forestry & Urban Greening*, *74*, 127636. [Crossref]

Gherbi, M. (2015). Instruments of Urban Planning in Algerian City: Reality and Challenges. *Journal of Civil Engineering and Architecture*, *9*(7), :

Gherraz, H., Guechi, I., & Alkama, D. (2020). Quantifying the effects of spatial patterns of green spaces on urban climate and urban heat island in a semi-arid climate. *Bulletin de La Société Royale Des Sciences de Liège*, *89*, 164–185. [Crossref]

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2), e1500052 [Crossref]

Herold, M., Couclelis, H., & Clarke, K. C. (2005). The role of spatial metrics in the analysis and modeling of urban land use change. *Computers, Environment and Urban Systems*, *29*(4), 369–399. [Crossref]

Herold, M., Scepan, J., & Clarke, K. C. (2002). The Use of Remote Sensing and Landscape Metrics to Describe Structures and Changes in Urban Land Uses. *Environment and Planning A: Economy and Space*, *34*(8), 1443–1458. [Crossref]

Huang, J., Lu, X. X. X., & Sellers, J. M. (2007). A global comparative analysis of urban form: Applying spatial metrics and remote sensing. *Landscape and Urban Planning*, *82*(4), 184–197. [Crossref]

Jia, B., Zhang, Z., Ci, L., Ren, Y., Pan, B., & Zhang, Z. (2004). Oasis land-use dynamics and its influence on the oasis environment in Xinjiang, China. *Journal of Arid Environments*, *56*(1), 11–26. [Crossref]

Jouve, J., & Jouve, P. (2012). Les oasis du Maghreb, des agro-écosystèmes de plus en plus menacés. Comment renforcer leur durabilité? (The oases of the Maghreb, agro-ecosystems increasingly threatened. How to enhance their sustainability?). *Courrier de l'environment de l'INRA*, *62*(62), 113–121. https://hal.archives-ouvertes.fr/hal-01222196/

Khebour Allouche, F., Abidi, I., Delaître, E., Abu-hashim, M. S. D., Ouerchfeni Bousaida, D., Hamad, S., & Riahi, R. (2021). *Assessing Tunisian Oasis Dynamics Using Earth Observation and Landscape Metrics: Case of Djerid and Nefzaoua Regions BT - Environmental Remote Sensing and GIS in Tunisia* (F. Khebour Allouche & A. M. Negm (eds.); pp. 285–301). Springer International Publishing. [Crossref]

Kouzmine, Y. (2012). *Le Sahara algérien. Intégration nationale et développement régional (The Algerian Sahara. National integration and regional development)*. L'Harmattan.

Lausch, A., Blaschke, T., Haase, D., Herzog, F., Syrbe, R.-U., Tischendorf, L., & Walz, U. (2015). Understanding and quantifying landscape structure – A review on relevant process characteristics, data models and landscape metrics. *Ecological Modelling*, *295*, 31–41. [Crossref]

Lechner, A. M., Langford, W. T., Bekessy, S. A., & Jones, S. D. (2012). Are landscape ecologists addressing uncertainty in their remote sensing data? *Landscape Ecology*, *27*(9), 1249–1261. [Crossref]

Leitao, A. B., & Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and urban planning*, *59*(2), 65-93. [Crossref]

Li, X., Lu, L., Cheng, G., & Xiao, H. (2001). Quantifying landscape structure of the Heihe River Basin, north-west China using FRAGSTATS. *Journal of Arid Environments*, *48*(4), 521–535. [Crossref]

Liu, C., Zhang, F., Carl Johnson, V., Duan, P., & Kung, H. (2021). Spatio-temporal variation of oasis landscape pattern in arid area: Human or natural driving? *Ecological Indicators*, *125*, 107495. [Crossref]

Liu, Y., Song, W., & Deng, X. (2019). Understanding the spatiotemporal variation of urban land expansion in oasis cities by integrating remote sensing and multi-dimensional DPSIR-based indicators. *Ecological Indicators*, *96*, 23–37. [Crossref]

Lu, D., & Weng, Q. (2007). A survey of image classification methods and techniques for improving classification performance. *International Journal of Remote Sensing*, *28*(5), 823–870. [Crossref]

Manandhar, R., Odeh, I. O. A., & Ancev, T. (2009). Improving the Accuracy of Land Use and Land Cover Classification of Landsat Data Using Post-Classification Enhancement. In *Remote Sensing* (Vol. 1, Issue 3). [Crossref]

McDonald, R. I., Marcotullio, P. J., & Güneralp, B. (2013). Urbanization and Global Trends in Biodiversity and Ecosystem Services. In T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, & C. Wilkinson (Eds.), *Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment* (pp. 31–52). Springer Netherlands. [Crossref]

McGarigal, K., Cushman, S. A., & Ene, E. (2012). FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. *Computer Software Program Produced by the Authors at the University of Massachusetts, Amherst. https://www.fragstats.org/*

Ming, G., Wenbing, Y., Mingguo, M., & Xin, L. (2008). Study on the oasis landscape fragmentation in northwestern China by using remote sensing data and GIS: a case study of Jinta oasis. *Environmental Geology*, *54*(3), 629–636. [Crossref]

Mörtberg, U. M., Balfors, B., & Knol, W. C. (2007). Landscape ecological assessment: A tool for integrating biodiversity issues in strategic environmental assessment and planning. *Journal of Environmental Management*, *82*(4), 457–470. [Crossref]

Norton, B. A., Evans, K. L., & Warren, P. H. (2016). Urban Biodiversity and Landscape Ecology: Patterns, Processes and Planning. *Current Landscape Ecology Reports*, *1*(4), 178–192. [Crossref]

O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L., Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988). Indices of landscape pattern. *Landscape Ecology*, *1*(3), 153–162. [Crossref]

Phiri, D., & Morgenroth, J. (2017). Developments in Landsat Land Cover Classification Methods: A Review. *Remote Sensing*, *9*(9), 967. [Crossref]

Ramachandra, T., Aithal, B. H., & Sanna, D. D. (2012). Insights to urban dynamics through landscape spatial pattern analysis. *International Journal of Applied Earth Observation and Geoinformation*, *18*, 329–343. [Crossref]

Rezzoug, A. (2013). *Laghouat : de l'oasis à la fabrication durable de la métropole (Laghouat: from oasis to sustainable metropolis)*. Thesis dissertation. Univ. Paris 10.

Riad, P., Graefe, S., Hussein, H., & Buerkert, A. (2020). Landscape transformation processes in two large and two small cities in Egypt and Jordan over the last five decades using remote sensing data. *Landscape and Urban Planning*, *197*, 103766. [Crossref]

Richards, J. A., & Jia, X. (2006). *Remote Sensing Digital Image Analysis: An Introduction* (4th ed.). Springer. [Crossref]

Southworth, J., Nagendra, H., & Tucker, C. (2002). Fragmentation of a Landscape: Incorporating landscape metrics into satellite analyses of land-cover change. *Landscape Research*, *27*(3), 253–269. [Crossref]

Sun, B., & Zhou, Q. (2016). Expressing the spatio-temporal pattern of farmland change in arid lands using landscape metrics. *Journal of Arid Environments*, *124*, 118–127. [Crossref]

Tang, J., Di, L., Rahman, M. S., & Yu, Z. (2019). Spatial–temporal landscape pattern change under rapid urbanization. *Journal of Applied Remote Sensing*, *13*(2), 24503. [Crossref]

Teqwa Bechaa, Krimo Dahmani, Djamel Alkama, & Assoule Dechaicha. (2024). The role and impact of vegetation on the urban fabric. Case of Guelma City. *International Journal of Innovative Technologies in Social Science, 3(43).* [Crossref]

Theodorou, P. (2022). The effects of urbanisation on ecological interactions. *Current Opinion in Insect Science*, *52*, 100922. [Crossref]

Trinder, J., & Liu, Q. (2020). Assessing environmental impacts of urban growth using remote sensing. *Geo-Spatial Information Science*, *23*(1), 20–39. [Crossref]

Turner, M. G., & Gardner, R. H. (1991). *Quantitative methods in landscape ecologythe analysis and interpretation of landscape heterogeneity*. Springer-Verlag.

Turner, M. G., & Gardner, R. H. (2015a). Introduction to Landscape Ecology and Scale. In M. G. Turner & R. H. Gardner (Eds.), *Landscape Ecology in Theory and Practice* (pp. 1–32). Springer New York. [Crossref]

Turner, M. G., & Gardner, R. H. (2015b). Landscape Metrics. In M. G. Turner & R. H. Gardner (Eds.), *Landscape Ecology in Theory and Practice: Pattern and Process* (pp. 97–142). Springer New York. [Crossref]

UN-Habitat. (2020). *World Cities Report 2020: The Value of Sustainable Urbanization*. https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization

UN Environment. (2019). *Global Environment Outlook – GEO-6: Healthy Planet, Healthy People*. [Crossref]

Wahyudi, A., Liu, Y., & Corcoran, J. (2019). Combining Landsat and landscape metrics to analyse large-scale urban land cover change: a case study in the Jakarta Metropolitan Area. *Journal of Spatial Science*, *64*(3), 515–534. [Crossref]

Wang, C., Wang, Y., Wang, R., & Zheng, P. (2018). Modeling and evaluating land-use/land-cover change for urban planning and sustainability: A case study of Dongying city, China. *Journal of Cleaner Production*, *172*, 1529–1534. [Crossref]

Weng, Y.-C. (2007). Spatiotemporal changes of landscape pattern in response to urbanization. *Landscape and Urban Planning*, *81*(4), 341–353. [Crossref]

Wilson, J. S., Clay, M., Martin, E., Stuckey, D., & Vedder-Risch, K. (2003). Evaluating Environmental Influences of Zoning in Urban Ecosystems with Remote Sensing. *Remote Sensing of Environment*, *86*(3), 303–321. [Crossref]

Wu, J. (2013). Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. *Landscape Ecology*, *28*(1), 1–11. [Crossref]

Wulder, M. A., Masek, J. G., Cohen, W. B., Loveland, T. R., & Woodcock, C. E. (2012). Opening the archive: How free data has enabled the science and monitoring promise of Landsat. *Remote Sensing of Environment*, *122*, 2–10. [Crossref]

Xie, Y., Gong, J., Sun, P., & Gou, X. (2014). Oasis dynamics change and its influence on landscape pattern on Jinta oasis in arid China from 1963a to 2010a: Integration of multi-source satellite images. *International Journal of Applied Earth Observation and Geoinformation*, *33*, 181–191. [Crossref]

Xie, Y., Gong, J., Sun, P., Gou, X., & Xie, Y. (2016). Impacts of major vehicular roads on urban landscape and urban growth in an arid region: A case study of Jiuquan city in Gansu Province, China. *Journal of Arid Environments*, *127*, 235–244. [Crossref]

Xue, J., Gui, D., Zeng, F., Yu, X., Sun, H., Zhang, J., Liu, Y., & Xue, D. (2022). Assessing landscape fragmentation in a desert-oasis region of Northwest China: patterns, driving forces, and policy implications for future land consolidation. *Environmental Monitoring and Assessment*, *194*(6), 394. [Crossref]

Young, C., Jarvis, P., Hooper, I., & Trueman, I. C. (2009). *Urban landscape ecology and its evaluation : a review*. New York : Nova Science. http://hdl.handle.net/2436/92006

Zhang, F., Tashpolat, T., Kung, H., & Ding, J. (2010). The change of land use/cover and characteristics of landscape pattern in arid areas oasis: An application in Jinghe, Xinjiang. *Geo-Spatial Information Science*, *13*(3), 174–185. [Crossref]