International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8, 2025
https://theaspd.com/index.php

The Transformation of Laghouat's Ghouts: Altered Oasis Landscapes and the Fragmentation of Urban Identity (1985–2024)

Zoubida Boulmerka[1*], Sihem Boucherit[2], Nassira Noui[3], Khaled Harizi[4]
[1]Department of Architecture, Ammar Telidji University - Laghouat (ATUL), Algeria. Laboratory for Architecture Urban Environment and Energy Efficiency, University 3 Constantine, Algeria.
[2]Architecture Department, Laboratory for Architecture Urban Environment and Energy Efficiency, University 3 Constantine, Algeria.
[3]Department of Architecture, Faculty of Earth Sciences, Badji Mokhtar Annaba University, Annaba, Algeria. Laboratory of. Architecture, urban Environment & energetique efficacity, and Laboratory of Architecture and Urbanism.
[4]Departement of Hydraulic, Laboratory for the Mobilization and Management of Water Resources; Batna 2 University, Algeria**z.boulmerka@lagh-univ.dz**

Received: 20/08/2025 ; Accepted: 30/09/2025

Abstract
Laghouat, a mid-sized oasis city on the northern fringe of the Algerian Sahara, has historically drawn its identity from the Ghouts—traditional agro-oasis gardens where date palms and crops are cultivated in hand-dug depressions that access shallow groundwater. The city's urban fabric has also been structured around the Oued M'zi, an intermittently flooded riverbed. This study examines urban transformations between 1985 and 2024, with the dual aim of quantifying vegetation decline and assessing its implications for urban identity, which is understood here as the interrelationships among built form, vegetation, and water systems. Multi-temporal Landsat imagery was processed through Google Earth Engine, focusing on April–May datasets to maximise phenological contrast. Vegetation dynamics were assessed using the Normalised Difference Vegetation Index (NDVI), while urban expansion was delineated through supervised classification. Morphological changes were further documented via high-resolution imagery (Google Earth, Maxar) and field observations. Results indicate that built-up areas expanded by 130.7% (+13.3 km²), whereas vegetated surfaces declined by 15.1% (−0.36 km²); overall vegetation cover fell from 23.3% to 8.6%, with green space per hectare reduced by 63%. Spatial analysis reveals a stratified urban landscape comprising the historic compact core, transitional hybrid zones, recent peripheral extensions, and institutional enclaves. These shifts have fragmented continuous tree canopies, weakened microclimatic regulation, and diminished the legibility of the city's oasis identity. The findings underscore the urgency of integrating oasis-based criteria into planning frameworks to reconcile demographic pressures with ecological resilience in desert-edge cities.
Keywords: *Laghouat (Algeria); Ghouts; Oasis urbanisation; Urban identity; Remote sensing; NDVI.*

INTRODUCTION

The transformation of historic cities is a significant challenge for spatial and heritage sciences. Inherited urban fabrics are often altered by globalisation, rapid urbanisation, and climate change. For example, Venice, Italy, now faces overtourism that has commodified its heritage environment. This has disrupted the balance among residents, cultural heritage, and urban identity (Kalla & Metaxas, 2024). Similar pressures affect hydraulic heritage landscapes in Saharan regions. In Tunisia's Gafsa oases, traditional gardens and irrigation systems face ongoing marginalisation. These include foggaras, which are subterranean galleries channelling groundwater (similar to qanats), and mkayel, or surface canals and calibrated devices for equitable water distribution. Urbanisation, mechanised water extraction, tourism, and modern irrigation systems have all contributed to these changes. This process marks a rupture with the oasis order; at Gafsa–El Guettar, the extinction and abandonment of hydraulic works combined with post-revolutionary territorial rearrangement have intensified competition over water and land resources (Mokadem et al., 2018; Carpentier & Gana, 2017). Regionally, in El Oued, Algeria, the Ghout system has receded under the combined effects of water scarcity, sand encroachment, urban sprawl, and the diffusion of modernised agricultural practices, which erode oasis agrobiodiversity and reshape the landscape and social forms (Khezzani, 2023; Daich et al., 2025). Outside the Saharan context, in Samarkand (Central Asia), landscape archaeology similarly highlights recompositions: diachronic

mapping of anthropogenic mounds (tepa) and irrigation remains reveals morphological and symbolic restructuring of the urban landscape (Mantellini et al., 2019). Collectively, these examples demonstrate that the articulation among ecological heritage, urban morphology, and social identity represents a transversal and universal issue transcending Saharan contexts alone.

From a scientific perspective, urban transformations are analysed using a range of methodological approaches. Remote sensing and vegetation indices, including the Normalised Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Soil-Adjusted Vegetation Index (SAVI), are particularly effective for monitoring intra-urban green space dynamics (Fatiha, 2013; Wu et al., 2020). In contrast, morpho-architectural methods address changes in urban form and street networks. For instance, Nassef and Ibrahim (2022) applied shape grammar to study residential housing in Cairo, Egypt, identifying generative rules of traditional urban fabric such as spatial sequences, neighbour relations, and privacy mechanisms, thereby clarifying the morphological logic of historic forms. In Tlemcen, Algeria, Boudalia (2024) examined the influence of traditional commercial spaces on street configuration, showing how urban morphology adapts to change while maintaining patrimonial and symbolic continuity. Integrative approaches that combine historical maps, satellite imagery, and Geographic Information Systems (GIS) facilitate the documentation of landscape and identity recomposition. Uhl et al. (2021) combined historical cartographies with Global Human Settlement Layer (GHSL) data to trace urban expansion patterns. Additionally, Stewart (2001) demonstrated that integrating historical plans with satellite imagery can reveal urban landscape transformations in heritage contexts.

1.1. The Rationale for Studying Oasis Urban Transformation

Heritage degradation extends beyond the loss of aesthetic value, as it also reduces climate resilience by disrupting shaded continuities and diminishing the capacity to regulate microclimates. This process further undermines urban biodiversity and interrupts the memory continuities that sustain collective identity (Erbach, 2025). Systematic documentation of these dynamics is essential for formulating preservation and adaptation strategies that are grounded in local contexts.

Building on this, since the 1970s, rapid modernisation in several Saharan cities in Algeria has often proceeded without alignment to local development logics. In Ghardaïa, Algeria, the adoption of external architectural forms has altered the Ksour (fortified villages) and disrupted the equilibrium among habitat, water, and vegetation (Bisson, 2003; Pliez, 2003). Elsewhere in Algeria, in Biskra and Touggourt, the fragmentation and loss of palm groves serve as indicators of ongoing de-oasianization (Dechaïcha & Alkama, 2021; Chaouche Bencherif, 2008). Collectively, these developments suggest that Algerian oases are undergoing rapid reconfiguration, with traditional landscape structures being increasingly marginalised in favour of standardised urban forms.

Within this evolving regional landscape, Laghouat emerges as a significant site for analysis. Situated on the right bank of the Oued M'zi —the main river traversing Laghouat— at a strategic crossroads connecting northern Algeria to the Sahara and east to west, and at an average altitude of 747 meters (Georges, 1950), its location, fertile rocky terrain, and favourable irrigation have shaped urban development around an agro-oasis system structured by Ghouts —traditional agro-oasis gardens in which date palms and associated crops are cultivated within hand-dug depressions that access shallow groundwater. These Ghouts serve as distinct landscape and identity markers. The urban identity of Laghouat has historically depended on the integration of the palm grove into the built environment and the Oued M'zi corridor, with urban planning and development regulations influencing the evolution of gardens and the oasis ecosystem (Benarfa, 2018; Benarfa, Khalfallah, & Alkama, 2024). Such arrangements, derived from vernacular hydraulic knowledge, combined urban compactness, parcel organisation, functional vegetation, and collective water management to ensure microclimatic regulation and shaded continuity. Such socio-ecological configurations are well documented across North African oases (Battesti, 2005; Idda et al., 2021).

However, since the 1980s, Laghouat has undergone accelerated transformation, including urban sprawl, morphological standardisation, and soil artificialisation, which have weakened the inherited oasis structures. At the Saharan scale, seminal studies have described the recomposition of Saharan urbanity and the erosion of oasis identity codes (Belguidoum, 2002; Bisson, 2003; Medouki & Selatnia, 2021). These dynamics are compounded by informal growth and the expansion of low bioclimatic quality housing (Korkaz & Madani, 2021), while regulatory instruments introduced since the 1980s have struggled to preserve the oasis ecosystem (Benarfa, Khalfallah, & Alkama, 2018).

In response to these transformations, this article addresses the outlined context through two primary objectives: quantifying the regression of oasis-originated vegetated spaces, with particular attention to the role of Ghouts within the urban footprint, and assessing the effects of this regression on the legibility of the city's identity, defined as the coherence among built form, vegetation framework, and hydraulic systems. The methodology integrates a Landsat time series (1985–2024) analysed using Google Earth Engine to calculate the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979; Gorelick et al., 2017; USGS, 2022), diachronic mapping of urban expansion via supervised classification with Random Forest (Belgiu & Drăguţ, 2016), and a morpho-architectural typology derived from high-resolution imagery and field surveys. This approach builds on previous research on urban extraction in arid contexts (Benkouider, Abdellaoui, & Hamami, 2019) and recent syntheses of Google Earth Engine applications (Tamiminia et al., 2020). The principal contribution of this study is to demonstrate the interdependence between ecological dynamics and urban identity in Laghouat, emphasising that the marginalisation of Ghouts has paralleled morphological standardisation and the fragmentation of identity.

1.2. Ghouts as Identity Markers of a Saharan City: The Case of Laghouat

The urban identity of Laghouat has historically centred on the relationship between the palm grove and the Oued M'zi. Collective water diversions from the riverbed irrigated gardens, fostering a compact settlement pattern that enhanced shade and regulated the microclimate. In recent decades, modern developments in the Ksar of Laghouat and its surrounding areas have led to substantial changes in both the urban fabric and land use patterns (Mahcar et al., 2024). The most widely accepted etymology attributes the name Laghouat to the Arabic phrase meaning "houses surrounded by gardens," as documented by Jean Mélia in 1923 (Mélia, 1923). The city is characterised as a large, compact oasis situated at the juncture of the northern Sahara and the southern slopes of the Saharan Atlas. Historically, Laghouat occupied a strategic position on caravan and trade routes linking northern Algeria to the Saharan interior. The city covers approximately 253 hectares (625 acres) and is believed to have undergone early development, often linked to the eleventh-century reorganisations.

This spatial arrangement underpins the persistent view of Laghouat as a "verdant threshold," where a dense palm grove shapes both settlement patterns and agricultural practices within an arid context. In addition to their productive role, Ghouts served defensive and ecological functions. During the 1852 conquest, conflict extended into the gardens and palm groves encircling the city (Monciaud, 2023). In recent years, interventions in and around the Ksar have further transformed the urban fabric and its uses (Mahcar et al., 2024).

Historical records and photographs (Figures 1–3) demonstrate the environmental significance of Ghouts, including their roles in providing shade, regulating temperature, enhancing soil fertility, and sustaining ecological continuity. Beyond their visual appeal, Ghouts represented a sophisticated territorial system that integrated collective water management, compact urban design, earthen construction, and cultivated biodiversity (Figure 4). This ancient knowledge system now faces increasing threats from mechanisation, land artificialisation, and urban expansion. Recent research documents a measurable decline in Ghouts (Remini & Kechad, 2011; Khezzani, 2023; Boulghobra, 2024), while the historical vision of the "garden city," with whitewashed houses among palm groves, is well documented in earlier sources (Baunard, 1894; Mélia, 1923).

There is an urgent need to revalorise Ghouts as both environmental assets and foundational elements of Saharan identity, as well as essential mechanisms for climate resilience and sustainable urban development.

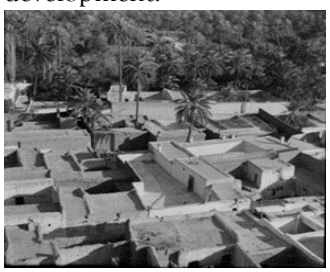

Figure 1
Traditional houses of Laghouat surrounded by gardens, with palm trees in the background.

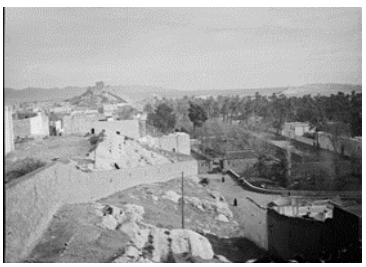

Figure 2
Panoramic view of Laghouat taken from a terrace, showing the integration of the urban fabric within the palm groves.

Figure 3
Oasis habitat in Laghouat, typical of earthen architecture integrated into the Ghouts. Photo by Philippe Joudiou.

Source: Gallica (CIRAD), National Library of France (Bibliothèque nationale de France).

Nineteenth-century colonial history had a significant impact on the identity of Laghouat. The 1852 conquest was marked by tribal resistance and Sufi mobilisations (Bouchène et al., 2014). Military accounts, such as those by Mangin (1895), documented the existence of productive palm groves and irrigation networks. These accounts use Orientalist and hierarchical frameworks. Still, they affirm the Ghouts' central role as agrarian and hydraulic landscapes. The Ghouts shaped both urban structure and social organisation. The sources highlight the resilience of an oasis system. In this system, agricultural production, water management, and compact settlement functioned as an integrated whole. In recent decades, these continuities have been undermined by urbanisation and the decline of traditional knowledge. This has led to a gradual process of identity fragmentation observed between 1985 and 2024.

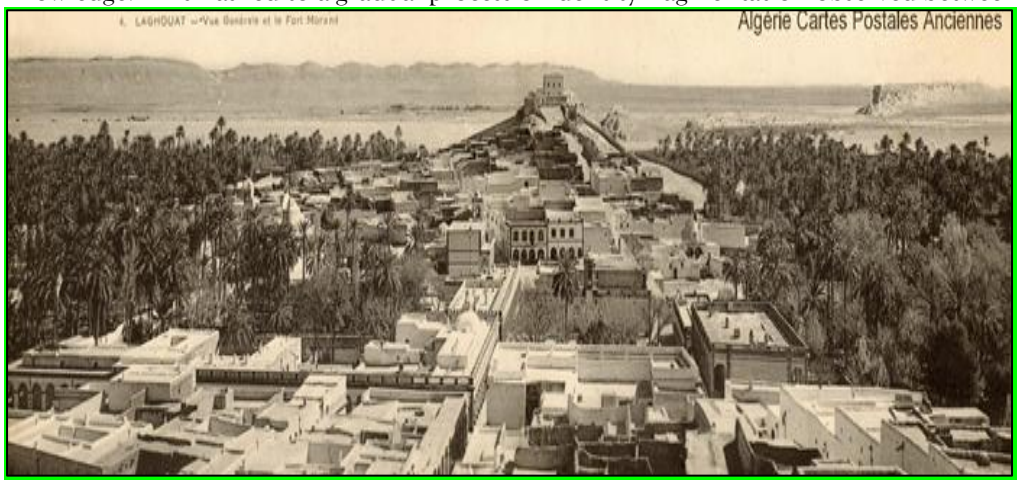

Figure 4. General view of the city of Laghouat in the early twentieth century. Source: Vintage postcard, Algérie Cartes Postales Anciennes. Author and year: Unknown.

The image in Figure 4 shows the two oases (north and south) with Fort Morand in the background. This historical photograph illustrates the integration of the Ghouts into the traditional urban fabric.

2. Presentation of the Study Area

2.1. Geographical Context

Laghouat city is located in the north-central Algerian Sahara and encompasses both pastoral and Saharan regions. The province spans 25,052 km² and holds a strategic position at the transition between steppe and desert environments. Its administrative boundaries are defined by Tiaret to the north, Djelfa to the east, El Bayadh to the west, and Ghardaïa to the south (Wilaya de Laghouat, n.d.) (see Figure 5).

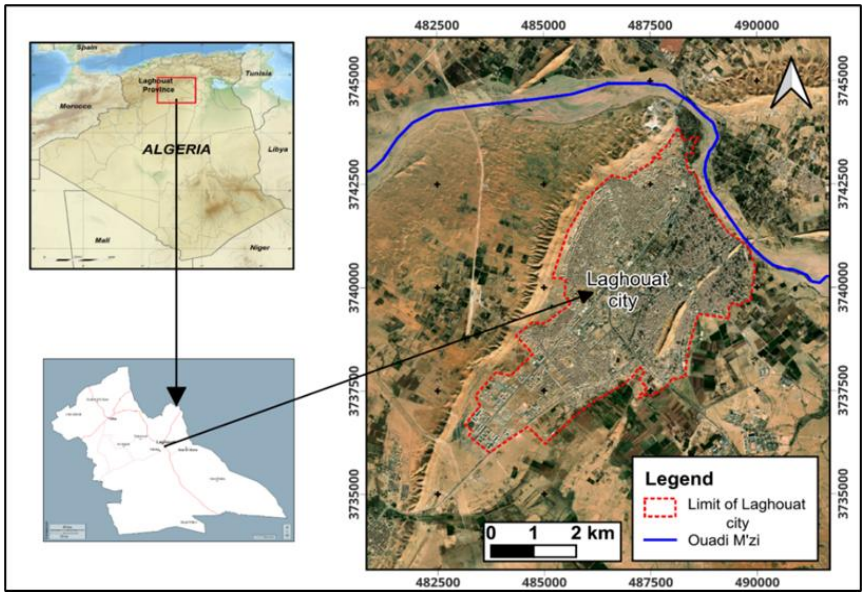

Figure 5. Geographical location of the study area: the province of Laghouat.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8, 2025
https://theaspd.com/index.php

2.2. Geomorphological Characteristics

Geomorphologically, Laghouat is divided into two principal natural units (Ministry of the Interior, n.d.). The Saharan Atlas in the northwest, particularly the Aflou and Brida regions, features elevations ranging from 1,000 to 1,700 meters and slopes of 12% to 25%. This region contains approximately 47,000 hectares of ancient forests, 315,000 hectares of esparto grasslands, and 1.5 million hectares of pastoral lands (Ministry of the Interior, n.d.). The area experiences significant aeolian activity, with sand movement extensively documented by remote sensing along the southern foothills of the Saharan Atlas near Laghouat (Abdellaoui & Marmi, 2010).

The High Plateaus and Saharan Plateaus in the southeast exhibit relatively flat topography, with elevations from 700 to 1,000 meters and slopes of 0% to 3%. These areas are dominated by extensive, though degraded, steppes covering about 1.9 million hectares (Ministry of the Interior, n.d.).

2.3. Climatic Characteristics

The climate of Laghouat Province exhibits a northwest-to-southeast gradient influenced by its topography. In the Aflou–Brida sector at the Saharan Atlas interface, the climate is characterised as continental semi-arid, with notably cold winters. Aridity intensifies toward the High Plateaus and Saharan Plateaus. The region experiences pronounced seasonality, with most rainfall occurring from autumn to spring and predominantly dry summers (Belala et al., 2018). These climatic constraints, including intense summer heat, desiccating winds, and significant thermal variation, have historically shaped the development of compact urban forms, shaded corridors, and oasis systems such as advanced water management and palm-orchard arrangements, which define the habitability and landscape identity of Laghouat (Mélia, 1923).

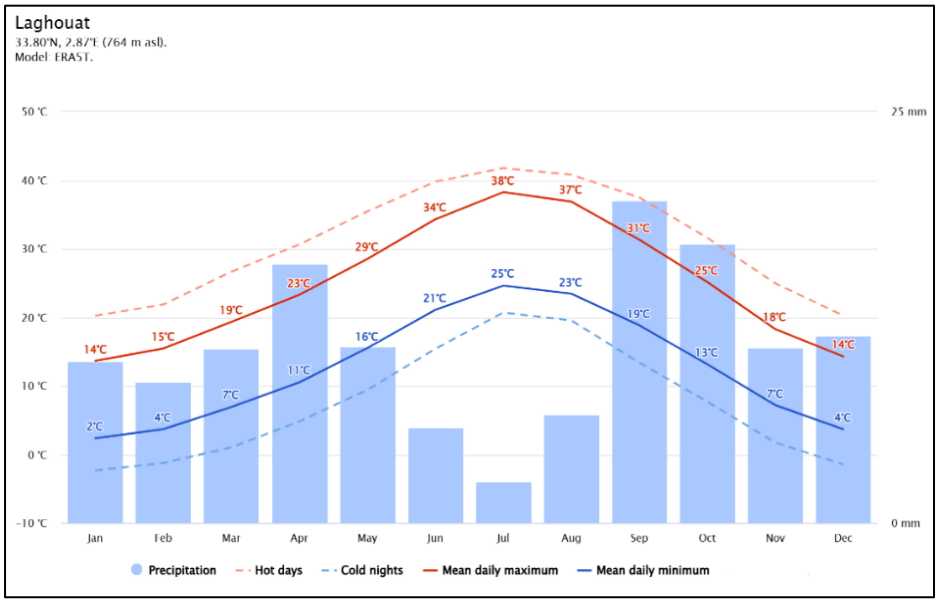

Figure 6. Mean Temperatures and Precipitation of Laghouat. Source: Meteoblue. Retrieved from https://www.meteoblue.com/fr/meteo/prevision/semaine

2.3. Urban and Demographic Evolution

Laghouat province has a total population of 730,543, with 84% residing in municipal centres, 8% in secondary agglomerations, and 8% in dispersed rural areas (Wilaya de Laghouat, n.d.). (See Figure 7). This distribution indicates a polarised and incomplete urbanisation process, marked by the concentration of activities and infrastructure in main centres and the gradual depopulation of rural areas. The average population density is 29 inhabitants per square kilometre, resulting in a generally sparse but highly uneven distribution between the urbanised northwest and the surrounding pastoral zones (Wilaya de Laghouat, n.d.; Ministère de l'Intérieur, n.d.). These demographic and spatial dynamics influence urban morphology through contrasting patterns of densification, the coexistence of traditional urban fabrics and modern extensions, and the reconfiguration of centralities. Consequently, Laghouat's urban identity is being redefined at the intersection of its oasis heritage and contemporary transformations.

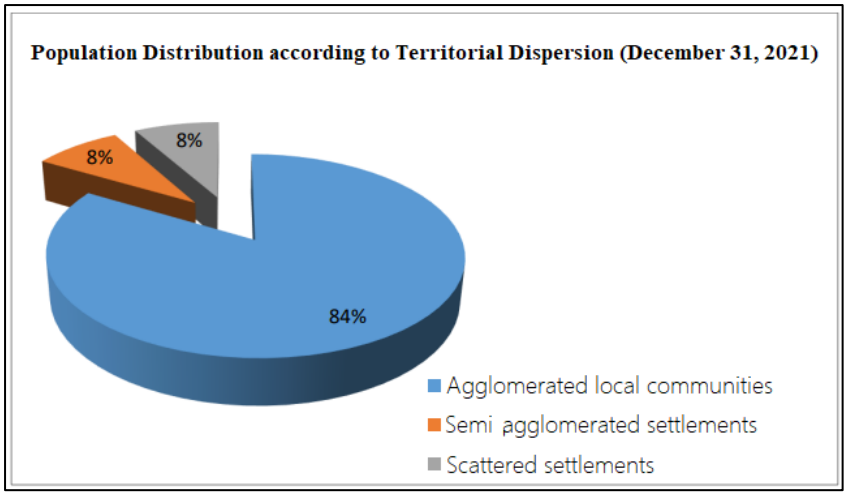

Figure 7. Population Distribution according to Territorial Dispersion. Source: Laghouat Province. Retrieved from http://www.wilaya-laghouat.dz/CTOIC/Fr/Data/Synthese_wilaya.pdf

3. MATERIALS AND METHODS

The Saharan city of Laghouat has developed a distinctive urban identity by integrating Ghouts, or traditional agro-oasis gardens, within its built environment. These gardens have historically maintained ecological, climatic, and social balance. In recent decades, however, contemporary urbanisation pressures have increasingly threatened this heritage-based urban structure. This article examines the transformation of Laghouat's urban landscape. The methodology integrates Geographic Information Systems (GIS), remote sensing through Google Earth Engine (GEE), field data, and historical cartography.

Google Earth Engine is a cloud-based platform for processing and analysing large-scale geospatial data. It offers access to a comprehensive catalogue of satellite imagery. In this research, GEE was used to extract, process, and analyse time series of satellite images, especially from the Landsat program. This approach enabled the monitoring of urban expansion and changes in green spaces using spectral indices, such as NDVI (Gorelick et al., 2017; Tamiminia et al., 2020). The resulting data were then integrated into GIS software (Quantum Geographic Information System). This enabled advanced cartographic processing, overlay with historical maps, and combination with field data. These steps facilitated a more contextualised and detailed analysis of urban dynamics. The study examines the period from 1985 to 2024, focusing on how urban growth relates to the reduction of vegetated areas (Noui et al., 2023), with special attention to the decline of the Ghouts. A typological analysis of the built environment is also conducted to evaluate the loss of architectural identity.

3.1. Data Sources and Methodological Approach

The methodological framework for this study integrates data from multiple sources. These are examined across three principal analytical dimensions: urban footprint evolution, dynamics of vegetated spaces, and morphological transformation of the built environment. Each dimension is studied from a diachronic perspective to interpret urban transformations in Laghouat over nearly four decades (1985–2024). The analysis also references a significant historical milestone in 1930. This approach is based on previous research that uses remote sensing to analyse urban dynamics in Saharan and semi-arid regions (Hartani, Baghdadi, Anteur, & Benaradj, 2021). In particular, it draws on studies focused on Saharan oasis settings (Dechaicha, Daikh, & Alkama, 2021).

The data used consist primarily of:

- Colour and wavelength-detecting images from satellites (multispectral satellite imagery, specifically Landsat 5 and Landsat 8) for tracking changes in land cover over time (spatio-temporal monitoring);
- Publicly available map data showing outlines of buildings (open-source vector data from Open Buildings) to examine building forms and patterns (morphological analysis);
- A Digital Elevation Model (DEM) to account for topographic constraints;
- Historical cartographic documents and urban development plans (Master Plan for Development and Urban Planning, PDAU) for urban contextualization.

An overview of these datasets, including their sources, spatial resolutions, and reference years, is presented in Table 1, which supports the methodological choices described above.

Table 1. Data mobilised in the study

Data Layer	Source	Spatial Resolution (m)	Years
Landsat five surface reflectance	GEE – USGS database	30	1985, 1995, 2005
Landsat 8 surface reflectance	GEE – USGS database	30	2014, 2024
Built-up footprints	GEE – Open Buildings database	Variable	2024
Digital Elevation Model (DEM)	GEE – USGS database	30	/
Urban Development Master Plan (PDAU)	Municipality of Laghouat / Technical Services	/	Recent documents
Historical map of Laghouat	Local archives / National Library	/	1930

All datasets were processed, analysed, and cross-referenced using an integrated methodological pipeline that incorporated two primary platforms:

- Google Earth Engine, used for time-series image analysis, calculation of spectral indices (NDVI, FCC, TCC), and extraction of building footprints;
- QGIS is used for georeferencing, manual digitisation, morpho-functional classification, and final map production.

The overall workflow was structured into three interdependent methodological components, as illustrated in Figure 8. First, a diachronic analysis of urban expansion (1930–2024) was conducted based on visual interpretation and vectorisation of the built-up footprint. Second, intra-urban green space dynamics were assessed using NDVI calculations and thematic classification. Finally, a morphological study of the built fabric was performed, relying on building footprint analysis cross-referenced with urban planning documents.

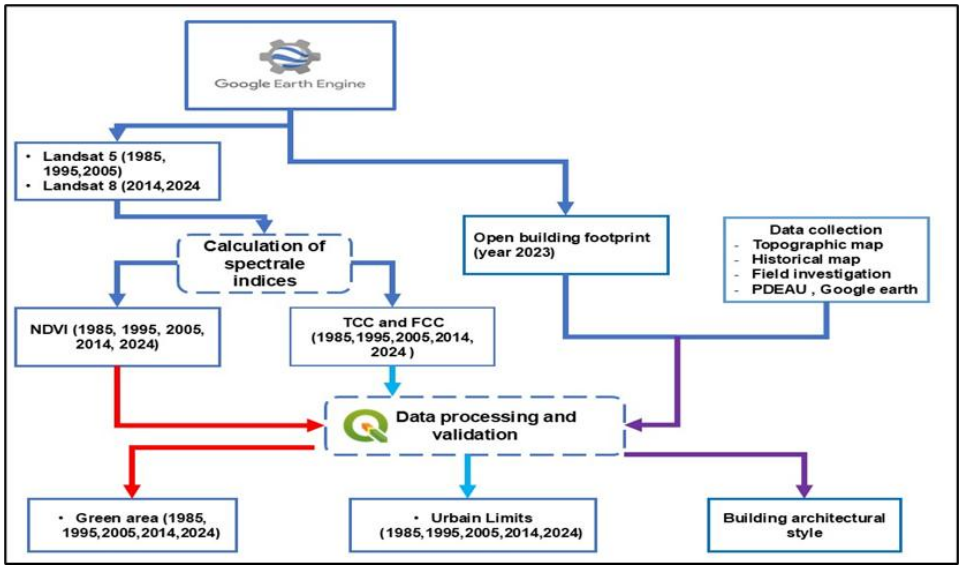

Figure 8. Flow chart of work. Source: Author's

This approach enables a comprehensive spatial diagnosis by integrating both quantitative and qualitative analyses of urban transformations in Laghouat. It highlights the significant challenges associated with preserving urban and landscape identity during contemporary urbanisation. To address the study objectives, a multifaceted methodological framework was implemented to examine the evolution of the urban environment, the Ghouts, and the architectural typologies of the built fabric within the city.

3.1.1. Diachronic Analysis of Urban Expansion

The spatial evolution of Laghouat was examined through a rigorous diachronic approach (Benarfa, 2018; Othmani Marabout Bouchareb, 2019; Korkaz, 2021; Hachemi & Benkouider, 2023), combining

historical cartographic sources with multispectral satellite imagery across six temporal benchmarks: 1930, 1985, 1995, 2005, 2014, and 2024.

- 1930: In the absence of satellite imagery, the urban area was reconstructed from a georeferenced historical map using QGIS, ensuring a faithful representation of the city's spatial extent at that time.
- Post-1985: Landsat 5 and Landsat 8 imagery were processed in Google Earth Engine (GEE) to generate two principal colour composites:
  - True Colour Composite (TCC): Provides near-natural rendering, supporting photointerpretation, classification validation, and clear visualisation of landscape dynamics.
  - False Colour Composite (FCC): Integrates near-infrared bands to enhance vegetation–built-up contrasts, improve spectral separability, and facilitate the detection of urban artificialization, complementing indices such as NDVI and NDBI.

These composites served as the basis for expert visual interpretation, followed by detailed manual digitisation of urban boundaries in QGIS. This process enabled precise documentation of spatial growth, capturing both morphological transformations and patterns of densification.

3.1.2. Monitoring the Evolution of Intra-Urban Green Spaces

The identification and quantification of urban vegetation were carried out through the calculation of the Normalised Difference Vegetation Index (NDVI), recognised for its robustness in assessing vegetation cover. The processing was performed in GEE using Landsat 5 image series (for the years 1985, 1995, and 2005) and Landsat 8 (for 2014 and 2024). The methodological steps are as follows:

- Pre-processing of images: cloud masking and radiometric correction (TOA);
- Calculation of NDVI, according to the classical formula:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

Variables used in the calculation of NDVI:
-NIR (Near Infrared): spectral band corresponding to the radiation reflected in the near infrared (about 0.7 to 1.1 μm). Healthy plants strongly reflect this wavelength thanks to the internal structure of their leaves.
-RED: Spectral band corresponding to the radiation reflected in the visible red (about 0.6 to 0.7 μm). It is highly absorbed by chlorophyll for photosynthesis.
This index reflects the contrast between the high reflectance in the near infrared and the strong absorption in the red, characteristic of active vegetation.

The results were exported in raster format and then integrated into QGIS for multi-temporal comparative mapping. These outputs enabled precise visualisation of the progressive reduction of Ghouts and vegetated areas in connection with urban expansion and land-use transformation. A similar approach has been applied in other Algerian cities, notably Boussaâda, where quantitative and qualitative analysis of green spaces through remote sensing confirmed the validity of this methodology (Malika et al., 2021).

3.1.3. Morphological Analysis of the Built Fabric and Typological Classification

The morphological analysis of Laghouat's built environment was conducted through an integrated methodology combining:

- Open datasets (building footprints from the Open Buildings database);
- Advanced geospatial processing in QGIS;
- Expert interpretation supported by urban planning documents (PDAU) and high-resolution satellite imagery.

This approach resulted in a morpho-functional typology of the urban fabric, structured into four main categories:

1. Historic Fabric: dense housing, narrow alleys, low-rise structures, strong integration of Ghouts.
2. Hybrid Housing: continuous built forms with partial modernisation, limited integration of private green spaces;
3. Modern Housing: planned, open urbanism dominated by residential subdivisions and collective housing;
4. Tertiary Zones: institutional facilities, administrative functions, and services.

The methodological workflow comprised four key steps:

- Extraction of building footprints from the Open Buildings database via GEE, providing updated coverage of built structures within the urban perimeter;

- Geometric processing in QGIS, including cleaning, merging, and removal of duplicates, followed by manual refinement to ensure spatial and topological consistency, particularly in dense or historically structured areas;
- Morphological adjustment, achieved through cross-referencing with PDAU planning documents and high-resolution imagery (Google Earth Pro), enabling typological attribution based on building form, spatial context, parcel structure, and density;
- Production of a typological map, illustrating the intra-urban distribution of architectural styles. This map serves as a strategic tool for interpreting urban transformations, highlighting the erosion f architectural identity and the impact of modernisation dynamics on Laghouat's historical fabric.

4. THE FINDINGS AND DISCUSSION

4.1. Urbanisation Dynamics in Laghouat (1930–2024): A Progressive Rupture with Oasis Morphology

The morphological evolution of Laghouat demonstrates a gradual reconfiguration of its spatial organisation, indicating a shift from a traditional oasis city to a contemporary Saharan city influenced by external planning paradigms. Spatio-temporal analysis identifies three principal phases:

The first phase, spanning from 1930 to 1985, was characterised by a compact and integrated oasis city. The urban fabric was concentrated around the historic core and organised by the Ghouts, which are agro-oasis gardens closely linked to traditional water management systems. This configuration exhibited strong compactness and spatial continuity, representing an adaptation to the Saharan climate. The integration of built structures, vegetation, and hydraulic networks created a coherent system that provided microclimatic comfort and reinforced landscape identity.

The second phase, around 1995, marks a transition toward extensive urbanisation. Urban growth followed a centrifugal pattern, expanding mainly toward the southwest and northeast. The once dense and continuous spatial model, rooted in oasis traditions, began to fragment as peripheral neighbourhoods developed with little integration. This shift marked the first break from traditional spatial patterns, as modern planning schemes were introduced but did not sufficiently take into account local characteristics.

The third phase, from 2005 to 2024, is characterised by the consolidation of a previously fragmented and standardised Saharan city. Recent urban expansion uses a sector-based and functional approach, resulting in a significant loss of compactness. New urban forms now diverge from earlier spatial regulations, including building orientation, climate adaptation, and proximity to irrigated areas. The urban fabric has become more dispersed and disconnected from the environment due to external urban models. This standardisation process speeds the disappearance of identity markers that once distinguished Laghouat as an oasis city. **Figure 9** below depicts the three phases.

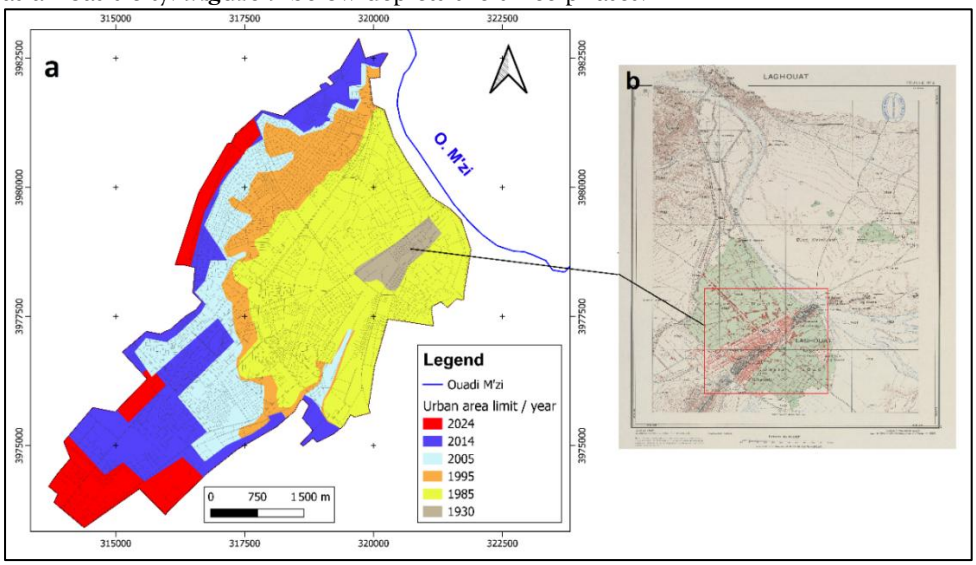

Figure 9. Spatio-temporal Evolution of Urbanisation in Laghouat (1930–2024) in Comparison with the 1930 Historical Plan.

4.2. Decline of Vegetation Cover and Marginalisation of the Ghouts: Toward the Disappearance of the Oasian Framework

Diachronic analysis of urban vegetation in Laghouat uses NDVI calculated during the chlorophyll peak in April and May. This approach demonstrates the effectiveness of NDVI for monitoring spatio-temporal

vegetation changes in semi-arid environments (Fatiha, 2013; Huang, 2021). The cartographic series in **Figure 10** illustrates a steady decline in intra-urban vegetated areas. There were high density and centrality in 1985, noticeable fragmentation by 1995, and significant retraction from 2005 onward. These findings align with previous research in Saharan oases that used Landsat imagery and landscape metrics (Dechaicha, Daikh, & Alkama, 2021).

This trend signifies a structural departure from the traditional oasian framework. The interdependence of built environments, vegetation, and hydraulic systems historically defined this framework. The Ghouts system consists of depressions that facilitate root access to the water table and contribute to microclimatic regulation. The system is particularly affected. Marginalisation is driven by land pressure, urban expansion, and changes in hydrogeological conditions. These patterns are also documented in the oases of El-Oued (Remini & Kechad, 2011; Khezzani, 2023).

Peripheral plantations established after 2014 have low density and limited morphological integration. They do not compensate for the ecosystem services or cultural identity provided by historical palm groves and Ghouts. Research in Biskra (Tolga) indicates that dense palm groves provide measurable microclimatic cooling and help mitigate thermal stress. In contrast, recent urban expansions lack substantial vegetation (Matallah et al., 2022).

A regional comparison situates Laghouat within a broader trend observed in Saharan cities. In Ghardaïa, the World Heritage Centre (2006) notes that uncontrolled urban growth harms palm groves and the M'Zab Valley riverbed. This growth poses a threat to the integrity of the oasis system. In the Biskra region, including Tolga and Sidi Khaled, several studies report a growing separation between urban development, agricultural zones, and palm groves (Khiari, 2018). These findings align with broader analyses of Saharan cities. These studies emphasise the spread of external urban models, increasing spatial uniformity, and the weakening of oasis regulatory mechanisms (Pliez, 2003; Bisson, 2003).

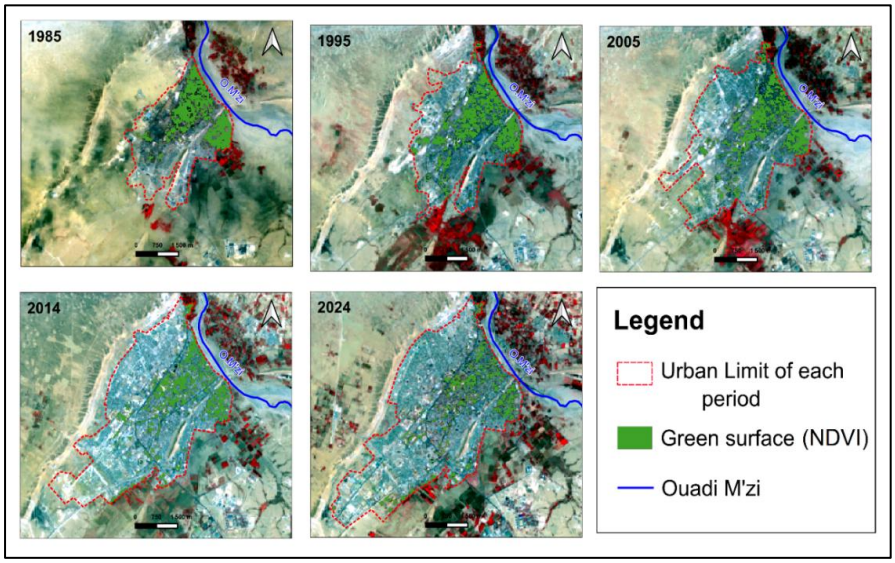

Figure 10. Diachronic evolution of Laghouat (1985–2024) in false-colour composites (FCC, NIR–R–G). Vegetation appears in bright red (FCC) and in green when extracted using NDVI, while built-up areas are shown in grey-blue. Successive urban boundaries (red dashed line) and the Oued M'zi (blue) complement the interpretation.

The multi-temporal analysis of NDVI (Normalised Difference Vegetation Index) maps, combined with the calculation of vegetated and urbanised areas, confirms three structural trends.

First, a progressive and marked reduction in vegetation is observed within the historic perimeter, particularly in the central core, which is traditionally organised around the Ghouts (traditional cultivation areas or gardens specific to oasis settlements).

Second, the vegetation rate relative to the urban surface has declined sharply. It dropped from 23.27% in 1985 to 8.57% in 2024, a decrease of 14.7 percentage points (–63.2% compared to 1985). This trajectory can be broken down into four phases. There was relative stability between 1985 and 1995 (+0.19 points). This was followed by an accelerated decline between 1995 and 2005 (–6.09 points), 2005 and 2014 (–5.30 points), and 2014 and 2024 (–3.50 points).

Third, the intensification of spatial fragmentation in vegetation cover has disrupted intra-urban ecological continuity and diminished the clarity of the landscape framework (the overall structure and organisation of visible landscape elements).

These trends are consistent with the literature. In semi-arid contexts, NDVI is recognised as a robust indicator for monitoring vegetation gradients and their inflexion points under urban pressure (Fatiha, 2013; Huang, 2021). Similarly, research in Saharan oases has documented, through remote sensing and landscape metrics, the long-term shift in the balance between built-up areas and vegetation (Dechaicha, Daikh, & Alkama, 2021).

The results in Table 2 indicate a structurally imbalanced urban dynamic. This dynamic is characterised by the rapid expansion of built-up areas and concurrent regression of green spaces. From 1985 to 2024, the urbanised surface more than doubled, increasing from 10.18 km² to 23.49 km² (+13.30 km²; +130.7%). Accelerated urbanisation, especially after 2005, reflects increasing demographic pressure and socio-economic transformations within the oasis landscape.

In contrast, vegetated surfaces decreased from 2.37 km² to 2.01 km² (–0.36 km²; –15.1%). Although this numerical decline appears less dramatic, it is particularly significant given the rapid urban expansion. The relative share of vegetation dropped from 23.3% to 8.6% between 1985 and 2024. Nearly two-thirds of the original green framework within the oasis urban system have been absorbed, fragmented, or eliminated. This indicates a profound fragmentation of the oasis landscape's identity.

Table 2:Evolution of Urban Areas and Green Spaces in Laghouat (1985–2024)

Year	Green surface area (m²)	Urban area (m²)	Vegetation rate relative to urban surface (%)
1985	2,369,157.00	10,182,197.20	23.27
1995	3,096,346.72	13,197,576.40	23.46
2005	2,908,701.06	16,741,571.40	17.37
2014	2,543,400.00	21,067,512.20	12.07
2024	2,012,474.33	23,487,074.07	8.57

Note. The vegetation rate corresponds to the percentage of green surface relative to the total urban area.

Figure 11 contrasts two trajectories. Urbanised surfaces (built-up land such as buildings, roads, and paved areas) have expanded almost exponentially since 1985. Vegetated areas (parks, lawns, and forests) have remained stagnant or declined. This divergence underscores a structural imbalance between the built environment and the green framework, the main elements of the Oasian identity.

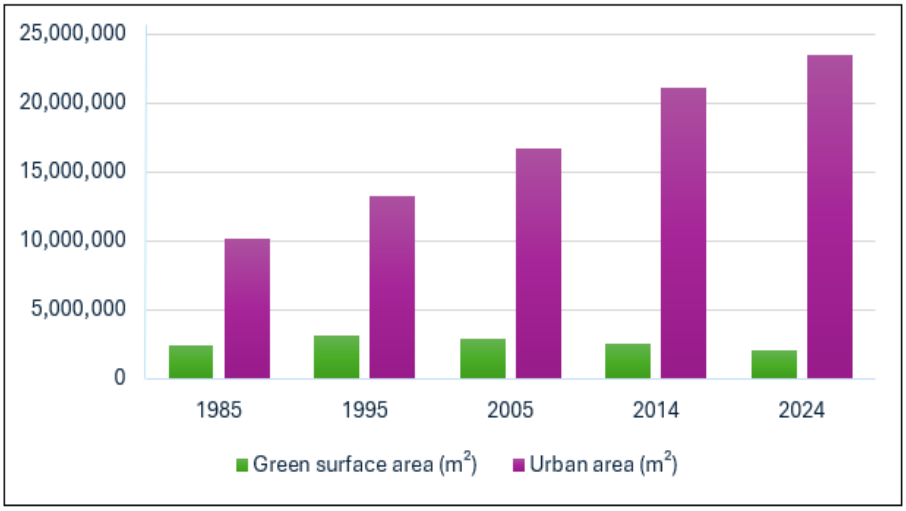

Figure 11. Evolution of urban and green surfaces in Laghouat between 1985 and 2024

Figure 12 illustrates the temporal evolution of the vegetation rate, defined as the proportion of land surface covered by vegetation relative to built-up structures. Between 1985 and 1995, the rate remained steady at approximately 23%. It then dropped to 17.4% in 2005, 12.1% in 2014, and under 9% in 2024. This ongoing decline signals an apparent rupture in the historic coexistence of built and vegetated areas.

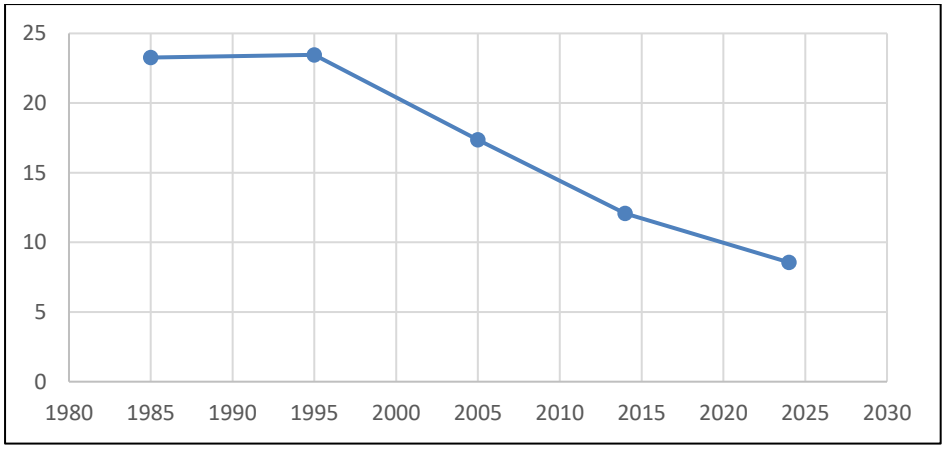

Figure 12. Percentage of vegetation relative to the urban footprint

The two figures collectively illustrate a dual process:

- Urban growth is rapid and ongoing, driven by demographic and socio-economic forces.
- The vegetative framework is experiencing regression and fragmentation, progressively losing its capacity to balance and structure the city.

The period from 1985 to 2024 marks both a quantitative and qualitative shift. There has been a loss of vegetated surfaces and a gradual erasure of the Ghouts and the green framework. These elements once defined Laghouat's identity.

These results show an increasing separation between the urban fabric and the oasian armature. Rapid expansion and densification drive contemporary urbanisation. This process tends to marginalise the vegetative framework, which remains fundamental to Laghouat's landscape and identity. The resulting identity fragmentation appears in three major trends:

- The urban fabric is expanding at the expense of vegetated perimeters, indicating accelerated land artificialization—meaning the conversion of natural land to urban surfaces—and inadequate control over land consumption.
- Buildings and green areas are no longer integrated, disrupting the city's oasian pattern that once linked buildings, water, and greenery.
- Vegetation per urban hectare has decreased sharply. It decreased from 2,327 square meters per hectare in 1985 to 857 in 2024, representing a 63% reduction. This decline shows both quantitative and qualitative regression in environmental and landscape comfort.

These findings show that current urban dynamics absorb the green framework and reshape urban identity. This process gradually separates the city from its oasian roots. Built-up areas and vegetation evolve together, but do not maintain harmony. Instead, there is fragmentation, morphological sameness, and ecological loss. This threatens the clarity of the city's identity and its environmental resilience. It also undermines the regulatory functions once provided by the green framework

4.3. Morphological Transformation of the Urban Fabric: Dilution of Identity and Standardisation of Forms

High-resolution satellite imagery from **Google Earth, provid**ed by Maxar Technologies through WorldView and GeoEye satellites, enabled the establishment of a morpho-architectural typology for Laghouat's built environment. Targeted field surveys supported this process. Four principal categories were delineated by parcel configuration, compactness, street network structure, patios or courtyards, and material characteristics.

- Traditional fabric (Red) is **c**oncentrated in the historic eastern core, next to the M'zi wadi corridor—a seasonal riverbed—and inside the pre-1984 urban boundaries. This category is defined by high compactness, narrow and irregular street networks, continuous alignments, and patios or courtyards linked to the Ghouts—planting depressions designed for agriculture. It demonstrates bioclimatic principles, including shading, thermal inertia (the ability of materials to store heat and release it slowly), and canopy continuity. It also reflects an integrated relationship with the oasis environment.
- Hybrid fabric (Orange) forms a transitional belt around the historic core. It results from incremental modernisation, such as material substitution, partial rectification of alignments, and localised openings.

Although compactness remains high, landscape coherence has diminished due to alternating building scales, standardised facades, and the reduction or loss of patios.

- Modern fabric (Blue) is located in peripheral areas, including the southwest, northwest, and suburban zones. This category uses an orthogonal subdivision grid and repetitive plots. Setbacks, gaps, and fences limit continuity in built frontage. Morphologically, it is distinct from oasis-based patterns. It prioritises automobile access, widens streets, reduces shade, and fragments the canopy. This type of urbanisation increases microclimatic vulnerability, as detailed in section 4.2.
- Institutional poles (Cyan) appear as single-use areas (monofunctional enclaves) along main thoroughfares (principal axes). They have large building sites (large footprints) and buildings of varying sizes (discontinuous building scales). These elements act as physical barriers in the area (morphological barriers), disrupting pedestrian pathways and the continuity of green spaces (landscape continuity), further dividing the connection between the historic town centre (core) and newer urban districts (urban extensions).

4.4. Cross-Spatial Reading: Urban Expansion and Architectural Transformation

Superimposing successive urban boundaries from 1930 to 2024 with the morpho-architectural typology of the built fabric enables a diachronic analysis. This approach elucidates the dynamics of spatial expansion and the morphological transformation of urban tissues **(Figure 13)**.

- **Historic core:** Situated along the M'zi wadi, the eastern nucleus primarily comprises traditional fabric (red). High compactness, a narrow and irregular street network, and continuous alignments define it. These are often associated with patios or courtyards connected to the Ghouts. This configuration continues to embody an integrated logic of the oasis. It combines canopy continuity, shading, thermal inertia, and the interrelation of housing, water, and vegetation.
- **Hybrid Belt:** Surrounding the core, a transitional belt (orange) has emerged through incremental modernisation, including material substitutions, realignment corrections, and localised openings. Despite its relative density, this zone reduces landscape coherence and diminishes traditional bioclimatic features such as patios and vegetated thresholds.
- **Modern Extensions:** Post-1995 expansions are characterised by modern fabric (blue), organised into orthogonal grids, repetitive parcels, and widened streets, especially in the southwest and northwest. This morphology, distinct from oasis logic, prioritises vehicular circulation, increases mineral surfaces, and fragments the urban canopy. It exemplifies a generic urbanisation model poorly adapted to local climatic conditions and identity.
- **Institutional Poles:** Located along principal axes, large footprints and discontinuous building scales define these monofunctional enclaves (cyan). They disrupt pedestrian and landscape continuity, intensifying the segmentation between the historic core and recent extensions.

The figure illustrates a centre–periphery gradient: traditional fabric at the core, a transitional hybrid belt, modern peripheral extensions, and institutional enclaves. This morphological stratification demonstrates a significant transformation, as Laghouat has shifted from a compact, integrated oasis city to a standardised model characterised by repetitive plots and orthogonal grids.

The accompanying orthophotographic insets depict this dissonant coexistence. Dense historic nuclei with shaded alleyways are juxtaposed with loosely compacted, sparsely vegetated modern blocks. This transformation results in the dilution of local identity through the loss of traditional materials and patios, as well as formal standardisation, including uniform building scales, increased mineral surfaces, and fragmentation of the green framework.

Consistent with the vegetation regression discussed in Section 4.2, these findings indicate that recent urbanisation not only absorbs the green framework but also promotes morphological and ecological homogenization. This process undermines both the legibility of local identity and the thermal resilience of Laghouat.

The map reveals a centre–periphery gradient; traditional fabric appears in the historic core, hybrid fabric in the intermediate belt, and modern fabric in the periphery. This stratification of urban forms signals a reversal of urban logic. Laghouat has shifted from a compact oasis city—integrated with water, vegetation, and climate-responsive architecture—to a standardised model defined by orthogonal grids, repetitive plots, and uniform-built forms.

These changes have two primary consequences:

1. First, identity fades as removing patios, landscape thresholds, and local materials weakens ties to the oasis model.

2. Second, a transition to formal standardisation is evident as uniform building scales are widely adopted. Increased mineral surfaces, the fragmentation of the green framework, and a reduction in microclimatic comfort accompany this shift.

These findings align with the observations in Section 4.2. As intra-urban vegetation declines and Ghouts become more marginalised, the city's form grows more uniform. This erodes the city's identity.

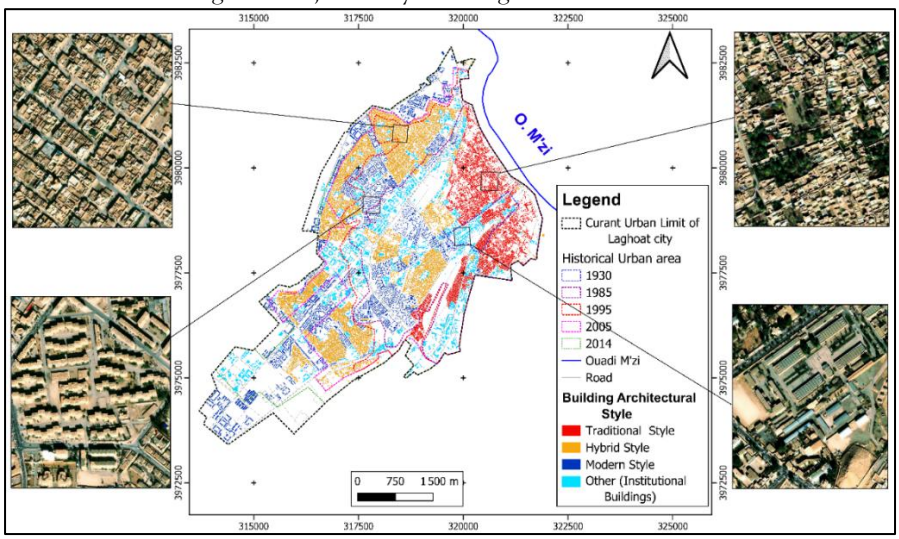

Figure 13. Cross-reading of urban evolution (1930–2024) and morpho-architectural styles in Laghouat.

Note. The historic and current boundaries (black dashed line) are superimposed onto the building classes: traditional (red), hybrid (orange), modern (blue), and institutional (cyan). The thumbnails illustrate the typical urban textures associated with each class.

4.5. Ghouts, Urbanisation of Laghouat, and Identity Erosion

Spatio-temporal analysis reveals that urban development in Laghouat since the 1980s has significantly altered the territorial structure, often diminishing the oasis framework. The observed decline in the intra-urban green network, as evidenced by NDVI analyses during the April to May phenological window, is consistent with findings from studies in (semi-)arid environments and local research on Saharan oases (Benkouider et al., 2013; Huang, 2021; Dechaicha, Daikh & Alkama, 2021). Beyond ecological consequences, this reduction in vegetation has led to the loss of cultural and social elements, such as shade, gardens, and circulation paths, which have historically defined the identity of an oasis. Morphological transformations are linked to the spread of standardised urban forms, including orthogonal subdivisions, reduced compactness, and street widening. These developments disrupt the continuity of shade and vegetation described in Section 4.2, obscuring the landscape features and daily practices that previously characterised the oasis town (ville-oasis).

The disintegration of the Ghout system represents a profound ecological and cultural rupture in this transformation. Historically, these basins enabled root-level access to the water table, provided hydric inertia, and maintained microclimatic stability. They formed the structural foundation of the oasis city (FAO–GIAHS, n.d.; Battesti, 2005). Their current marginalisation is not limited to a reduction in area. It also signifies the breakdown of an integrated hydro-agro-social system. This occurs through processes such as infilling, groundwater rise, and artificialization, as documented by fieldwork and remote sensing studies (Remini & Kechad, 2011; Boulghobra, 2024). This decline has led to the loss of traditional knowledge, landscape features, and collective identity that are central to Laghouat.

Research conducted in El-Oued and the broader Oued Righ valley supports this pattern. It documents the degradation of Ghouts as a result of land pressure, dispersed urbanisation, and increased groundwater levels (Remini & Kechad, 2011; Khezzani et al., 2023; Satouh et al., 2021). Conversely, recent studies in Biskra (Tolga) show that dense palm groves generate a measurable cooling effect in adjacent areas (Matallah et al., 2023). Collectively, this evidence highlights the dual role of the oasis framework. It serves as both climatic infrastructure and a foundation for local identity and social cohesion.

The morpho-architectural standardisation observed in Laghouat (see Subsections 4.3–4.4) reflects a broader regional trend. In Ghardaïa, UNESCO has documented that uncontrolled urban expansion damages palm groves and the riverbed. This expansion threatens the integrity of the oasis system (UNESCO World Heritage Centre, 2006). Syntheses on Saharan cities further demonstrate the

proliferation of exogenous urban models and standardised built forms. These developments frequently undermine oasis-based regulations that historically safeguarded habitat, vegetation, and water systems (Pliez, 2003). In this context, Laghouat exemplifies a significant transformation. The city has shifted from a compact oasis form to a fragmented and ecologically degraded state. Local regulations intended to protect the oasis have been only partially effective (Benarfa, Alkama, & Khalfallah, 2018). As a result, Laghouat has lost distinctive features such as continuous shade, living palm groves, and hydraulic devices. This has led to the gradual erosion of its urban identity.

Quantitative analysis (see Figures 10–12 and Table 2) shows key changes from 1985 to 2024. During this period, the urban footprint expanded from 10.18 to 23.49 million square meters, a 130.7% increase. At the same time, intra-urban green spaces declined from 2.37 to 2.01 million square meters. This represents a 15.1% reduction. Vegetation within the built-up area decreased from 23.27% to 8.57%. This equates to a loss of 14.7 percentage points, or approximately 63%. Three periods of decline are clear: 1995 to 2005 (–6.09 points), 2005 to 2014 (–5.30 points), and 2014 to 2024 (–3.50 points). True Colour Composites (TCC) and False Colour Composites (FCC, NIR-R-G) support these findings. They illustrate the fragmentation and contraction of the green network. The loss of landscape continuities that once defined the urban oasis environment is now visible.

In summary, the goal is not to preserve historical models unchanged. Instead, it is essential to reintroduce oasis strategies. These include detailed water management, continuous shading, and planted gradients. Such measures enhance climatic resilience and help maintain urban identity.

5. Limitations of the Study

The analysis uses NDVI data from the Landsat series at a 30-meter resolution. This ensures robust diachronic comparability. However, this method may fail to detect micro-vegetated areas, such as residual Ghouts, alignments, and courtyards. It is also affected by interannual and inter-sensor variability. To mitigate these limitations, the study applies a fixed phenological window from April to May and uses cloud-free composites. These steps help but do not completely resolve the issues (Tucker, 1979).

The historical reconstruction is based on plans, maps, and photographs. Each source has a different level of accuracy. Toponymic changes, local distortions, and georeferencing uncertainties influence the precise localisation of features and the measurement of spatial transformations (Jenny & Hurni, 2011).

The study mainly uses a morpho-spatial perspective. It does not include systematic sociological or anthropological surveys. Regulatory analyses are also omitted. These omissions limit the ability to attribute causality to the observed dynamics. These limitations show several avenues for future research. Potential improvements include using higher-resolution imagery (Sentinel-2 or Pléiades). Adding complementary indicators, such as LST, NDWI, and NDBI, may enhance the analysis. Systematic ground-truthing would further improve interpretation and support public policy development.

CONCLUSION

Laghouat faces not only urban expansion and vegetation loss but, more significantly, a transformation of its urban identity. Historically, this identity was shaped by three foundational elements: Ghouts, the Oued M'zi, and a compact vernacular morphology. These features established Laghouat as an oasis city, resulting in a distinctive urban environment defined by shade, vegetated patios, microclimatic regulation, and a strong connection to soil and water.

A diachronic analysis from 1985 to 2024 shows increasing separation between urban expansion and the green framework. Vegetation cover dropped from 23.3% to 8.6%. During this time, Ghouts were marginalised, and standard urban grids spread. As a result, Laghouat's oasis-based urban structure has shifted into a more generic form, losing key cultural and landscape features. The ongoing loss of urban identity is the primary concern.

This erosion of identity is evident in both the physical form and function of the city. Increased fragmentation and the loss of shaded areas, combined with canopy decline, have eliminated the city's traditional climatic infrastructure that supported Laghouati lifestyles. However, this transformation is reversible. The analysis indicates that sustainable modernisation should reinforce, rather than overlook, local identity. Restoration can be achieved by reactivating Ghouts, establishing shaded corridors along the Oued M'zi, reintroducing traditional patio features, and mandating that urban extensions maintain standards for compactness and canopy coverage.

The study suggests developing an oasian Urban Identity Index for Laghouat. This index would measure features like compactness, shade, and patio proportions. It would also account for ecological indicators, such as canopy cover, peak NDVI, and permeability, as well as heritage elements like Ghout and building

integrity, and local customs. Monitoring the index at the neighbourhood level would help track recovery, evaluate projects, and guide urban growth.

To ensure a resilient future for Laghouat, city planners and policymakers must urgently adopt oasis-based criteria in all planning processes. This includes robustly protecting Ghouts and historic structures through enforceable heritage regulations, and mandating that urban expansion is aligned with climate adaptation strategies. Recognising and strengthening the oasis model as both heritage and infrastructure is essential. Only by committing to these actions can Laghouat effectively accommodate population growth, confront environmental challenges, and preserve its unique urban identity.

REFERENCES

1. Abdellaoui, A., & Marmi, R. (2010). Mise en évidence de mouvements de sable à partir d'images satellitales: Application au piémont sud de l'Atlas saharien (Algérie). Analele Universităţii Bucureşti – Geografie, 10(2), 2–14. https://annalsreview.geo.unibuc.ro/2010/2010
2. Belala, F., Hirche, A., Muller, S. D., Tourki, M., Salamani, M., Grandi, M., Ait Hamouda, T., & Boughani, M. (2018). Rainfall patterns of Algerian steppes and the impacts on natural vegetation in the 20th century. Journal of Arid Land, 10(4), 561–573. https://doi.org/10.1007/s40333-018-0095-x
3. Belguidoum, S. (2002). Urbanisation et urbanité au Sahara. Méditerranée, 99(3–4), 53–64. https://shs.hal.science/halshs-01487524/document
4. Belgiu, M., & Drăguţ, L. (2016). Random forest in remote sensing: A review of applications and future directions. ISPRS Journal of Photogrammetry and Remote Sensing, 114, 24–31. https://doi.org/10.1016/j.isprsjprs.2016.01.011
5. Benarfa, K. (2018). Développement urbain et préservation de la palmeraie – Cas de Laghouat [Doctoral dissertation, Université de Biskra].
6. Benarfa, K., Khalfallah, B., & Alkama, D. (2018). Rôle de la réglementation urbaine dans la préservation de l'oasis de Laghouat. Courrier du Savoir, 26, 175–186. https://www.researchgate.net/publication/328130678
7. Benkouider, F., Abdellaoui, A., & Hamami, L. (2019). New and improved built-up index using SPOT imagery: Application to an arid zone (Laghouat and M'Sila, Algeria). Journal of the Indian Society of Remote Sensing, 47, 185–192. https://doi.org/10.1007/s12524-018-0895-7
8. 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. https://doi.org/10.1016/j.egypro.2013.07.077
9. Baunard, L. (1894). Le général de Sonis: D'après ses papiers et sa correspondance (41e éd., revue et augm.). Paris: C. Poussielgue.
10. Battesti, V. (2005). Jardins au désert: Évolution des pratiques et savoirs oasiens – Jérid tunisien. Paris: IRD Éditions.
11. Bisson, J. (2003). Mythes et réalités d'un désert convoité: Le Sahara. Paris: L'Harmattan.
12. Bouchène, A., Peyroulou, J.-P., Siari Tengour, O., & Thénault, S. (Eds.). (2014). Histoire de l'Algérie à la période coloniale, 1830–1962. Paris: La Découverte.
13. Boulghobra, N. (2024). Remotely sensed data and GIS for long-term monitoring of the Ghout oases degradation in the region of Oued Souf (Northeastern Algerian Sahara). In A. M. F. Al-Quraishi & Y. T. Mustafa (Eds.), Natural resources deterioration in MENA region: Land degradation, soil erosion, and desertification (pp. 37–53). Cham: Springer. https://doi.org/10.1007/978-3-031-58315-5_3
14. Boudalia, N., Kasmi, A. M., Neglia, G. A., & Alili, A. (2024). The role of traditional commercial spaces in urban evolution: A morphological study of the medina of Tlemcen. Tourism and Heritage Journal, 6, 120–140. https://revistes.ub.edu/index.php/tourismheritage/article/view/45820
15. Carpentier, I., & Gana, A. (2017). Changing agricultural practices in the oases of Southern Tunisia: Conflict and competition for resources in a post-revolutionary and globalisation context. In E. Lavie & A. Marshall (Eds.), Oases and globalization: Ruptures and continuities (pp. 153–176). Cham: Springer. https://doi.org/10.1007/978-3-319-50749-1_9
16. Chaouche Bencherif, M. (2008). Touggourt ou la dynamique d'une ville aux sept ksour. Sciences & Technologie D, Sciences de la Terre, 28, 9–18. https://asjp.cerist.dz/en/downArticle/409/0/28/58193
17. Daich, S., Saadi, M. Y., Santoro, A., Piras, F., & Boumaraf, B. (2025). Analyse spatio-temporelle, surveillance et prédiction future des changements d'utilisation des terres/couverture terrestre dans les Ghouts: Un système agricole durable dans les oasis d'El Oued, Algérie. Environmental Monitoring and Assessment, 197(9), 1062. https://doi.org/10.1007/s10661-025-14488-3
18. Dechaicha, W., Arab, D., & Alkama, D. (2025). The ecological impact of urban expansion in oasis environments: A combined cartographic and landscape analysis. Geoplanning: Journal of Geomatics and Planning, 12(1), 123–138. https://doi.org/10.14710/geoplanning.12.1.123-138
19. 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), 209–219. https://doi.org/10.25034/ijcua.2021.v5n2-5
20. Erbach, T. (2025). Using cultural heritage in climate adaptation: Fields of action and emerging examples, contributing to urban resilience. WIREs Climate Change. https://doi.org/10.1002/wcc.70011
21. Georges, H. (1950). Essai sur l'évolution sociale et politique de la région de Laghouat depuis 1830. Paris: Imprimerie Nationale.
22. Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031
23. Hachemi, K., & Benkouider, F. (2023). Study of the urban extension of Laghouat (Algeria) between 2007 and 2020 using the modified built-up index (MBAI) from SPOT-5 and Sentinel-2 images. In Selected studies in geotechnics, geo-informatics and remote sensing (pp. 161–176). Cham: Springer. https://doi.org/10.1007/978-3-031-43759-5_13

24. Hartani, A., Baghdadi, D., Anteur, D., & Benaradj, A. (2021). Detection of urban spot in the plain of Mina (Western Algeria). Biodiversity Journal, 12(1), 155–169. https://doi.org/10.31396/Biodiv.Jour.2021.12.1.155.169
25. Huang, S., Tang, L., Hupy, J. P., Shrestha, S., & Jiang, Z. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. Journal of Forestry Research, 32(1), 1–6. https://doi.org/10.1007/s11676-020-01155-1
26. Idda, S., Bonté, B., Kuper, M., & Mansour, H. (2021). Revealing the foggara as a living irrigation system through an institutional analysis: Evidence from oases in the Algerian Sahara. International Journal of the Commons, 15(1), 431–448. https://doi.org/10.5334/ijc.1128
27. Kalla, M., & Metaxas, T. (2024). Cultural and heritage tourism, urban resilience, and sustainable development: Comparative analysis of the strategies of Athens and Rome. Journal of Sustainability Research, 6(4), e240073. https://doi.org/10.20900/jsr20240073
28. Khezzani, B., Khechekhouche, E. A., & Bousbia Brahim, A. (2023). Community awareness of Agricultural Heritage Systems (GHIAS) sites: The case of the Ghout system in the Souf Oasis. The Journal of Rural and Community Development, 18(1), 19–31. https://journals.brandonu.ca/jrcd/article/download/2209/604
29. Khiari, A. (2018). Systèmes oasiens traditionnels, entre pérennité et abandon: Les cas de Sidi Khaled et Tolga. Les Cahiers d'EMAM. Études sur le Monde Arabe et la Méditerranée, 30. https://doi.org/10.4000/emam.1531
30. Korkaz Harzallah, H. (2023). Mutations urbaines dans la ville de Laghouat – Cas du quartier Essadikia [Doctoral dissertation, Université Sétif 1].
31. Mahcar, F. I., Durak, S., Benabbou, R., & Vural Arslan, T. (2024). The impact of the colonial architecture on the urban sustainability of Laghouat city in Algeria: Ksar of Laghouat as a case. npj Heritage Science, 12, 191. https://doi.org/10.1186/s40494-024-01272-8
32. Malika, O. U., Boudjemaa, K. H., Salim, D. E., & Abla, K. A. (2021). Quantitative and qualitative assessment of urban green spaces in Boussaada City, Algeria using remote sensing techniques. Journal of Geography and Regional Planning, 14(3), 123–133.
33. Mangin, É. (1895). Notes sur l'histoire de Laghouat. Alger: Adolphe Jourdan.
34. Mantellini, S., & Berdimuradov, A. E. (2019). Evaluating the human impact on the archaeological landscape of Samarkand (Uzbekistan): A diachronic assessment of the Taylak district by remote sensing, field survey, and local knowledge. Archaeological Research in Asia, 20, 100143. https://doi.org/10.1016/j.ara.2019.100143
35. Matallah, M. E., Ahriz, A., Zitouni, D. C., Arrar, H. F., Ratmia, M. A. E. B., & Attia, S. (2023). A methodological approach to evaluate the passive cooling effect of oasis palm groves. Sustainable Cities and Society, 99, 104887. https://doi.org/10.1016/j.scs.2023.104887
36. Medouki, M., & Selatnia, K. (2021). L'impact de la dimension sociale sur la morphologie des ksour sahariens: Cas d'étude: Ouargla, Touggourt et El Oued [The impact of the social dimension on the morphology of the Saharan ksour]. Revue des Sciences Humaines de l'Université d'Oum El Bouaghi, 8(3), 2149–2167. https://asjp.cerist.dz/en/downArticle/93/8/3/181484
37. Mélia, J. (1923). Laghouat: ou, Les maisons entourées de jardins. Paris: Librairie Plon.
38. Ministère de l'Intérieur. (n.d.). Monographie de la wilaya de Laghouat. https://interieur.gov.dz/Monographie/article_detail.php?lien=2110&wilaya=3
39. Mokadem, N., Redhaounia, B., Besser, H., Ayadi, Y., Khelifi, F., Hamad, A., Hamed, Y., & Bouri, S. (2018). Impact of climate change on groundwater and the extinction of ancient "foggara" and springs systems in arid lands in North Africa: A case study in Gafsa basin (Central of Tunisia). Euro-Mediterranean Journal for Environmental Integration, 3, 28. https://doi.org/10.1007/s41207-018-0070-0
40. Nassef, M. M., & Ibrahim, M. A. (2022). Designing alternatives for residential apartments in Cairo using shape grammars. Journal of Mediterranean Cities, 2(1), 15–28. https://doi.org/10.38027/mediterranean-cities_vol2no1_2
41. Noui, N., Rouag Saffeddine, D., & Harizi, K. (2023). Detecting changes in land occupation and use (1984–2021) using GEE and GIS tools: Focus on the green structure of the future metropolis of Annaba (North-East Algeria). Indonesian Journal of Social Science Research, 4(2), 155–170. https://doi.org/10.11594/ijssr.04.02.08
42. Othmani Marabout Bouchareb, Z. (2019). Introduction de nouveaux modes de composition urbaine: Le renouvellement urbain à Laghouat. Maison d'édition européenne.
43. Pliez, O. (2003). Villes du Sahara. Paris: CNRS Éditions.
44. Remini, B., & Kechad, R. (2011). Impact of the water table raising on the degradation of El Oued palm plantation (Algeria): Mechanisms and solutions. Geographia Technica, 13(1), 48–56. https://technicalgeography.org/pdf/1_2011/05_boualem_remini_rabah_kec.pdf
45. Satouh, A., Bouselsal, B., Chellat, S., & Benaabidate, L. (2021). Determination of groundwater vulnerability using the DRASTIC method in Ouargla shallow aquifer (Algerian Sahara). Journal of Ecological Engineering, 22, 12–19. https://doi.org/10.12911/22998993/137680
46. Stewart, D. J. (2001). New tricks with old maps: Urban landscape change, GIS, and historic preservation in the less developed world. The Professional Geographer, 53(3), 361–373. https://doi.org/10.1111/0033-0124.00290
47. Tamiminia, H., Salehi, B., Mahdianpari, M., Quackenbush, L., Adeli, S., & Brisco, B. (2020). Google Earth Engine for geo–big data applications: A meta-analysis and systematic review. ISPRS Journal of Photogrammetry and Remote Sensing, 164, 152–170. https://doi.org/10.1016/j.isprsjprs.2020.04.001
48. Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0
49. Uhl, J. H., Leyk, S., Li, Z., Duan, W., Shbita, B., Chiang, Y.-Y., & Knoblock, C. A. (2021). Combining remote-sensing-derived data and historical maps for long-term back-casting of urban extents. Remote Sensing, 13(18), 3672. https://doi.org/10.3390/rs13183672
50. UNESCO World Heritage Centre. (2006). State of conservation – M'Zab Valley (Algeria): Uncontrolled urban growth in palm groves and wadi bed. Paris: UNESCO.

51. USGS. (2022). Landsat Collection 2 Level-2 science products. https://www.usgs.gov/landsat-missions/landsat-collection-2-level-2-science-products
52. Wilaya de Laghouat. (n.d.). Présentation géographique et socio-économique. http://www.wilaya-laghouat.dz/CTOIC/Fr/Data/Synthese_wilaya.pdf
53. Wu, S., Gao, X., Lei, J., Zhang, X., & Chen, L. (2020). Spatial and temporal changes in the NDVI and their driving factors in the Sahel transition zone. Remote Sensing, 12(24), 4119. https://doi.org/10.3390/rs12244119