

Research article

# Fine-scale GIS Modelling of Peri-urban Industrial Agglomeration: Accessibility, Land-price Gradients and Growth Dynamics in Oulad Azzouz, Morocco

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## Abstract

Industrial expansion on the metropolitan fringe rarely follows a random geography. Firms respond to accessibility, land markets and the cumulative advantages of co-location, while inherited territorial structure constrains where new investment can be directed. Fine-scale evidence from North African peri-urban communes nevertheless remains scarce, particularly regarding emerging industrial spaces at the edge of major metropolitan economies. This study therefore develops a GIS-based analytical framework to map and explain the spatial distribution and growth dynamics of industrial establishments in the Commune of Oulad Azzouz, Casablanca-Settat, Morocco. Verification and satellite-image interpretation were integrated with transport infrastructure, administrative boundaries, and land-price information. The analysis combined temporal establishment profiling, proximity analysis, proximity-based interpretation of transport infrastructure, land-price gradient interpretation, kernel density estimation, and average nearest-neighbor statistics. Industrial growth was shown to follow a strongly clustered pattern: the observed mean nearest-neighbor distance between establishments was 289.21 m, against an expected distance of 453.07 m, yielding a nearest-neighbor ratio of 0.63 ( $z = -8.83$ ,  $p < 0.001$ ). Density was markedly uneven. 38% of the commune fell within high or very high-density classes, while 32% remained low or very low. Establishments concentrated along accessible road corridors and in zones where land values are moderate relative to more expensive locations near Casablanca. Once establishment counts were normalized by period length, the 2021–2023 phase indicated renewed formation intensity rather than decline. The findings deliver commune-scale geospatial evidence of industrial agglomeration on a Moroccan metropolitan fringe and support infrastructure-led, land-sensitive and environmentally cautious industrial planning.

Keywords: industrial agglomeration; peri-urbanization; GIS; accessibility; land-price gradient; spatial planning; Casablanca-Settat; Morocco.

## 1. Introduction

Industrial growth on metropolitan fringes is a spatially selective process. Firms locate where transport, infrastructure, available land, market reach, labor pools and agglomeration economies converge, not where land is simply vacant. In rapidly urbanizing regions, these forces become sharply visible because peri-urban territory operates as a contested transition zone in which agriculture, residential expansion, logistics corridors and industrial investment compete for the same parcels. Recent evidence from China shows that expressway access, highway expansion and logistics connectivity reorganize the concentration of firms and regional integration (Li *et al.*, 2025; Zhang & Chen, 2025); in long-run U.S. data, the cumulative effect of interstate networks on establishment growth is similarly extensive (Frye, 2026). Industrial geography is therefore not only an economic question, but a spatial-planning problem involving land conversion, infrastructure allocation, territorial equity and environmental management.

Recent research reframes industrial development as a territorial process rather than a sectoral outcome. Investment and employment concentrate where development advantages already exist, deepening regional inequality unless planning institutions actively redirect growth (Chakraborty, 2024). Foreign direct investment reinforces this geography: external capital is rarely neutral in space and tends to gravitate toward existing concentration, supplier networks and accessibility advantages, strengthening local agglomeration (Hsu *et al.*, 2023; cf. Dunning, 2000). The co-agglomeration of manufacturing and producer services can support regional green innovation (Yang *et al.*, 2024), and manufacturing performance more broadly depends on the joint influence of technology, environmental conditions and policy (Sun *et al.*, 2024). In turn, sustainable industrial growth depends on the integration of industrial activities with urban systems, infrastructure and environmental governance, not on the proliferation of isolated industrial enclaves (Al-Asadi *et al.*, 2024; Nasser *et al.*, 2025). The relevance for emerging industrial zones in the Global South



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is direct: industrial investment is often promoted as a development engine, while simultaneously intensifying land competition, infrastructure pressure and environmental exposure.

Methodologically, the field has moved decisively toward geospatially explicit analysis. GIS, remote sensing and spatial statistics are now standard for examining clustering, urban expansion, land-use transformation, accessibility and the externalities of industrial growth. Parveen *et al.* (2023) linked industrial transformation to built-up expansion using Landsat and geospatial techniques, while Biswas and Dey (2023) demonstrate the spatio-temporal effects of industrial-corridor development on built-up growth. Their later work shows that industrial growth reshapes urban morphology through infilling, edge expansion and outlying development (Biswas & Dey, 2025), and that LULC analysis can measure industrial urban transformation over time (Biswas & Dey, 2026). Night-time light imagery and space-time data mining now extend the toolkit beyond conventional land-use mapping (Hutasavi & Chen, 2024). Madhavi *et al.* (2024) document measurable spatial and socio-economic spillovers of industrial clusters beyond the formal boundaries of estates. Studies of urban expansion and land-surface temperature confirm that industrial and built-up expansion modify environmental conditions across metropolitan fringes (Bala & Dar, 2024; Permanasari *et al.*, 2024), while evidence on industrial blocks in Greater Shanghai indicates that industrial relocation can produce industrial heat-island formation (Wu *et al.*, 2025). Industrial growth must therefore be evaluated by spatial patterns, accessibility structure and environmental consequences, not by establishment counts alone.

At the regional scale, infrastructure, economic specialization and place-based industrial policy remain central. Transport infrastructure supports productivity by reducing logistics costs and connecting firms to ports, airports, suppliers and markets (Keji *et al.*, 2025; Qin *et al.*, 2025; Liu *et al.*, 2026), while waterway endowments can equally restructure regional economic geography (Liang *et al.*, 2026). Highways and expressways improve market accessibility, stimulate firm concentration and strengthen local manufacturing, although the spatial benefits are uneven (H. Li *et al.*, 2025; Zhang & Chen, 2025). In polycentric urban regions, industrial growth also reflects specialization and complementarity among neighboring centers, as recent evidence from Rabat-Salé-Kénitra shows (Mazouz *et al.*, 2025). However, the Moroccan and wider MENA context is exposed to macroeconomic vulnerabilities and transition pressures, financial crises, industrial restructuring and the reconciliation of growth with climate-energy objectives (Madeira, 2025; Tafrata, 2025; Ikram & Nahdi, 2025). Industrial planning in Morocco therefore requires empirical evidence linking industrial location to local spatial conditions while remaining sensitive to regional-development and sustainability agendas.

Three gaps remain. First, much of the industrial-location and agglomeration literature operates at the national, regional, citywide or sectoral scale, leaving the micro-geography of establishments within peri-urban communes thinly documented. Recent work on special economic zones, development zones and business parks has produced important evidence on place-based industrial policy, structural change and the governance of organized industrial land, but these studies generally concern formally designated zones rather than dispersed commune-scale industrial landscapes (Abagna, 2025; Diamantidis *et al.*, 2025; Manilet & Sulistyaningrum, 2026; Otchia & Wiryawan, 2025; Wardhana *et al.*, 2025; Ye *et al.*, 2024). Second, studies that mobilize spatial methods often concentrate on land-use change, urban morphology or environmental effects, while comparatively few integrate establishment-level distribution, transport accessibility, land-price gradients or temporal growth dynamics in a single commune-scale framework. Third, North African peri-urban industrial spaces remain underrepresented in fine-scale GIS-based industrial-location research, despite their rapid transformation under metropolitan expansion, infrastructure development and industrial-policy agendas. These gaps limit the ability of local authorities to move from descriptive mapping toward evidence-based industrial land management.

The commune of Oulad Azzouz in Casablanca-Settat offers a strategically meaningful relevant case. Sitting at the interface between metropolitan Casablanca, the Atlantic coastal corridor and the rural hinterland, the commune lies near major logistical assets, the Port of Casablanca, Mohammed V International Airport and regional road infrastructure. This location attracts industrial investment, but also raises pertinent planning questions: where do industries cluster?; is clustering statistically significant?; how do industrial locations relate to accessibility and land-price gradients?; and which parts of the commune remain weakly integrated into industrial growth?

The novelty of our analysis lies in commune-scale GIS modelling of peri-urban industrial growth that combines establishment distribution, temporal formation, transport accessibility, industrial land prices, kernel density patterns and average nearest-neighbor statistics. Oulad Azzouz is treated not as a generic emerging industrial area, but as a spatial system in which agglomeration advantages, infrastructure corridors and land-market constraints interact. The study contributes

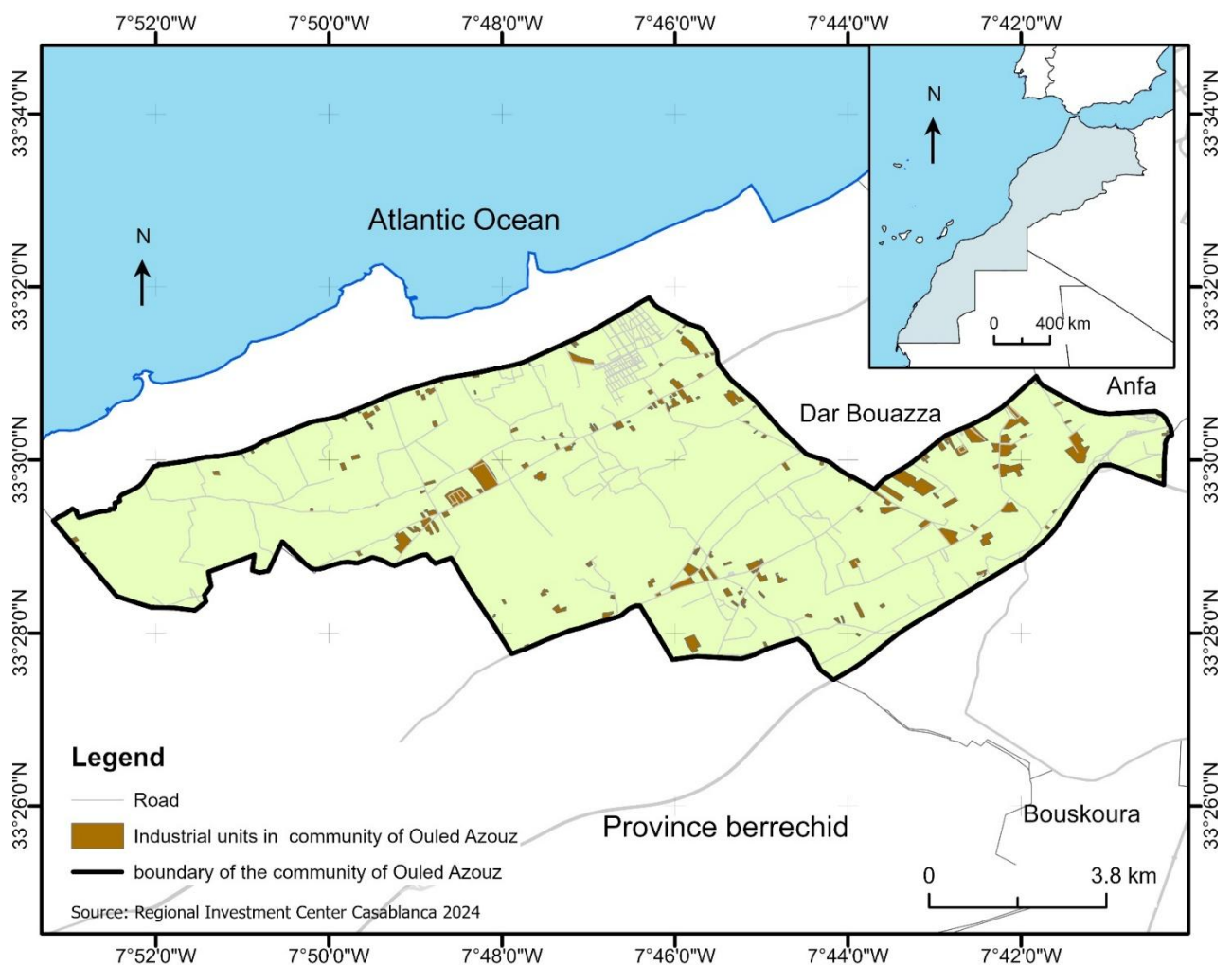
fine-scale evidence from a Moroccan peri-urban commune and offers a transferable analytical framework for industrial-growth assessment in comparable metropolitan fringes.

Industrial geography is not merely an economic phenomenon, but also a spatial-planning challenge involving land conversion, infrastructure allocation and territorial equity. While recent literature has moved decisively toward geospatially explicit analysis, three critical gaps remain: the lack of documentation on the micro-geography of establishments within peri-urban communes; the limited integration of land-price gradients with temporal dynamics; and the underrepresentation of North African metropolitan fringes in fine-scale GIS research. The study addresses these gaps by treating the commune of Oulad Azzouz not as a generic industrial area, but as a spatial system where agglomeration advantages and corridor-based accessibility interact. The novelty of the work also lies in its transferable analytical framework, which allows local authorities to move from descriptive mapping toward evidence-based industrial land management in rapidly transforming metropolitan fringes.

## 2. Methods

### 2.1. Study area

The study area is the commune of Oulad Azzouz in northwestern Morocco, within the Casablanca-Settat region (Figure 1). The commune extends along the Atlantic Ocean to the northwest and is bordered by the urban communes of Dar Bouazza and Anfa to the north and northeast. To the southeast it adjoins Bouskoura, while to the south it borders Berrechid Province. This location places Oulad Azzouz within Casablanca's functional influence, while preserving meaningful peri-urban and semi-rural land-use characteristics.



**Figure 1.** Location of the commune of Oulad Azzouz in the Casablanca-Settat metropolitan fringe.

The commune (latitude 33°25'0"N to 33°33'0"N., longitude 7°56'0"W to 7°36'0"W) covers an area of approximately 86 km<sup>2</sup> within Nouacer Province. Situated in the northwestern Atlantic coastal corridor, the study area is characterized by a semi-arid climate with significant maritime influence. As a strategic transition zone between metropolitan Casablanca and the rural hinterland,

the commune is uniquely exposed to land-use competition between agriculture, residential expansion and industrial investment

## 2.2. Research design and data sources

A spatial-analytical research design was employed, combining a documentary review, official data compilation, field-based georeferencing and GIS-based analysis. The analytical unit was industrial establishment, represented as a point feature with attributes for establishment period, industrial activity (where available), administrative location and spatial relationship to infrastructure and land-price zones. The workflow moved from data acquisition and validation to spatial modelling, statistical testing and planning interpretation.

Data were compiled from administrative departments and local institutions, including the commune of Oulad Azzouz, economic services, regional planning institutions, industrial associations, the urban agency, and land-use planning authorities. These sources provided information on establishments, construction and industrial activity licences, industrial land prices, planned industrial zones and infrastructure connections (Table 1). Field validation used mobile GIS applications (SW Maps, QField, Mobile Topographer), while Google Forms was employed to gather supplementary attributes from stakeholders. Satellite imagery and Google Earth Pro supported the visual verification of establishment locations and surrounding land-use context. The integration of field mapping, GIS and satellite-based interpretation follows recent Moroccan applications of spatial modelling and remote-sensing analysis (Ait Zamzami *et al.*, 2024, 2025; Elaanouzli *et al.*, 2025; Elmotawakkil *et al.*, 2024).

**Table 1.** Data sources and analytical functions used in the GIS-based assessment.

| Dataset                                        | Main sources                                                            | Spatial representation                                 | Analytical use                                                                         |
|------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------------------------|----------------------------------------------------------------------------------------|
| Industrial establishments                      | Official records, licences, field verification, stakeholder survey      | Point layer with temporal and activity attributes      | Temporal profiling, density mapping, nearest-neighbor analysis, cluster interpretation |
| Transport network and logistics nodes          | Administrative maps, satellite-image interpretation, field verification | Line and point layers (roads, port and airport access) | Proximity analysis, accessibility interpretation, corridor-based pattern assessment    |
| Industrial land prices                         | Administrative and field-based land-market information                  | Polygon or classified surface of land-price zones      | Interpretation of land-price gradient and industrial location trade-offs               |
| Administrative boundaries and land-use context | Commune and regional planning datasets                                  | Boundary and contextual layers                         | Map overlay, spatial normalization, planning interpretation                            |
| Satellite imagery and base maps                | Google Earth Pro, Terra Incognita, GIS basemaps                         | Raster and reference layers                            | Location validation, visual interpretation, cartographic production                    |

## 2.3. Spatial data processing and quality control

To ensure methodological transparency, all spatial layers were processed using the WGS 84/UTM Zone 29N (EPSG:32629) coordinate reference system. The primary industrial database represents the 2025 dataset. Kernel Density Estimation (KDE) was performed using a 500 m search radius (bandwidth) and a 30 m grid-cell resolution, utilizing a natural breaks (Jenks) classification to identify hotspots. While Figure 2 illustrates a comprehensive conceptual workflow, our assessment prioritizes proximity-based interpretation and spatial association through overlay analysis, rather than a full regression or network-travel-time model. Consequently, accessibility is measured via straight-line proximity to major road corridors and logistics nodes, serving as a proxy for logistical advantage.

## 2.4. Spatial and statistical analysis

The analysis combined descriptive, spatial and statistical techniques following the overall workflow (Figure 2). Temporal establishment dynamics were examined by grouping establishments into historical periods. Because these periods have unequal lengths, counts were also interpreted as approximate annualized formation intensity, an adjustment that prevents short recent periods from appearing falsely small in absolute terms.

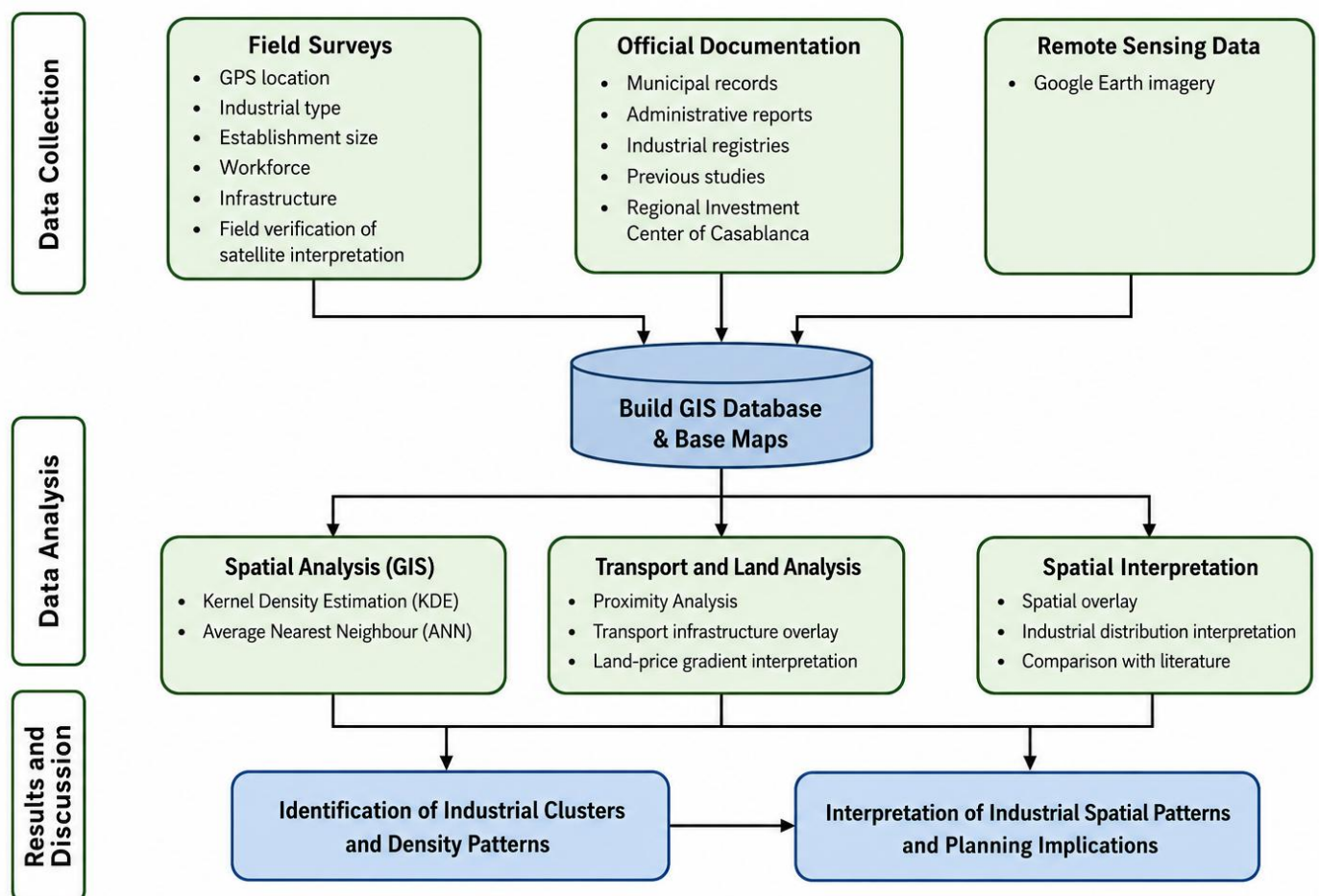
Kernel density estimation (KDE) was used to convert industrial establishment points into a continuous density surface. KDE estimates local intensity around each location by weighting nearby points more strongly than distant points; the resulting surface was classified into very low, low, moderate, high and very high density classes to identify hotspots and weak-presence areas. KDE is informative for industrial-location analysis because it reveals concentration patterns that point maps obscure (O'Sullivan & Unwin, 2010; Biswas & Dey, 2026).

Average nearest-neighbor (ANN) analysis was employed to test whether the industrial point pattern was clustered, random or dispersed. The nearest-neighborr ratio was calculated as:

$$R = \frac{\bar{d}_{obs}}{\bar{d}_{exp}} \quad (1)$$

The observed mean nearest-neighbor distance and the expected distance under complete spatial randomness. Values of R below 1 indicate clustering, those close to 1 randomness, and ones above 1 dispersion. Statistical significance was assessed by z-scores and p-values. The ANN test provides a formal complement to visual interpretation of density maps.

Proximity and accessibility analyses examined the relationship between establishments and transport infrastructure. Distances to major roads, the airport and port-related access corridors were interpreted as logistics-advantage indicators. Land-price analysis overlaid establishment points and density classes on price zones to evaluate whether establishments concentrate in high-cost strategic zones, low-cost peripheral zones or intermediate areas combining accessibility with lower land-market pressure. Together, these methods deliver a multi-factor explanation of industrial location rather than a purely descriptive map of industrial points.



**Figure 2.** GIS-based methodological workflow for mapping, modelling and interpreting industrial growth dynamics.

## 2.5. Data Validation

The positional reliability of the spatial database was evaluated using a two-stage validation procedure combining independent field verification and high-resolution image-based cross-checking. First, a simple random sample representing 15% of all mapped locations was selected and re-surveyed in the field using georeferenced ground observations. Independent field measurements provide an important reference for assessing the positional reliability of remotely derived or compiled spatial datasets, particularly when coordinate deviations are explicitly evaluated against ground-based observations (Ahmed & Mahmud, 2022; Subedi & Zurqani, 2026). Comparison

between the database coordinates and their corresponding field-verified positions showed that 98% of the sampled locations satisfied the predefined positional-accuracy criterion, indicating a high level of spatial consistency in the database.

As an additional quality-control step, all sampled locations were visually and spatially cross-checked against identifiable features in high-resolution imagery available through Google Earth Pro. A maximum horizontal displacement of 5 m between the mapped point and its corresponding image feature was adopted as the operational acceptance threshold. High-resolution Google Earth imagery has been widely used as an auxiliary source for positional verification and ground-reference identification, although its absolute positional accuracy can vary geographically and therefore should complement, rather than replace, field-based validation (Pulighe *et al.*, 2016; Goudarzi & Landry, 2017). Locations exceeding the 5-m threshold were re-examined and, where necessary, corrected against the field reference coordinates. This combined field- and imagery-based validation procedure was used to minimize geolocation errors and ensure that the final spatial database was sufficiently reliable for subsequent spatial analysis.

### 3. Results

#### 3.1. Temporal dynamics of industrial establishment formation

Establishment creation in Oulad Azzouz has unfolded in distinct phases rather than through linear growth (Table 2). Following post-independence consolidation (1956–1980) with 136 establishments, the subsequent decades saw fluctuating activity: 96 in 1981–1990; 108 in 1991–2000; 113 in 2001–2010; 53 in 2011–2020; and 58 in 2021–2023. While absolute numbers for the most recent period appear lower than historical peaks, normalizing for period length is essential. The 2021–2023 window, covering only three years, reveals an annualized formation intensity of approximately 19.3 units/year, a rate indicating a significant recent acceleration rather than a decline. This high intensity suggests renewed industrial pressure or post-crisis recovery, signaling an urgent need for infrastructure, land servicing and environmental management planning, even if cumulative counts remain below those of longer historical periods.

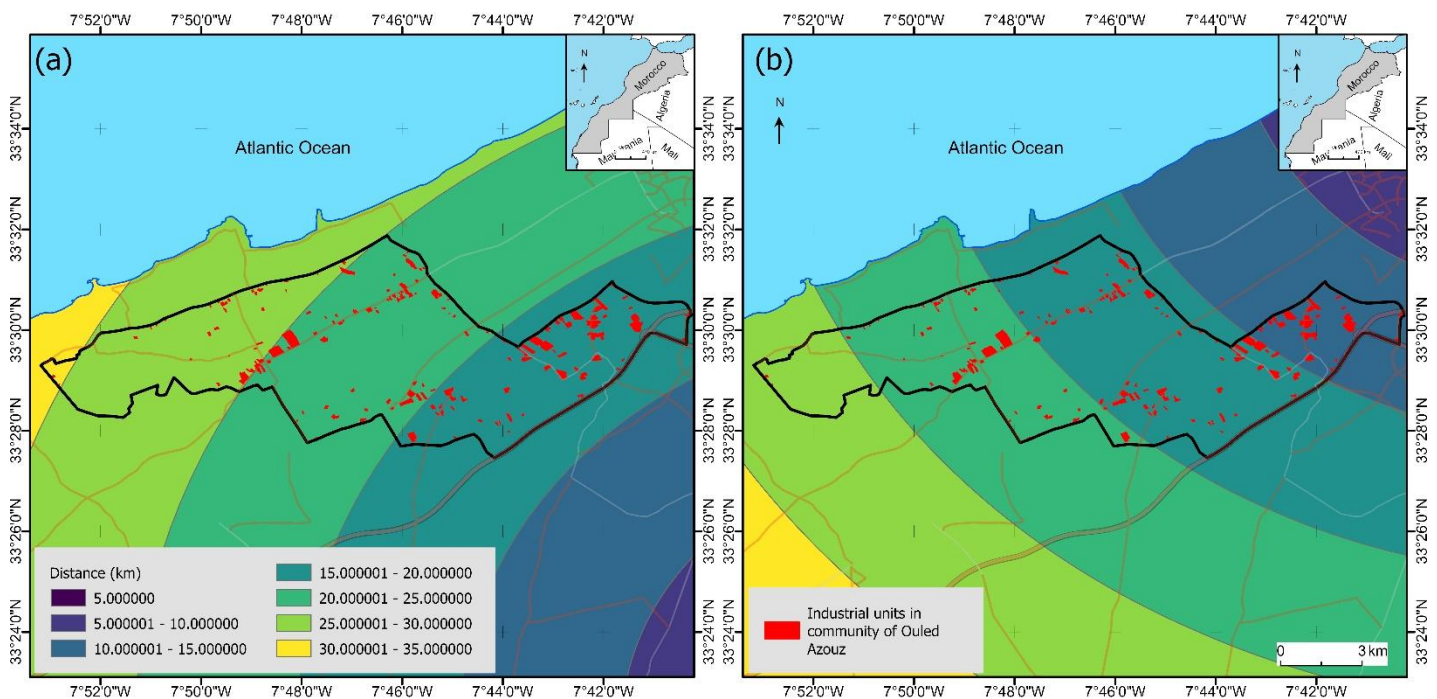
**Table 2.** Temporal profile of industrial establishment formation in Oulad Azzouz.

| Period    | Establishments | Approx. period length | Interpretation                                                                                                   |
|-----------|----------------|-----------------------|------------------------------------------------------------------------------------------------------------------|
| Pre-1956  | 20             | Historical baseline   | Predominantly rural and agricultural territorial structure                                                       |
| 1956–1980 | 136            | 25 years              | Initial post-independence industrial consolidation near Casablanca                                               |
| 1981–1990 | 96             | 10 years              | Continued growth under macroeconomic adjustment conditions                                                       |
| 1991–2000 | 108            | 10 years              | Recovery and investment reorientation under economic liberalization                                              |
| 2001–2010 | 113            | 10 years              | Consolidation of peri-urban industrial attractiveness                                                            |
| 2011–2020 | 53             | 10 years              | Slower cumulative formation, plausibly linked to competition from planned industrial zones and rising land costs |
| 2021–2023 | 58             | 3 years               | High recent annualized formation intensity; warrants cautious interpretation and continued monitoring            |

#### 3.2. Transport infrastructure and accessibility

The spatial configuration of Oulad Azzouz confers a clear logistical advantage. The commune sits roughly 20 km from the Port of Casablanca, with the most distant locations approximately 25 km from the port, and it lies close to Mohammed V International Airport (about 6 km from the commune centre, up to 16 km from the periphery) (Figure 3). It is crossed or bordered by major road infrastructure—highway and regional road connections that link Oulad Azzouz to Casablanca, Bouskoura, Nouacer and other surrounding economic centers.

Mapping of transport infrastructure shows that establishments are not evenly distributed. They follow accessible corridors and concentrate where road connectivity supports logistics, supplier access and market reach. The pattern echoes broader research on transport networks and employment concentration, which has found that connectivity reinforces cumulative spatial advantages (Frye, 2026). Transport infrastructure functions here not only as a mobility asset, but as a spatial organizer of industrial investment.



**Figure 3.** Transport infrastructure, logistics accessibility and industrial establishments in Oulad Azzouz. (a) distance to airport, (b) distance to seaport.

### 3.3. Industrial land-price gradients

Industrial land prices follow a strong spatial gradient (Figure 4). Most interior areas record prices of around 3,500–4,000 MAD/m<sup>2</sup>, while locations closer to Casablanca and major infrastructure corridors reach 8,001–15,000 MAD/m<sup>2</sup>. Some highly accessible locations along the northeastern boundary register prices between 15,001 and 35,000 MAD/m<sup>2</sup>. The gradient reflects the capitalization of accessibility, metropolitan proximity and investor demand in land values.

The spatial distribution of industrial establishments indicates a concentration in areas characterized by relatively good transport connectivity and moderate land-price levels. Higher land-price zones located near Casablanca and major transport infrastructure also contain industrial establishments, whereas some lower-priced peripheral areas exhibit lower industrial presence, particularly where transport infrastructure and services are less developed. These observations are based on the spatial overlay of industrial locations, transport infrastructure and land-price zones, and should be interpreted as spatial associations rather than statistically verified relationships. The observed pattern is broadly consistent with concepts in land-use economics and agglomeration theory, which recognize the influence of land values and transport accessibility on industrial location patterns (Behrens *et al.*, 2014; Cheshire & Sheppard, 2005; Glaeser & Gottlieb, 2009).

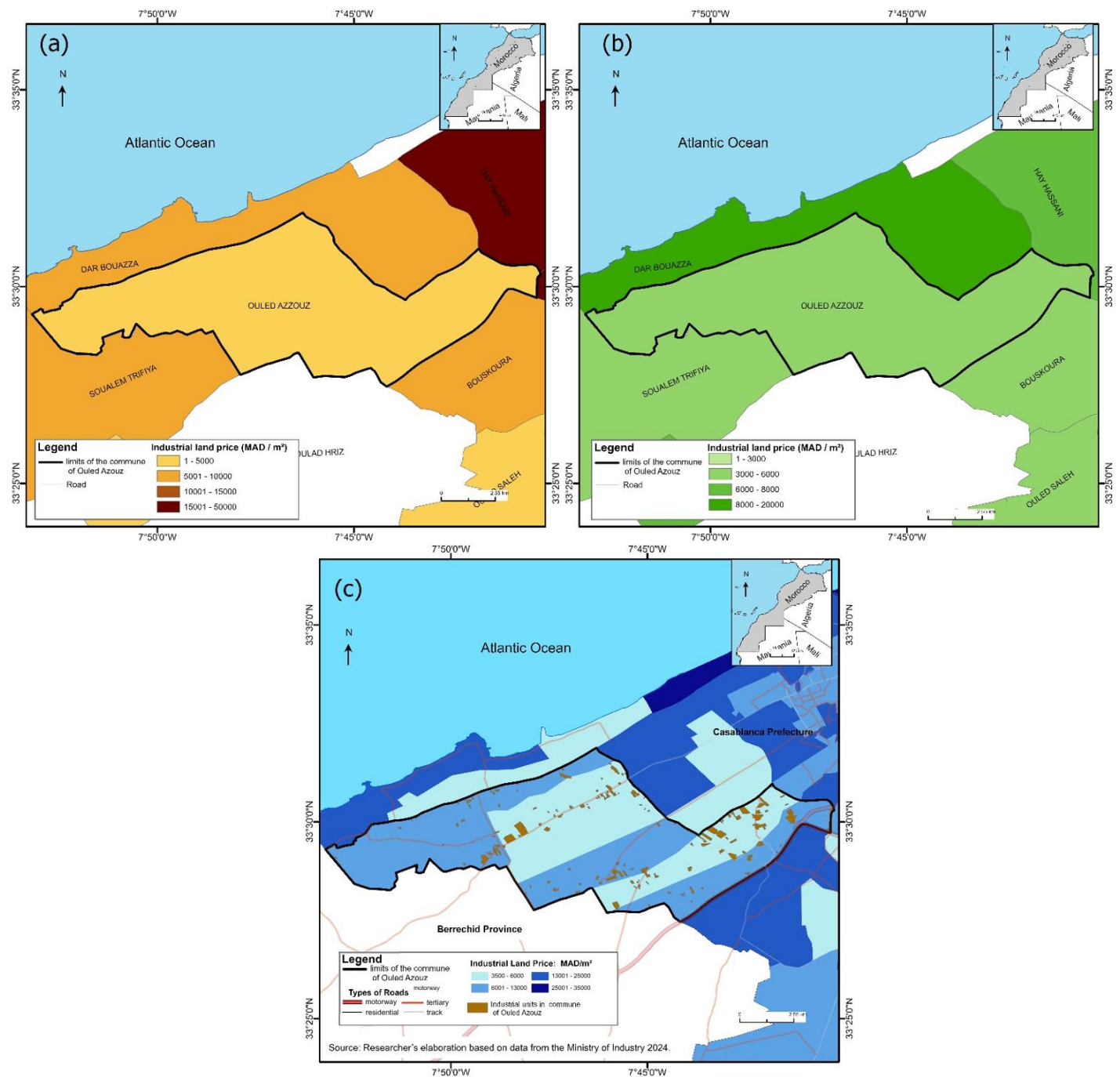
### 3.4. Industrial density and spatial clustering

The density map reveals a pronounced spatial imbalance, with 38% of the commune falling within high or very high-density classes (Table 3). This concentration is not random, but forms well-defined industrial hotspots. The ANN test confirmed this clustered pattern with a ratio of 0.63 ( $z=-8.83$ ,  $p<0.001$ ), indicating that establishments are significantly grouped near logistics assets.

The results suggest that the observed distribution is highly unlikely to have occurred by chance. While this clustered pattern reflects the combined influence of transport accessibility, land-price trade-offs and agglomeration benefits, by which firms benefit from shared suppliers, labor and service networks, the ANN analysis establishes spatial association rather than direct causality (Figure 5). Consequently, while the patterns suggest that firms respond to infrastructure corridors and land-price variations, confirmation of the drivers of individual firm-level decision-making requires further regression-based evidence.

This concentration creates significant planning risks. Dense industrial nodes heighten localized pressure on roads, utilities and environmental quality, whereas low-density areas risk becoming disconnected from industrial opportunities. The overarching policy challenge for the municipality is to support productive agglomeration, leveraging the economic benefits of clustering, without allowing growth to become spatially exclusionary or environmentally unmanaged. Balancing

these competing spatial needs remains essential for the future sustainability of the commune's industrial development strategy.



**Figure 4.** Industrial land-price zones in Oulad Azzouz. (a) The highest industrial land-price, (b) The lowest industrial land-price, (c) The average industrial land-price.

**Table 3.** Summary of industrial density and nearest-neighbor statistics.

| Indicator                          | Value    | Meaning                                   | Planning implication                                                             |
|------------------------------------|----------|-------------------------------------------|----------------------------------------------------------------------------------|
| Very low-density area              | 15%      | Weak industrial presence                  | Potential reserve or constrained space requiring infrastructure diagnosis        |
| Low-density area                   | 17%      | Limited industrial activity               | Candidate areas for selective servicing where environmentally suitable           |
| Moderate-density area              | 30%      | Transitional industrial intensity         | Important zones for managed expansion                                            |
| High- and very-high density area   | 38%      | Established industrial hotspots           | Infrastructure upgrading, traffic management and environmental controls required |
| Observed nearest-neighbor distance | 289.21 m | Industrial units lie close to one another | Evidence of agglomeration and shared-location advantages                         |

| Indicator                          | Value             | Meaning                                     | Planning implication                                   |
|------------------------------------|-------------------|---------------------------------------------|--------------------------------------------------------|
| Expected nearest-neighbor distance | 453.07 m          | Reference distance under spatial randomness | Observed pattern deviates strongly from randomness     |
| Nearest-neighbor ratio             | 0.63              | Clustered pattern                           | Industrial concentration warrants explicit management  |
| z-score / p-value                  | -8.83 / p < 0.001 | Statistically significant clustering        | Quantitative support for spatial planning intervention |

KDE analysis identifies that the highest concentration of firms is situated along the northeastern road corridors, where infrastructure connectivity is at its peak, while the southern periphery remains largely under-industrialized.

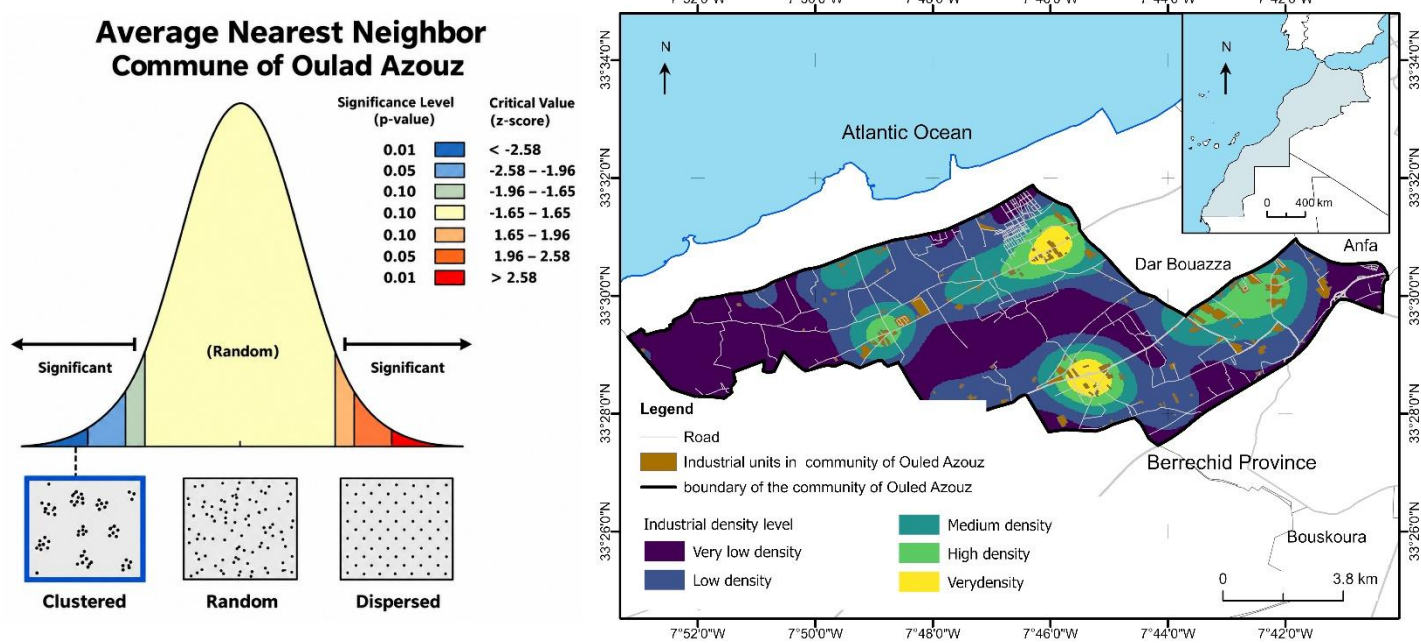


Figure 5. Industrial density classes and clustered industrial hotspots in Oulad Azzouz.

4. Discussion

4.1. Principal findings and contribution

Industrial development in Oulad Azzouz exhibits a spatially clustered and temporally uneven pattern that is associated with transport accessibility and land-price gradients. The ANN analysis provides statistical evidence of clustering: the observed mean nearest-neighbor distance (289.21 m) is substantially lower than the expected mean under spatial randomness (453.07 m), and a highly significant negative z-score. These results indicate that the observed spatial pattern is highly unlikely to have occurred by chance and suggests a significant degree of industrial clustering. The clustered distribution may reflect the combined influence of multiple location factors, including transport connectivity, land-price conditions and agglomeration processes; however, the ANN analysis alone does not establish a causal relationship between these factors and the observed clustering. Kernel density estimation further supports the presence of spatial concentration, with high- and very high-density classes occupying a significant proportion of the industrialized area, while other parts of the commune remain characterized by relatively low industrial density

The contribution of the is twofold. Empirically, the analysis provides fine-scale evidence from a Moroccan peri-urban commune—a scale less visible in industrial-location literature than national, provincial or metropolitan analyses. Conceptually, it shows that industrial growth in Oulad Azzouz emerges from interacting spatial forces: firms pursue accessibility to road, port and airport infrastructure, but also respond to land-price constraints and to the benefits of co-location. The case adds support to the broader argument that industrial clustering is produced by cumulative locational advantages and can deepen spatial inequality without deliberate territorial planning (Chakraborty, 2024; Mazouz et al., 2025).

4.2. Drivers of agglomeration: infrastructure and land markets

Industrial clustering along major corridors in Oulad Azzouz highlights the decisive role of transport infrastructure in shaping peri-urban geography. Proximity to primary road networks and logistics nodes minimizes transport costs, while enabling localized externalities, such as shared

access to labor, utility networks and supplier connections. This corridor-oriented concentration aligns with established evidence that transport expansion intensifies industrial clustering and restructures metropolitan linkages (H. Li *et al.*, 2025; Keji *et al.*, 2025; Zhang & Chen, 2025). In Oulad Azzouz, while this pattern enhances economic competitiveness and integrates the commune into Casablanca's broader metropolitan dynamics, it also poses infrastructure challenges, notably localized road congestion and spatial disparities between well-connected corridors and isolated peripheries.

In tandem with infrastructure, land-price gradients act as a critical driver governing firm distribution. Higher land values near Casablanca and primary transport arteries push establishments toward areas offering a functional compromise, with moderate accessibility combined with manageable land costs. This trade-off positions Oulad Azzouz as a land-market compromise zone, where firms balance accessibility premiums against land scarcity rather than opting for prime urban nodes or remote, unserved locations (Behrens *et al.*, 2014; Glaeser & Gottlieb, 2009; Yao *et al.*, 2025).

These dual dynamics have direct implications for peri-urban governance. Rising land prices along strategic corridors risk pricing out small and medium-sized enterprises, driving them toward unserved peripheral areas and inducing fragmented, informal expansion (Biswas & Dey, 2026; Lin *et al.*, 2015). Conversely, promoting peripheral expansion without simultaneous infrastructure delivery and environmental safeguards leads to inefficient land conversion and localized ecological pressure (Zhu *et al.*, 2025). Incorporating land-price monitoring alongside infrastructure hierarchy is therefore essential to guide orderly industrial growth and maintain spatial equity.

#### 4.3. Implications for industrial sustainability and spatial governance

Economic gains from clustering must be balanced against sustainability risks. While concentrated nodes enhance productivity and logistics efficiency, they simultaneously intensify traffic congestion, utility demand and thermal stress. Recent research emphasizes that industrial expansion significantly alters land-use and intensifies heat-island effects, necessitating closer integration between industrial development and urban environmental management (Al-Asadi *et al.*, 2024; Bala & Dar, 2024; Toor & Khalid, 2026; Wu *et al.*, 2025). Importantly, co-agglomeration is not inherently unsustainable; under appropriate institutional governance, it can even catalyze green innovation (Yang *et al.*, 2024). In Morocco, this imperative is sharpened by the urgent alignment of industrial policy with national energy transition and climate-resilient development goals (Ikram & Nahdi, 2025; Tafrata, 2025).

Consequently, industrial growth in Oulad Azzouz should move beyond mere establishment counts. A sustainable strategy requires the alignment of spatial concentration with robust environmental safeguards, such as green buffers, wastewater control and emissions monitoring. Practical templates from established industrial estates confirm that effective management of industry-neighborhood interfaces is critical (Sulistiyandari *et al.*, 2026). Broadly, sustainability gains are most likely when industrial planning is coordinated with ecological constraints and community needs, rather than treated as an isolated sectoral policy (Al-Asadi *et al.*, 2024; Diamantidis *et al.*, 2025; Nasser *et al.*, 2025).

While this study does not directly measure emissions, the identified industrial hotspots, with 38% of the commune in high-density classes, serve as critical planning hypotheses for future risk assessment. These high-density nodes represent primary areas of concern for traffic congestion and localized thermal stress. To bridge the gap between spatial association and environmental impact, future research should employ spatial regression and longitudinal remote sensing to formally confirm the causal relationship between these industrial clusters and localized urban environmental degradation. By moving from static observation to integrated management, the commune can support productive agglomeration while proactively mitigating the cumulative negative externalities of its rapid industrial evolution.

#### 4.4. Planning and policy implications for Oulad Azzouz

The findings support a shift from reactive land allocation towards corridor-based and node-based industrial planning. The commune should identify priority industrial nodes where accessibility, land availability and environmental suitability overlap, while avoiding uncontrolled expansion into areas where infrastructure is weak or ecological sensitivity is high. Territorial spatial-planning research argues that industrial growth should be guided by land-development suitability, resource-carrying capacity and the coordination of economic, settlement and ecological objectives

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## Author Contributions

Conceptualisation: A.Z., H. A.Z., A. E., B. E. and T.B.; methodology: A.Z., H. A.Z., M.E., J.J. and O.B.; data collection and field validation: A.Z., S.M., A.E., B.E. and J.S.; spatial analysis and visualisation: A.Z., H.A.Z., S. M., and M.E.; writing original draft: A.Z. H. A.Z.; writing—review and editing: all authors. All authors have read and agreed to the final version of the manuscript.

## Conflict of interest

All authors declare that they have no conflicts of interest.

## Data availability

The datasets generated and analyzed during the study are available from the corresponding author upon reasonable request, subject to administrative data-sharing restrictions.

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(Fang *et al.*, 2024; J. Li *et al.*, 2025). Lessons from special economic zones and development-zone studies indicate that place-based industrial policies can promote industrialization and structural change, but that their impacts depend on local institutional capacity, integration with surrounding economies, and the quality of planning implementation (Abagna, 2025; Manilet & Sulistyaningrum, 2026; Otchia & Wiryawan, 2025; Wardhana *et al.*, 2025; Ye *et al.*, 2024). Spatial-modelling frameworks for industrial land suitability based on ensemble machine learning offer transferable methods for evaluating industrial location decisions across Moroccan communes (Mujtabe *et al.*, 2026). For Oulad Azzouz, industrial zoning should be linked to road hierarchy, logistics access, utility capacity, land-price monitoring and environmental risk screening. Specifically, the commune must identify the northeastern corridors bordering Casablanca as priority industrial nodes. These specific areas overlap high accessibility and moderate land prices, making them the primary candidates for immediate infrastructure upgrading and environmental monitoring.

Several practical steps should be taken. Infrastructure investment should prioritize missing links between existing industrial clusters and strategic logistics corridors, rather than distributing road upgrades evenly across the commune. Land-policy instruments should protect affordable, serviced industrial plots for small and medium-sized enterprises so that rising land prices do not exclude local investors. In addition, industrial-density hotspots should be paired with environmental monitoring and infrastructure-capacity audits to contain cumulative negative externalities. Low-density areas should be evaluated carefully before being promoted for industrial expansion: low density may reflect underused potential or genuine constraints related to accessibility, land suitability, environmental exposure or infrastructure deficits. Finally, the commune should develop an updated geospatial industrial database recording establishment type, age, employment, utility demand, land parcel characteristics, environmental compliance and firm turnover. Such a database would let local authorities track whether industrial growth was consolidating into productive planned clusters, or dispersing into unmanaged peri-urban land conversion—a distinction that recent firm-dynamics and business-park studies show is decisive for territorial governance (Diamantidis *et al.*, 2025; Lin *et al.*, 2024).

## 4.5. Limitations and future work

The study has certain limitations. The analysis depends on administrative and field-verified establishment data whose accuracy reflects the completeness of local records and the availability of establishment dates. In addition, the work tests spatial association and clustering, but does not establish causal effects between infrastructure, land prices and firm-location decisions. The land-price layer captures spatial variation in industrial land value, but does not extend to parcel-level negotiation, ownership structure, tenure security or speculative behavior. The analysis also omits firm-level variables—employment, turnover, productivity, energy consumption, emissions, water demand and supply-chain relations—that would deepen evaluation of industrial performance and sustainability.

Four extensions would advance this line of work. Longitudinal remote sensing could quantify the relationship between industrial establishment growth, built-up expansion, land-use conversion and thermal environmental effects (Bala & Dar, 2024; Biswas & Dey, 2026; Parveen *et al.*, 2023). In addition, night-time light imagery and space-time data mining would complement establishment data by capturing broader industrial intensity and socio-economic change (Hutasavi & Chen, 2024). Network-based accessibility modelling could replace straight-line proximity with travel-time estimates to ports, airports, highways and labor-market centers, allowing direct comparison with recent transport-infrastructure studies (H. Li *et al.*, 2025; Zhang & Chen, 2025), while firm surveys could identify decision-making factors behind site selection: land cost, labor availability, logistics, regulation and access to finance. Finally, comparative analysis with other communes in Casablanca-Settat would clarify whether Oulad Azzouz represents a distinctive industrial trajectory or a wider peri-urban industrialization pattern in Morocco's Atlantic metropolitan corridor.

## 5. Conclusion

The study has examined the spatial distribution and growth dynamics of industrial establishments in the commune of Oulad Azzouz, using a GIS-based framework that integrates temporal establishment profiling, accessibility assessment, land-price interpretation, density mapping and nearest-neighbor statistics. Industrial development in Oulad Azzouz is strongly clustered, rather than randomly distributed. The ANN result (nearest-neighbor ratio = 0.63,  $z = -8.83$ ,  $p < 0.001$ ) provides quantitative evidence of significant industrial agglomeration, and the density map shows that 38% of the commune lies within high or very high industrial density classes.

Industrial agglomeration in Oulad Azzouz is shaped jointly by logistics accessibility and land-price gradients. Establishments are concentrated along accessible corridors and in areas where firms can balance proximity to roads, the airport and the Casablanca metropolitan economy against land-cost constraints. The temporal analysis adds an important caveat: although cumulative counts after 2011 appear lower than earlier longer periods, the 2021–2023 phase registers high annualized establishment intensity.

The principal contribution of the work is a fine-scale geospatial account of peri-urban industrial growth in a Moroccan metropolitan fringe. For policy and planning, the findings indicate that Oulad Azzouz needs integrated industrial spatial governance: infrastructure upgrading in dense industrial nodes; land management to support small and medium-sized enterprises; and buffer zones to reduce land-use conflict and environmental monitoring to ensure that industrial competitiveness does not compromise sustainable territorial development. These insights can inform balanced, evidence-based industrial planning in Casablanca-Settat and in other comparable peri-urban regions.

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