Uncovering patterns of urban growth and infrastructure progress in Grand Casablanca: a descriptive multi-indicator approach

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Abstract. Urbanization in Morocco has intensified, with 65% of the population living in cities by 2022 despite slowing growth rates. Road infrastructure plays a pivotal role in shaping urban form, land-use change, and socio-economic development. This study examines the spatial interplay between road network topology and urban expansion in the Grand Casablanca region, focusing on Casablanca, Nouaceur, Mediouna, and Mohammedia. Using a multi-indicator visual analytics framework—combining radar plots, correlation matrices, Kernel Density Estimation (KDE), and dimensionality reduction—the analysis explores links among urban density, land-use change, population distribution, and infrastructure access. KDE maps road network density against urbanization indices to reveal spatial disparities and typologies rather than merely statistical regularities. Findings highlight how road infrastructure drives uneven development trajectories and provide context-sensitive insights to guide equitable and strategic planning in rapidly urbanizing metropolitan regions.

1 Introduction

In the 21st century, over half of humanity now lives in cities—up from 13% in 1900—and this share is projected to exceed 70% by 2050, adding 2.8 billion urban dwellers (United Nations, 2019). Morocco mirrors this trend: its population tripled since 1960 but growth slowed from 2.6% (1960–1982) to 0.85% (2014–2024). Urbanization rose from 29.2% in 1960 to 62.8% in 2024 and will reach nearly 75% by 2050 (Lall et al., 2019). Urbanization stems from natural increase and rural migration—responsible for 43% of urban growth between 1971–1992 (HCP, 2005)—and remains uneven. Over 70% of the population concentrates in five regions, led by Casablanca-Settat (20.9%). Between 2014–2024, these and two other regions absorbed 86.2% of growth, underscoring intense demographic dynamics along major corridors. Casablanca-Settat alone holds 27.8% of Morocco's population with an annual growth of 1.14%, exceeding the national average. This concentration demands robust transport networks—ports, airports, rail, and roads—that already account for 32.4% of national GDP.

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Infrastructure shapes mobility, accessibility, and socio-economic structure. Morocco has invested heavily in infrastructure development—2030 National Port Strategy, Vision 2023–2030 for tourism, and PRM 2040 Rail Strategy—improving its Global Competitiveness Index ranking: 71/137 overall and 54/137 for infrastructure in 2017–2018 (Klaus Schwab, 2017).

Casablanca's built-up area grew 88% from 1989–2019, outpacing population growth and creating sprawl (Benchelha et al., 2022). Infrastructure—roads, electricity, sanitation—remains pivotal for health, education, and economic resilience (Canning & Pedroni, 2004; El-Bouayady & Radoine, 2023). Yet urbanization's benefits remain uneven, with persistent poverty and spatial disparities (Bounoua et al., 2020). Remote sensing and GIS help map sprawl and guide evidence-based planning (El Garouani et al., 2017). Small-N spatial studies further capture regional specificities—such as Casablanca's distinct urbanization pattern—by using detailed, place-based indicators. Combining these with multivariate methods yields typologies across provinces, balancing contextual richness and analytical coherence to inform locally grounded policies.

2 Data and methods

2.1 Study area

The Casablanca-Settat region covers an area of 20110 km2 and has a population of 7688 562 (Direction régionale de Casablanca-Settat 2017), resulting in a population density of 382.3 inhabitants per km2 and occupying 2.7% of the national territory (HCP projections).

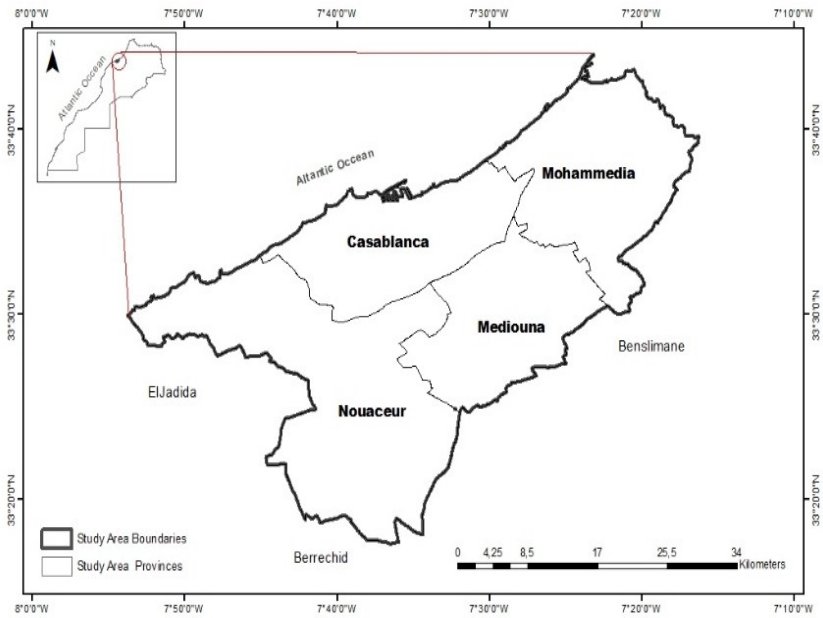

Fig. 1. Study Area of Grand Casablanca, including Mohammedia, Nouaceur, Mediouna and Casablanca

Although the administrative region of Casablanca–Settat consists of seven provinces (Casablanca, Mohammedia, Nouaceur, Mediouna, Settat, Berrechid, and Benslimane), our study focuses exclusively on the territory of Grand Casablanca region. This area includes the

four provinces of Casablanca, Mohammedia, Nouaceur, and Mediouna. These provinces were selected based on the quality of available satellite imagery and the completeness of socio-economic data. Geographically, the study area spans from 8°7'23.40" W to 6°47'4.51" W longitude and from 32°20'57.35" N to 33°49'49.50" N (Fig. 1).

2.2 Data

Table 1. Definition of variables and summary statistics

Variable Abbreviation	Variable Definition	Conceptual interpretation	Mean	Standard Deviation
TA	Total Area (km²)	Territorial extent	285,7	104,19
RDPR	Rural Distance to Paved Road	Accessibility constraint	0,34	0,27
ARUSE	Annual Rate of Urban Spatial Expansion	Urban expansion velocity	0,02	0,02
ULCR	Urban Land Conversion Rate	Land transformation intensity	0,45	0,27
UCS	Urban Commune Share	Urban presence	0,58	0,3
PDI	Population Density Index	Population concentration and intensity	4776,18	7532,04
UDI	Urban Density Index	Built-up density / urban compactness	10654,16	9854,24
APNC	Avg. Price of New Constructions (MAD)	Land/housing market value	838788,6	1674748,98
EEC	Electricity Energy Consumption (kWh)	Energy demand / service penetration	344053,8	219294,83
IR	Industrial Revenue (MAD)	Economic productivity	90108777	107418557,7
NEFP	Expected Jobs from Favorable Projects	Employment potential from public/private investment	3064,58	2270,86
LR	Literacy Rate	Human capital / education	0,81	0,03
DPR	Doctor per Residence	Medical service provision	1,16	0,6
PCHP	Primary Care Health Points per Residence	Basic health services accessibility	0,53	0,29
RND	Road Network Density	Infrastructure connectivity	2,32	2,2

This study uses a panel of 15 multidimensional indicators to characterize urbanization and infrastructure dynamics across Grand Casablanca region. Variables definition and summary statistics are provided in Table 1. These indicators span aspects including population density, road accessibility, land use change, socio-economic vitality, and service provision. Population and socio-economic variables were gathered from national census, while urban expansion and land use indexes were computed based on remote sensed data using GEE platform. In remote sensing studies, impervious surface area is the most effective indicator of urban land (Chester & Gibbons, 1996). Consequently, we used GAIA dataset to derive expansion metrics (Gong et al., 2020). The standardized variables serve as inputs for

multivariate analysis for the four areas of interest. GAIA dataset was used to develop urban growth and land transformation indicators, offering a replicable approach to monitor urban growth in data-scarce settings.

2.3 Methods

This study adopts a multi-method approach to analyze how road infrastructure and socio-spatial indicators interact with urban expansion dynamics across four Moroccan provinces. The analysis combines geospatial processing, descriptive analytics including correlation analysis.

2.3.1. Spatial estimation of road network density

To quantify the distribution and intensity of road infrastructure, we computed the Road Network Density (RND) using a Kernel Density Estimation (KDE) approach applied to road vector data extracted from OpenStreetMap (OSM). KDE is widely used in spatial analysis to derive a continuous surface representing the density of linear features such as roads or rivers, capturing spatial concentration more effectively than basic length-per-area metrics (Silverman, 2018; Xie & Levinson, 2007).

For the analysis, road layers were categorized into five major classes: motorway, trunk, primary, secondary, and tertiary roads. Railway infrastructure included both rail and tram categories. These road and railway layers were merged into a unified transportation network, ensuring a comprehensive and integrated analysis of infrastructure density that captures the joint impact of both mobility modes on urban development across municipalities.

After creating the unified network, Kernel Density Estimation was applied to the combined dataset. The output density raster was then classified into five equal-interval classes, enabling consistent comparison of infrastructure intensity across municipalities. This classification scheme allows for the identification of low, medium, and high-density zones. By using standardized class intervals in ArcGIS, the analysis reveals spatial disparities in transportation infrastructure distribution — critical for understanding urbanization dynamics and informing regional planning efforts.

2.3.2. Urban growth and land transformation indicators

To evaluate the spatial and temporal dimensions of urban growth across the study area, we computed four core indicators: the Annual Rate of Urban Spatial Expansion (ARUSE), Urban Land Conversion Rate (ULCR), Urban Density Index (UDI), and Population Density Index (PDI). These indices were derived from GAIA data using GEE platform. Visual validation and cross-referencing with official land use maps confirmed the reliability of outputs.

This dual-indicator approach is grounded in prior research emphasizing that urban expansion is both temporally dynamic and spatially heterogeneous (Liu et al., 2010; Zeng et al., 2014). ARUSE captures the pace of urban land growth over time, while ULCR reflects the spatial extent and intensity of land transformation. Together, they provide a more complete picture of urbanization processes, offering critical insights into how rapidly and extensively non-urban land is being reallocated for urban use.

a. Annual rate of urban spatial expansion

To assess the pace and extent of urban growth over time, this study employs the Annual Rate of Urban Spatial Expansion (ARUSE), a metric designed to capture both the temporal rate and spatial magnitude of land conversion from non-urban to urban uses. This indicator reflects the changing footprint of built-up areas and serves as a standardized measure of urbanization dynamics (Schneider and Woodcock 2008).

The ARUSE is calculated as:

$$\text{ARUSE} = \left(\frac{UL_t - UL_{t-1}}{UL_t \times n}\right) \times 100 \quad (1)$$

Where UL_t and UL_{t-1} are the total urban areas of the study area in kilometers at time t and time $t-1$; and n is the total number of years from time t to $t-1$.

This indicator quantifies the annualized rate of urban land expansion, accounting for both the intensity and persistence of growth. It enables meaningful comparisons across municipalities and time periods, and is particularly valuable for evaluating the influence of infrastructure development and planning interventions on the spatial dynamics of urbanization.

b. Urban land conversion rate

The Urban Land Conversion Rate (ULCR) captures the annual rate at which non-urban land is transformed into urban land across the study area. Unlike the ARUSE, which measures the growth of the urban footprint itself, ULCR relates that growth to the entire land base, providing insight into the relative intensity of land-use change. This index is expressed as:

$$ULCR = \left(\frac{UL_t - UL_{t-1}}{TL_t \times n}\right) \times 100 \quad (2)$$

Where TL_t is the total land areas in kilometers at time t. ULCR is useful for identifying broader land-use shifts, highlighting how land previously designated for non-urban purposes is increasingly allocated to urban development.

c. Urban density index

A population density index is critical in analyzing spatial temporal urban growth and transport analysis (G. Xu et al., 2020; Zhang & Guindon, 2006). Urban density index is defined as the ratio of change in urban population to change in amount of built-up land area. Many urban studies have calculated population density as the total urban population to the total urban area. Here, a population density index (PDI) is implemented as follows:

$$UDI = \frac{UP_t}{UL_t} \quad (3)$$

where UP_t is total urban population; UL_t is the total urban land in kilometers at time t.

d. Population density index

The population density index measures the total population per sq km of total land. It reflects the efficiency of land use, how much land is needed per person added.

$$PDI = \frac{TP_t}{TL_t} \quad (4)$$

where TP_t is total population density; TL_t is the total land in kilometers at time t.

2.3.3. Descriptive and visual analysis

To explore patterns and variation across the four provinces, we construct first a radar chart to profile each province across the 15 indicators, emphasizing multi-dimensional disparities. Secondly, a correlation matrix was generated to examine inter-variable relationships and detect multi-collinearity, guiding subsequent dimensionality reduction.

3 Results and discussion:

3.1 Spatial patterns of road network density

The Grand Casablanca region's spatial configuration shows pronounced differences in the network density and distribution of roads. Table 2 presents some of the key statistics based on Kernel Density Estimation (KDE) performed in ArcGIS on the major roads (motorway, trunk, primary, secondary and tertiary) obtained from OpenStreetMap layers. The results of the KDE analysis for the province's highways and roads were calculated using a fixed

bandwidth approach and classed using the Natural Breaks (Jenks) classification algorithm, which optimizes thresholds based on inherent data groupings in each province. The spatial distribution and density values of road network are displayed in Fig.2 and Fig.3.

Table 2. Summary statistics of roads in in Grand Casablanca region, 2024

	Casablanca	**Mediouna**	**Mohammedia**	**Nouaceur**
Count	4593	354	900	923
Minimum	0,00032	0,00036	0,00177	0,00149
Maximum	9,783	6,551	8,555	10,862
Sum	1225,09306	187,498691	409,493924	561,575875
Mean (km)	0,266	0,529	0,454	0,608
Standard deviation	0,542	1,131	0,935	1,275
Area (km2)	219,137	217,606	268,056	437,974
Road density (km/km2)	5,59	0,86	1,53	1,28

In terms of road network density, Casablanca ranked first with the highest with 5.59 km/km², which illustrates the compact urban form and extensive road infrastructure system. The city has 4593 road segments giving a total length of over 1225 km, with the mean segment length being 0.266 km and relatively low dispersion (SD=0.542). The values of the raster output of KDE lie between 0 and 53.26 and are categorized into five classes with the surface displaying dense infrastructure in the core urban zones (31.75-53.26).

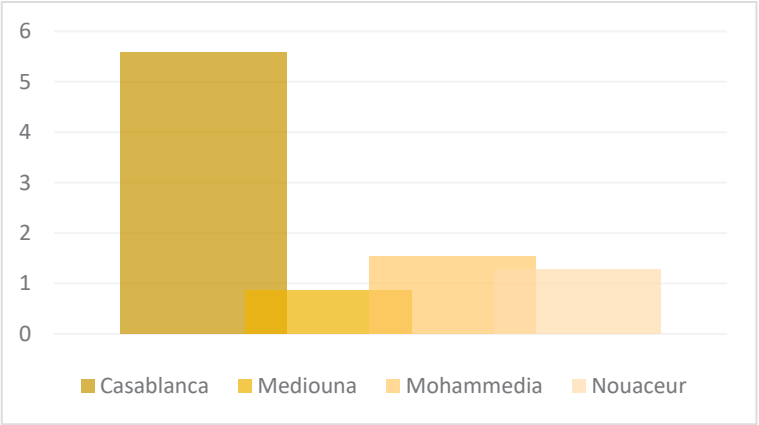

Fig. 2. Selected road density values in studied municipalities for 2024

Mediouna in comparison has sparse network density of 0.86 km/km² and only 354 road segments at a total length of 187.5 km. Even though there is a higher mean segment length of 0.529 km, the total road length of 187.5 km limits the area. KDE classification shows that most of the region's areas are within the range of the lowest density class. Only a few urban areas have a density higher than 26 km/km².

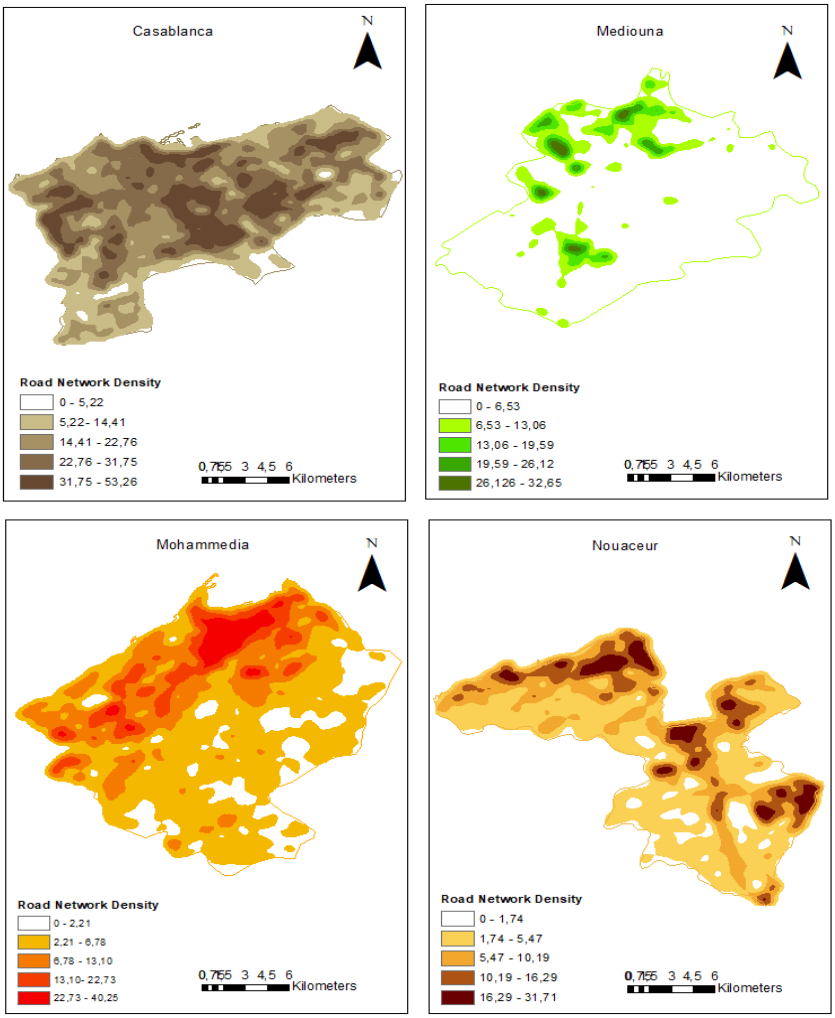

Fig. 3. Distribution of road network density in the Study Area

The densities of Mohammedia and Nouaceur are in the middle (1.53 and 1.28 km/km², respectively). Mohammedia has 900 segments and KDE values that range from 0 to 40.25 km/km². This shows that there are both densely connected urban cores and less densely connected transition zones. Nouaceur's KDE raster covers a wider range (0–31.71) because it serves as both an urban expansion zone and an industrial corridor. It also has a relatively long mean segment length (0.608 km) and the highest variability (SD = 1.275).

3.2 Urban growth and land transformation dynamics

The period from 2014 to 2024 indicates that urban growth in the entire Grand Casablanca area has shown particular areas of more concentrated growth. Using GAIA-derived built-up area layers, changes were assessed through four key indicators: Annual Rate of Urban Spatial Expansion (ARUSE), Urban Land Conversion Rate (ULCR), Urban Density Index (UDI), and Population Density Index (PDI) (Fig.4). The spatial evolution of built-up versus non-

built-up land over this decade is also clearly visualized in Fig.5, highlighting the outward urban expansion patterns across the four provinces.

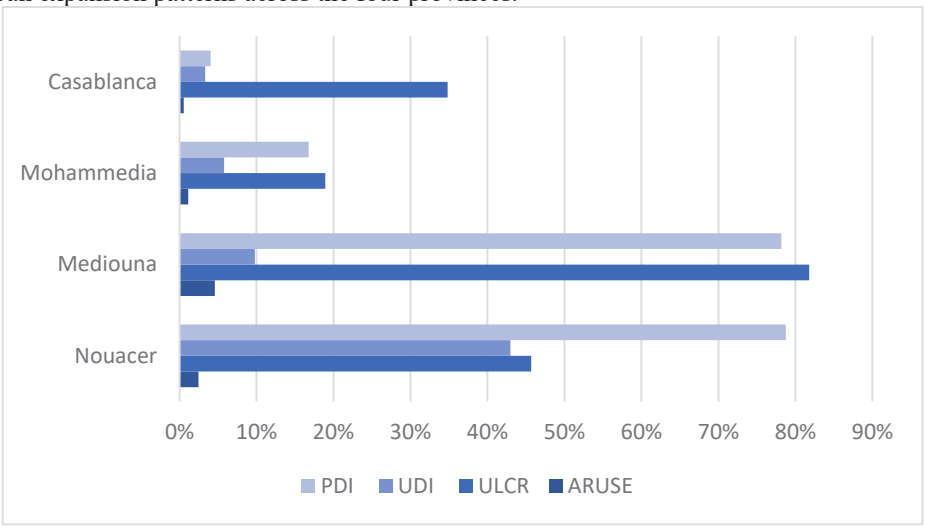

Fig. 4. Urban Spatial Expansion and Density Metrics (2014–2024)

Among the provinces, Mediouna underwent the most intensive urban growth during the period with an ARUSE of 5 % and very high ULCR of 82 %. This reflects exceptional conversion of non-urban land into built-up area. Followed by Nouaceur, with a moderate ARUSE of 2 % and ULCR of 46 %, which still indicates ongoing peri-urban development in relation to infrastructure development. On the other hand, Mohammedia and Casablanca displayed relatively steady rates of expansion (both at 1% ARUSE). However, Casablanca did record some densification, as indicated by a 35% ULCR, suggesting densification in previously underutilized urban areas.

In urban form, Nouaceur had the greatest increase in density with UDI and PDI values of 43% and 79%, respectively, indicating an increase in both population growth and spatial expansion. Mediouna showed similar demographic intensification with PDI 78%, but lower urban compactness with UDI 10%, suggesting even more dispersed development. Casablanca's growth pattern was relatively contained with minimal changes in both UDI 3% and PDI 4%, indicating its already saturated urban fabric. In general, the findings indicate an active process of suburbanization for Nouaceur and Mediouna compared to the greater intensification in Casablanca. These patterns correspond to changes in infrastructure and land use throughout the metropolitan area, reinforcing evidence that the configuration and accessibility of road networks are major contributing factors to urban spatial development.

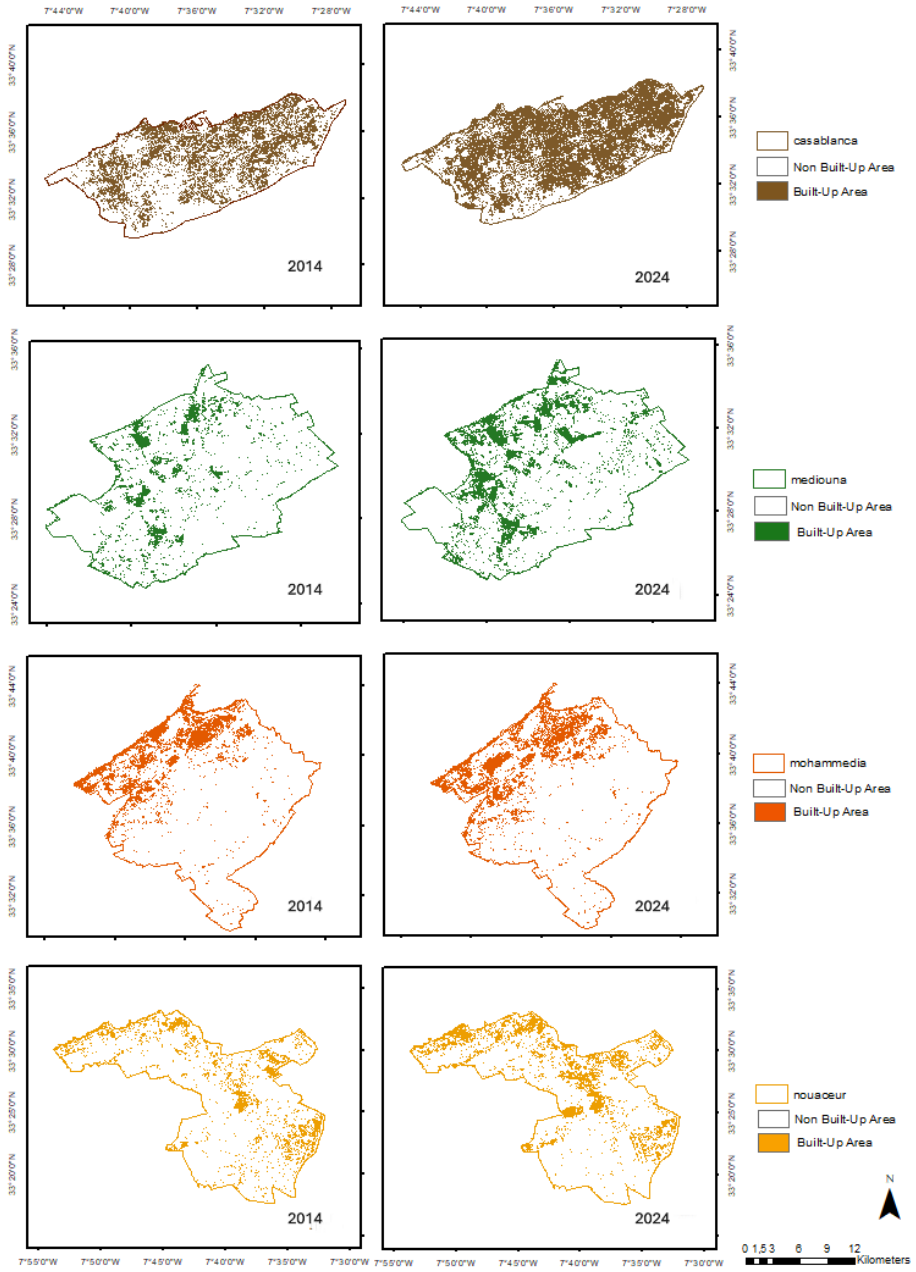

Fig. 5. Built-up Area Changes in Grand Casablanca (2014–2024)

3.3 Descriptive patterns and inter-variable relationships

3.3.1. Radar plotting

The radar plot (Fig. 6) indicates how urbanization, infrastructure and the socioeconomic factors differ across the four provinces, providing the context for analyzing the drivers of spatial change. This helps in positioning every province along an urbanization continuum

starting from consolidated core to expanding periphery. Casablanca emerges as a highly energetic city core that is dense and urbanized, as evidenced by extensive energy consumption, industrial output, and metropolitan population, further confirming its axial economic function. On the other hand, Mediouna and Nouaceur show more urban and population growth together with increased land use activities but lower compactness, reflecting more dynamic transitional profiles. This combination indicates greater urban sprawl and peri-urban growth tendencies.

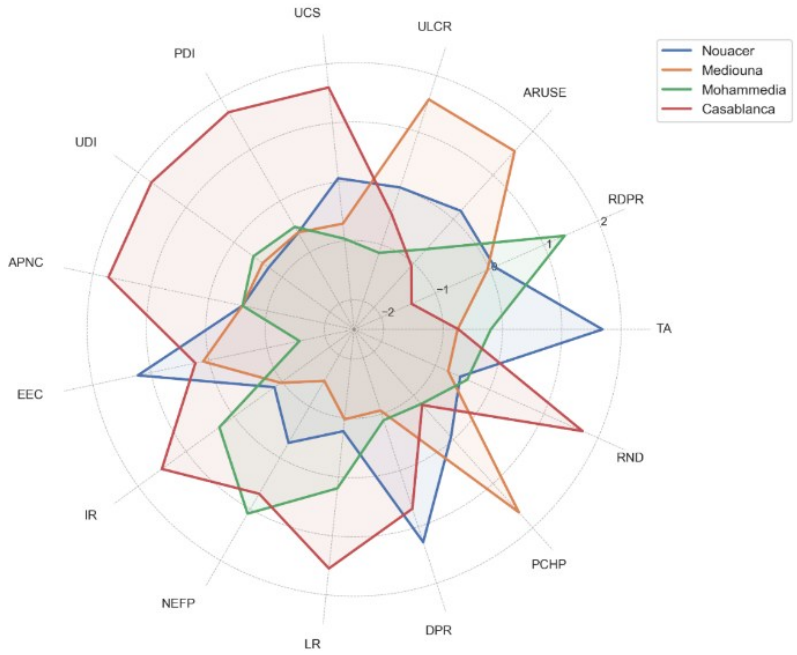

Fig. 6. Comparative radar plot of scaled indicators across provinces

Mohammedia strikes a balance in terms of population density and compactness, as well as strong urban identity. It is characterized by a moderate density, marked with a structural form and strong industrial base accompanied by the highest property values indicative of advanced real estate development suggesting, a more stable and perhaps formalized urban setting.

3.3.2. Correlation analysis

In this section, we quantify the associations between urbanization, infrastructure, and socioeconomic indicators. We used Kendall's correlation coefficient to capture both linear and non-linear associations, which is particularly useful given the complex nature of urban systems, where interactions are not always strictly linear. Fig. 6 visually represents the non-linear correlations between existing and computed variables considered for this study, including socio-economic, demographic, and infrastructural derived from both census data, remote sensed variables.

a. Urbanization and spatial expansion dynamics

The Annual Rate of Urban Spatial Expansion (ARUSE) measures how rapidly urban land grows each year and shows strong links with key socio-economic variables. Its high positive correlation with the Urban Land Conversion Rate (ULCR) (0.67) reveals that fast expansion coincides with intensive land conversion from non-urban to urban uses, reflecting sprawl in

Grand Casablanca. This pattern indicates that rapid growth is also land-consuming, producing inefficient land use and low densities (G. Xu et al., 2019; X. Xu & Min, 2013).

ARUSE is negatively correlated with economic activity (–1.0), employment (–0.667) and education (–1.0), suggesting expansion occurs in peripheral zones with weaker economic and social profiles, echoing African evidence of peri-urban growth driven more by accessibility than by strong economic bases (Doan & Oduro, 2012).

Conversely, ARUSE correlates positively with basic health-service access (0.667), hinting at targeted investments to offset socio-economic lag in expansion zones. Similar dynamics have been observed in Bogotá and Accra, where peri-urban areas attracted new residents and required compensatory service provision (Escorcia Hernández et al., 2024)(Adugbila et al., 2023).

b. Infrastructure access and spatial inequities

Rural Distance to Paved Roads (RDPR) is a major constraint on accessibility, showing negative correlations with urban share, density, health services and housing values. Greater distance from paved roads corresponds to lower urbanization, reduced population and built-up density, and limited access to services, reinforcing spatial disparities (Zhou et al., 2024). Yet RDPR is uncorrelated with the pace of urban growth (ARUSE) despite its negative link to land-use change (ULCR), indicating that low-density sprawl can occur even without paved corridors, often through informal or disconnected processes (Doan & Oduro, 2012; Yanhao Zhang et al., 2021).

By contrast, Road Network Density (RND) is strongly and positively associated with urban density, industrial revenue, literacy, job creation potential, and new construction prices—underscoring the enabling role of transport connectivity in driving economic activity and land value appreciation (Chen et al., 2014). However, its negative correlation with primary health points suggests compensatory planning, where basic services are deployed in less-connected zones to offset infrastructure deficits. More broadly, the weak link between ARUSE and socioeconomic indicators points to a decoupling between land expansion and development outcomes. This mirrors findings from China, where rapid land growth diverged from economic performance and population growth (Yang et al., 2018). Together, these patterns highlight the need to align transport networks, services, and land-use planning to prevent unsustainable or inefficient urban expansion.

c. Socio-economic interdependencies

A cluster of strong positive interdependencies emerges among PDI, UDI, Average Price of New Constructions (APNC), IR, NEFP, and LR, with Kendall's values ranging from 0.333 to 1.0. For instance, UDI correlates positively with IR ($\tau = 0.667$) and LR ($\tau = 0.667$), suggesting that denser urban areas are associated with both economic productivity and higher literacy levels. These synergistic dynamics point to a virtuous cycle of urbanization, investment, and human development.

Interestingly, the Doctor per Residence (DPR) variable exhibits a positive correlation with Electricity Energy Consumption (EEC) ($\tau = 0.667$) and APNC ($\tau = 0.333$), indicating that healthcare personnel tend to be more available in areas with higher service provision and housing values. However, DPR and PCHP are not significantly correlated, pointing to a possible spatial mismatch between medical personnel distribution and basic healthcare infrastructure availability.

d. Urban-rural divide and planning implications

The inverse correlations between RDPR and almost all development indicators—notably with APNC ($\tau = -0.667$), UDI ($\tau = -0.333$), and LR ($\tau = 0$)—highlight a persistent urban-rural divide. These findings reinforce the evidence that remoteness inhibits land value appreciation, density accumulation, and access to education, all of which are crucial for sustained development (Un-Habitat, 2020).

In light of these patterns, it is imperative for spatial planning and policy frameworks to focus on equitable infrastructure provision, especially in underserved rural and peri-urban areas. Targeted investments in road connectivity, healthcare services, and electrification could help bridge these divides, catalyzing balanced territorial development.

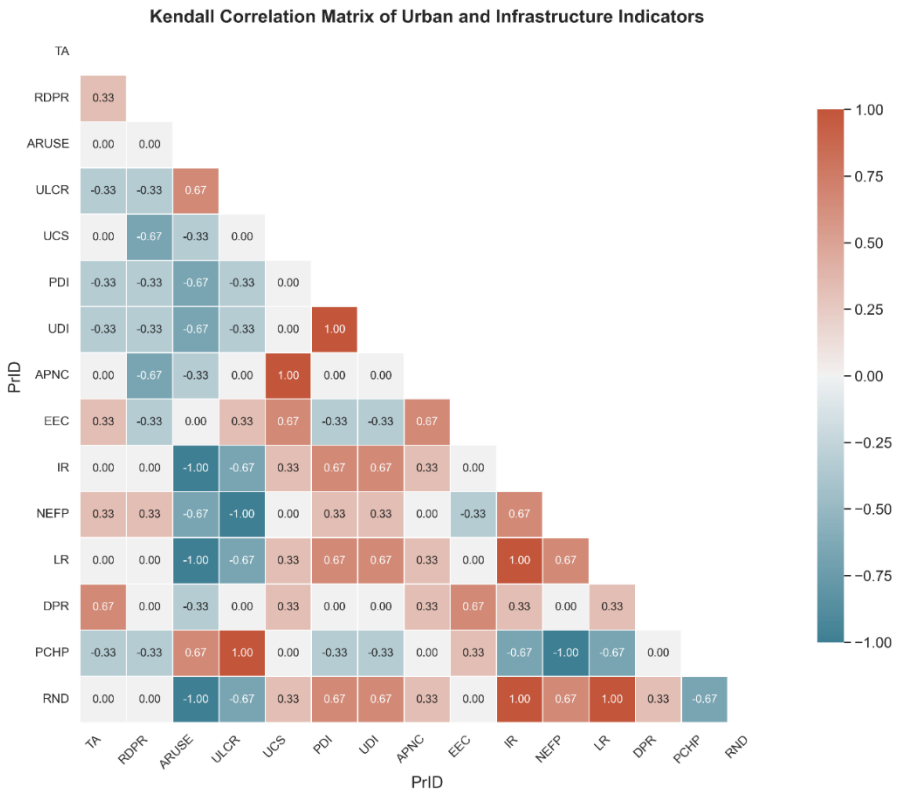

Fig. 7. Correlation heatmap of key urban, infrastructure and socioeconomic metrics

4 Conclusion

This study demonstrates that urban growth and infrastructure development in the Grand Casablanca region are deeply intertwined yet spatially uneven. Casablanca exhibits a dense, consolidated urban core with extensive road networks, high economic activity, and elevated service provision, whereas peripheral provinces—Mediouna, Nouaceur, and Mohammedia—display transitional growth characterized by lower connectivity, dispersed urbanization, and variable socio-economic development. The analysis of road network density, urban expansion metrics (ARUSE, ULCR, UDI, PDI), and socio-economic indicators reveals a core–periphery gradient where infrastructure accessibility strongly shapes land-use transformation, population distribution, and investment patterns. Rapid peri-urban expansion, particularly in Mediouna and Nouaceur, occurs in areas with weaker economic and educational profiles, often relying on compensatory public service provision. Correlation patterns indicate a decoupling between land expansion and meaningful development outcomes, highlighting risks of inefficient sprawl and underutilized infrastructure. Conversely, high road network density facilitates densification, economic productivity, and property value appreciation, illustrating the enabling role of connectivity in supporting

sustainable urbanization. Overall, these findings emphasize the need for integrated spatial planning that aligns transport networks, service delivery, and land-use policies. By identifying territorial typologies, spatial disparities, and infrastructure–urbanization linkages, this study provides context-sensitive insights to guide equitable and strategic urban development in rapidly urbanizing metropolitan regions.

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