Received: 30 Aptil 2025
Accepted: 17 October 2025
Published: 02 November 2025

Italian Journal of Planning Practice
ISSN: 2239-267X

Volume 15, Issue 1, 2025

Transformation of Spatial Structure from Monocentric to Polycentric: The Case of Qazvin Province, Iran

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Keywords: Polycentricity, LISA, Morphological, LandScan, COVID-19

Abstract: The transition from monocentric to polycentric spatial structures is recognized as a key strategy for achieving balanced regional development. Focusing on a developing region, this study empirically analyses this process in Qazvin province, Iran, over a 23-year period (2001-2023). Using the Local Moran's I (LISA) index for spatial autocorrelation analysis, the study assesses the morphological dimension of polycentricity. The findings reveal a three-stage evolution: (1) a period of consolidation and spatial refinement (2001-2007) where the central core was strengthened; (2) a qualitative transition period (2008-2013) focusing on the densification and intensification of the main centers; and (3) a period of polycentric rise (2014-2023) characterized by the emergence of new poles and geographical differentiation, forming a more networked and complex structure. The results indicate that Qazvin province has been moving towards a more distributed, differentiated, and resilient spatial system, not only quantitatively but also in qualitative and structural terms.

1. Introduction

Achieving balanced spatial development has always been a fundamental objective in regional and national planning (Davoudi, 2003; Faludi, 2006). In recent decades, with the unprecedented pace of urbanization worldwide, the spatial structures of regions have undergone profound transformations. The traditional development model, primarily based on a monocentric structure, emphasized the concentration of population, capital, and economic activities in a single main metropolis (Champion, 2001). While this model could lead to capital accumulation and economic growth in its initial stages, in the long term, it has been associated with adverse consequences such as excessive congestion, environmental pollution, severe regional inequalities, and immense pressure on the primary center's infrastructure (Richardson, 1995).

In response to these challenges, the polycentricity paradigm emerged in the spatial planning literature as an alternative and effective approach. This concept, which gained particular prominence in European Union policies since the 1990s, advocates for a more balanced distribution of activities within a network of urban centers in a region (Davoudi, 2003). The core idea is to form a region with several dynamic and complementary urban centers interconnected through functional linkages, instead of a dominant center and a passive periphery (Meijers, 2005; Meijers, 2007; Sofianou, 2016). This approach promises benefits such as increased economic productivity, reduced social inequalities, and the achievement of environmental sustainability (Kloosterman & Musterd, 2001).

Despite the growing importance of this concept, a large portion of empirical research has been dedicated to analysing urban regions in developed countries, particularly in Europe, with less attention paid to developing regions. This study aims to fill this research gap by focusing on Qazvin province as a case study in Iran. Due to its strategic location, significant industrial centers, and notable population dynamics, Qazvin province provides a suitable context for analysing the transition process from a monocentric spatial structure towards a polycentric pattern (Shahabi-Shahmiri & Khodabandeh, 2025). Therefore, the main research question is: What transformations has the spatial structure of Qazvin province experienced during the period 2001-2023, and to what extent do these transformations align with the logic of a transition to a polycentric structure?

To answer this question, the paper will first review the theoretical and conceptual foundations of polycentricity. Next, the research methodology, based on spatial autocorrelation analysis (Local Moran's I), will be described. In the findings section, the results of the spatial evolution analysis will be presented in three time periods. Finally, in the discussion section, these findings will be explained and interpreted within the framework of regional development theories.

2. Literature Review: Roots, Dimensions, and Goals of Polycentric Development

The concept of polycentricity has deep roots in the history of urban planning thought. Its initial ideas can be traced to Ebenezer Howard's “Garden City” movement in the late 19th century (Howard et al., 1898/2013), which sought to create a network of small, self-sufficient towns around large cities (Sober, 2000). However, the concept in its modern form is a product of post-World War II European spatial policymaking, particularly the European Spatial Development Perspective (ESDP) in 1999, where polycentric development was introduced as a key strategy for achieving territorial cohesion and global competitiveness (Faludi, 2005).

A key distinction in the literature is the separation between two main dimensions of polycentricity: the morphological and the functional. The morphological dimension, which can be described as "polycentricity in form," pertains to the physical and spatial distribution of urban centers. This dimension is primarily measured by indicators such as the number, size, and population distribution of urban centers within a region (Doorudinia et al., 2025; Luo et al., 2025; Parr, 2004; Yue et al., 2025). In other words, a region is morphologically polycentric if no single urban center dominates the others in terms of population (Meijers, 2008).

In contrast, the functional dimension, also referred to as "polycentricity in process," emphasizes the inter-relationships and flows between urban centers (Green, 2007). This dimension involves the analysis of daily commuting flows, economic exchanges, institutional collaborations, and information flows between cities. A region is functionally polycentric only when its various centers form a dense network of interactions and operate as an integrated system (Burger & Meijers, 2012). Many researchers argue that true polycentricity is achieved only when both morphological and functional dimensions are strengthened simultaneously (Derudder et al., 2021; H. Li et al., 2024; Li & Lee, 2025; Y. Li et al., 2024; Wu et al., 2023). However, it must be acknowledged that due to severe limitations in accessing flow data in many countries, a large body of research, including the present study, is compelled to focus on analysing the morphological dimension.

Beyond being an analytical tool, polycentricity is also presented as a normative goal in spatial planning (Davoudi, 2003; Masip-Tresserra, 2017; Waterhout et al., 2005). Proponents of this approach believe that polycentric spatial development can contribute to the three goals of sustainable development. From an economic perspective, by distributing agglomeration economies across several centers, this model can enhance the entire region's competitiveness and prevent the external costs arising from excessive density in a single metropolis (Meijers & Burger, 2010; Pan et al., 2024). From a social perspective, it helps to increase spatial justice and social cohesion by providing more balanced access to job opportunities, services, and infrastructure across the region (W. Li et al., 2024). Finally, from an environmental perspective, this model can aid in the conservation of natural resources and improve environmental quality by reducing the need for long-distance daily commutes and preventing uncontrolled urban sprawl (Hague & Kirk, 2003; Khodabandeh & Shahabi-Shahmiri, 2025). These normative goals are the primary reason for the widespread attention given to this paradigm by policymakers and planners worldwide.

3. Methodology

3.1. Study Area

This study focuses on Qazvin province as its area of research (Figure 1). Qazvin province, with a population of 1,873,761, ranks 14th among the 31 provinces of Iran. The selection of this province was based on several key features: 1) its strategic geographical location as one of the country's main industrial and agricultural hubs, situated on the communication corridor connecting the capital to the western and northern regions of Iran; 2) its diverse demographic structure, comprising a large provincial capital, multiple intermediate cities, and populous rural areas; and 3) the absence of prior research specifically analysing the evolution of its polycentric structure. These characteristics make Qazvin province a natural laboratory and an ideal case for studying spatial transformations in a developing region.

Figure 1 | Study area

The research timeframe covers the period from 2001 to 2023. This long-term span was chosen for two main reasons: First, it covers the entire available range of high-quality, consistent LandScan Global data, enabling a reliable long-term trend analysis and mitigating concerns related to short-term studies. Second, this 23-year period encompasses significant economic, social, and infrastructural developments in the province, as well as external shocks like the COVID-19 pandemic. Analysing the pandemic within this framework provides an opportunity to assess the resilience of the province's emerging spatial structure against unexpected crises.

3.2. Data

In this study, LandScan Global data from 2001 to 2023 were utilized to measure the polycentric structures of Qazvin Province (Bright & Coleman, 2002, 2003; Bright et al., 2004, 2005, 2006, 2007; Bright et al., 2008; Bright et al., 2009; Bright et al., 2010, 2011, 2012; Bright et al., 2013, 2014, 2015, 2016; Bright et al., 2017; Lebakula et al., 2024; Rose et al., 2020, 2021; Rose et al., 2018; Rose et al., 2019; Sims et al., 2023; Sims et al., 2022). This dataset, generated using an advanced combination of geospatial science, remote sensing, and machine learning, provides the most accurate and high-quality global population distribution data. By employing intelligent algorithms and multivariate modelling, these data disaggregate census information within administrative boundaries and display population distribution with very high resolution. LandScan Global models not only residential locations but also daily and nightly activity patterns of individuals, making it an ideal tool for demographic analyses and spatial planning. The data are specifically adjusted for the geographical and cultural conditions of each region, enhancing their accuracy and applicability (Fan et al., 2025; He et al., 2025; Shahabi-Shahmiri & Khodabandeh, 2025; Yan & Wu, 2025).

LandScan data offer significant advantages for spatial analysis due to the use of advanced spatial redistribution algorithms and ancillary data. These data have the ability to display small and distinct population clusters, leading to a more accurate identification of population spatial patterns. Additionally, LandScan captures greater spatial variability compared to many other datasets, a feature that makes it ideal for local analyses such as Moran's I and the identification of population centers. The high accuracy and spatial resolution of these data allow researchers to examine polycentric structures and population distribution more effectively, which is particularly valuable in urban studies and regional planning (Sabesan et al., 2007).

3.3. Identification of Potential Centers through Local Moran's I

To analyse the morphological dimension of polycentricity, the first step is the objective and statistical identification of population density cores. In this research, the Local Moran's I or LISA (Local Indicators of Spatial Association) index was used for this purpose (Anselin, 1995). Unlike visual analyses or administrative definitions, this method allows us to statistically determine where high population densities are significantly clustered next to other high-density points, forming a true "spatial cluster" (such as HH - High-High). This method was specifically employed to identify population clusters and spatial outliers. The Local Moran's I is calculated using the following formula:

$$I_i = \left(\frac{z_i - \bar{z}}{\sigma^2}\right) \sum_{j \neq i} \left[W_{ij}\left(z_j - \bar{z}\right)\right]$$

In this formula, Ii represents the Moran's I coefficient calculated for each location. The variable zi denotes the population density at a specific location i, while z¯ represents the average population density across the entire study area. The variable zj indicates the population density at other locations (excluding location i). σ2 represents the variance of population density in the study area, and Wij is the spatial weight.

In this study, the Local Moran's I (LISA) statistic was used as a spatial autocorrelation indicator, calculated with 499 permutations at a significance level of $p < 0.05$ (Lalor & Zhang, 2001). To define neighborhood and spatial weight (Wij), a fixed distance band of 1.5 kilometers was used. This distance was selected after examining the settlement pattern of the province's urban and rural areas and conducting preliminary tests, as it best represents the sphere of influence of local centers and small towns without causing them to merge into one another. Positive and significant values of Ii (HH and LL clusters) indicate potential centers, while negative values (HL and LH clusters) represent spatial outliers and transitional zones (Zhang et al., 2008).

4. Findings

4.1. Analytical Framework: Tracking Spatial Evolution through Multidimensional Indicators

To achieve a deep and valid understanding of the transformations in Qazvin province's spatial structure, this analysis is based on four key categories of indicators that together paint a multidimensional picture of a 23-year transformation (from 2001 to 2023) (Table 1). The first indicator is the total number of high-density population clusters (HH), which shows the quantitative scale and geographical extent of urban centers. The second indicator is the number and percentage of Strong Clusters, which addresses the quality, intensity, and statistical significance of these centers, distinguishing between a simple cluster and a true urban core. The third indicator is the geographical analysis of clusters at the county and city level, allowing us to identify the main actors of this transformation (such as Qazvin, Alborz, and Takestan counties) and the dynamics of spatial power among them. Finally, the fourth indicator is the annual spatial correlation matrix, which measures the speed and depth of structural changes by assessing the similarity of spatial patterns in consecutive years. This analytical framework helps us move beyond a simple linear narrative and recount the complex story of the province's spatial evolution in all its detail.

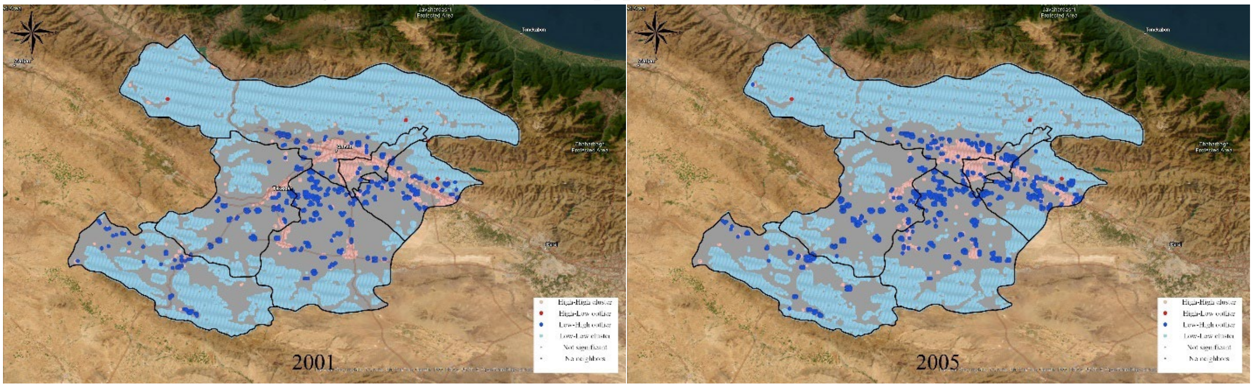
Table 1 | Indicators for Analyzing Spatial Evolution (2001–2023)

Year	HH	LL	HL	LH	Year	HH	LL	HL	LH
2001	2094	26065	4	545	2013	1579	25425	1	843
2002	2074	26427	4	582	2014	2003	24029	5	885
2003	1969	25102	3	820	2015	2105	23719	3	917
2004	1890	25302	3	818	2016	2176	22956	3	887
2005	1843	25103	3	833	2017	2143	22861	3	897
2006	1832	25110	3	833	2018	2176	22999	3	900
2007	1837	25155	3	853	2019	2140	23792	2	871
2008	1773	25143	3	814	2020	2177	0	3	890
2009	1799	25141	3	802	2021	2182	0	3	881
2010	1829	25207	3	794	2022	2164	0	3	875
2011	1930	25295	3	773	2023	1906	0	3	671
2012	1542	25221	4	798					

4.2. The Consolidation Period (2001-2007): Initial Cluster Reduction and Core Formation

The story of the province's spatial evolution begins in 2001 with a notable trend: the total number of high-density population clusters (HH) entered a downward path, decreasing from 2094 clusters in 2001 to 1837 in 2007. This quantitative reduction might at first be interpreted as a sign of urban stagnation or weakening processes, but it actually signifies a process of “spatial refinement” and structural consolidation (Wolff et al., 2018; Yu et al., 2018). During this period, the urban system was naturally eliminating weak, temporary, and marginal clusters to concentrate its energy on primary and stable centers. This process is akin to pruning a plant to strengthen its main branches. The strong clusters indicator confirms this hypothesis; throughout these years, the percentage of strong clusters remained in a stable and significant range of 24% to 33%, indicating that despite the decrease in the total number, the core backbone of the urban system was not weakening but rather strengthening.

Figure 2 | Distribution of population clusters (2001 & 2005)



Source: Authors' Analysis Based on LandScan Population Data

4.3. Geography of Power during Consolidation: Dominance of the Qazvin-Alborz Bipolar Axis

Urban power and dynamism during this period were clearly concentrated along a specific geographical axis: the Qazvin-Alborz bipolar axis. On one hand, Qazvin County, as the historical, political, and service center, played the role of the province's traditional anchor. The city of Qazvin and its surrounding areas hosted a large portion of the HH clusters. On the other hand, the newly established Alborz County, relying on its massive industrial parks and worker towns like Alvand, Mohammadiyeh, and Sharifiyeh, was rapidly becoming an independent demographic and economic pole. The disaggregated data show that these two counties together constituted the dominant share of the province's strong clusters, creating a “large central core” that was the main engine of provincial development. Other counties like Takestan and Abyek played subsidiary roles during this period; although they had small urban cores, they were not yet considered serious competitors to this bipolar axis. This bipolar structure was the dominant spatial order of the period, and its high stability is well reflected in the spatial correlation matrix (with coefficients close to 0.99 between consecutive years).

4.4. The Qualitative Transition Period (2008-2013): The Phenomenon of Cluster Reduction and the Logic of Urban Density

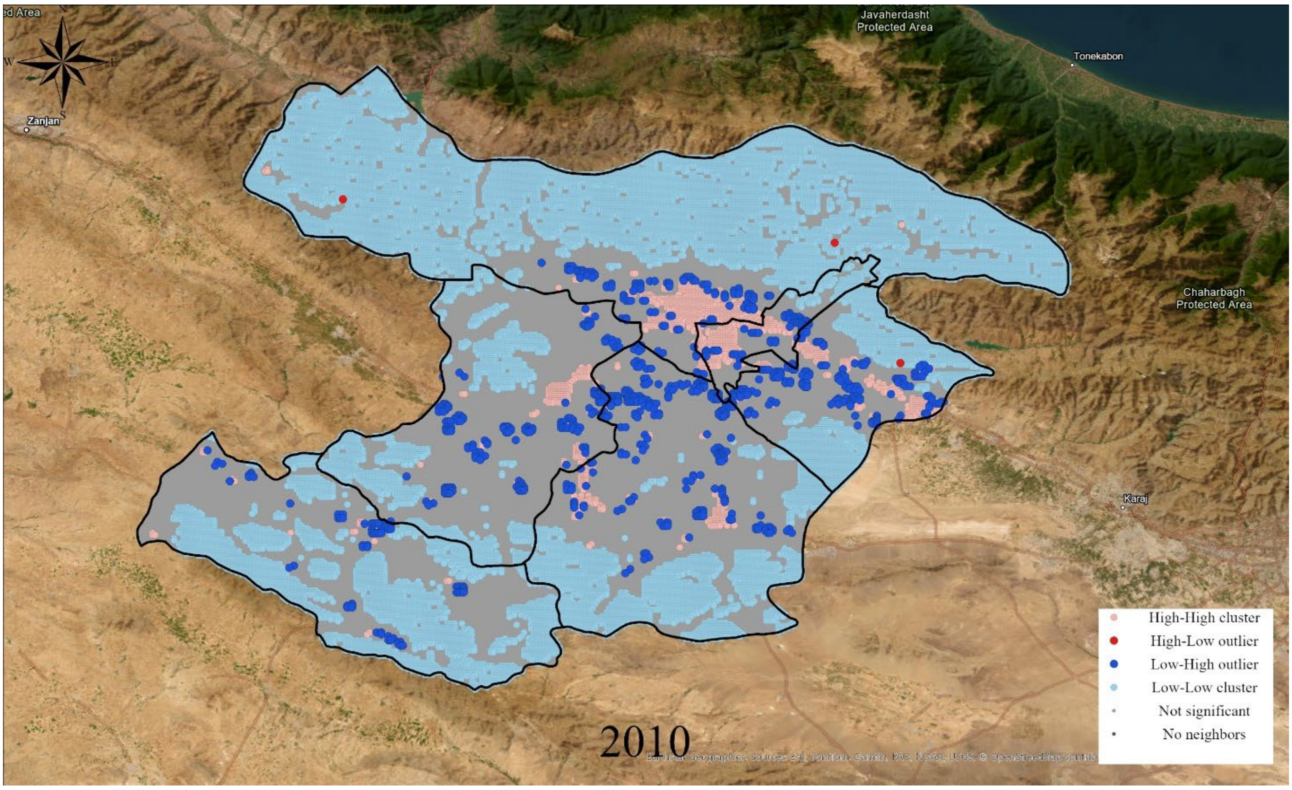
This period witnessed a complex and seemingly strange phenomenon that marked a turning point in the logic of spatial development in the province. The downward trend in the total number of HH clusters continued with greater momentum, reaching its lowest point in the entire analytical range in 2012 (1542 clusters). This sharp decline could have been mistakenly interpreted as an urban crisis or a “de-urbanization” process (Potts, 2005). However, the reason for this phenomenon was a silent revolution in quality and density. Simultaneously with the decrease in the total number of clusters, two qualitative indicators were growing sharply: first, the percentage of strong clusters, which jumped from 26% to over 33%, and second, the average Z-Score, which indicates the statistical intensity of the clusters (Table 2).

Table 2 | Cluster Characteristics by County during the Qualitative Transition Period (2008–2013)

County	*Cluster*	*Count*	*Mean Zscore*	*Max Zscore*	*Min Zscore*	*Strong Significant*	*Very Strong*
Boein Zahra	HH	6597	1.67	35.629	0.028	1337	979
Avaj		2219	1.094	11.251	0.018	268	122
Abyek		6661	-2.61	71.573	-367.838	1651	1263
Takestan		7415	-6.681	117.511	-368.647	2732	2358
Alborz		14401	-86.533	165.177	-368.742	10259	9674
Qazvin		36395	-95.656	308.714	-368.688	25712	24788
Abyek	HL	10	-0.195	-0.169	-0.267	0	0
Qazvin		51	-0.232	-0.163	-0.459	0	0
Avaj		10	-0.261	-0.243	-0.296	0	0
Boein Zahra	LH	4455	-0.689	-0.003	-10.758	244	136
Avaj		1695	-0.727	-0.014	-6.743	71	34
Takestan		3636	-0.921	-0.005	-12.42	306	196
Abyek		3258	-1.027	-0.011	-25.44	217	161
Qazvin		4038	-1.11	0.014	-47.796	368	211
Alborz		1700	-1.548	-0.047	-28.333	323	229
Boein Zahra	LL	65993	0.225	0.623	0.116	0	0
Takestan		38228	0.223	0.628	0.125	0	0
Abyek		33062	0.221	0.612	0.122	0	0
Alborz		3996	0.22	0.601	-0.058	0	0
Qazvin		248853	0.219	0.638	-0.001	0	0
Avaj		79970	0.207	0.639	-48.728	47	47

These two inverse trends followed a clear economic and spatial logic: the logic of density and efficiency. It appears the province during this period concluded that instead of supporting a large number of scattered, low-density clusters, it was better to direct resources and population towards primary and efficient centers. This process of “urban compaction” (Dieleman & Wegener, 2004) made the main cores (especially along the Qazvin-Alborz axis) denser, stronger, and more economically dynamic. In effect, this quantitative reduction came at the cost of a major qualitative leap, preparing the province's urban structure for the next phase of development based on network expansion. This period showed that urban evolution does not always mean horizontal growth; sometimes it manifests as “intensification” and “deepening”.

Figure 3 | Distribution of population clusters (2010)

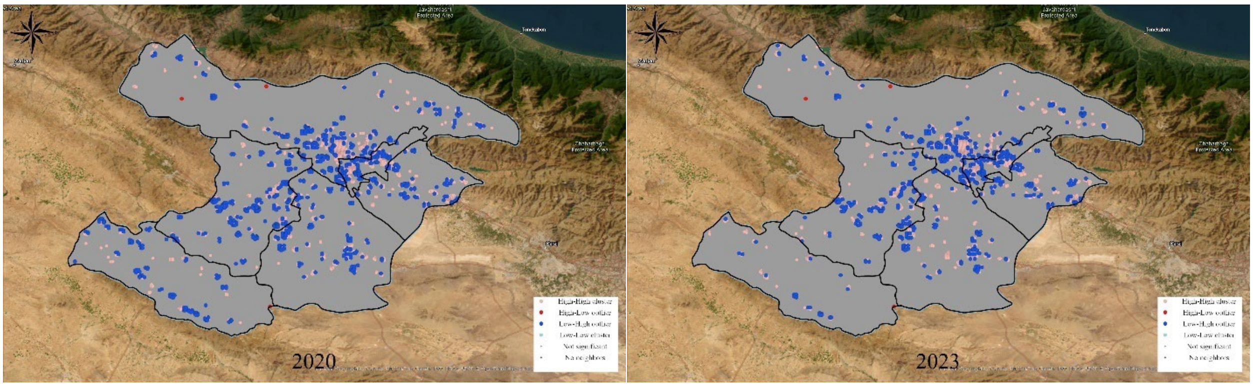


Source: Authors' Analysis Based on LandScan Population Data

4.5. The Polycentric Rise Period (2014-2023): Simultaneous Growth in Cluster Quantity and Quality

The final decade of the analysis is a period of a full-fledged rise and the emergence of a new spatial order. All trends from the previous period were reversed, and the total number of HH clusters resumed an upward trajectory with a powerful comeback. But this growth was not a repetition of the first decade's pattern. The unique feature of this period was the simultaneous growth of quantity and quality. As the number of centers increased, the percentage of strong clusters also made a historic and unprecedented leap from 32% in 2014 to a record 43.7% in 2023. These statistics show that the new wave of development in the province was powerful, sustainable, and of high quality. There were no more weak and scattered clusters; the new centers that formed or the old ones that expanded during this period were characterized by high intensity and density from the outset. This period marks the full maturity of the province's urban system, where both the geographical scope of development and its depth and quality increased.

Figure 4 | Distribution of population clusters (2020 & 2023)



Source: Authors' Analysis Based on LandScan Population Data

4.6. Geographical Differentiation: The Emergence of Takestan as a Third Pole and the Complexity of the Urban Network

The most important geographical feature of this period was the transition from a bipolar structure to a complex, multi-polar network. While in the past, development was largely confined to the Qazvin-Alborz axis, this decade witnessed the emergence of new players and spatial differentiation. Takestan county, which had a marginal role in previous periods, emerged as a powerful third pole in the west of the province, thanks to its strategic location and economic capacities. The continuous growth of HH clusters in the city of Takestan and its surrounding towns turned this county into an important balancing weight in the province's spatial structure. In addition to Takestan, we witnessed the formation of smaller but stable urban cores in Boein Zahra County, indicating the diffusion of development to the southernmost parts of the province. This more balanced distribution of spatial power reduced the entire system's dependence on one or two centers and transformed the province's structure into a true network where multiple centers of different sizes and functions interact with each other.

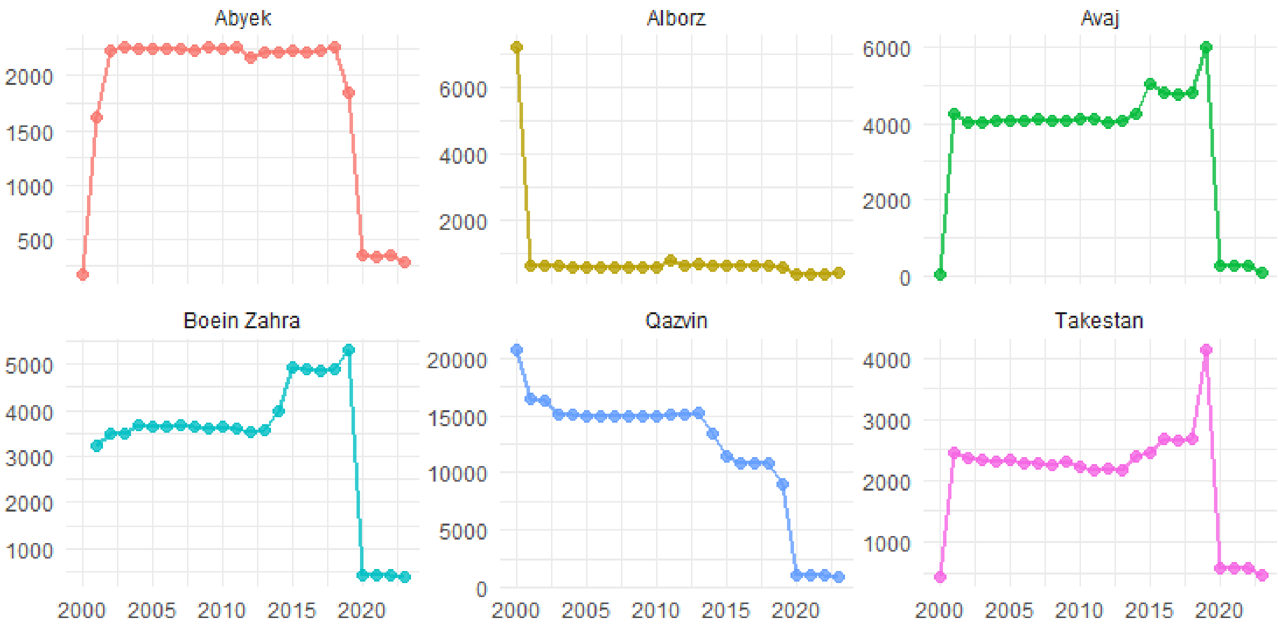
4.7. Measuring Structural Stability: Analysis of the Correlation Matrix and the Pace of Change

To measure the depth and stability of these transformations, a spatial correlation matrix analysis was used (see Appendix 1 for the full correlation matrix). This matrix shows how similar the population's spatial pattern is in any given year to previous years. In the first period (2001-2007), the correlation coefficient between consecutive years was almost always above 0.99, indicating a very stable and static structure. However, in the third period (2014-2023), although the correlations were still high, their rate of decrease over time became more pronounced. This gradual decrease in similarity is the statistical fingerprint of a real structural change. These statistics show that the "spatial face" of the province is fundamentally changing, and these changes are not temporary fluctuations but are following a new and stable evolutionary path that distinguishes the province from its past.

4.8. A Test of Resilience: The Impact of the COVID-19 Pandemic and the Strength of the New Networked Structure

Every system needs a real-world test to prove its strength, and for the new spatial structure of Qazvin province, this test was the COVID-19 pandemic in 2020. The data show that this global crisis inflicted a short-term shock on the province's urban system (Dadashpoor & Adeli, 2016; Ramírez-Aldana et al., 2020), causing a slight dip in some indicators that year (Figure 5). However, the key point was the speed and strength of the system's recovery in the following years. From 2021 onwards, all indicators quickly returned to their upward trajectory and even set new records. This rapid recovery attests to the high resilience of the new networked and polycentric structure. The logic of this resilience is simple: in a monocentric system, any disruption in the main center can paralyze the entire system. But in a networked structure with several powerful centers (Qazvin, Alborz, Takestan, etc.), the pressure from a crisis is distributed among several points, and the system as a whole has a greater capacity to absorb the shock and continue its functions. The province's success in this test is the best evidence of the efficiency and sustainability of the new spatial order that has taken shape over the past two decades (Lorens & Golędzinowska, 2022; Schmitt et al., 2013).

Figure 6 | Trend of HH clusters and the COVID-19 impact in Qazvin province (2001–2023)



Source: Authors' Analysis Based on LandScan Population Data

5. Discussion

The findings of this research, which depict the evolution of Qazvin province's spatial structure over a 23-year period, go beyond a mere statistical description and require explanation and contextualization within the framework of urban and regional development theories. This section of the paper attempts to answer the key question of “why” the province's spatial structure has followed such a path by linking the empirical findings to theoretical foundations.

5.1. The Evolution of the Urban System: From Spatial Refinement to the Consolidation of Primary Cores

The first period of analysis (2001-2007), characterized by a decrease in the total number of high-density (HH) clusters alongside a stable percentage of strong clusters, should not be interpreted as a period of urban stagnation. This phenomenon can be explained by the theory of “urban systems evolution” and the concept of “spatial sorting” (Eeckhout et al., 2010; Zhang et al., 2025). Urban systems, particularly in their early stages of development or after periods of rapid and scattered growth, enter a phase of reorganization in which inefficient and marginal units are eliminated, and resources are directed towards stable cores with a comparative advantage. This process, similar to natural selection in ecosystems, leads to an increase in the overall efficiency of the system and a strengthening of its “backbone”. The stability in the percentage of strong clusters during this period indicates that despite the quantitative reduction, the fundamental structure of the province's urban system was not weakening but was, in fact, consolidating. This period was a necessary stage for the formation of a “path dependency,” where the Qazvin-Alborz bipolar axis was being prepared as the central core and main engine for subsequent stages of development. This initial consolidation was a prerequisite for the qualitative and quantitative leaps in the decades that followed.

5.2. The Logic of Density and Efficiency: Explaining the Qualitative Transition Period

The second period (2008-2013), in which we witness a simultaneous decrease in the total number of clusters and a significant increase in statistical intensity (Z-Score) and the percentage of strong clusters, presents an apparent paradox. The key to understanding it lies in the concept of “agglomeration economies” (Goffette-Nagot & Schmitt, 1999; Meijers et al., 2018; Meijers et al., 2016; Shahabi-Shahmiri & Khodabandeh, 2025). Urban economic theories, from Alfred Marshall to Paul Krugman, have consistently emphasized that the concentration and density of economic activities and population in one location lead to increased productivity and efficiency by facilitating the sharing of labour, knowledge, and infrastructure (Baptista, 2003; Carlino et al., 2007; Fujita & Thisse, 2009; Glaeser & Resseger, 2010). The decrease in the number of clusters during this period signifies an unconscious or conscious strategic move within the province's urban system towards “compaction” and “densification”. Instead of horizontal and scattered expansion, the system was “deepening” within its existing cores, especially along the Qazvin-Alborz axis. This process, marked by the increased statistical intensity of the clusters, shows that these centers did not just grow larger; they became economically and socially “stronger” and more “dynamic”. This qualitative transition period was a structural investment for the future; by concentrating resources in the main centers, it created the necessary potential for development to spill over into peripheral areas and for a more complex network to form in the following decade.

5.3. The Emergence of a Networked Structure: The Role of Intermediate Cities in Polycentric Development

The final decade of analysis (2014-2023), characterized by the simultaneous growth in the quantity and quality of clusters and the emergence of Takestan county as a powerful third pole, is the practical manifestation of a transition from a hierarchical-bipolar structure to a "Polycentric Urban Region" (Brezzi & Veneri, 2017; Goess et al., 2016; Kloosterman & Lambregts, 2001). This transformation is in complete alignment with modern regional development theories that emphasize the importance of "intermediate cities" or "secondary centers" (Garcia-López & Muñiz, 2010). Intermediate cities like Takestan play a vital role in achieving a more balanced distribution of development, reducing pressure on the main centers, and increasing the resilience of the entire system. The emergence of these centers indicates that development in Qazvin province has moved beyond a simple "centre-periphery" logic to a more complex networked model. In this model, different centers, while maintaining relative independence, are connected through functional linkages (the analysis of which requires future research) and form an integrated system. The simultaneous growth of quantity and quality during this period is also a testament to the system's maturity; development no longer comes at the expense of quality. Instead, geographical expansion is accompanied by the deepening and strengthening of centers, which is the main characteristic of a sustainable and endogenous regional development.

5.4. Driving Forces of Transformation: Explaining the Underlying Factors of Spatial Change

The spatial transformations observed in this study did not occur in a vacuum; they are the product of the interplay of a set of economic, social, and political driving forces. Although this research did not directly measure these factors, we can propose hypotheses to explain them based on the regional development literature. The development of transportation and communication infrastructure, especially in recent decades, has reduced the "friction of distance," allowing peripheral centers to access larger markets and become more attractive locations for investment and residence (Huo et al., 2024; Lorens & Golędzinowska, 2022). Industrial decentralization policies and the establishment of large industrial parks in counties like Alborz and Takestan have helped to form independent economic bases for these centers, reducing their dependency on the provincial capital. Furthermore, land and housing market dynamics in the provincial center (the city of Qazvin) may have pushed a portion of the population and activities towards smaller and more affordable cities due to rising costs. Together, these factors have paved the way for the transition from a monocentric structure to a polycentric network.

5.5. Measuring the Depth of Transformation: Distinguishing Between Fluctuation and Sustainable Structural Change

One of the fundamental questions in temporal analysis is whether the observed changes are temporary, short-term fluctuations or indicators of a deep and sustainable structural transformation. The analysis of the spatial correlation matrix, mentioned in the findings, provides a powerful tool to answer this question. The high but gradually decreasing correlation coefficient between the spatial patterns of consecutive years is the statistical signature of an “evolutionary structural change”. This finding indicates that the province's urban system is subject to “structural inertia” (Hallowell & Baran, 2021; Martellozzo & Clarke, 2011); that is, changes do not occur suddenly or revolutionarily but follow a clear and directional path. The gradual decrease in the similarity of the province's current spatial pattern with its past is evidence that these transformations are deep-rooted and that the province is moving away from its past “path dependency” and entering a new evolutionary trajectory. This stability and directionality underscore the importance of policymaking to guide this trend, as it shows that these changes are not a reversible phenomenon.

5.6. Resilience in the Network: Explaining System Stability Against External Shocks

The response of the province's urban system to the global COVID-19 pandemic was a real-world test of the strength of its new structure. The rapid return of indicators to a growth path after a short-term dip beautifully demonstrates the concept of “urban resilience” (Abdollahpour et al., 2025). The scientific literature increasingly shows that polycentric and networked spatial structures are inherently more resilient than monocentric ones due to the distribution of resources, population, and functions (Burger, 2011; Dadashpoor et al., 2023; Marull et al., 2023). In a monocentric system, any shock to the main center (such as mobility restrictions or business closures) can bring the entire regional system to a crisis, as there is a “single point of failure”. In contrast, in a polycentric structure like the one that has formed in Qazvin in the last decade, the existence of several independent and semi-independent centers (Qazvin, Alborz, Takestan) allows the system to distribute the shock across the network and compensate for the disruption through surplus capacities in other centers. The province's success in this test is not merely a statistical finding but a structural achievement that proves the efficiency and sustainability of the polycentric development model in practice.

6. Conclusion

This study, aimed at empirically analysing the transition process from a monocentric to a polycentric spatial structure, examined the morphological evolution of Qazvin province over a 23-year period (2001-2023). The main findings of the research indicate that this transition was not a simple, linear process but a complex, three-stage evolution. The process began with a period of consolidation and refinement, where the province's central cores were strengthened. It then continued with a period of qualitative transition, in which the logic of development shifted from quantitative expansion to the densification and qualitative intensification of the main centers. Finally, it led to a period of polycentric rise and differentiation, where the emergence of new poles like Takestan county and the strengthening of Alborz county's position formed a more complex, distributed, and resilient spatial network. These findings suggest that the spatial structure of Qazvin province has been moving towards a more mature polycentric system, which could provide new opportunities for achieving balanced spatial development.

Despite the effort to provide a comprehensive analysis, this research faced specific limitations that must be acknowledged for a correct understanding of the results and for charting the course for future research.

The first and most significant limitation is the exclusive focus of this study on the morphological dimension of polycentricity. A complete assessment of this phenomenon requires an analysis of the functional dimension, i.e., examining the actual flows of transport, economic exchanges, and social interactions between urban centers. The reason for this limitation was the lack of access to reliable and consistent data in this area. Existing data on transport and economic flows in Iran are often incomplete, aggregated at coarse geographical scales, or lack the necessary standards for a rigorous scientific analysis. Therefore, measuring functional polycentricity was not feasible in this research.

The second limitation pertains to the data used. During the data preparation process, it was found that the statistics for the year 2000 had significant anomalies and inconsistencies with the subsequent 23-year trend, likely due to differences in the initial data processing methods or potential errors. To maintain the integrity and statistical validity of the long-term trend analysis, it was decided to exclude this anomalous and outlying year from the analytical framework to ensure the robustness of the results.

The findings of this research have important implications for regional policymakers and planners. The transition to a polycentric structure presents an opportunity to reduce pressure on the provincial capital and to distribute opportunities more equitably. For this potential to be fully realized, it is recommended that spatial development policies shift from a traditional center-periphery approach to a networked approach. This means investing in infrastructure that not only connects emerging centers (like Alborz and Takestan) to the main center (Qazvin) but also strengthens the horizontal linkages among these emerging centers themselves. Such an approach will help form an integrated and sustainable urban system and lead to a reduction in spatial inequalities.

To complement this research and address the aforementioned limitations, the following paths for future research are proposed:

I. The top priority is to endeavour to collect and analyse data related to the functional dimension. Using novel data sources such as mobile phone data (for analysing commuting flows) or data on inter-firm transactions could provide a complete picture of the interaction network in the province.
II. Conducting more in-depth case studies to analyse the socio-economic consequences of this spatial transformation. For example, what impact has this transition had on the housing market, employment patterns, and access to public services in different urban centers?
III. Carrying out comparative studies between Qazvin province and other industrial provinces in Iran to determine whether this evolutionary pattern is a unique phenomenon or part of a broader national trend in the country's spatial rearrangement.

References

Abdollahpour, S. S., Le, H. T. K., & Hankey, S. (2025). Changes in the predictors of transit ridership in post-COVID-19 US metropolitan areas. *Travel Behaviour and Society*, 40, 101002. https://doi.org/10.1016/j.tbs.2025.101002

Anselin, L. (1995). Local Indicators of Spatial Association—LISA. Geographical Analysis, 27(2), 93-115. https://doi.org/10.1111/j.1538-4632.1995.tb00338.x

Baptista, R. (2003). "Productivity and the Density of Local Clusters". In J. Bröcker, D. Dohse, & R. Soltwedel (Eds.), *Innovation Clusters and Interregional Competition* (pp. 163-181). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-24760-9_9

Brezzi, M. and P. Veneri (2017), "Assessing Polycentric Urban Systems in the OECD: Country, Regional and Metropolitan Perspectives", *OECD Regional Development Working Papers*, No. 2014/01, OECD Publishing, Paris, https://doi.org/10.1787/5jz5mpdkmvnr-en.

Bright, E., & Coleman, P. (2002). *LandScan Global 2001* (Version 2001) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524197

Bright, E., & Coleman, P. (2003). *LandScan Global 2002* (Version 2002) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524198

Bright, E., Coleman, P., & King, A. (2004). *LandScan Global 2003* (Version 2003) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524199

Bright, E., Coleman, P., & King, A. (2005). *LandScan Global 2004* (Version 2004) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524200

Bright, E., Coleman, P., & King, A. (2006). *LandScan Global 2005* (Version 2005) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524201

Bright, E., Coleman, P., & King, A. (2007). *LandScan Global 2006* (Version 2006) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524202

Bright, E., Coleman, P., King, A., & Rose, A. (2008). *LandScan Global 2007* (Version 2007) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524203

Bright, E., Coleman, P., King, A., Rose, A., & Urban, M. (2009). *LandScan Global 2008* (Version 2008) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524204

Bright, E., Coleman, P., Rose, A., & Urban, M. (2010). *LandScan Global 2009* (Version 2009) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524205

Bright, E., Coleman, P., Rose, A., & Urban, M. (2011). *LandScan Global 2010* (Version 2010) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524206

Bright, E., Coleman, P., Rose, A., & Urban, M. (2012). *LandScan Global 2011* (Version 2011) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524207

Bright, E., Rose, A., & Urban, M. (2013). *LandScan Global 2012* (Version 2012) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524215

Bright, E., Rose, A., & Urban, M. (2014). *LandScan Global 2013* (Version 2013) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524208

Bright, E., Rose, A., & Urban, M. (2015). *LandScan Global 2014* (Version 2014) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524209

Bright, E., Rose, A., & Urban, M. (2016). *LandScan Global 2015* (Version 2015) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524210

Bright, E., Rose, A., Urban, M., & McKee, J. (2017). *LandScan Global 2016* (Version 2016) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524211

Burger, M. (2011). Structure and *cooptition* in *urban networks* (Publication No. EPS-2011-243-ORG) [Doctoral dissertation, Erasmus University Rotterdam]. http://hdl.handle.net/1765/26178

Burger, M., & Meijers, E. (2012). Form Follows Function? Linking Morphological and Functional Polycentricity. *Urban Studies*, 49(5), 1127-1149. https://doi.org/10.1177/0042098011407095

Carlino, G. A., Chatterjee, S., & Hunt, R. M. (2007). Urban density and the rate of invention. *Journal of Urban Economics*, 61(3), 389-419. https://doi.org/10.1016/j.jue.2006.08.003

Champion, A. G. (2001). A Changing Demographic Regime and Evolving Poly centric Urban Regions: Consequences for the Size, Composition and Distribution of City Populations. *Urban Studies*, 38(4), 657-677. https://doi.org/10.1080/00420980120035277

Dadashpoor, H., & Adeli, Z. (2016). Measuring the Amount of Regional Resilience in Qazvin Urban Region. *Emergency Management*, 4(2), 73-84. https://www.joem.ir/article_18579_7c9150d1b9eea9c6179e6e3815d1e8e2.pdf

Dadashpoor, H., Doorudinia, A., & Meshkini, A. (2023). Polycentricity: The last episodes or the new season? *Progress in Planning*, 177, 100776. https://doi.org/10.1016/j.progress.2023.100776

Davoudi, S. (2003). EUROPEAN BRIEFING: Polycentricity in European spatial planning: from an analytical tool to a normative agenda. *European Planning Studies*, 11(8), 979-999. https://doi.org/10.1080/0965431032000146169

Derudder, B., Liu, X., Wang, M., Zhang, W., Wu, K., & Caset, F. (2021). Measuring polycentric urban development: The importance of accurately determining the 'balance' between 'centers'. *Cities*, 111, 103009. https://doi.org/10.1016/j.cities.2020.103009

Dieleman, F., & Wegener, M. (2004). Compact city and urban sprawl. *Built Environment*, 30(4), 308-323. https://doi.org/10.2148/benv.30.4.308.57151

Doorudinia, A., Dadashpoor, H., & Meshkini, A. (2025). Wrong polycentricity-right polycentricity?: Insights from an empirical study in Tehran metropolitan region, Iran. *Papers in Regional Science*, 104(1), 100075. https://doi.org/10.1016/j.pirs.2024.100075

Eeckhout, J., Pinheiro, R., & Schmidheiny, K. (2010). Spatial sorting: Why New York, Los Angeles and Detroit attract the greatest minds as well as the unskilled, *CESifo, Working Paper, No. 3274*, Center for Economic Studies and ifo Institute (CESifo), Munich. Available at: https://hdl.handle.net/10419/46491

Faludi, A. (2005). Polycentric territorial cohesion policy. *Town Planning Review*, 76(1), 107-118. https://www.jstor.org/stable/40112634

Faludi, A. (2006). From European spatial development to territorial cohesion policy. *Regional Studies*, 40(6), 667-678. https://doi.org/10.1080/00343400600868937

Fan, J., Wang, Y., Zhou, L., Xu, L., & Wang, Z. (2025). Can digital economy reshape urban spatial structure? Evidence from the perspective of urban sprawl. *The Annals of Regional Science*, 74(3), 73. https://doi.org/10.1007/s00168-025-01404-3

Fujita, M., & Thisse, J.-F. (2009). New Economic Geography: An appraisal on the occasion of Paul Krugman's 2008 Nobel Prize in Economic Sciences. *Regional Science and Urban Economics*, 39(2), 109-119. https://doi.org/10.1016/j.regsciurbeco.2008.11.003

Garcia-López, M.-À., & Muñiz, I. (2010). Employment Decentralisation: Polycentricity or Scatteration? The Case of Barcelona. *Urban Studies*, 47(14), 3035-3056. https://doi.org/10.1177/0042098009360229

Glaeser, E. L., & Resseger, M. G. (2010). THE COMPLEMENTARITY BETWEEN CITIES AND SKILLS. *Journal of Regional Science*, 50(1), 221-244. https://doi.org/10.1111/j.1467-9787.2009.00635.x

Goess, S., de Jong, M., & Meijers, E. (2016). City branding in polycentric urban regions: identification, profiling and transformation in the Randstad and Rhine-Ruhr. *European Planning Studies*, 24(11), 2036-2056. https://doi.org/10.1080/09654313.2016.1228832

Goffette-Nagot, F., & Schmitt, B. (1999). Agglomeration Economies and Spatial Configurations in Rural Areas. *Environment and Planning A: Economy and Space*, 31(7), 1239-1257. https://doi.org/10.1068/a311239

Green, N. (2007). Functional Polycentricity: A Formal Definition in Terms of Social Network Analysis. *Urban Studies*, 44(11), 2077-2103. https://doi.org/10.1080/00420980701518941

Hague, C., & Kirk, K. (2003). Polycentricity scoping study. Office of the Deputy Prime Minister London.

Hallowell, G., & Baran, P. (2021). Neighborhood Dynamics and Long-Term Change. *Geographical Analysis*, 53(2), 213-236. https://doi.org/10.1111/gean.12240

He, X., Zhou, Y., & Yuan, Y. (2025). Exploring the relationship between urban polycentricity and consumer amenity development: An empirical study using Dianping Data in China. *Cities*, 166, 106197. https://doi.org/10.1016/j.cities.2025.106197

Howard, E., Osborn, F. J., & Mumford, L. (1898/2013). *Garden cities of to-morrow*. Routledge.

Huo, Z., Yuping, S., Silu, Z., Meixia, M., Daniel, B. L., & and Ma, X. (2024). Monocentricity or polycentricity? The study on the enterprise environmental performance of urban spatial structure. *Journal of The Asia Pacific Economy*, 1-31. https://doi.org/10.1080/13547860.2024.2370152

Khodabandeh, A., & Shahabi-Shahmiri, M. S. (2025). The multifaceted effects of spatial polycentricity on air pollutant emissions: A systematic review. *Sustainable Futures*, 10, 101210. https://doi.org/10.1016/j.sftr.2025.101210

Kloosterman, R. C., & Lambregts, B. (2001). Clustering of Economic Activities in Polycentric Urban Regions: The Case of the Randstad. *Urban Studies*, 38(4), 717-732. https://doi.org/10.1080/00420980120035303

Kloosterman, R. C., & Musterd, S. (2001). The Polycentric Urban Region: Towards a Research Agenda. *Urban Studies*, 38(4), 623-633. https://doi.org/10.1080/00420980120035259

Lalor, G. C., & Zhang, C. (2001). Multivariate outlier detection and remediation in geochemical databases. *Science of The Total Environment*, 281(1-3), 99-109. https://doi.org/10.1016/S0048-9697(01)00839-7

Lebakula, V., Epting, J., Moehl, J., Stipek, C., Adams, D., Reith, A., Kaufman, J., Gonzales, J., Reynolds, B., Basford, S., Martin, A., Buck, W., Faxon, A., Cunningham, A., Roy, A., Barbose, Z., Massaro, J., Walters, S., Woody, C., et al. (2024). *LandScan Silver Edition Version* [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1531770

Li, H., Han, Y., Wang, T., Wang, Z., Li, Y., & Shen, H. (2024). Evolution of urban morphological polycentricity and the thermal response in Wuhan from 2000 to 2020. *Sustainable Cities and Society*, 100, 105055. https://doi.org/10.1016/j.scs.2023.105055

Li, W., Schmidt, S., & Siedentop, S. (2024). Can polycentric urban development simultaneously achieve both economic growth and regional equity? A multi-scale analysis of German regions. Environment and Planning A: Economy and Space, 56(2), 525-545. https://doi.org/10.1177/0308518x231191943

Li, Y., & Lee, S. (2025). Central nodes and polycentricity at the micro-scale: Evaluating carbon emissions across Beijing's subdistricts. *Transactions in Planning and Urban Research*, 4(1), 38-64. https://doi.org/10.1177/27541223241299821

Li, Y., Lyu, S., Gao, Q., & Lee, S. (2024). Does morphological polycentric spatial structure improve subjective well-being? – Evidence from China based on the moderating perspective of the urban-rural income inequality. *Journal of Urban Management*. https://doi.org/10.1016/j.jum.2024.10.002

Lorens, P., & Golędzinowska, A. (2022). Developing Polycentricity to Shape Resilient Metropolitan Structures: The Case of the Gdansk–Gdynia–Sopot Metropolitan Area [Gdansk Metropolitan Area; metropolitan planning; Poland; polycentrism; resilience; Tri-City; urban planning]. *Urban Planning*, 7(3), 13. https://doi.org/10.17645/up.v7i3.5502

Luo, C., Yujie, H., & and Wang, F. (2025). A big data approach to modelling urban population density functions: from monocentricity to polycentricity. *Annals of GIS*, 31, 1-14. https://doi.org/10.1080/19475683.2025.2472769

Martellozzo, F., & Clarke, K. C. (2011). Measuring Urban Sprawl, Coalescence, and Dispersal: A Case Study of Pordenone, Italy. *Environment and Planning B: Planning and Design*, 38(6), 1085-1104. https://doi.org/10.1068/b36090

Marull, J., Farré, M., Espuña, M. A., Prior, A., Galletto, V., & Trullén, J. (2023). How to measure large-scale complex urban network structures using night-time light satellite databases.

Application to European metropolitan regions. *Environment and Planning B: Urban Analytics and City Science*, 50(7), 1947-1963. https://doi.org/10.1177/23998083231151689

Masip-Tresserra, J. (2017). Polycentricity, Performance and Planning: Concepts, Evidence and Policy in Barcelona, Catalonia. A+BE, *Architecture and the Built Environment*, 6(7), 1-348. https://doi.org/10.7480/abe.2016.7.1155

Meijers, E. (2005). Polycentric Urban Regions and the Quest for Synergy: Is a Network of Cities More than the Sum of the Parts? *Urban Studies*, 42(4), 765-781. https://doi.org/10.1080/00420980500060384

Meijers, E. (2008). Measuring Polycentricity and its Promises. *European Planning Studies*, 16(9), 1313-1323. https://doi.org/10.1080/09654310802401805

Meijers, E., Hoogerbrugge, M., & Cardoso, R. (2018). Beyond Polycentricity: Does Stronger Integration Between Cities in Polycentric Urban Regions Improve Performance? *Tijdschrift voor Economische en Sociale Geografie*, 109(1), 1-21. https://doi.org/10.1111/tesg.12292

Meijers, E. J. (2007). Synergy in Polycentric Urban Regions: Complementarity, organising capacity and critical mass (Vol. 13). Ios Press.

Meijers, E. J., & Burger, M. J. (2010). Spatial Structure and Productivity in US Metropolitan Areas. *Environment and Planning A: Economy and Space*, 42(6), 1383-1402. https://doi.org/10.1068/a42151

Meijers, E. J., Burger, M. J., & Hoogerbrugge, M. M. (2016). Borrowing size in networks of cities: City size, network connectivity and metropolitan functions in Europe. *Papers in Regional Science*, 95(1), 181-199. https://doi.org/10.1111/pirs.12181

Pan, H., Yao, Y., Ming, Y., Hong, Z., & Hewings, G. (2024). Whither less is more? Understanding the contextual and configurational conditions of polycentricity to improve urban agglomeration efficiency. *Cities*, 149, 104884. https://doi.org/10.1016/j.cities.2024.104884

Parr, J. (2004). The Polycentric Urban Region: A Closer Inspection. *Regional Studies*, 38(3), 231-240. https://doi.org/10.1080/003434042000211114

Potts, D. (2005). Counter-urbanisation on the Zambian Copperbelt? Interpretations and Implications. *Urban Studies*, 42(4), 583-609. https://doi.org/10.1080/00420980500060137

Ramírez-Aldana, R., Gomez-Verjan, J. C., & Bello-Chavolla, O. Y. (2020). Spatial analysis of COVID-19 spread in Iran: Insights into geographical and structural transmission determinants at a province level. *PLOS Neglected Tropical Diseases*, 14(11), e0008875. https://doi.org/10.1371/journal.pntd.0008875

Richardson, H. W. (1995). Economies and Diseconomies of Agglomeration. In H. Giersch (ed.), *Urban Agglomeration and Economic Growth* (pp. 123-155). Publications of the Egon-Sohmen-Foundation. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-79397-4_6

Rose, A., McKee, J., Sims, K., Bright, E., Reith, A., & Urban, M. (2020). *LandScan Global 2019* (Version 2019) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524214

Rose, A., McKee, J., Sims, K., Bright, E., Reith, A., & Urban, M. (2021). *LandScan Global 2020* (Version 2020) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1523378

Rose, A., McKee, J., Urban, M., & Bright, E. (2018). *LandScan Global 2017* (Version 2017) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524212

Rose, A., McKee, J., Urban, M., Bright, E., & Sims, K. (2019). *LandScan Global 2018* (Version 2018) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1524213

Sabesan, A., Abercrombie, K., Ganguly, A. R., Bhaduri, B., Bright, E. A., & Coleman, P. R. (2007). Metrics for the comparative analysis of geospatial datasets with applications to high-resolution grid-based population data. *GeoJournal*, 69(1), 81-91. https://doi.org/10.1007/s10708-007-9103-y

Schmitt, P., Harbo, L. G., Diş, A. T., & Henriksson, A. (2013). Urban Resilience and Polycentricity: The Case of the Stockholm Urban Agglomeration. In A. Eraydin & T. Taşan-Kok (Eds.), *Resilience Thinking in Urban Planning* (pp. 197-209). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-5476-8_12

Shahabi-Shahmiri, M., & Khodabandeh, A. (2025). Assessing Morphological Polycentricity at the Supra-Regional Scale (Tehran, Alborz, and Qazvin Provinces) Using LandScan Big Data. *Urban Structure and Function Studies*, *12*(4), 89-120. https://doi.org/10.22080/usfs.2025.28492.2498

Sims, K., Reith, A., Bright, E., McKee, J., & Rose, A. (2022). *LandScan Global 2021* (Version 2021) [raster digital data]. Oak Ridge National Laboratory. https://doi.org/10.48690/1527702

Sims, K., Reith, A., Bright, E., Kaufman, J., Pyle, J., Epting, J., Gonzales, J., Adams, D., Powell, E., Urban, M., & Rose, A. (2023). *LandScan Global 2022* (Version 2022) [raster digital data]. Oak Ridge National Laboratory. Available at: https://doi.org/10.48690/1529167

Sober, R. (2000). Book review: Peter Hall and Colin Ward, Sociable Cities: The Legacy of Ebenezer Howard. *Urban History*, 27(2), 292-320. https://doi.org/10.1017/S0963926800350283

Sofianou, P.-K. (2016). Cultural Heritage as a Tool of Polycentricity, Synergy and Territorial Cohesion: A Case Study from Northern Greece. *Procedia - Social and Behavioral Sciences*, 223, 687-692. https://doi.org/10.1016/j.sbspro.2016.05.238

Waterhout, B., Zonneveld, W., & Meijers, E. (2005). Polycentric development policies in Europe: Overview and debate. *Built Environment*, 31(2), 163-173. https://doi.org/10.2148/benv.31.2.163.66250

Wolff, M., Haase, D., & Haase, A. (2018). Compact or spread? A quantitative spatial model of urban areas in Europe since 1990. PLOS ONE, 13(2), e0192326. https://doi.org/10.1371/journal.pone.0192326

Wu, Y., Shi, K., Cui, Y., Liu, S., & Liu, L. (2023). Differentiated effects of morphological and functional polycentric urban spatial structure on carbon emissions in China: an empirical analysis from remotely sensed nighttime light approach. *International Journal of Digital Earth*, 16(1), 532-551. https://doi.org/10.1080/17538947.2023.2176558

Yan, S., & Wu, Q. (2025). How does intra-city spatial structure influence green economic efficiency? A nonlinear and spatial spillover perspective. *Habitat International*, 162, 103455. https://doi.org/10.1016/j.habitatint.2025.103455

Yu, Z., Xiao, L., Chen, X., He, Z., Guo, Q., & Vejre, H. (2018). Spatial restructuring and land consolidation of urban-rural settlement in mountainous areas based on ecological niche perspective. *Journal of Geographical Sciences*, 28(2), 131-151. https://doi.org/10.1007/s11442-018-1464-2

Yue, H., Pan, Y., & Guan, Q. (2025). Measuring the spatial and size polycentricity: An empirical study of China's urban agglomerations using population distribution data. *Applied Geography*, 176, 103529. https://doi.org/10.1016/j.apgeog.2025.103529

Zhang, C., Luo, L., Xu, W., & Ledwith, V. (2008). Use of local Moran's I and GIS to identify pollution hotspots of Pb in urban soils of Galway, Ireland. Science of The Total Environment, 398(1), 212-221. https://doi.org/10.1016/j.scitotenv.2008.03.011

Zhang, Y., Wang, S., & Zhou, R. (2025). Spatial sorting and selection within urban agglomerations: a tripartite evolutionary game model approach. *Humanities and Social Sciences Communications*, 12(1), 57. https://doi.org/10.1057/s41599-024-04281-x

Appendix

Appendix Table A1 | Spatial Correlation Matrix of Population Distribution (2001–2023)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
2001	1	0.996856	0.903996	0.937375	0.921993	0.912896	0.940136	0.915269	0.914355	0.912795	0.900683	0.894028
2002	0.996856	1	0.91682	0.947216	0.934038	0.928843	0.948576	0.931506	0.924047	0.925209	0.917159	0.908972
2003	0.903996	0.91682	1	0.994635	0.997672	0.996603	0.9928	0.995863	0.997851	0.998675	0.97095	0.966772
2004	0.937375	0.947216	0.994635	1	0.998445	0.995585	0.998767	0.993763	0.996609	0.996312	0.967138	0.961667
2005	0.921993	0.934038	0.997672	0.998445	1	0.997817	0.997244	0.996982	0.998604	0.999076	0.971837	0.966581
2006	0.912896	0.928843	0.996603	0.995585	0.997817	1	0.993346	0.998746	0.994472	0.997499	0.972626	0.966907
2007	0.940136	0.948576	0.9928	0.998767	0.997244	0.993346	1	0.992721	0.996101	0.995807	0.966612	0.961126
2008	0.915269	0.931506	0.995863	0.993763	0.996982	0.998746	0.992721	1	0.993452	0.997544	0.980191	0.974501
2009	0.914355	0.924047	0.997851	0.996609	0.998604	0.994472	0.996101	0.993452	1	0.998737	0.966634	0.96215
2010	0.912795	0.925209	0.998675	0.996312	0.999076	0.997499	0.995807	0.997544	0.998737	1	0.974415	0.969547
2011	0.900683	0.917159	0.97095	0.967138	0.971837	0.972626	0.966612	0.980191	0.966634	0.974415	1	0.997187
2012	0.894028	0.908972	0.966772	0.961667	0.966581	0.966907	0.961126	0.974501	0.96215	0.969547	0.997187	1
2013	0.890955	0.89868	0.938786	0.939137	0.940368	0.934816	0.94148	0.944342	0.937445	0.943307	0.98039	0.984905
2014	0.897018	0.896473	0.895856	0.903585	0.899963	0.887569	0.907547	0.900383	0.899644	0.902094	0.950502	0.954797
2015	0.897475	0.896157	0.887228	0.896541	0.891901	0.879541	0.899914	0.89236	0.890284	0.892922	0.941517	0.947247
2016	0.914732	0.911303	0.879147	0.893923	0.885851	0.87213	0.897838	0.884431	0.885641	0.886502	0.931022	0.933249
2017	0.90791	0.906413	0.882592	0.894782	0.889386	0.876282	0.899121	0.890032	0.887751	0.890445	0.940025	0.944141
2018	0.902798	0.899488	0.869649	0.882855	0.876596	0.862721	0.88664	0.876958	0.876325	0.878149	0.928627	0.932719
2019	0.900292	0.896306	0.857594	0.870967	0.863335	0.850251	0.87585	0.86443	0.86119	0.86463	0.919755	0.924025
2020	0.872829	0.86979	0.848571	0.857632	0.852957	0.838311	0.862524	0.854887	0.852591	0.855793	0.919247	0.924415
2021	0.891918	0.887538	0.86228	0.873286	0.867503	0.85238	0.877772	0.867079	0.866726	0.868817	0.924385	0.928278
2022	0.897265	0.892539	0.86462	0.875199	0.869301	0.854305	0.882077	0.869685	0.86886	0.871452	0.924452	0.927725
2023	0.819	0.811753	0.796165	0.799807	0.797355	0.7827	0.808313	0.803469	0.797831	0.802589	0.874743	0.885122

2023	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013
0.819	0.897265	0.891918	0.872829	0.900292	0.902798	0.90791	0.914732	0.897475	0.897018	0.890955
0.811753	0.892539	0.887538	0.86979	0.896306	0.899488	0.906413	0.911303	0.896157	0.896473	0.89868
0.796165	0.86462	0.86228	0.848571	0.857594	0.869649	0.882592	0.879147	0.887228	0.895856	0.938786
0.799807	0.875199	0.873286	0.857632	0.870967	0.882855	0.894782	0.893923	0.896541	0.903585	0.939137
0.797355	0.869301	0.867503	0.852957	0.863335	0.876596	0.889386	0.885851	0.891901	0.899963	0.940368
0.7827	0.854305	0.85238	0.838311	0.850251	0.862721	0.876282	0.87213	0.879541	0.887569	0.934816
0.808313	0.882077	0.877772	0.862524	0.87585	0.88664	0.899121	0.897838	0.899914	0.907547	0.94148
0.803469	0.869685	0.867079	0.854887	0.86443	0.876958	0.890032	0.884431	0.89236	0.900383	0.944342
0.797831	0.86886	0.866726	0.852591	0.86119	0.876325	0.887751	0.885641	0.890284	0.899644	0.937445
0.802589	0.871452	0.868817	0.855793	0.86463	0.878149	0.890445	0.886502	0.892922	0.902094	0.943307
0.874743	0.924452	0.924385	0.919247	0.919755	0.928627	0.940025	0.931022	0.941517	0.950502	0.98039
0.885122	0.927725	0.928278	0.924415	0.924025	0.932719	0.944141	0.933249	0.947247	0.954797	0.984905
0.924967	0.959889	0.960723	0.958492	0.959275	0.962227	0.970919	0.962262	0.977567	0.982937	1
0.965471	0.99273	0.992937	0.991735	0.991517	0.993761	0.99617	0.993431	0.996993	1	0.982937
0.973248	0.992442	0.992976	0.99156	0.993383	0.994259	0.995752	0.992767	1	0.996993	0.977567
0.963672	0.995655	0.994831	0.991688	0.995369	0.996973	0.996312	1	0.992767	0.993431	0.962262
0.967697	0.996875	0.996565	0.995208	0.996591	0.997286	1	0.996312	0.995752	0.99617	0.970919
0.973367	0.995475	0.995607	0.993733	0.996388	1	0.997286	0.996973	0.994259	0.993761	0.962227
0.971167	0.996389	0.996667	0.995075	1	0.996388	0.996591	0.995369	0.993383	0.991517	0.959275
0.97887	0.997327	0.996822	1	0.995075	0.993733	0.995208	0.991688	0.99156	0.991735	0.958492
0.974364	0.997515	1	0.996822	0.996667	0.995607	0.996565	0.994831	0.992976	0.992937	0.960723
0.974557	1	0.997515	0.997327	0.996389	0.995475	0.996875	0.995655	0.992442	0.99273	0.959889
1	0.974557	0.974364	0.97887	0.971167	0.973367	0.967697	0.963672	0.973248	0.965471	0.924967