

# Does Compactness Matter? Comparative Study of Medium-Sized Shrinking Cities' Compactness in Germany and Poland

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## Abstract

Urban shrinkage is an increasingly pressing phenomenon in Europe, affecting medium-sized cities that are vital to regional stability. However, large-scale, longitudinal research on the relationship between urban form characteristics and shrinkage remains limited. This study examines whether urban compactness influences the trajectory of shrinking cities by comparing all medium-sized cities (20,000–100,000 inhabitants) in Germany and Poland over 15 years. Using geospatial tools and multi-criteria indicators, we quantify urban shrinkage through a composite score and assess urban form compactness based on CORINE Land Cover data, employing two measures: urban population density and the Schwartzberg compactness index. Pearson's correlation analysis is used to examine how the relationship between urban shrinkage and compactness evolves over time. The findings indicate that medium-sized German cities show a clear and consistent negative correlation between urban shrinkage and the two compactness measures throughout the period. In other words, the more compact and dense a medium-sized city is, the less likely it is to shrink. Polish cities exhibit more mixed trends. The correlation results show that there is a temporal positive coefficient between shrinkage and density, but a negative correlation between compactness measures and shrinkage. Overall, results suggest that urban compactness, among other factors, can play an important role in medium-sized cities' shrinkage management. This study identifies patterns in medium-sized cities in both countries regarding compactness and shrinkage trends, supporting cross-national knowledge exchange and the development of context-sensitive planning strategies.

## Keywords

compactness; Germany; medium-sized cities; Poland; urban shrinkage

## 1. Introduction

The UN-Habitat *World Cities Report 2022* highlighted that half of the cities in so-called developed nations experienced depopulation from 2000 to 2018, predominantly in Europe, Japan, and North America (UN-Habitat, 2022). Substantial population losses have also been documented in cities across Australia, Latin America, and China (Gao et al., 2024; Pallagst et al., 2021; Wang & Fukuda, 2019; Wang et al., 2022). Consequently, urban shrinkage has become a significant challenge for many countries worldwide, including Poland. The projected 18.5% decline in Poland's urban population by 2050 (Central Statistical Office, 2023) underscores the urgent need for action. Negative demographic trends can lead to financial instability, rising vacancy rates, the loss of services and shops, deteriorating infrastructure, and ultimately, a decline in the quality of life in affected cities. While resilience theories suggest that cities can adapt and transform (Alves et al., 2016), informed urban planning strategies are essential to support this process.

Understanding urban shrinkage and its cause-and-effect relationships is crucial for developing effective strategies to mitigate its adverse effects. However, it remains challenging due to its multidisciplinary and complex nature. Research on urban shrinkage has primarily focused on large cities, while smaller cities, which are often the most affected, have received less attention (Gajewski & Knippschild, 2024; Gao et al., 2024; Śleszyński, 2017; Terfrüchte & Growe, 2024). Moreover, while major urban centres often reap the benefits by attracting capital, people, and innovation, smaller ones are frequently sidelined, struggling to remain competitive. Medium-sized cities (MSCs) often experience more severe and prolonged urban shrinkage processes (Śleszyński, 2017). According to urban scaling theory, the characteristics of an urban area depend on its size (D'Acci, 2024); thus, MSCs experience different challenges when compared to large or small urban centres. Large European cities are typically the first to recover from shrinkage and become migration destinations (Rink et al., 2014). They also densify more easily after temporary population outflux (Cortinovis et al., 2022). This trajectory is uncommon for medium and small cities. Such patterns were evidenced in Germany (Gatzweiler & Milbert, 2009), France (Chouraqui, 2021), Poland (Śleszyński, 2017; Szymczyk & Bukowski, 2023), and Spain (Escudero-Gómez et al., 2023), among other European countries.

While MSCs are projected to experience a significant population decline, the way they manage shrinkage will affect the overall stability of the urban settlement network. It is crucial to examine whether effective local-level urban planning strategies can enhance resilience to population decline. The question of how urban planning can promote sustainable development in shrinking cities is complex, primarily because existing planning theories focus on growth. Reis et al. (2016) call for tools specifically designed to address urban shrinkage. This article addresses the above gap by investigating the relationship between the urban form in MSCs and patterns of urban growth and shrinkage.

The article is structured as follows: Section 1 provides a context on urban shrinkage processes in Germany and Poland. Section 2 reviews the literature on urban shrinkage and its relationship to urban form. Section 3 outlines the data, study area, and methodology. Section 4 presents the empirical findings from the analysis. Section 5 discusses the results. Finally, Section 6 concludes with implications for planning and suggestions for further research.

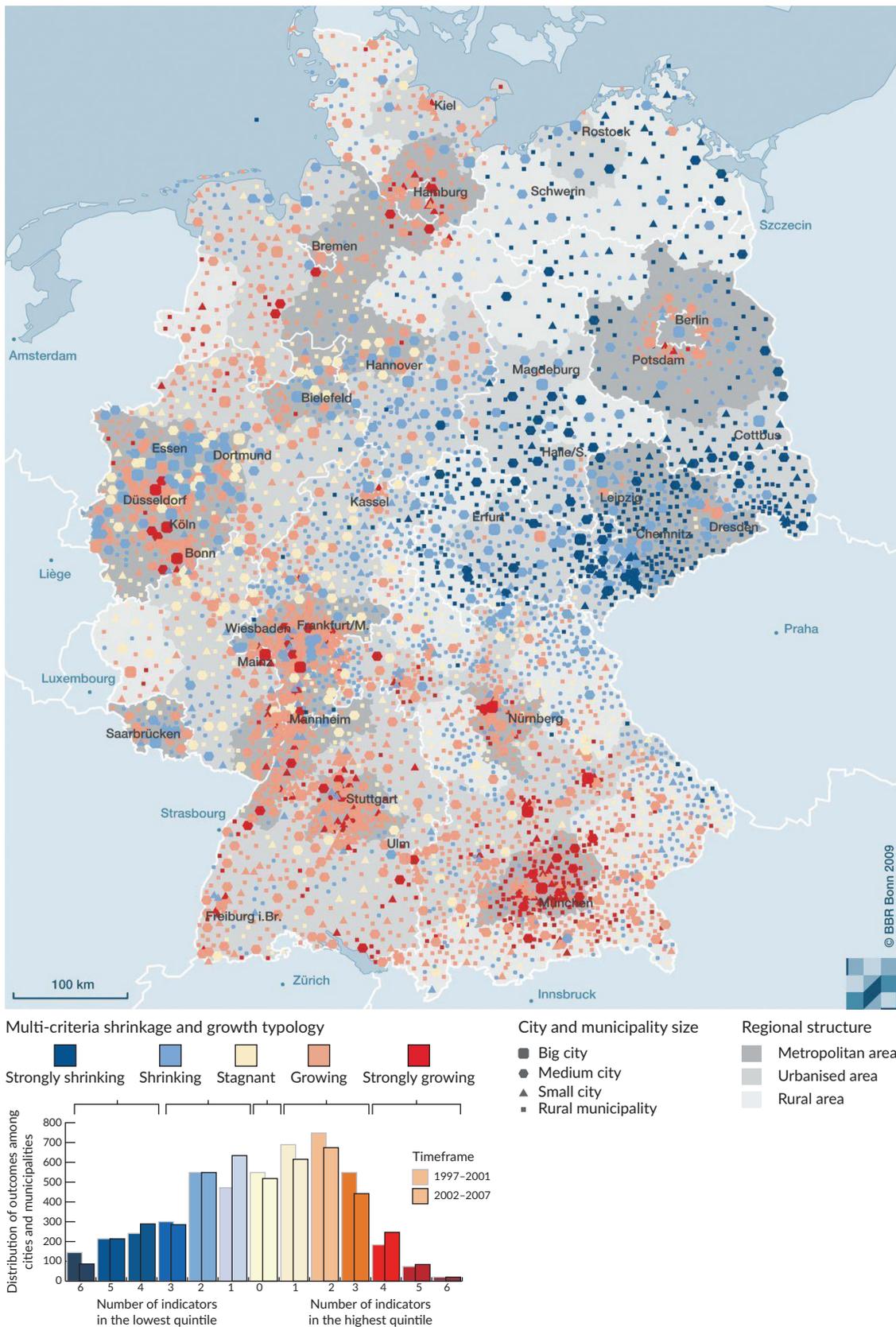
## 1.1. Contextual Overview

In Europe, urban shrinkage, defined comprehensively as an interplay among demographic, social, and economic changes (Häußermann & Siebel, 1988), has emerged as one of the most frequently discussed topics in urban research over the past two decades (Slach et al., 2020). Deindustrialisation and demographic trends were seen as the leading causes of urban decline in the late 1990s (Döringer et al., 2019; Pallagst et al., 2021). However, the cause-and-effect relationship is hard to disentangle, and planning responses to this phenomenon differ by country. This study looks at the two European countries, Germany and Poland, which showed a similar degree of urban shrinkage between 1990 and 2010 (Strykiewicz et al., 2014) but responded with different planning approaches.

### 1.1.1. Germany

In Germany, urban shrinkage in the early 2000s was particularly prominent among MSCs in East Germany, the former German Democratic Republic, as shown in Figure 1 (Gatzweiler et al., 2003). In response to the “one million empty flats” problem (Pfeiffer et al., 2001), German planning answered with proactive “right-sizing,” combining building demolitions with a holistic “smart decline” strategy (Hollander & Nemeth, 2011). Overall, the outcomes of German policies are viewed positively when compared to those of many other countries, particularly the *Stadtumbau Ost* (Urban Redevelopment East program) and the complementary *Internationale Bauausstellung* (International Building Exhibition) Saxony-Anhalt 2010, which have become reference points of good shrinkage management practice.

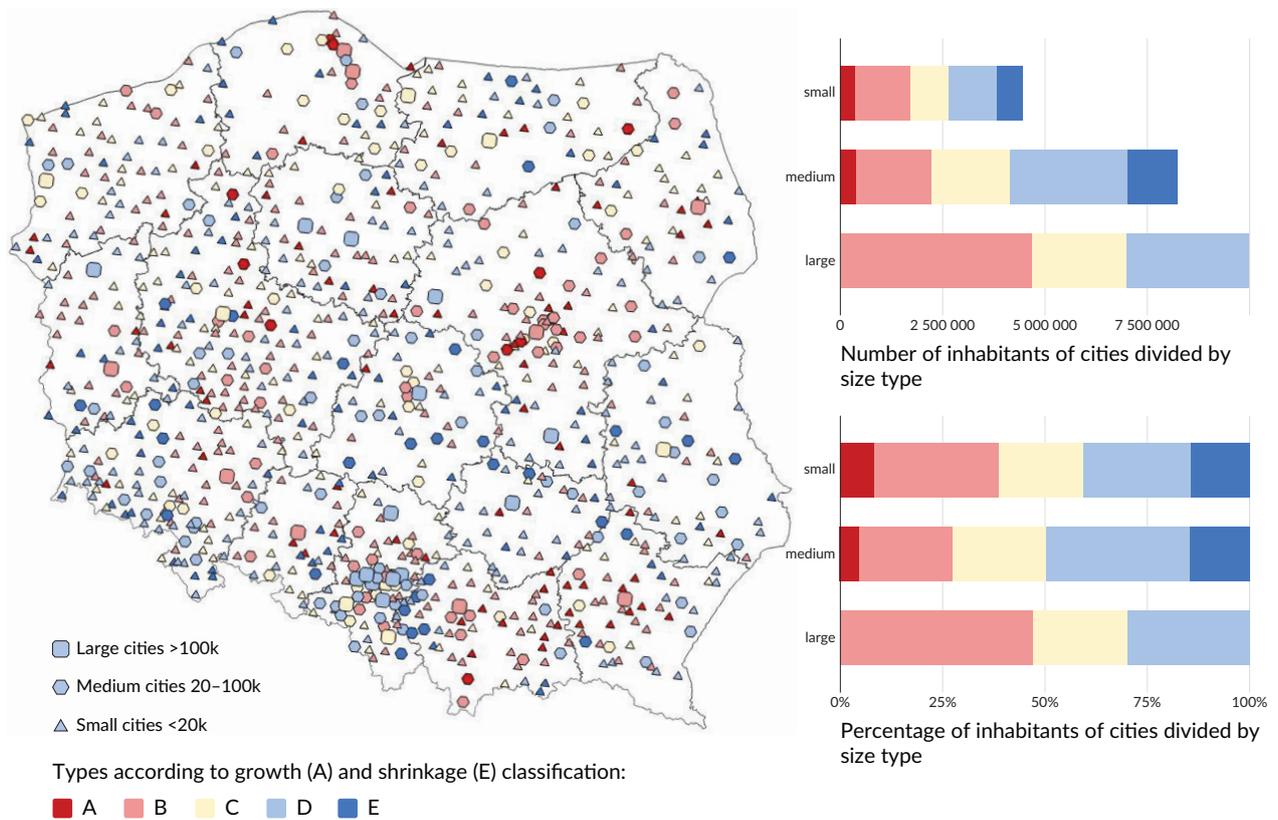
Significant progress was made in addressing shared challenges among small to medium-sized towns during the eight-year urban renewal programs (2002–2010). A primary goal was to promote compact city principles, encouraging a shift from peripheral housing estates to urban centres (*Internationale Bauausstellung*, 2011). Over a decade later, most participating cities reported improvements, showcasing stable de-growth or re-growth and a change of perception among their citizens (*Internationale Bauausstellung*, 2011). Attributing the success of urban renewal solely to the *IBA Saxony-Anhalt* and *Stadtumbau Ost* would be an overstatement, as national and global economic factors also contributed to the process. However, by enhancing spatial qualities, densifying urban centres, and mitigating urban sprawl, shrinking cities in East Germany have effectively navigated their futures without relying on growth, and have developed new identities and ways forward (*Internationale Bauausstellung*, 2011).



**Figure 1.** Multi-criteria shrinkage and growth assessment of German cities and municipalities 2003–2008. Source: Gatzweiler et al. (2003).

### 1.1.2. Poland

In contemporary Poland, urban shrinkage began to emerge around 2002 as the initial effects of the economic “shock therapy” (Bontje, 2004) became evident. While urban demographics have been a focal point of Polish researchers for several decades, the concept of urban shrinkage was first identified by Zborowski (2002) and Parysek (2004). This was followed by broader comparative studies, including Cities Re-growing Smaller (CIRES) and Shrink Smart (Krzysztofik & Szymytkie, 2011), as well as multi-criteria assessments by Śleszyński (2017, 2019), Sroka (2021), and others. As shown in Śleszyński (2019) and confirmed in more recent studies (Szymczyk & Bukowski, 2023) for 2006–2021, urban shrinkage is especially prevalent in MSCs (see Figure 2), which tend to have fewer resources and less planning capacity to respond than large cities.



**Figure 2.** Classification of shrinking and growing cities in the years 2016–2021, divided by growth and shrinkage (A–growing significantly, B–growing, C–stagnant, D–shrinking, E–shrinking significantly). Source: Author based on Central Statistical Office (2025) and Milbert (2020) methodology.

In the coming years, urban shrinkage in Poland is expected to intensify and, according to Jaroszewska (2019), will constitute one of the greatest challenges of the country’s spatial policy. The importance of the problem is evidenced by the Senate report entitled *Management of Shrinking Cities* (Polish Senate, 2013) and the National Spatial Development Concept 2030, which acknowledged these issues and proposed strategies to counteract negative effects. However, no tangible actions in the form of strategic support followed, leaving MSCs in need of guidance on how to plan for future challenges.

## 2. State of the Literature

### 2.1. *Measuring Urban Shrinkage*

The process of urban shrinkage varies due to historical, geographical, and socio-economic factors (Strykiewicz et al., 2014). It can occur on various urban scales (e.g., district, city, or regional scale) and may occur alongside urban growth (Ribant & Chen, 2019), complicating comprehension. While the term “urban shrinkage” encompasses the multifaceted nature of the process—including economic, demographic, spatial, and structural changes—much of the research has focused on its demographic dimension, with population change as the predominant indicator (Döringer et al., 2019). A meta-analysis by Reis et al. (2016) indicates that spatial aspects of shrinkage remain less explored because built-up areas persist even as populations decline.

Theories that aim to understand the cycles of urban growth and shrinkage in relationship to space suggest that shrinkage can be seen as part of a city’s life cycle, alternating with phases of reurbanisation that affect different parts of the city (Klaassen, 1988; van den Berg et al., 1982). Here, shrinkage is viewed not solely as a result of population change but as a sign of deeper structural and spatial cyclical transformations. In the United States, urban shrinkage, often termed “urban decline,” was historically observed in cities such as Detroit, where post-industrial job loss and suburbanisation (“white flight”) triggered population decline and sprawl (Beauregard, 2009). In Central and Eastern Europe, by contrast, declining inner-city densities have been linked not only to demographic and economic change but also to market-driven suburban growth (Schmidt et al., 2014). Comparing German and Polish cities, therefore, provides insight into how urban form relates to socio-economic processes.

### 2.2. *Research on Urban Form and Shrinkage*

Research indicates that compact, contiguous urban areas have significantly lower infrastructure costs compared to dispersed ones (Carruthers & Ulfarsson, 2003; Miyauchi & Setoguchi, 2023). In dispersed service areas, the length of inter-neighbourhood service components is above average (Burchell et al., 1998). As a result, infrastructure costs can be several times higher than in more compact urban areas. In shrinking cities, there is already “too much town for too small a population” (Internationale Bauausstellung, 2011). Such an imbalance often leads to a weakened fiscal base, disrupted infrastructure maintenance, less vibrant and walkable public spaces, and, as a result, diminished quality of life. In a study conducted in China, researchers found that a higher degree of urban shrinkage correlates with lower compactness and reduced land use efficiency (Wang et al., 2022). Consequently, many shrinking cities struggle to sustain themselves (Hollander, 2009). Siedentop and Fina’s (2008) research on spatial patterns of growth and shrinkage illustrates the divergence between urban form expansion and urban population decline, resulting in lower urban population density. A recent study (Szymczyk et al., 2024) found that from 2006 to 2018, Polish MSCs became less compact and less dense. A follow-up analysis (Szymczyk & Bukowski, 2025) revealed that urban areas in urban municipalities exhibited a positive relationship between compactness and resilience to shrinkage. Denser cities were initially more prone to population loss (2006–2016), but this trend diminished in the subsequent period (2016–2021), suggesting an evolving relationship between urban form and decline. In conclusion, the study (Szymczyk & Bukowski, 2025) underscored the need for further research into the relationship between urban compactness and shrinkage across different national and regional contexts.

### 2.3. Comparative Studies

Recent years have seen a rise in case study research on shrinking cities. However, comparative cross-national analyses remain scarce, even though they reveal how local and national planning frameworks shape similar dynamics (Großmann et al., 2013). Großmann et al. (2013) argue that a comparative approach “provides an opportunity to broaden attention and discover overlooked phenomena and drivers in shrinking cities” (p. 222). Comparing Germany and Poland is particularly valuable, as both face shrinkage in MSCs but differ in policy traditions.

Although numerous studies compare shrinking cities in Germany and Poland, contributing valuable insights on specific case cities (Rink et al., 2014) or regions (Al-Alawi et al., 2022; Sroka et al., 2025), a longitudinal, empirical, comparative study covering entire urban networks is still missing. Moreover, studies examining urbanisation trends across entire urban networks tend to focus exclusively on demographics (ESPON, 2023). This study therefore examines the relationship between urban form and shrinkage using a composite score that incorporates socio-economic and demographic aspects relative to national statistics.

### 2.4. Research Concept

German programmes such as Stadtumbau Ost and Internationale Bauausstellung Saxony-Anhalt 2010 demonstrate the potential of compact-city strategies in managing shrinkage. Building on these experiences, this study analyses whether compact, densely populated MSCs, in Germany and Poland, exhibit similar resilience to shrinkage than more dispersed ones. It covers 814 cities, measuring compactness and shrinkage/growth dynamics over 15 years using a composite score (Milbert, 2020) and spatial metrics calculated in QGIS. Pearson’s correlation is used to test the relationship between compactness and shrinkage, addressing two key questions:

- Do MSCs in Poland and Germany show the same relationship between the compactness measures and urban growth and shrinkage?
- How does this relationship change over time?

## 3. Data and Methods

This section outlines the data sources and methodological approach used to investigate the relationship between urban form measures of compactness and the degree of urban growth and shrinkage in MSCs in Germany and Poland.

### 3.1. Input Data on Urban Shrinkage

The study uses existing composite shrinkage and growth scores ( $S_c$ ) for cities based on six indicators, as developed by Milbert (2015, 2020). In short, each of the six socio-economic indicators (see Table 1 in the Supplementary File) is assigned a point value, resulting in a composite score (0–24). Cities are classified, based on the score, as shrinking (0–10), stagnating (11–13), or growing (14–24). For Germany, data were drawn from assessments by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (2021), covering three five-year periods: 2003–2008, 2008–2013, and 2013–2018 (Bukowski

& Szymczyk, 2025c). For Poland, assessments were also divided into three five-year periods: 2006–2011, 2011–2016, and 2016–2021 (Bukowski & Szymczyk, 2024).

For this research, only MSCs, defined by Polish and German national statistics as 20,000–100,000 inhabitants, were considered. Data at the municipality level (*Gemeinde* in Germany, *Gmina* in Poland) serve as the unit of analysis. In total, 814 medium-sized urban municipalities were analysed. These include 634 MSCs in Germany and 180 in Poland (184 MSCs in the period 2011–2016).

It should be noted that in Poland, municipalities are classified as “urban,” “urban-rural,” and “rural.” While cities (*miasto* in Polish) can belong to both “urban” and “urban-rural” municipalities, the latter often cover areas with multiple small settlements and villages. While the calculations were conducted for both municipal types, only “urban” municipalities were considered for the correlation stage. This is because the 33 “urban-rural” municipalities were not comparable to German medium-sized urban municipalities from an urban form perspective.

### 3.2. Input Data on Urban Form

The spatial study relies on widely available land-use data to analyse urban form metrics. The dataset is sourced from CORINE Land Cover (CLC). CLC data are a key resource for understanding land use and landscape dynamics from a European perspective. They represent the only consistent and harmonised multinational collection of land-use information at a continental scale. CLC uses a standardised methodology to produce comprehensive continent-wide land cover data based on 44 land classes. The product, updated every six years, has a minimum mapping unit (MMU) of 25 hectares (ha) for aerial phenomena and a minimum width of 100 m for linear phenomena. This study employs the latest datasets from 2006, 2012, and 2018. However, it should be acknowledged that the 2006 dataset differs—within the accepted margin of variation—from those of 2012 and 2018 (CLC, 2025). This variation is due to improvements in data quality, methodology, and the integration of revised datasets.

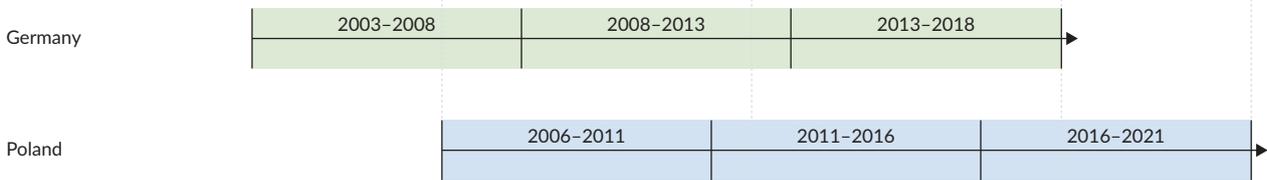
Spatial data on administrative boundaries were retrieved from national geospatial registries. For Poland, boundary data were obtained from the National Register of Geographical Names (2025) and converted to datasets (Bukowski & Szymczyk, 2025b), and for Germany, from the Geodata Centre of the Federal Agency for Cartography and Geodesy (2025) and converted to datasets (Bukowski & Szymczyk, 2025a). Each municipality was linked to the corresponding dataset via a unique identifier.

### 3.3. Research Timeframe

The timeframe of this research is determined by data availability. Since both the spatial data and composite score periods must be aligned, the timeframes for Poland and Germany differ. Figure 3 illustrates how the periods of various datasets align.

Three five-year periods of multicriteria indicator analysis of urban growth and shrinkage.

Outcome: **composite score (Sc) for every city**



Three datasets for spatial analysis using Corine Land Rover (CLC).

Outcome: **numeric compactness measures for every city**

- Compactness index (Ci)
- Urban population density (Pd)



**Figure 3.** Research timeframe aligning Sc and compactness analysis based on the available Corine Land Cover (2025) database. Source: Authors.

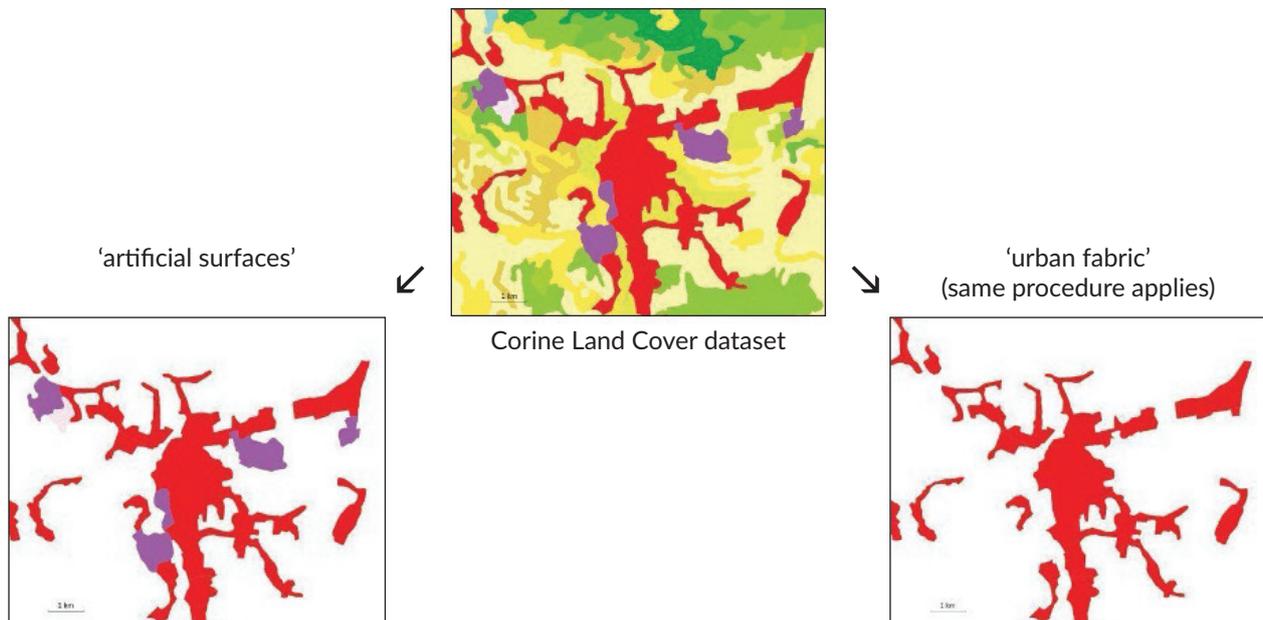
### 3.4. Compactness Measures

Urban compactness is commonly seen as the opposite of urban sprawl, which is associated with significant social and environmental costs (Squires, 2002; Tsai, 2005). Though the term “compact city” has various definitions, it generally refers to dense, mixed-use development with good public transport and access to services and jobs (OECD, 2012). Originating with Dantzig and Saaty (1973) as a model for efficient resource use, the concept has evolved to encompass economic, morphological, and functional dimensions—measured through indicators such as population or employment density, land-use mix, and urban boundaries (Ahlfeldt & Pietrostefani, 2017). A methods review was conducted in a study on compactness measures by Szymczyk and Bukowski (2025). This resulted in Szymczyk and Bukowski (2025) selecting two commonly used measures: urban population density (Pd) and the urban areas’ shape compactness index (Ci). Considering the aim and scope of this study, the available data, and the prerequisites mentioned above, these two measures are employed to describe the compactness of MSCs’ urban areas in this study.

Pd is calculated using the urban area ( $A_D$ ) calculated based on CLC layers and the municipality population (Pop) in the corresponding year, using the formula:

$$Pd = \frac{Pop}{A_D}$$

Compared to the simplified Pd reported by Statistics Poland (Central Statistical Office, 2025), this method excludes agricultural land, forests, water bodies, and other non-urban uses, providing a more accurate picture of Pd. Urban areas were defined in two ways: “artificial surfaces” (11 CLC layers) and “urban fabric” (2 CLC layers; see Figure 4), to ensure that both approaches allow for control of potential errors related to urban form definition.



**Figure 4.** Compactness analysis based on the CLC dataset selects urban areas as “artificial surfaces” and as “urban fabric” for comparison. Source: Szymczyk et al. (2025).

$C_i$  measures how irregular or dispersed the shape of an urban area is. As described by Reis et al. (2016), it helps determine whether a city is more continuous and concentrated or more fragmented and scattered. In general, an area is considered more compact if it is centred around a core, resembling a circle, with less scattered development.

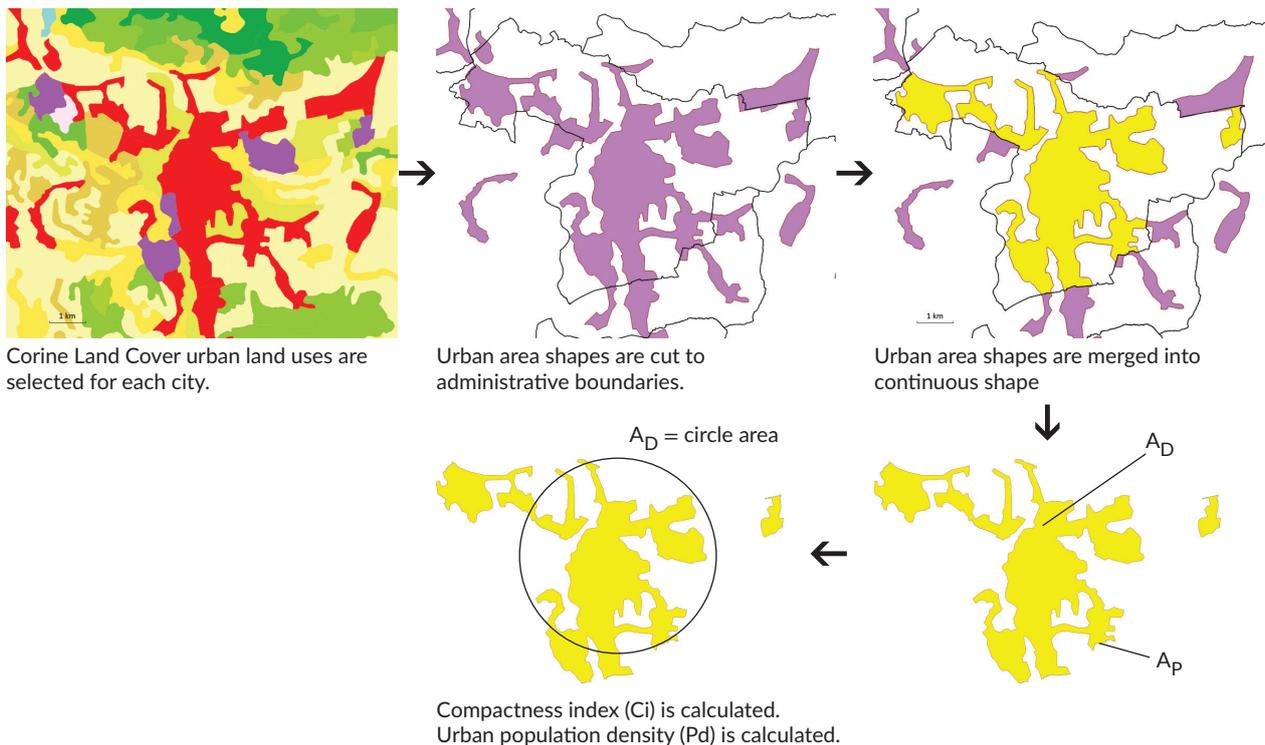
While there are many ways to calculate compactness (e.g., Altman, 1998; Chambers & Miller, 2010; Niemi et al., 1990), this study focuses on one commonly used method: the Schwartzberg Index (Schwartzberg, 1966). This index, like the similar Polsby–Popper Index (Polsby & Popper, 1991), compares the shape of an urban area to a circle, which is considered the ideal compact form. The Schwartzberg Index ( $C_i$ ) compares the perimeter of an urban area ( $A_p$ ) to the circumference of a circle with the same area ( $A_D$ ), with a circle representing the most compact shape. To ensure  $C_i$  is comparable with other methods (e.g., Polsby–Popper Index), the formula was inverted, resulting in values from the range 0–1:

$$C_i = \frac{1}{\frac{A_p}{2\pi\sqrt{A_D/\pi}}}$$

This formula was simplified to:

$$C_i = \frac{2\pi\sqrt{A_D/\pi}}{A_p}$$

This inverted version is used throughout the remainder of the manuscript. Figure 5 illustrates the step-by-step methodology for defining urban area shapes and calculating the two compactness measures (for a more detailed explanation, see Szymczyk et al., 2024).



**Figure 5.** Urban form measures analysis diagram based on the Jasto urban municipality example. Source: Szymczyk et al. (2024).

### 3.5. Correlation

A correlation analysis was conducted between  $S_c$  (range 0–24) and  $C_i$  (range 0–1), and separately between  $S_c$  and  $P_d$ , using Pearson’s correlation. The Pearson correlation coefficient ( $r$ ) was used to assess the relationship between these variables. The coefficient, calculated from the normalised values of two variables across a sample of  $n$  values, ranges from +1 (maximum positive correlation) to –1 (maximum negative correlation), with values near 0 indicating no correlation. While Pearson’s correlation traditionally assumes normally distributed data, it is generally robust to modest departures from normality, including slight skewness, particularly in the absence of strong outliers. Classic simulation studies (e.g., Havlicek & Peterson, 1976) have shown that the sampling distribution and Type I error rate of  $r$  remain reliable under non-extreme non-normality. More recent reviews (e.g., Schober et al., 2018) support this, noting that serious distortions in results typically arise only with severe skewness or heavy-tailed distributions. Given that the distribution of the  $S_c$ ,  $C_i$ , and  $P_d$  dataset exhibits only mild skewness, the use of Pearson’s correlation is considered appropriate. Statistical significance was assessed using the  $p$ -value, with correlations considered significant at  $p < 0.05$ . This threshold guided the interpretation of the research questions. Correlation analyses were conducted separately for urban areas defined as “artificial surface” and “urban fabric” to account for potential discrepancies in urban form delineation. In addition to the Pearson correlation analysis, a non-parametric Spearman’s rank correlation was applied to verify the robustness of the results.

### 3.6. Tools

This research was conducted using the open-source QGIS program for spatial analysis and data visualisation. Data harmonisation and management were handled with the Python language and Pandas libraries. All resulting datasets and outputs were published in open-access data repositories (Bukowski & Szymczyk, 2024, 2025a, 2025b, 2025c).

## 4. Results

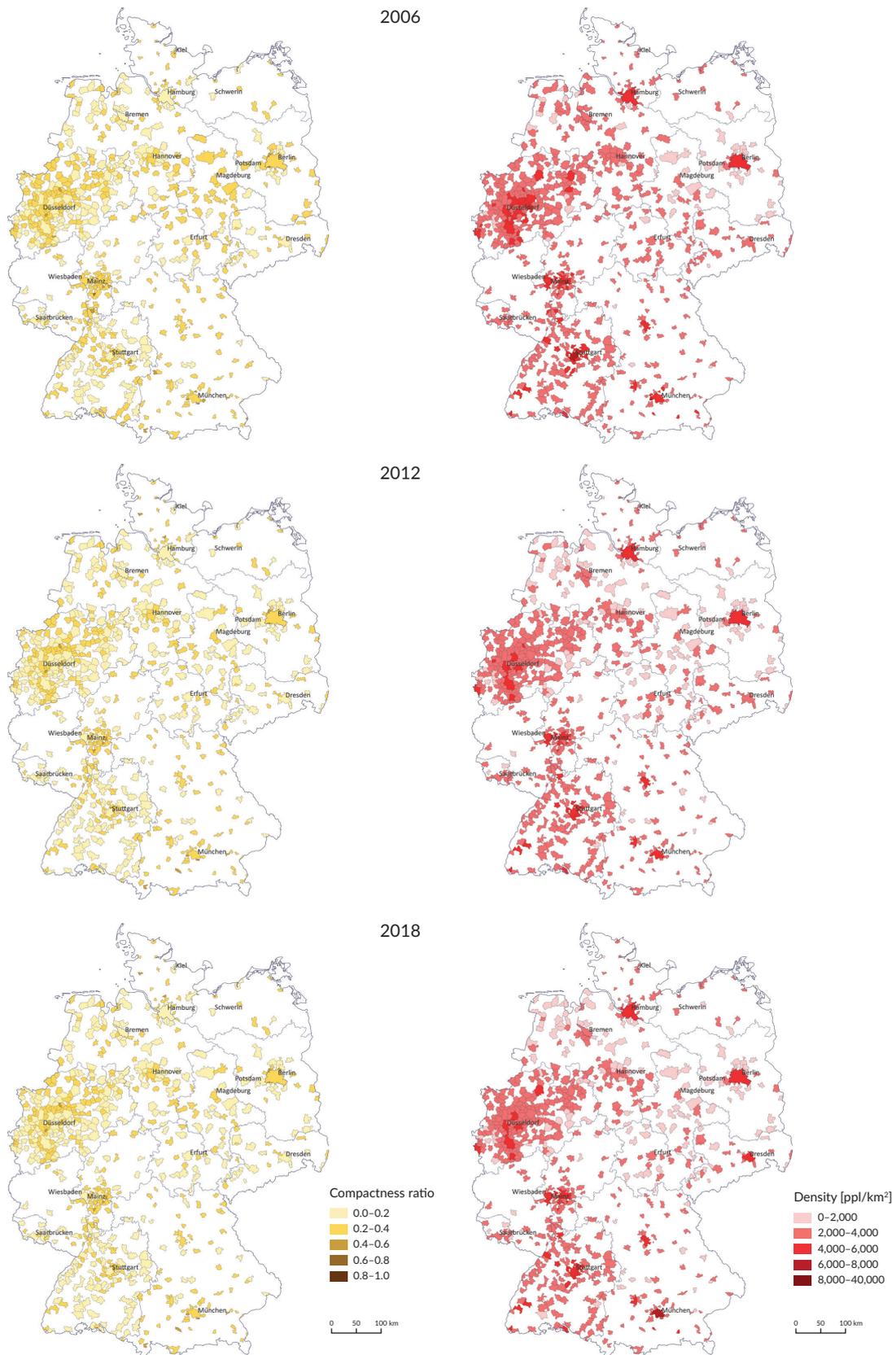
The results are presented in two stages. The first stage (Section 4.1) reports the outcomes of the spatial compactness measures— $C_i$  and  $P_d$ —separately for each country. The second stage (Section 4.2) presents correlation analyses between these variables and  $S_c$ , also disaggregated by country and compared.

### 4.1. Urban Compactness Measures

#### 4.1.1. Germany

The urban compactness analysis for MSCs in Germany displays relatively consistent patterns across the three periods (Table 2 in the Supplementary File and Figure 6). The Schwartzberg  $C_i$  is expressed in numbers ranging from 0 to 1, with 1 being the most compact. It shows a close to normal distribution across all years. While the maximum values for  $C_i$  decreased over time, the maximum values for  $P_d$  increased. The minimum values of  $C_i$  also declined, while those for  $P_d$  increased in 2012 and 2018. The medians of both measures indicate a slight increase in spatial dispersion among MSCs. Among the most compact and dense cities across the analysed timeframes were Germering, Griesheim, Bad Soden am Taunus, and Obertshausen, each consistently ranking in the top 10 in all analysed periods.

The results, presented in Figure 6, show MSCs alongside large cities (>100,000 inhabitants) to support comparative interpretation. As expected, the  $P_d$  of large cities is generally higher than that of MSCs. At the same time,  $C_i$  values vary, with many MSCs exhibiting higher compactness than their larger counterparts.



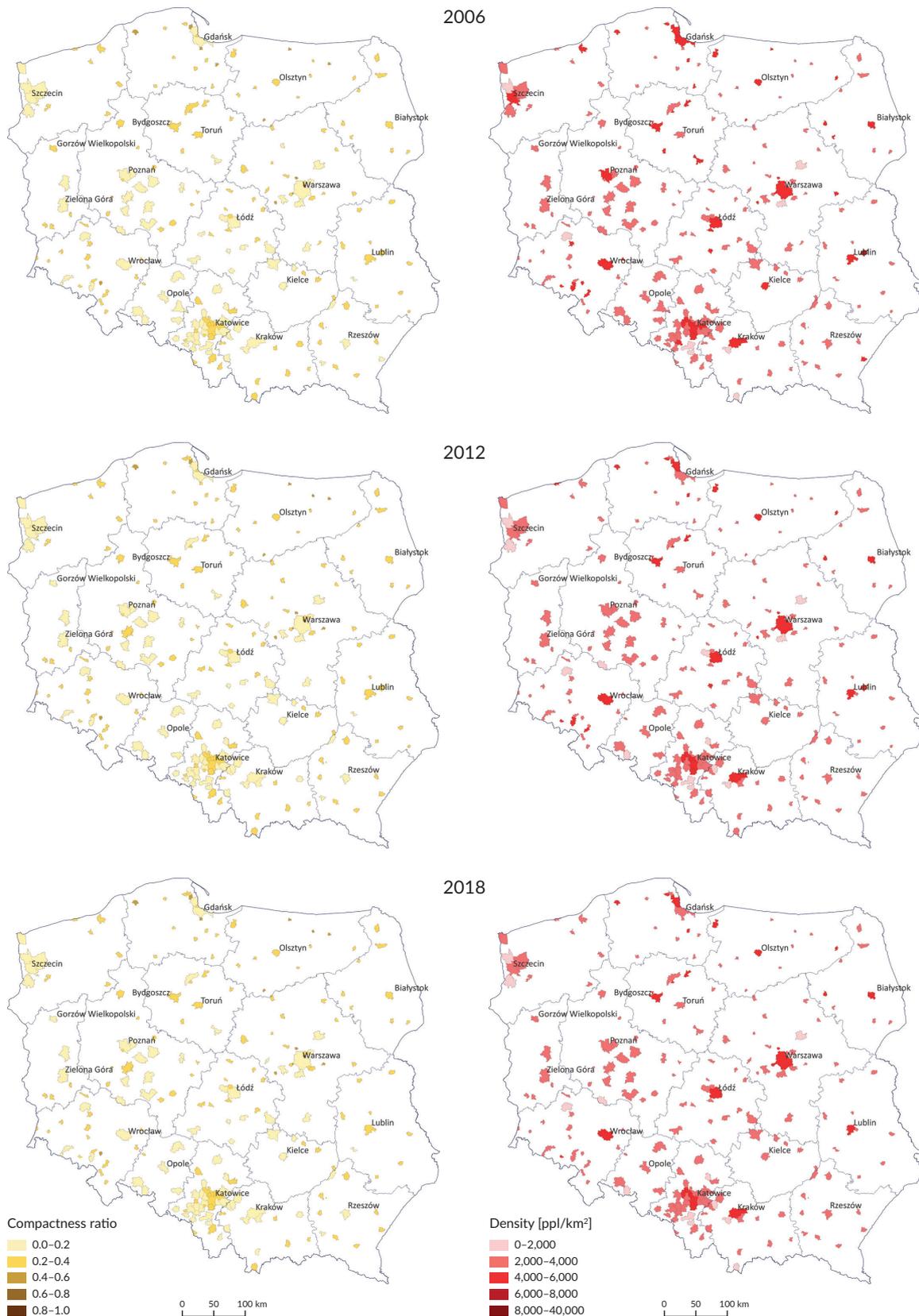
**Figure 6.** Ci (left) and Pd (right) results for German large (>100,000 inhabitants) and MSCs (20,000–100,000 inhabitants). Source: Authors' calculation based on Corine Land Cover (2025).

#### 4.1.2. Poland

The results of the urban compactness analysis for MSCs in Poland show broadly similar patterns to those observed in Germany across the three analysed periods (see Table 3 in the Supplementary File and Figure 7). Both the minimum and maximum values for Ci and Pd declined over time. The average Ci was 0.22 in Germany and 0.21 in Poland. Average Pd values were 3,414 people per km<sup>2</sup> in Germany and 2,343 people per km<sup>2</sup> in Poland. While the median values for Poland were initially higher, they declined more steeply, indicating a stronger trend toward spatial dispersion in Polish MSCs. Among the most compact cities throughout the analysed timeframes were Ząbki, Piastów, Żyrardów, Legionowo, Słupsk, Giżycko, Świdnica, and Rumia—consistently holding top 10 positions across all periods. The least compact cities included Wyszaków, Świebodzin, Opoczno, Jastrzębie-Zdrój, and Pszczyna.

The results, presented in Figure 7, show, similar to Germany, that the density of large cities is higher than that of MSCs. At the same time, Ci is typically higher for MSCs than for the large ones.

In summary, the outcomes of compactness analysis, measured by Ci and Pd, reveal broadly similar spatial dispersion trends. While Polish MSCs are, on average, more compact and dense than German MSCs, they are experiencing a more rapid decline in density over time. The next section presents the outcomes of the correlation analysis between these urban form indicators and urban growth and shrinkage dynamics.



**Figure 7.** Ci (left) and Pd (right) results for Polish large (>100,000 inhabitants) and MSCs (20,000–100,000 inhabitants). Source: Authors' calculation based on Corine Land Cover (2025).

## 4.2. Relationship Between Compactness Measures and Sc

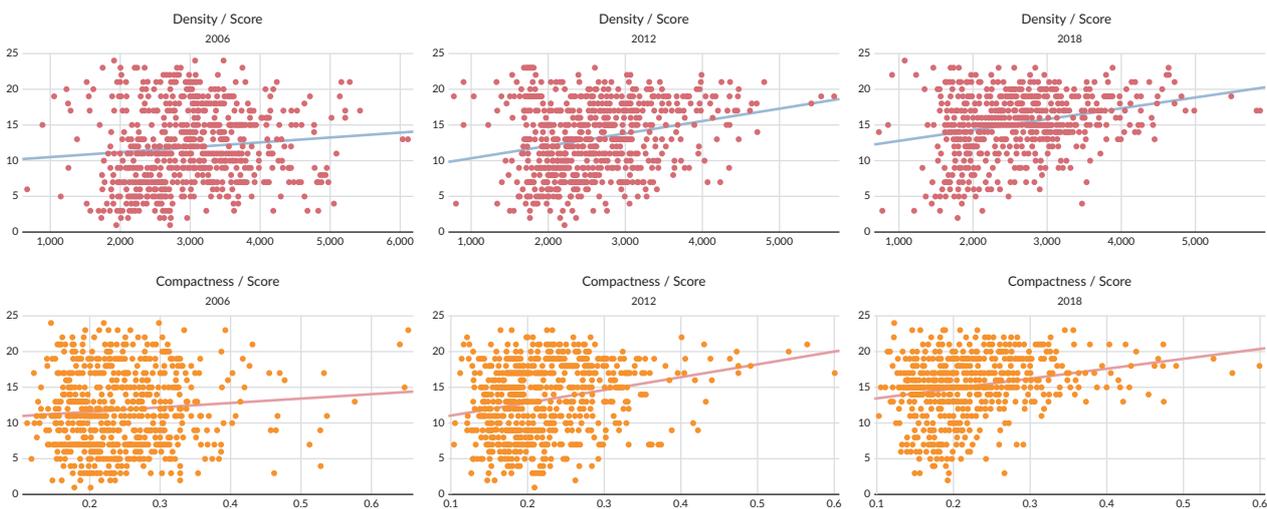
This section presents the results of Pearson’s correlation analysis between Sc and spatial indicators (Ci and Pd) in Germany and Poland. In the case of Poland, the analysis was further disaggregated to distinguish between “urban” and “urban-rural” municipalities. This differentiation was necessary because “urban-rural” municipalities encompass not only the central town but also surrounding villages and dispersed settlements, which significantly alter the characteristics of the urban form. To ensure comparability with German MSCs, which are strictly urban in administrative classification, only urban municipalities in Poland were included in the final correlation analysis.

### 4.2.1. Germany

Correlation was analysed across three time periods for both Germany and Poland. The relationship with the shrinkage score is presented in Figure 8 and in two tables: Table 4 for Ci and Table 5 for Pd (both are found in the Supplementary File), including divisions into “urban fabric” and “artificial surfaces.”

The results reveal a significant and positive correlation coefficient ( $r$ ) between Sc and Ci across all analysed periods. This indicates that cities with more compact urban forms, whether measured by “urban fabric” or “artificial surfaces,” are less likely to experience shrinkage. The strength of this relationship increases over time, with correlation coefficients reaching positive, moderate levels in the later periods.

The correlation reveals a significant, positive coefficient between Sc and Pd across almost all analysed periods except for the first one for “urban fabric.” This, in other words, indicates that the denser the urban area, the less likely the city is to shrink. The trend becomes stronger over time, showing positive, moderate/strong values.



**Figure 8.** Scatter plots of Sc and urban compactness measures: Pd on top and Ci on the bottom, for MSCs (only urban municipalities) in Germany. Source: Authors.

In addition to Pearson’s correlation analysis, a non-parametric Spearman’s rank correlation was applied to the full dataset to verify the robustness of the results. Spearman’s test was selected because it does not assume linear relationships or normally distributed data, which is particularly relevant when working with

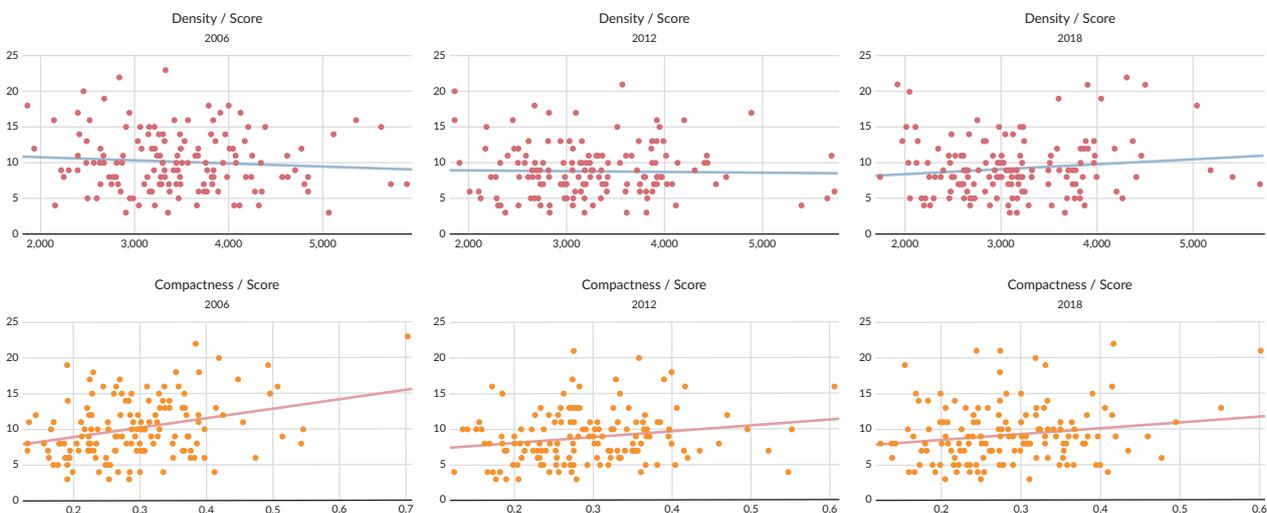
spatial indicators such as Ci and Pd. The results of both correlation methods were consistent, confirming both the direction and statistical significance of the observed associations.

#### 4.2.2. Poland

The results of the correlation analysis for Polish cities are presented in Figure 9 and in two tables: Table 6 shows the relationship between Sc and Ci, while Table 7 presents the correlation between Sc and Pd (both tables are in the Supplementary File). As with the German dataset, both tables distinguish between urban form defined as “urban fabric” and “artificial surfaces.”

The results reveal a significant and positive correlation between Sc and Ci across all analysed periods. This indicates that the more compact the shape of an urban area—whether defined by “urban fabric” or “artificial surfaces”—the less likely it is to experience shrinkage. However, in contrast to Germany, where the strength of the correlation increased over time, the trend in Poland weakened: Initially strong coefficients declined to a moderate level in the later periods.

The results show only one significant, negative correlation between Sc and Pd. The later periods show no statistical significance. This, in other words, indicates that temporarily, between 2006 and 2011, more dense urban areas (only “urban fabric”) were more likely to experience shrinkage. In contrast to Germany, there is no clear trend, as the coefficient is low, and later results show no statistical significance.



**Figure 9.** Scatter plots of Sc and urban compactness measures: Pd on top and Ci on the bottom, for MSCs (only urban municipalities) in Poland. Source: Authors.

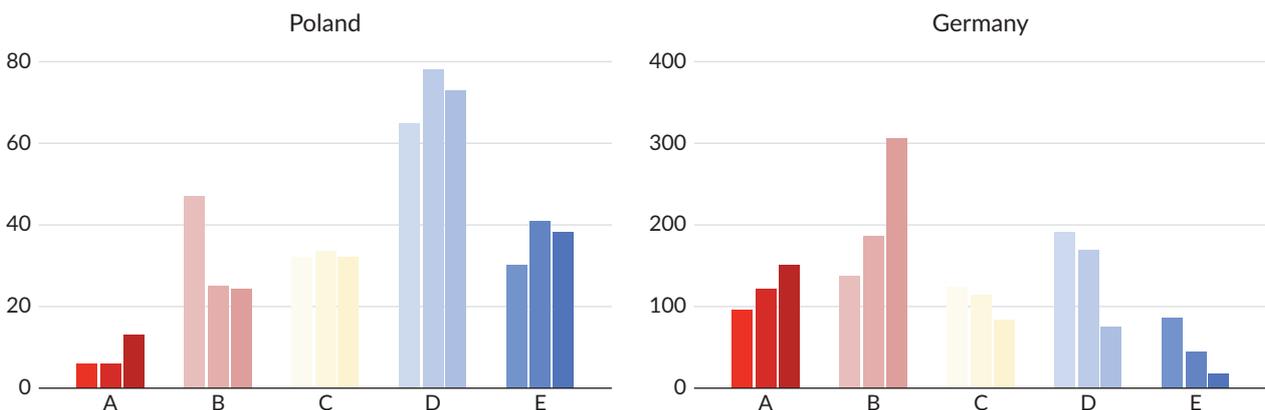
## 5. Discussion of Results

Urban shrinkage is increasingly challenging the stability of broader settlement systems worldwide. Understanding its relationship with urban form is essential for developing planning strategies that move beyond growth-centric paradigms (Reis et al., 2016). While most existing research focuses on large metropolitan areas, MSCs (20,000–100,000 inhabitants) remain understudied, despite their critical role in regional networks (Gajewski & Knippschild, 2024; Gao et al., 2024; Terfrüchte & Growe, 2024). This study

addresses this gap by examining how compactness and Pd relate to growth and shrinkage patterns in German and Polish MSCs.

### 5.1. Relationship Between Urban Shrinkage and Compactness Among MSCs

Analysis of urban shrinkage indicates that MSCs were among the most affected groups during the analysed periods. However, the trajectories and patterns of shrinkage diverged considerably between the two countries. Figure 10 illustrates the classification of MSCs across three time periods, using five categories: A—above-average growth, B—growth, C—stability, D—shrinkage, E—above-average shrinkage. In Germany, the shrinkage strongly affects Eastern cities, but Sc values show that the average MSC score lies closer to the growth range. In Poland, shrinkage is more widespread across different areas of the country, and the mean score is positioned nearer to the shrinking range. Moreover, in the German context, shrinkage was most pronounced in the early 2000s, followed by a gradual reversal towards growth after 2010. By contrast, in Poland, the early 2000s saw shrinkage primarily concentrated in large cities, with the phenomenon subsequently shifting towards MSCs. Consequently, the share of growing MSCs is substantially higher in Germany than in Poland. This divergence is less prominent in the outcomes of the compactness analysis.



**Figure 10.** Changes in the numbers of MSCs included in each group in the three five-year periods in Poland (left) and Germany (right). Groups show the following types: A—above-average growth, B—growth, C—stability, D—shrinkage, E—above-average shrinkage. Source: Authors.

Both Pd values and Ci underscore a persistent trend of dispersion across the analysed urban municipalities in both countries. These findings confirm those of Cortinovis et al. (2022), thereby adding to the discourse on urban dispersion in European cities. Notably, the median values of both Ci and Pd are higher in Poland; however, the maximum values are greater in Germany. Especially in the first analysed period, the maximum Ci was 0.65 in Germany. In the last analysed period, the maximum Pd was over 6,100 people per km<sup>2</sup>. Several cities exemplify high scores, compactness, and density, often situated in the southwestern regions. For example, Griesheim, located near Darmstadt (see Figure 11 in the Supplementary File), was experiencing a high population and migration increase in relation to other cities in the country. It remained dense and compact, which is reflected in the diagram showing how the shape of the city fits in the circle with the same area size.

In Poland, the median values of both Ci and Pd were higher than in German MSCs, although numbers have been dropping rapidly. In the most recent analysed period, the maximum Ci was 0.51, and Pd reached only

4,500 people per km<sup>2</sup>. Compared to Germany, Polish MSCs tend to be more compact overall, but there are fewer exceptionally dense and compact examples. Moreover, cities with high compactness and density—such as Gniezno, Koło, or Słupsk—are often located away from major urban centres. Their compactness can be attributed to historical patterns of growth rather than recent planning policies. Słupsk (see Figure 12 in the Supplementary File), for instance, is a compact and dense MSC that has recently experienced low population growth and low migration figures. Despite this, it continues to perform well economically, with low unemployment and moderate levels of own revenue.

## 5.2. Correlation Results

The correlation analysis reveals two distinct yet complementary trajectories between Germany and Poland in the relationship between urban form and shrinkage dynamics. In Germany, both compactness (Ci) and population density (Pd) exhibit weak to moderate but statistically significant positive associations with urban growth, which strengthen over time—from  $r = 0.15$  between 2003 and 2008 to  $r = 0.28$  between 2008 and 2013 and  $r = 0.26$  between 2013 and 2018. This indicates that, as shrinkage pressures declined, more compact and dense urban forms tended to coincide with less shrinkage. In Poland, by contrast, correlations show an opposite trend: Shrinkage increased overall while compactness declined. The initially strong association between compactness and growth ( $r = 0.34$ ,  $p < 0.001$  for 2006–2011) weakened over time, falling to  $r = 0.22$  ( $p = 0.005$ ) by 2016–2021. The relationship between Pd and growth was weak or negative in Poland, particularly in the early period, suggesting that higher urban population density alone did not translate into shrinkage resilience.

The distributions (Figures 8 and 9) indicate a more heterogeneous urban form spectrum in Germany, with a sizable core of mid-density/compact cities and a distinct tail of very dense, highly compact outliers that increasingly coincide with higher scores. Polish MSCs are more homogeneously clustered in mid-compactness and mid-density, with fewer extremes and a weaker, less stable urban form–shrinkage link. In both contexts, compactness is positively associated with Sc, but Germany’s wider upper tail (very compact/dense cases) and the strengthening slopes over time suggest a clearer emergence of compact-dense growing MSCs, whereas Poland’s narrower range and fading slopes point to limited separation by form and a stronger role of other (e.g., institutional or temporal socio-economic) factors.

Germany’s long-established compact settlement structure and consistent urban policies (e.g., Stadtumbau Ost, Internationale Bauausstellung Saxony-Anhalt) supported compactness, whereas Poland’s post-socialist transformations might have led to periods of unregulated expansion and likely contributed to morphological dispersion. Overall, the results point to a context-dependent but consistent pattern: Urban compactness is associated with less shrinkage in both countries, although its stabilising effect appears more persistent in Germany. It’s important to note that these differences should be interpreted as indicative rather than causal, reflecting broader structural and planning contrasts between the two contexts. While the analysis shows that more compact or dense cities are less likely to experience shrinkage, particularly in the German case, the directionality of this relationship remains open to interpretation. It is equally plausible that cities experiencing less shrinkage maintain their density, rather than density being a protective factor against shrinkage. Furthermore, as urban boundaries typically remain fixed, a shrinking population may naturally lead to declining density, even without spatial expansion. This highlights the need for further research and caution when interpreting spatial form as a driver rather than a consequence of urban shrinkage and underlines the importance of future longitudinal and causal studies to better understand these dynamics.

### 5.3. Policy Implications

In Germany, the trend of urban shrinkage of MSCs is much less prominent than in the early 2000s. However, given demographic projections (fertility rates and an ageing society), planning efforts should persist in promoting compact and dense cities to avoid the increasing costs of extensive land use. In Poland, both measures of urban compactness decline significantly, alongside rising rates of urban shrinkage. Consequently, Polish MSCs continue to face urban dispersion, which, as noted in both the statistical findings and literature (Carruthers & Ulfarsson, 2003; Miyauchi & Setoguchi, 2023), can lead to increased infrastructure cost. Therefore, Polish MSCs could focus on maintaining their urban form compactness by reusing existing infrastructure and consolidating or reinvesting in urban brownfields, which could strengthen fiscal resilience in shrinking cities. Moreover, state planning could support MSCs in finding sustainable development paths without urban growth.

### 5.4. Research Limitations

While compactness (Ci) in Polish urban municipalities shows a positive relationship with urban growth, density (Pd) demonstrates no significant correlation or, in some cases, a weak negative one. This divergence highlights that compactness and density are not synonymous, supporting the literature that warns against using density as the only indicator of compact urban form (Ahlfeldt & Pietrostefani, 2017). In this study, compactness was measured using only two indicators, which may not fully reflect the complexity of the concept. Important aspects such as proximity to services, efficient mobility networks (especially public transport and cycling), urban morphology (building types), and connectivity of public spaces are also vital for understanding urban compactness. However, due to the scope and methodological limitations of this research, including these additional variables was not possible.

### 5.5. Future Research

This study adds to the growing literature on the relationship between urban form and socio-economic dynamics. While much of the existing research on the link between compactness and urban shrinkage has been conducted in the Chinese context (Wang et al., 2022), this study presents evidence that compactness is also statistically linked to patterns of urban shrinkage and growth in Europe. Future research could build on these findings to support data-driven planning strategies. In particular, studies could explore different planning contexts and additional variables to define urban compactness more comprehensively. Additionally, research could help identify spatial characteristics relevant to compact city planning. Further investigation is also necessary to better connect these spatial attributes with effective planning policies and strategies.

## 6. Conclusions

This study examined the relationship between urban form and urban shrinkage in MSCs in Germany and Poland over a 15-year period, addressing a gap in comparative research on spatial resilience. The results confirm that compactness and density relate differently to composite shrinkage score in each country. While the findings suggest that compactness (Ci and Pd) is associated with greater resilience to shrinkage, the direction of causality remains ambiguous and may be context dependent. Shrinking cities may become less dense as a result of depopulation, not necessarily the other way around.

In Germany, higher urban compactness (Ci) and population density (Pd) are consistently negatively correlated with urban shrinkage. In Poland, MSCs show a statistically significant but weakening relationship between compactness and shrinkage. Pd was not a stable predictor of shrinkage, possibly reflecting other factors influencing this phenomenon. While urbanisation trends in the two countries appear to be temporally displaced, with Germany experiencing significant shrinkage in the early 2000s and Poland only entering this phase around 2010, there are also notable differences in the distribution of urban compactness measures between German and Polish MSCs. In Germany, the distributions reflect a more heterogeneous spectrum, characterised by a considerable core of mid-density/compact cities and a distinct tail of very dense, highly compact outliers, which increasingly align with higher scores. Conversely, Polish MSCs tend to cluster more homogeneously in the mid-compactness and mid-density range, featuring fewer extremes.

As seen in international cases such as China (Wang et al., 2022), lower compactness is often associated with reduced land-use efficiency and a higher likelihood of urban shrinkage. However, longitudinal research on this relationship has rarely been conducted at a national comparative scale. While compact and dense urban forms are often promoted as a means to limit the external land-use impacts of sprawl, many environmental costs of land consumption remain difficult to internalise. Instead, the resilience benefits of compactness are more clearly observed in endogenous factors, lower infrastructure maintenance costs, more efficient service provision, and reduced per-capita expenditure on utilities and transport. Overall, compactness contributes to spatial and fiscal resilience, but its effectiveness ultimately depends on governance capacity and integrated planning approaches. Thus, future research should continue to explore how planning policies and spatial strategies can guide MSCs in proactively managing shrinkage, enabling them to adapt to demographic change while maintaining functional and spatial cohesion.

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### Conflict of Interests

The authors declare no conflict of interests.

### Data Availability

The data used and created for this research were made available via a public repository. The following data were used: Bukowski and Szymczyk (2024, 2025a, 2025b, 2025c).

### Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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