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Centrality Index Revealing the Central and Hidden Places in Mazowieckie Voivodeship

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ABSTRACT

Objective: This article aims to calculate a centrality index for Mazowieckie voivodeship using an empirical application of Christaller's central place theory.

Research Design & Methods: We calculate the value of a centrality index for 89 cities in Mazowieckie voivodeship using data for 32 central activities (independent variables). The proposed centrality index (synthetic indicator based on a non-model method) can be used to identify cities that are important for regional development. The population-adjusted centrality index shows which cities overperform, or underperform, compared to their size; the scores are useful for the identification of the hidden centres of urban activity.

Findings: The analysis identifies three types of cities that are of interest in light of the central place theory: 16 central places (centrality index ≥ 3), 27 hidden places (population-adjusted centrality index ≥ 2), and three hidden central places (classified as both central places and hidden

places). The regional supremacy of Warsaw is visible in its perfect centrality index score; other central places include Radom and Płock. On the other hand, hidden places are exemplified by Lipsko, Przysucha, and Podkowa Leśna. Wołomin, Grodzisk Mazowiecki, and Wyszków are classified as the three hidden central places of the Mazowieckie voivodeship.

Implications/Recommendations: Hidden central places can be crucial for the future growth of the region. The dominant role of Warsaw is not going to be challenged, but, with sufficient support, the hidden central places could disperse geographically some of the essential functions in a more sustainable, inclusive, and accessible way.

Contribution: The research contributes to the understanding of the regional development of Mazovia and the practical applications of the central place theory. The devised method can be used in the analysis of different regions.

Article type: original article.

Keywords: centrality index, central place theory, cities, Mazovia, Poland.

JEL Classification: R10, R12, R58, O18.

1. Introduction

Walter Christaller introduced the central place theory in the 1930s (Christaller, 1933, 1966). Its core concept lies in the idea that a large city will form functional ties with other smaller cities in its vicinity, thus limiting the need to replicate said functions in those smaller cities. Originally based on the data and urban areas of Southern Germany, the theory underscores the importance of cities as hubs of regional development. The framework of such analysis delves into the role played by influential central places, the functional hierarchies of large and small cities, and ties between centres and their surrounding areas.

Centrality refers to the significance of a city or location within a regional or national system, typically characterised by its ability to provide goods and services to surrounding areas. The concept originates from Christaller's theory, which posits that settlements function as "central places" offering specialised services to a dispersed population. Centrality is measured by the city's capacity to attract flows of people, goods, and services, establishing its role as a hub within a hierarchical urban network. Accordingly, higher-order central places provide a wider range of goods and services than lower-order ones, which tend to serve smaller, more localised populations.

This article aims to calculate a centrality index for 89 cities in the Mazowieckie voivodeship using an empirical application of central place theory. The study seeks to classify the cities into central places, hidden places, and hidden central places, contributing to a better understanding of regional development dynamics and providing insights for informed policymaking. To achieve this objective, we propose

three research questions: [RQ1] Which cities in Mazowieckie voivodeship can be classified as central places, hidden places, or hidden central places? [RQ2] How can a centrality index be applied in regional policymaking? [RQ3] Is Christaller's central place theory still relevant for the regional development of modern Poland?

Mazowieckie voivodeship, which includes the Capital City of Warsaw, is a region of Poland characterised by rapid economic growth, uneven level of economic development, and a strong monocentric structure (Napiórkowski & Radło, 2022; Radło & Szczech-Pietkiewicz, 2022; Szczech-Pietkiewicz, Radło & Tomeczek, 2022). For this study, we define a city as a settlement with Poland's official administrative designation of a city, regardless of its population. As such, to complement the existing central place theory we omit the classical division of cities/towns/hamlets, and instead, we introduce the concepts of hidden places and hidden central places. The initial results of the model were published as a part of a monograph (Szczech-Pietkiewicz, Radło & Tomeczek, 2022). This article extends that analysis by providing an expanded literature review, detailed methodology (e.g., procedure steps), results (e.g., categories scores), and interpretations.

Central places are defined as cities of high importance for their surrounding regions; most of them have a large population. They have a relatively high centrality index value of at least 3. The best example is Warsaw, followed by Radom and Płock.

Hidden places are cities whose centrality is not high enough to be classified as central places, but relative to their population, they serve as important functional centres for their regions. According to the central place theory (Christaller, 1933, 1966), centrality refers to the ability of a city to provide goods and services to surrounding areas, making it a hub within the urban network. In the case of hidden places, although their centrality index does not meet the criteria for central places, their population-adjusted centrality index is high (at least 2), reflecting their hidden yet significant role in the region. Examples of hidden places include Lipsko, Przysucha, and Podkowa Leśna.

To be classified as a hidden central place, a city must combine the characteristics of both central and hidden places. These cities have enough centrality to influence surrounding areas (centrality index ≥ 3) and maintain a relatively small population (population-adjusted centrality index ≥ 2), making them hidden within the urban system. Wołomin, Grodzisk Mazowiecki, and Wyszków are examples of such cities, showcasing the complexity of centrality where functional importance outweighs population size in determining regional significance.

The article comprises five sections, including this introduction. Section 2 reviews the literature on central places and the measurement of centrality. Section 3 details the methodology (synthetic indicator based on a non-model method) and data sources (e.g., Local Data Bank of Statistics Poland). Section 4 explores the results

of the analysis, namely centrality index scores and population-adjusted centrality index scores. Section 5 concludes the study and provides implications of the results.

2. Literature Review

The central place theory originated from the seminal works of Christaller (1966) in the 1930s. There have been numerous explorations and expansions of this theory through the decades. Christaller's contributions have been acknowledged by many influential economic studies such as those by Arthur (1994), Hall (2014), Krugman (1991), and Smith (2008).

Boussauw, van Meeteren and Witlox (2014) look at the central place theory through the lens of the home-school distance data for Belgium. Peredo and Chrisman (2006) show how local community-based enterprises can strengthen growth in poor neighborhoods. Davies (1968) puts forward a concept of central place morphology, where cities and their buildings evolve with the additions of new commercial activities. According to Siddall (1961), the crucial measure of centrality is the employment in wholesale trade, as a city with a high wholesale/retail ratio is engaging in trade with numerous clients from surrounding areas. Nowosielska (1992) provides an extended theoretical overview of Christaller's theory. Castells and Hall (1994) explore the concept of technopoles, local technology centres that serve as engines of growth for high-tech industries and overall economic development. Fleming and Hayuth (1994) look at the combination of traffic in transport networks: passengers for airports and containers for seaports. Naess (2012) reviews the high impact of urban areas on travel. The central place theory incorporates accessibility by organising settlements in a hierarchical and hexagonal pattern, ensuring efficient access to goods and services. The proximity and ease of reaching central places depend on transportation networks, with lower-order centres offering more frequent access to basic services and higher-order centres providing specialised services at greater distances.

A valid criticism of the central place theory is that it only describes reality and does not explore the in-depth causal relationship (Fujita, Krugman & Venables, 1999). Bird (1973) underscores that seaport cities' centrality tends to be underrated in the classical approach. Derudder and Witlox (2004) state that the classic central place theory is unable to adequately model globalisation, which caused a shift from manufacturing and local trade to knowledge creation, services, and international inter-city flows.

A rising trend in urban studies is the use of network analysis to calculate various centralities and identify central places. An early example of this notion is the article by Irwin and Hughes (1992). A study by Neal (2011) shows that the functional networks now dominate the urban landscape of the United States in lieu of the size-

-based hierarchies. Tsiotas and Polyzos (2015) use network analysis to examine the commuting and road transportation networks in Greece, while Gonçalves, Portugal and Nassi (2009) analyse railway networks in Brazil.

There is a growing notion of mid-size and small cities' importance for economic development (Bell & Jayne, 2009; Dijkstra, Garcilazo & McCann, 2013). The previous studies on the topic include those by Jamal (2018) for mid-sized cities in Canada, Audretsch, Belitski and Desai (2015) for various European cities of all sizes, Fahmi *et al*. (2014) for small and mid-sized cities in Indonesia, Véron (2010) for small cities in India, Erickcek and McKinney (2006) for small and mid-sized cities in the United States, Henríquez, Azócar and Romero (2006) for mid-sized cities in Chile, and van Dijk and Mingshun (2005) for mid-sized cities in China. Our article seeks to accentuate the role played by small and mid-sized urban areas by looking at the centrality of cities with various population sizes.

Both centrality and synthetic indicators have an important place in economic literature. Davies (1967) calculates a synthetic centrality index for the area of South Wales around Pontypridd. Berry and Garrison (1958) calculate one for Snohomish County, Washington. Brush's (1953) research encompasses southwestern Wisconsin. Bracey (1953) calculates a service-based centrality index for Somerset. He later expanded his index to other counties of the United Kingdom (Bracey, 1956). Preston (1971) computes a monetary centrality index for the Pacific Northwest region, using the value of sales and services, median income, and consumption. Zhong *et al*. (2017) construct a centrality index based on density (concentration of activities) and diversity (how mixed the activities are) using travel survey data for Singapore. In their overview of creative cities, Lewis and Donald (2010) find that synthetic indicators usually tend to favour big cities over small cities. Mokhtarian (1998) uses a synthetic indicator in the study of how remote work changes travel patterns. Taylor, Hoyler and Verbruggen (2010) extend central place theory to incorporate flows (central flow theory), in which the focus is not on the cities but rather on the business networks connecting them. Capello (2000) shows the positive impact of externalities in cooperative networks of cities. For regions of Poland, Gwosdz (2004), Mularczyk (2014), and Sokołowski (1999) calculate centrality indices for Upper Silesia, Świętokrzyskie voivodeship, and small settlements, respectively. Sokołowski (2006) also made a significant contribution to the study of urban systems in Poland by analysing the functional hierarchy of cities and the structure of their central activities. Additionally, Biderman and Kamiński (1993) examined the role of Poznań in the regional redistribution of population, also contributing to the body of research on the central functions of cities. Further applications of synthetic indicators based on Polish data include capital markets (Dmitruk & Gawinecki, 2017) and demographics (Mastalerz-Kodzis & Pośpiech, 2015).

3. Methodology and Data

Synthetic indicators based on a non-model method are a useful tool for comparing relatively similar objects when their description requires consideration of multiple diagnostic variables. Most commonly, it is achieved through classification. Such indicators are an example of the application of multidimensional comparative analysis. In contrast to the model method, the non-model method construction does not require a comparison with the model. Its simple design makes it possible to compare objects with both stimulant, destimulant, and nominant descriptor variables. This necessitates a process of transformation of variables and unification of their nature in the first place (Panek, 2009, p. 33). A simple formula based on a weighted arithmetic mean can be used in the construction of a synthetic indicator based on a non-model method (Panek, 2009, p. 137). The identified diagnostic variables can have the same or different weights depending on their importance for the description of the object (Panek, 2009, p. 32). Such indicators can be normalised and take values within a certain range, usually from 0 to 1, from 0 to 10, or from 0 to 100.

We calculate the value of a centrality index (C) for 89 cities in Mazowieckie voivodeship [*województwo mazowieckie*] using data for 32 central activities (independent variables). For simplicity, we use the Polish spelling for the names of all the cities other than Warsaw [*Warszawa*]. Our centrality index is a synthetic indicator based on a non-model method. Since every one of the central activities we chose has a positive impact on the centrality score, the following simple Min-Max normalisation has been utilised in the preparation of the data (Kukuła, 1999, pp. 7, 16; Panek, 2009, p. 39; Patro & Sahu, 2015, p. 20):

$$v_{ij} = \frac{x_{ij} - \min\limits_{i} x_{ij}}{\max\limits_{i} x_{ij} - \min\limits_{i} x_{ij}}, \quad \max_{i} x_{ij} \neq \min_{i} x_{ij},$$

where v_{ij} is the normalised variable of central activity j for city i, and x is the original data. Normalisation provides us with variables with a range of values [0, 1]. Every variable is then multiplied by 100, which gives us 32 variables with a range of values between 0 (for the city/cities with the lowest score) and 100 (for the city/cities with the highest score).

Next, we calculate weights for every variable (central activity), which tells us how important they are for the centrality of the cities. The weight for every variable is taken from the following equation (Gwosdz, 2004, p. 18; Mularczyk, 2014, p. 384; Sokołowski, 1999, p. 298):

$$w_j = 100 - \frac{m_j}{m} \cdot 100,$$

where w_j is the weight for variable j, m_j is the number of cities where variable j is higher than 0, m is the total number of analysed cities. The weight of a variable

is directly proportional to its rarity as a central activity (the number of cities where the variable equals 0). Since variables have been Min-Max normalised, the lowest possible weight is 1.12 (when an activity is present in every city but one) and the highest possible weight is 98.88 (when an activity is absent in every city but one).

Finally, the centrality index is calculated using the following equation (Davies, 1967, p. 63; Sokołowski, 1999, p. 298; Gwosdz, 2004, p. 18; Mularczyk, 2014, p. 385):

$$C_i = \frac{\sum_{j=1}^{k}(w_j)}{\sum_{j=1}^{v}(w_j)} \cdot 100,$$

where C_i is the value of the centrality index for city i, w_j is the weight for variable j, k is the number of analysed central activities (variables higher than 0) in a given city, v is the number of all analysed central activities (total variables). After calculating all the weights (Table 2) we can estimate the weighted average for every city. We multiply the 32 normalised variables for a city by the 32 calculated weights, sum up the results, and then divide the sum by the sum of all weights. The result is the centrality index (full results for every city are available in Table A.1 attached in the Appendix). Additionally, we calculate a simple index of the population (Warsaw = 100) to compare the centrality of a city (as measured by our centrality index) to its size. Population-adjusted centrality index is centrality index divided by population index: Values higher than 1 suggest that a city's centrality is higher than its size might suggest, and values lower than 1 suggest the inverse.

The data comes from the most recent available year (mostly from 2018), but for the cases where such data is not available (e.g., it is not updated annually or it is no longer updated for cities), we take older data as long as it is available for every city in that period. Most of the data used in this article, including cities' population, come from Local Data Bank, Statistics Poland (bdl.stat.gov.pl) [*Bank Danych Lokalnych*]; other data sources are as indicated in Table 1.

Table 1. Central Activities (Variables) and Data Sources

Category	Central Activity (Variable)	Source	Description
Public administration	1.1 – police	bip.gov.pl	The number of police headquarters of various levels (e.g., district, national), 2020
	1.2 – courts	bip.gov.pl	The number of courts, excluding courts of appeals and the Supreme Court, 2020
	1.3 – tax and civic registry offices	dane.gov.pl, podatnik.info	The number of tax and civic registry offices, 2020

Table 1 cnt'd

Category	Central Activity (Variable)	Source	Description
Culture and arts	2.1 – museums, theatres, philharmonics, and operas	bdl.stat.gov.pl, baza-firm.com.pl	The number of museums, theatres, philharmonics, and operas, 2018–2020
	2.2 – public libraries and community centres	bdl.stat.gov.pl	The number of public libraries and community centres, 2018
	2.3 – concerts and festivals	bdl.stat.gov.pl	The number of concerts and festivals (mass gatherings), 2019
	2.4 – cinemas	bdl.stat.gov.pl	The number of cinemas, 2018
Healthcare	3.1 – general hospitals	bdl.stat.gov.pl	The number of general hospitals, 2003 (data discontinued for cities)
	3.2 – clinics	bdl.stat.gov.pl	The number of clinics [*przychodnie*], 2018
	3.3 – pharmacies	bdl.stat.gov.pl	The number of pharmacies, 2018
Public interest and education	4.1 – hotels	bdl.stat.gov.pl	The number of hotels (any standard), 2019
	4.2 – sports stadiums	bdl.stat.gov.pl	The number of sports stadiums, 2018
	4.3 – higher education institutions	bdl.stat.gov.pl, rgsw.edu.pl	The number of higher education institutions [*uczelnie*], 2018–2020
	4.4 – general secondary education institutions	bdl.stat.gov.pl	The number of general secondary education institutions [*szkoły ogólnokształcące*], 2018
Organisations	5.1 – associations, etc.	ekrs.ms.gov.pl	The number of associations and foundations of various kind [*stowarzyszenia*, *inne organizacje społeczne i zawodowe*, *fundacje*, *ZOZ*], 2020
	5.2 – foundations under Ministries: of Environment, of Climate, of National Defence	dane.gov.pl	The number of foundations under the Ministry of Environment, Ministry of Climate, Ministry of National Defence, 2020
	5.3 – sports clubs	bdl.stat.gov.pl	The number of sports clubs of various levels, 2018

Table 1 cnt'd

Category	Central Activity (Variable)	Source	Description
Retail trade	6.1 – supermarkets	bdl.stat.gov.pl	The number of supermarkets, 2018
	6.2 – hypermarkets	bdl.stat.gov.pl	The number of hypermarkets, 2018
	6.3 – permanent and seasonal markets	bdl.stat.gov.pl	The number of permanent and seasonal markets (including stands), 2018
	6.4 – gas stations	bdl.stat.gov.pl	The number of gas stations, 2003 (data discontinued for cities)
Professional services	7.1 – construction companies	baza-firm.com.pl	The number of construction companies, 2020
	7.2 – energy companies	stat.gov.pl	The number of energy companies (Sekcja D, PKD), 2019
	7.3 – finance and insurance companies	stat.gov.pl	The number of finance and insurance companies (Sekcja K, PKD), 2019
	7.4 – consulting, scientific, and technical companies	stat.gov.pl	The number of consulting, scientific, and technical companies (Sekcja M, PKD), 2019
Labour market	8.1 – commuting to work: arrivals	bdl.stat.gov.pl	The number of persons commuting to a city, 2011 (data from National Census of 2011)
	8.2 – commuting to work: balance	bdl.stat.gov.pl	The balance of the number of persons commuting to and from a city, 2011 (data from National Census of 2011)
	8.3 – employment	bdl.stat.gov.pl	Total employment, 2018
Transport	9.1 – taxis	bdl.stat.gov.pl	The number of officially licensed taxis registered in the city, 2018
	9.2 – postal offices	bdl.stat.gov.pl	The number of post offices, 2000 (data discontinued for cities)
	9.3 – Park & Ride	bdl.stat.gov.pl	The number of Park & Ride car-parks [*system Parkuj i Jedź*], 2018
	9.4 – railway stations	koleo.pl	The number of railway stations (Polish State Railways [*Polskie Koleje Państwowe*]), 2020

Source: the authors.

4. Results

Table 2 shows the results of the weight calculation for each variable. Immediately, an intuitive solution would be to remove the variables with the lowest weight. However, this makes the centrality index very unreliable for the smallest cities, where the central activities with high weights might not occur at all. Centrality scores of the cities in the lowest deciles of the rank depend in large part on these seemingly unimportant variables. Since the official administrative designation of Poland recognises only cities and villages, our data represent a wide spectrum of settlements that in other studies on central places would be considered cities, towns, or hamlets. Thus, we believe that the study warrants the inclusion of all variables. However, for future studies of similarly-sized settlements, a version of the index where only several central activities with the highest weights are chosen would be accurate and much easier to calculate.

Table 2. Weights

Variable	Weight	Variable	Weight	Variable	Weight	Variable	Weight
1.1	59.55	3.2	1.12	5.3	6.74	7.4	1.12
1.2	62.92	3.3	1.12	6.1	4.49	8.1	1.12
1.3	58.43	4.1	50.56	6.2	82.02	8.2	1.12
2.1	59.55	4.2	21.35	6.3	2.25	8.3	1.12
2.2	5.62	4.3	84.27	6.4	5.62	9.1	24.72
2.3	43.82	4.4	16.85	7.1	40.45	9.2	2.25
2.4	51.69	5.1	1.12	7.2	34.83	9.3	80.90
3.1	51.69	5.2	76.40	7.3	1.12	9.4	42.70

Source: the authors' own calculations based on data from Table 1.

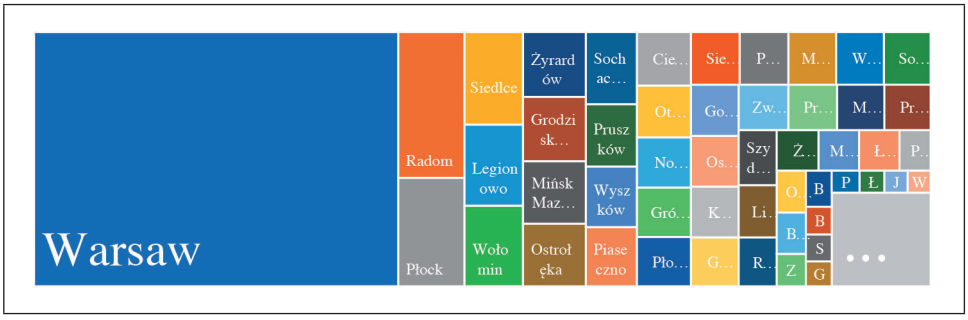

Fig. 1. Centrality Index

Source: the authors' own calculations based on data from Table 1.

Figure 1 visualises the centrality index for all the cities, Figure 2 presents ranks 2–45, and Figure 3 shows ranks 46–89. The key takeaway from the results of our centrality index is that Mazowieckie voivodeship is extremely centralised around Warsaw, to the point where the entire region could be considered its hinterlands in the traditional nomenclature.

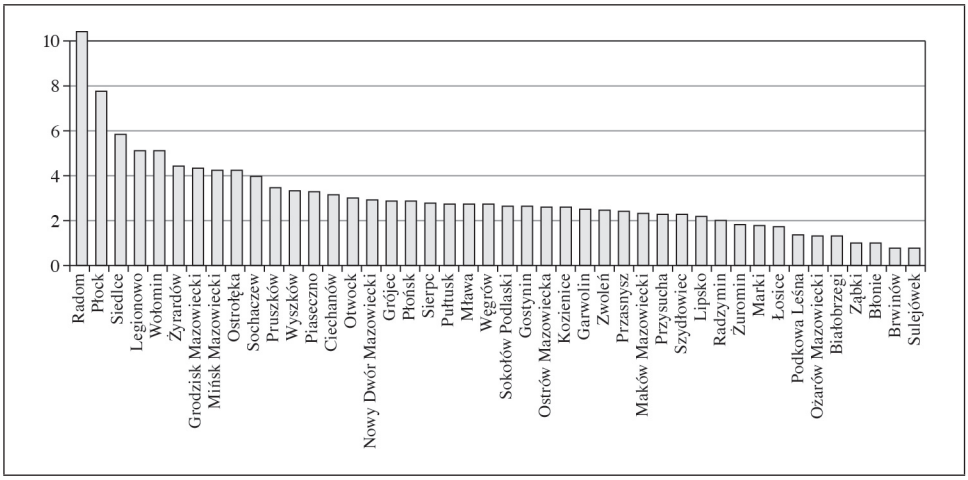

Fig. 2. Centrality Index, Ranks 2–45

Source: the authors' own calculations based on data from Table 1; also available in Szczech-Pietkiewicz, Radło & Tomeczek (2022, p. 64).

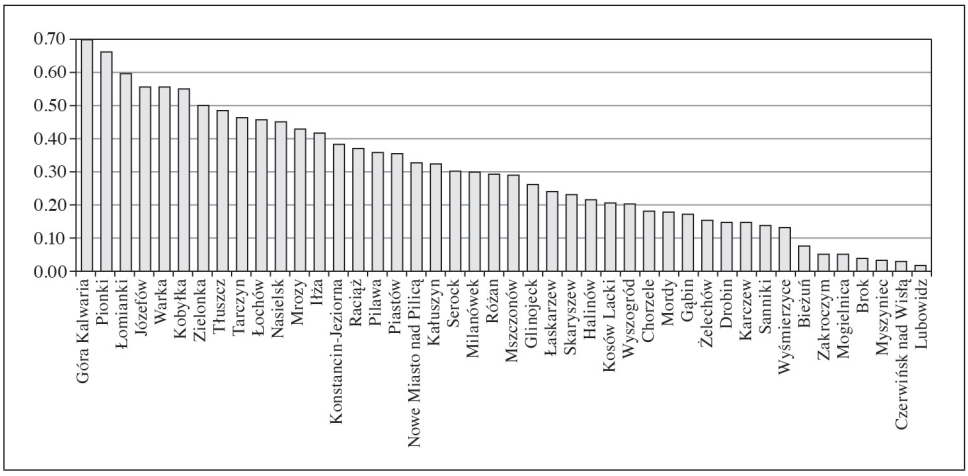

Fig. 3. Centrality Index, Ranks 46–89

Source: the authors' own calculations based on data from Table 1; also available in Szczech-Pietkiewicz, Radło & Tomeczek (2022, p. 65).

Figure 4 and Figure 5 give unweighted averages for central activities included in the nine categories – the former is concerned with cities with the highest centrality index (excluding Warsaw, which makes the data easier to visualise) and the latter with cities with the highest population-adjusted centrality index.

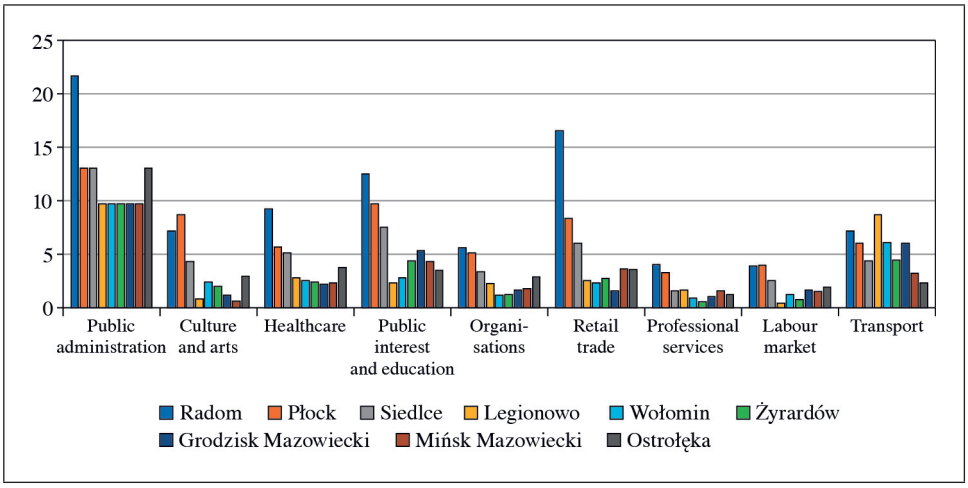

Fig. 4. Unweighted Averages for Categories, Cities with Highest Centrality Index (Excluding Warsaw)

Source: the authors' own calculations based on data from Table 1.

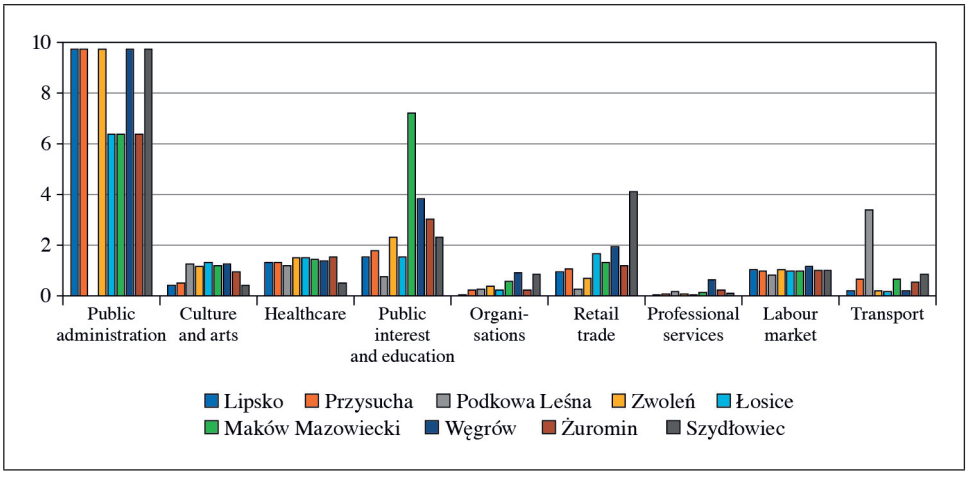

Fig. 5. Unweighted Averages for Categories, Cities with the Highest Population-adjusted Centrality Index

Source: the authors' own calculations based on data from Table 1.

Table 3. Central Places, Hidden Places, and Hidden Central Places of Mazowieckie Voivodeship

Central Places (Centrality Index ≥ 3)	Hidden Places (Population-adjusted Centrality Index ≥ 2)	Hidden Central Places (Central Places ∩ Hidden Places)
Warsaw 100.00	Lipsko 7.05	Wołomin
Radom 10.43	Przysucha 6.98	Grodzisk Mazowiecki
Płock 7.77	Podkowa Leśna 6.30	Wyszków
Siedlce 5.86	Zwoleń 5.67	
Legionowo 5.12	Łosice 4.39	
Wołomin 5.11	Maków Mazowiecki 4.22	
Żyrardów 4.41	Węgrów 3.84	
Grodzisk Mazowiecki 4.33	Żuromin 3.65	
Mińsk Mazowiecki 4.25	Szydłowiec 3.46	
Ostrołęka 4.22	Białobrzegi 3.40	
Sochaczew 3.99	Grójec 3.08	
Pruszków 3.45	Radzymin 2.79	
Wyszków 3.34	Sierpc 2.75	
Piaseczno 3.28	Kozienice 2.70	
Ciechanów 3.14	Wyśmierzyce 2.63	
Otwock 3.00	Gostynin 2.53	
	Garwolin 2.53	
	Pułtusk 2.51	
	Sokołów Podlaski 2.48	
	Przasnysz 2.48	
	Grodzisk Mazowiecki 2.45	
	Wołomin 2.44	
	Płońsk 2.30	
	Wyszków 2.21	
	Mrozy 2.13	
	Ostrów Mazowiecka 2.06	
	Ożarów Mazowiecki 2.04	

Source: the authors' own calculations based on data from Table 1; also available in Szczech-Pietkiewicz, Radło & Tomeczek (2022, p. 67).

Table 3 represents the central places, hidden places, and hidden central places that we have identified during our research. The cities of interest, in light of the central place theory, can be grouped into three types: 16 central places (cities with centrality index ≥ 3), 27 hidden places (cities with population-adjusted centrality index ≥ 2), and three hidden central places (cities classified as both central places and hidden places). By far, the most important central place is Warsaw (100.00), distantly followed by Radom (10.43), Płock (7.77), Siedlce (5.86), Legionowo (5.12), and Wołomin (5.11).

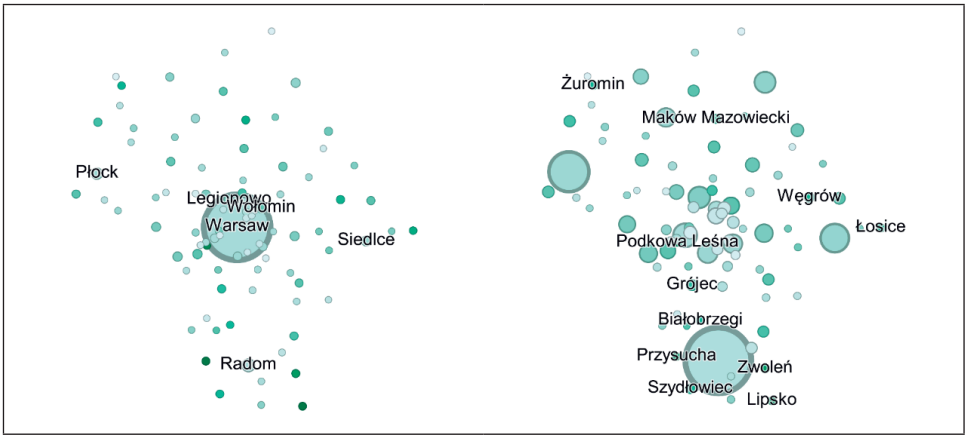

Fig. 6. Centrality Map (Size: Centrality Index, Colour: Population-adjusted Centrality Index, Left Labels: Centrality Index ≥ 5, Right Labels: Population-adjusted Centrality Index ≥ 3)
Source: the authors' own calculations based on data from Table 1.

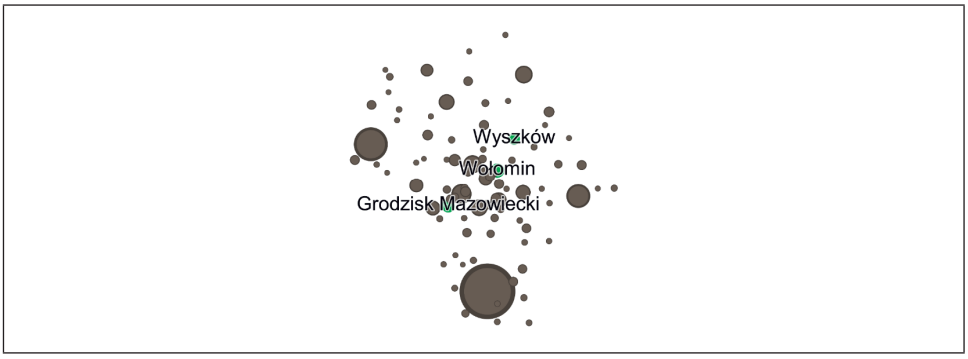

Fig. 7. Centrality Maps, Excluding Warsaw (Size: Centrality Index, Colour: Hidden Central Places, Labels: Hidden Central Places)
Source: the authors' own calculations based on data from Table 1.

The centrality index reflects a city's ability to provide goods and services to surrounding areas; thus, a higher score indicates a stronger influence over its region. For example, Warsaw's centrality index score means it is the dominant city, serving as the main hub for the entire region, whereas Radom's much lower score shows that, while still important, its influence is significantly smaller compared to Warsaw. The list of hidden places includes cities like Lipsko (7.05), Przysucha (6.98), Podkowa Leśna (6.30), Zwoleń (5.67), Łosice (4.39), and Maków Mazowiecki (4.22). Similarly, within the hidden places category, higher population-adjusted centrality index scores

indicate a stronger functional significance relative to the city's population size. Finally, there are three hidden central places, which combine the characteristics of central places and hidden places: Wołomin, Grodzisk Mazowiecki, and Wyszków. The context for drawing implications of our study is also given by Sokołowski (2005), who distinguishes centrality as the exogenous component of employment and nodality as a broader concept that includes both centrality and local consumption (endogenous employment). While centrality measures a city's external influence, nodality provides a more comprehensive view of a city's overall economic function. In our study, we focus on centrality as a regional influence measure, but future research should incorporate nodality to better capture the economic roles of smaller cities, especially those with strong local consumption.

Figure 6 and shows a centrality map where nodes representing cities are sized according to their centrality index and coloured according to their population-adjusted centrality index; the graph on the right is based on the same data, but Warsaw is excluded to better accentuate the differences between other cities. Labels are visible for nodes above a certain threshold. Lastly, Figure 7 explores the location of the three hidden central places identified in this research. Nodes representing cities are sized according to their centrality index, and the green color and labels indicate hidden central places. The full results for 89 cities in Mazowieckie voivodeship are presented in Table A.1 attached in the Appendix.

5. Discussion of Results

This section is organised around three research questions to examine the findings of the centrality index. The discussion integrates these findings with the existing literature to highlight theoretical and practical implications. The results identify three categories of cities based on the centrality index: 16 central places, 27 hidden places, and three hidden central places [RQ1]. The dominance of Warsaw is evident, with its perfect centrality index score of 100, far surpassing other cities such as Radom, Płock, and Siedlce. These cities, alongside smaller centres like Wołomin and Legionowo, serve as key central places in the region.

The hidden places, including cities such as Lipsko, Przysucha, and Podkowa Leśna, demonstrate high population-adjusted centrality scores. These cities, despite their smaller size, provide important regional services and function as crucial "hidden" hubs within their local economies. This supports the literature that highlights the growing importance of mid-sized and smaller cities in regional development (Bell & Jayne, 2009; Dijkstra, Garcilazo & McCann, 2013).

Hidden central places – cities like Wołomin, Grodzisk Mazowiecki, and Wyszków – are unique because they combine high centrality and population-adjusted scores. These cities play a dual role, serving both as central hubs and as hidden places relative to their size, reinforcing the concept that functional

significance can surpass population size in determining a city's influence (Lewis & Donald, 2010).

The centrality index offers a powerful tool for identifying key urban centres that should be prioritised for regional policy interventions [RQ2]. In the case of Mazowieckie voivodeship, the overwhelming centrality of Warsaw reflects a monocentric structure, which can lead to regional inequalities. Policies aimed at decentralising some of the region's functions could benefit hidden central places like Grodzisk Mazowiecki and Wołomin, which are well-positioned to take on additional economic activities.

The literature on regional development (Capello, 2000; Neal, 2011) suggests that mid-sized and smaller cities can relieve pressure from dominant urban centres by acting as secondary growth hubs. The identification of hidden places and hidden central places supports this notion, as cities like Lipsko and Przysucha, despite their small size, could play a larger role in regional economic strategies through targeted investments.

The findings support the continued relevance of the central place theory in understanding regional development, particularly in its application to the Mazowieckie voivodeship [RQ3]. The hierarchical structure of cities identified in this study – central places, hidden places, and hidden central places – aligns with the traditional framework of central place theory, where larger cities provide a broader range of services to surrounding areas.

However, the concept of hidden places introduces a modern adaptation to Christaller's theory, as it reflects the functional importance of cities that might not traditionally be recognised as central places. This is in line with contemporary urban studies, which highlight the increasing significance of smaller cities and their functional roles (Derudder & Witlox, 2004). Additionally, Sokołowski (2005) introduces the idea of nodality, a broader concept that includes both centrality and local consumption, offering a more comprehensive view of a city's economic role.

The centrality index reveals the hierarchical structure of cities in Mazowieckie voivodeship, with Warsaw's dominance and the presence of important hidden places and hidden central places. The findings suggest that decentralisation policies focusing on these hidden centres could contribute to more balanced regional development. Christaller's central place theory remains a useful framework, but future research should integrate concepts such as nodality to better capture the complexities of modern urban systems.

6. Summary and Policy Implications

The article explores the regional development of Mazovia in the context of Christaller's central place theory. We calculate the value of the centrality index

revealing the central and hidden places in Mazowieckie voivodeship. The proposed centrality index is a synthetic indicator based on a non-model method. The population-adjusted version of the centrality index indicates which cities overperform compared to their size (values higher than 1) and which cities underperform (values lower than 1). The centrality index can be used to identify cities that are important for regional development. Especially the population-adjusted centrality index is useful for the identification of the hidden centres of urban activity. As expected, and in line with the central place theory, the index scores show the overwhelming role of Warsaw in the regional economy of the Mazowieckie voivodeship. The devised method can be used in the analysis of different regions.

The analysis identifies three types of cities that are of interest in light of the central place theory: 16 central places (centrality index ≥ 3), 27 hidden places (population-adjusted centrality index ≥ 2), and three hidden central places (classified as both central places and hidden places). The regional supremacy of Warsaw is visible in its perfect centrality index score; other central places include Radom (10.43), Płock (7.77), Siedlce (5.86), Legionowo (5.12), and Wołomin (5.11). Hidden places are exemplified by Lipsko (7.05), Przysucha (6.98), Podkowa Leśna (6.30), Zwoleń (5.67), Łosice (4.39), and Maków Mazowiecki (4.22). Wołomin, Grodzisk Mazowiecki, and Wyszków are classified as the three hidden central places of the Mazowieckie voivodeship.

The research contributes to the understanding of the regional development of Mazovia and the practical applications of the central place theory. Hidden central places can be crucial for the future growth of the region. These cities could potentially take on the role of local growth centres in Mazovia. The dominant role of Warsaw is not going to be challenged, but if the hidden centres were to be sufficiently supported by the government, they might disperse geographically some of the crucial functions in a more sustainable, inclusive, and accessible way.

In terms of policy implications, the centrality index provides a valuable tool for identifying cities that could be targeted for investment to alleviate the over-reliance on Warsaw. By supporting hidden central places and smaller urban hubs, regional development can become more balanced, inclusive, and sustainable. This study affirms the continued relevance of Christaller's central places but also suggests the need for integrating modern concepts such as nodality to capture the full scope of a city's economic role. Future research should explore the interplay between centrality, nodality, and local economic functions, particularly in the context of smaller and mid-sized cities, to inform more comprehensive regional development policies.

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Authors' Contribution

The authors' individual contribution is as follows: Each contributed a third.

Conflict of Interest

The authors declare no conflict of interest.

References

Arthur, W. B. (1994). *Increasing Returns and Path Dependence in the Economy*. University of Michigan Press.

Audretsch, D. B., Belitski, M., & Desai, S. (2015). Entrepreneurship and Economic Development in Cities. *The Annals of Regional Science*, *55*(1), 33–60. https://doi.org/10.1007/s00168-015-0685-x

Bell, D., & Jayne, M. (2009). Small Cities? Towards a Research Agenda. *International Journal of Urban and Regional Research*, *33*(3), 683–699. https://doi.org/10.1111/j.1468-2427.2009.00886.x

Berry, B. J. L., & Garrison, W. L. (1958). The Functional Bases of the Central Place Hierarchy. *Economic Geography*, *34*(2), 145–154. https://doi.org/10.2307/142299

Biderman, E., & Kamiński, Z. (1993). Rola Poznania w procesie regionalnej redystrybucji ludności. *Kronika Miasta Poznania*, 3–4, 404–421.

Bird, J. H. (1973). Of Central Places, Cities and Seaports. *Geography*, *58*(2), 105–118.

Boussauw, K., van Meeteren, M., & Witlox, F. (2014). Short Trips and Central Places: The Home-school Distances in the Flemish Primary Education System (Belgium). *Applied Geography*, *53*, 311–322. https://doi.org/10.1016/j.apgeog.2014.06.025

Bracey, H. E. (1953). Towns as Rural Service Centres: An Index of Centrality with Special Reference to Somerset. *Transactions and Papers* (*Institute of British Geographers*), 19, 95–105. https://doi.org/10.2307/621230

Bracey, H. E. (1956). A Rural Component of Centrality Applied to Six Southern Counties in the United Kingdom. *Economic Geography*, *32*(1), 38–50. https://doi.org/10.2307/141929

Brush, J. E. (1953). The Hierarchy of Central Places in Southwestern Wisconsin. *Geographical Review*, *43*(3), 380–402. https://doi.org/10.2307/211754

Capello, R. (2000). The City Network Paradigm: Measuring Urban Network Externalities. *Urban Studies*, *37*(11), 1925–1945. https://doi.org/10.1080/713707232

Castells, M., & Hall, P. (1994). *Technopoles of the World: The Making of Twenty-first-century Industrial Complexes*. Routledge.

Christaller, W. (1933). *Die zentralen Orte in Süddeutschland*. Gustav Fisher Verlag.

Christaller, W. (1966). *Central Places in Southern Germany*. Prentice-Hall.

Davies, W. K. D. (1967). Centrality and the Central Place Hierarchy. *Urban Studies*, *4*(1), 61–79. https://doi.org/10.1080/00420986720080041

Davies, W. K. D. (1968). The Morphology of Central Places: A Case Study. *Annals of the Association of American Geographers*, *58*(1), 91–110. https://doi.org/10.1111/j.1467-8306.1968.tb01638.x

Derudder, B., & Witlox, F. (2004). Assessing Central Places in a Global Age: On the Networked Localization Strategies of Advanced Producer Services. *Journal of Retailing and Consumer Services*, *11*(3), 171–180. https://doi.org/10.1016/S0969-6989(03)00023-7

Dijkstra, L., Garcilazo, E., & McCann, P. (2013). The Economic Performance of European Cities and City Regions: Myths and Realities. *European Planning Studies*, *21*(3), 334–354. https://doi.org/10.1080/09654313.2012.716245

Dmitruk, J., & Gawinecki, J. (2017). Methods of Multidimensional Comparative Analysis – Construction and Application. *Bulletin of the Military University of Technology*, *66*(4), 103–119. https://doi.org/10.5604/01.3001.0010.8224

Erickcek, G. A., & McKinney, H. (2006). "Small Cities Blues": Looking for Growth Factors in Small and Medium-sized Cities. *Economic Development Quarterly*, *20*(3), 232–258. https://doi.org/10.1177/0891242406290377

Fahmi, F. Z., Hudalah, D., Rahayu, P., & Woltjer, J. (2014). Extended Urbanization in Small and Medium-sized Cities: The Case of Cirebon, Indonesia. *Habitat International*, *42*, 1–10. https://doi.org/10.1016/j.habitatint.2013.10.003

Fleming, D. K., & Hayuth, Y. (1994). Spatial Characteristics of Transportation Hubs: Centrality and Intermediacy. *Journal of Transport Geography*, *2*(1), 3–18. https://doi.org/10.1016/0966-6923(94)90030-2

Fujita, M., Krugman, P. R., & Venables, A. (1999). *The Spatial Economy: Cities, Regions and International Trade*. MIT Press. https://doi.org/10.7551/mitpress/6389.001.0001

Gonçalves, J. A. M., Portugal, L. da S., & Nassi, C. D. (2009). Centrality Indicators as an Instrument to Evaluate the Integration of Urban Equipment in the Area of Influence of a Rail Corridor. *Transportation Research Part A: Policy and Practice*, *43*(1), 13–25. https://doi.org/10.1016/j.tra.2008.06.010

Gwosdz, K. (2004). *Ewolucja rangi miejscowości w konurbacji przemysłowej: Przypadek Górnego Śląska*. Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego.

Hall, P. (2014). *Cities of Tomorrow: An Intellectual History of Urban Planning and Design since 1880* (4th ed.). Wiley-Blackwell.

Henríquez, C., Azócar, G., & Romero, H. (2006). Monitoring and Modeling the Urban Growth of Two Mid-sized Chilean Cities. *Habitat International*, *30*(4), 945–964. https://doi.org/10.1016/j.habitatint.2005.05.002

Irwin, M. D., & Hughes, H. L. (1992). Centrality and the Structure of Urban Interaction: Measures, Concepts, and Applications. *Social Forces*, *71*(1), 17–51. https://doi.org/10.2307/2579964

Jamal, A. C. (2018). Coworking Spaces in Mid-sized Cities: A Partner in Downtown Economic Development. *Environment and Planning A: Economy and Space*, *50*(4), 773–788. https://doi.org/10.1177/0308518X18760857

Krugman, P. (1991). Increasing Returns and Economic Geography. *Journal of Political Economy*, *99*(3), 3. https://doi.org/10.1086/261763

Kukuła, K. (1999). Metoda unitaryzacji zerowanej na tle wybranych metod normowania cech diagnostycznych. *Acta Scientifica Academiae Ostroviensis*, *4*, 5–31.

Lewis, N. M., & Donald, B. (2010). A New Rubric for 'Creative City' Potential in Canada's Smaller Cities. *Urban Studies*, *47*(1), 29–54. https://doi.org/10.1177/0042098009346867

Mastalerz-Kodzis, A., & Pośpiech, E. (2015). Wielowymiarowa analiza porównawcza w ujęciu dynamicznym na przykładzie wybranych charakterystyk ekonomicznych. *Metody Ilościowe w Badaniach Ekonomicznych*, *16*(4), 24–33.

Mokhtarian, P. L. (1998). A Synthetic Approach to Estimating the Impacts of Telecommuting on Travel. *Urban Studies*, *35*(2), 215–241. https://doi.org/10.1080/0042098984952

Mularczyk, M. (2014). Hierarchia funkcjonalna miast a dominujące funkcje ich wiejskiego otoczenia (przykład woj. świętokrzyskiego). In: W. Kamińska, K. Heffner (Eds), *Obszary wiejskie, wielofunkcyjność, migracje, nowe wizje rozwoju* (pp. 379–404). KPZK PAN.

Naess, P. (2012). Urban Form and Travel Behavior: Experience from a Nordic Context. *Journal of Transport and Land Use*, *5*(2), 21–45. https://doi.org/10.5198/jtlu.v5i2.314

Napiórkowski, T. M., & Radło, M.-J. (2022). *Czynniki wzrostu gospodarczego regionów i podregionów województwa mazowieckiego*. Oficyna Wydawnicza SGH – Szkoła Główna Handlowa w Warszawie. https://doi.org/10.33119/978-83-8030-530-4.2022

Neal, Z. P. (2011). From Central Places to Network Bases: A Transition in the U.S. Urban Hierarchy, 1900–2000. *City & Community*, *10*(1), 49–75. https://doi.org/10.1111/j.1540-6040.2010.01340.x

Nowosielska, E. (1992). *Teoria Christallera – prawda i mity. W sprawie nieporozumień pojęciowych*. Zakład Narodowy im. Ossolińskich – Wydawnictwo PAN.

Panek, T. (2009). *Statystyczne metody wielowymiarowej analizy porównawczej*. Oficyna Wydawnicza SGH.

Patro, S. G. K., & Sahu, K. K. (2015). Normalization: A Preprocessing Stage. *International Advanced Research Journal in Science*, *Engineering and Technology*, *2*(3), 20–22. https://doi.org/10.17148/IARJSET.2015.2305

Peredo, A. M., & Chrisman, J. J. (2006). Toward a Theory of Community-based Enterprise. *Academy of Management Review*, *31*(2), 2. https://doi.org/10.5465/amr.2006.20208683

Preston, R. E. (1971). The Structure of Central Place Systems. *Economic Geography*, *47*(2), 136–155. https://doi.org/10.2307/143042

Radło, M.-J., & Szczech-Pietkiewicz, E. (2022). *Przedsiębiorstwa w regionach i podregionach województwa mazowieckiego i ich powiązania w łańcuchach wartości*. Oficyna Wydawnicza SGH – Szkoła Główna Handlowa w Warszawie. https://doi.org/10.33119/978-83-8030-529-8.2022

Siddall, W. R. (1961). Wholesale-retail Trade Ratios as Indices of Urban Centrality. *Economic Geography*, *37*(2), 124–132. https://doi.org/10.2307/141843

Smith, N. (2008). *Uneven Development: Nature, Capital, and the Production of Space* (3rd ed.). University of Georgia Press.

Sokołowski, D. (1999). Funkcje centralne w zbiorze małych miast i większych osiedli wiejskich w Polsce. *Przegląd Geograficzny*, *71*(3), 295–316. https://doi.org/10.5281/zenodo.1146068

Sokołowski, D. (2005). Centralność a węzłowość większych miast w Polsce. *Przegląd Geograficzny*, *77*(4), 507–526. https://doi.org/10.5281/zenodo.1120377

Sokołowski, D. (2006). *Funkcje centralne i hierarchia funkcjonalna miast w Polsce*. Wydawnictwo Uniwersytetu Mikołaja Kopernika w Toruniu.

Szczech-Pietkiewicz, E., Radło, M.-J., & Tomeczek, A. F. (2022). *Powiązania miast w województwie mazowieckim. Determinanty i konstrukcja modelu funkcjonalnego województwa*. Oficyna Wydawnicza SGH – Szkoła Główna Handlowa w Warszawie. https://doi.org/10.33119/978-83-8030-527-4.2022

Taylor, P. J., Hoyler, M., & Verbruggen, R. (2010). External Urban Relational Process: Introducing Central Flow Theory to Complement Central Place Theory. *Urban Studies*, *47*(13), 2803–2818. https://doi.org/10.1177/0042098010377367

Tsiotas, D., & Polyzos, S. (2015). Introducing a New Centrality Measure from the Transportation Network Analysis in Greece. *Annals of Operations Research*, *227*, 93–117. https://doi.org/10.1007/s10479-013-1434-0

van Dijk, M. P., & Mingshun, Z. (2005). Sustainability Indices as a Tool for Urban Managers, Evidence from Four Medium-sized Chinese Cities. *Environmental Impact Assessment Review*, *25*(6), 667–688. https://doi.org/10.1016/j.eiar.2004.10.001

Véron, R. (2010). Small Cities, Neoliberal Governance and Sustainable Development in the Global South: A Conceptual Framework and Research Agenda. *Sustainability*, *2*(9), 2833–2848. https://doi.org/10.3390/su2092833

Zhong, C., Schläpfer, M., Müller Arisona, S., Batty, M., Ratti, C., & Schmitt, G. (2017). Revealing Centrality in the Spatial Structure of Cities from Human Activity Patterns. *Urban Studies*, *54*(2), 437–455. https://doi.org/10.1177/0042098015601599

Appendix

Table A.1. Centrality Index

Rank	City	Centrality Index (0–100)	Population--adjusted Centrality Index	Population Index (Warsaw = 100)
1	Warsaw	100.00	1.00	100.00
2	Radom	10.43	0.88	11.89
3	Płock	7.77	1.16	6.72
4	Siedlce	5.86	1.33	4.40
5	Legionowo	5.12	1.68	3.04
6	Wołomin	5.11	2.44	2.09
7	Żyrardów	4.41	1.96	2.25
8	Grodzisk Mazowiecki	4.33	2.45	1.77
9	Mińsk Mazowiecki	4.25	1.85	2.29
10	Ostrołęka	4.22	1.44	2.93
11	Sochaczew	3.99	1.95	2.05
12	Pruszków	3.45	0.99	3.47
13	Wyszków	3.34	2.21	1.51
14	Piaseczno	3.28	1.21	2.71
15	Ciechanów	3.14	1.26	2.48
16	Otwock	3.00	1.19	2.52
17	Nowy Dwór Mazowiecki	2.91	1.81	1.61
18	Grójec	2.89	3.08	0.94
19	Płońsk	2.86	2.30	1.24
20	Sierpc	2.77	2.75	1.01
21	Pułtusk	2.75	2.51	1.09
22	Mława	2.73	1.55	1.76
23	Węgrów	2.72	3.84	0.71
24	Sokołów Podlaski	2.64	2.48	1.07
25	Gostynin	2.64	2.53	1.04
26	Ostrów Mazowiecka	2.59	2.06	1.26
27	Kozienice	2.59	2.70	0.96
28	Garwolin	2.50	2.53	0.99
29	Zwoleń	2.46	5.67	0.43
30	Przasnysz	2.39	2.48	0.97
31	Maków Mazowiecki	2.31	4.22	0.55
32	Przysucha	2.28	6.98	0.33

Table A.1 cnt'd

Rank	City	Centrality Index (0–100)	Population--adjusted Centrality Index	Population Index (Warsaw = 100)
33	Szydłowiec	2.27	3.46	0.66
34	Lipsko	2.16	7.05	0.31
35	Radzymin	2.02	2.79	0.72
36	Żuromin	1.81	3.65	0.50
37	Marki	1.78	0.93	1.91
38	Łosice	1.74	4.39	0.40
39	Podkowa Leśna	1.37	6.30	0.22
40	Ożarów Mazowiecki	1.33	2.04	0.65
41	Białobrzegi	1.32	3.40	0.39
42	Ząbki	1.02	0.49	2.06
43	Błonie	1.01	1.46	0.69
44	Brwinów	0.77	1.01	0.76
45	Sulejówek	0.75	0.68	1.11
46	Góra Kalwaria	0.70	1.03	0.68
47	Pionki	0.66	0.65	1.02
48	Łomianki	0.60	0.63	0.95
49	Józefów	0.56	0.48	1.16
50	Warka	0.56	0.83	0.67
51	Kobyłka	0.55	0.41	1.33
52	Zielonka	0.50	0.50	0.99
53	Tłuszcz	0.49	1.06	0.46
54	Tarczyn	0.46	1.99	0.23
55	Łochów	0.46	1.19	0.38
56	Nasielsk	0.45	1.04	0.43
57	Mrozy	0.43	2.13	0.20
58	Iłża	0.42	1.57	0.27
59	Konstancin-Jeziorna	0.38	0.40	0.96
60	Raciąż	0.37	1.50	0.25
61	Pilawa	0.36	1.38	0.26
62	Piastów	0.36	0.28	1.27
63	Nowe Miasto nad Pilicą	0.33	1.56	0.21
64	Kałuszyn	0.32	1.99	0.16
65	Serock	0.30	1.22	0.25
66	Milanówek	0.30	0.33	0.92

Table A.1 cnt'd

Rank	City	Centrality Index (0–100)	Population--adjusted Centrality Index	Population Index (Warsaw = 100)
67	Różan	0.29	1.91	0.15
68	Mszczonów	0.29	0.81	0.36
69	Glinojeck	0.26	1.54	0.17
70	Łaskarzew	0.24	0.88	0.27
71	Skaryszew	0.23	0.95	0.24
72	Halinów	0.22	1.02	0.21
73	Kosów Lacki	0.21	1.75	0.12
74	Wyszogród	0.20	1.40	0.15
75	Chorzele	0.18	1.04	0.18
76	Mordy	0.18	1.82	0.10
77	Gąbin	0.17	0.75	0.23
78	Żelechów	0.15	0.70	0.22
79	Drobin	0.15	0.92	0.16
80	Karczew	0.15	0.27	0.56
81	Sanniki	0.14	1.25	0.11
82	Wyśmierzyce	0.13	2.63	0.05
83	Bieżuń	0.08	0.72	0.10
84	Zakroczym	0.05	0.29	0.18
85	Mogielnica	0.05	0.40	0.13
86	Brok	0.04	0.35	0.11
87	Myszyniec	0.03	0.17	0.19
88	Czerwińsk nad Wisłą	0.03	0.49	0.06
89	Lubowidz	0.02	0.18	0.09

Source: the authors' own calculations based on data from Table 1; also available in Szczech-Pietkiewicz, Radło & Tomeczek (2022, pp. 62–63).