sciendo

Bulletin of Geography. Socio-economic Series, No. 52 (2021): 123–144
http://doi.org/ 10.2478/bog-2021-0018

ISSN 1732–4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
https://content.sciendo.com/view/journals/bog/bog-overview.xml
http://apcz.umk.pl/czasopisma/index.php/BGSS/index

Using Spatial Autocorrelation for identification of demographic patterns of Functional Urban Areas in Poland

Sławomir Kurek[1] CDM, Mirosław Wójtowicz[2] CFM, Jadwiga Gałka[3] DMR

[1,2]*Pedagogical University of Krakow,* Institute of Geography, Department of Socio-Economic Geography., [3]*Jagiellonian University Cracow* [1]e-mail: slawomir.kurek@up.krakow.pl, https://orcid.org/0000-0002-7251-8410, [2]e-mail: miroslaw.wojtowicz@up.krakow.pl , https://orcid.org/0000-0003-3633-745X, [3]e-mail: jadwiga.galka@uj.edu.pl, https://orcid.org/0000-0002-6728-8497

How to cite: Kurek, S., Wójtowicz, M., Gałka, J. (2021). Using Spatial Autocorrelation for identification of demographic patterns of Functional Urban Areas in Poland. *Bulletin of Geography. Socio-economic Series*, 52(52): 123-144. DOI: http://doi.org/10.2478/bog-2021-0018

Abstract. Functional Urban Areas (FUAs) leads to a better knowledge of urban spatial organisation, which may play a significant role in regional policy making and may be helpful in understanding the connection between urbanisation and demographic development. An explanation of population change in urban regions can be associated the second demographic transition comprising fertility decline below replacement level and postponement of births.

The aim of this paper is to focus on establishing similarity patterns and anomalous values of selected demographic variables in the cores and peripheral areas of Functional Urban Areas. At the background of this study lies an assumption that population development of FUA's is shaped by different factors connected with second demographic transition and migrations. To achieve the aims the following demographic characteristics were used: population growth rate, dependency ratio, rate of natural increase, the net migration rate, and the dynamic economic ageing index, Spatial methods play an increasingly important role in contemporary socio-demographic research. In order to identify spatial systems Global Moran Statistics and the Local Indicators of Spatial Association (LISA) including Local Moran statistics as well as Getis-Ord Gi* statistics were used.

The research showed global and local autocorrelation of demographic processes in Functional Urban Areas in Poland, namely population growth, natural increase, net migration and population ageing.The use of local Moran's I statistic and the Getis-Ord Gi* method has led to identification of spatial clusters and dispersions representing different demographic variables. Spatial autocorrelation methods can be useful in an analysis of demographic variables including changes in time. The main contribution of this study to the research on demographic processes in urban areas was an application of spatial groupings techniques not only to find out similarity and dissimilarity patterns of demographic indicators but also to apply this findings for the needs of spatial planning.

Article details:
Received: 19 August 2020
Revised: 15 October 2020
Accepted: 22 March 2021

Key words:
functional urban areas,
spatial autocorrelation,
Poland,
population,
demographic variables

Contents:

1. Introduction

Functional Urban Areas, not only in Poland but also in whole European countries, are characterised by dynamic demographic changes. Most studies on demographic change in functional urban regions refer to the "stages of urban development" model (Klaassen et al. 1981, van den Berg et al. 1982, Turok and Mykhnenko 2006, Buzar et al. 2007, Kabisch and Haase 2011). However, model of urban development by van den Berg is presently criticised, because the particular stages do not always appear in sequential order. The present coexistence of the different stages (i.e. suburbanisation, de-urbanisation and reurbanisation) in the metropolitan areas of Europe (Buzar et al. 2007, Kabisch and Haase 2011), confirms that there may be different trajectories for European urban development (Kurek et al. 2020).

In Western European urban regions suburbanisation and reurbanisation processes are observed (Buzar et al. 2007, Haase et al. 2010, Rèrat 2012). Gil-Alonso et al. (2016) also noticed that the urban centres in Spain started to gain population after a long term loss (Kurek et al. 2020). In post-socialist countries, suburbanisation has intensified from the 1990s onwards and has become one of the major processes shaping the spatial development and population dynamics of functional urban areas (Leetmaa and Tammaru 2007, Novák and Sýkora 2007, Ouředníček 2007, Zborowski 2007, Leetmaa et al. 2009, Kurek et al. 2015). Kurek et al. (2020) noted, that not only suburbanisation, but also de-urbanisation and the beginning of reurbanisation stages can be observed in Polish Functional Areas as a result of economic, social and demographic changes after political transition in 1989.

Many researchers refers to second demographic transitions and mentions the factors influencing population growth in the urban areas - especially in cores: fertility decline, non-family households, aging of population (Rèrat 2012, Sobotka 2008, Lesthaeghe 2010). Despite of migration of population, suburban areas record population growth from natural growth (Kurek et al. 2014). The procreative intentions of the new suburbanites may have a significant influence on suburban fertility rates and it is widely known that suburban areas record higher fertility levels than urban centres (Kulu and Boyle 2009, Kulu et al. 2009, Kulu and Washbrook 2014).

In Poland previous studies indicated disparities in population processes like dynamics of population growth, population ageing and different values of natural increase and variation of migration trends associated with the process of suburbanisation. Metropolitan areas are characterized by population concentration and positive population growth against peripheral areas experiencing population ageing and shrinking. Changes in fertility patterns and household formation described by the concept of second demographic transition also has been taking place leading to advanced population ageing (Kurek 2011a, Kurek 2011 b, Kurek, Lange 2013, Kurek et al 2014, Walford, Kurek 2016, Śleszyński et al 2018). There are also differences between cores and external zones of Functional Urban Areas being the result of suburbanisation and to some extent, reurbanisation processes (Śleszyński 2013, Kurek et al 2020). This article contributes to research on clustering and dispersion between units under study on the background of ongoing processes. The main novelty in this study is the application of GIS spatial grouping techniques into demographic processes in Functional Urban Areas in Poland.

The aim of this paper is to investigate whether demographic processes in the cores and peripheral areas of FUA's follow a similar pattern and whether these similarities are evident for the same rank of FUA's and for FUA's lying in close proximity (in the same regions). At the background of this study lies an assumption that population development of FUA's is shaped by different factors connected with second demographic transition and migrations. To achieve the aims selected demographic characteristics were used: population growth rate, dependency ratio, rate of natural increase, the net migration rate, and the dynamic economic ageing index, to find out if these indicators take similar or opposite values within FUA's; in which types of FUA's there are similarities and in which there are none between cores and peripheral zones; and whether FUA's showing similarities between cores and periphery and those not showing such similarities show visible regularities in spatial distribution. The spatial dependencies occurring in Functional Urban Areas in Poland in terms of selected demographic variables will be identified using spatial autocorrelation methods (global and local). The analysis was carried out for two time periods (2005 and 2016), i.e. one year after Poland's accession to the EU, and recent available data. The methodology of the study is not new, but it was used for the first time to study spatial diversification of Functional Urban Areas in Poland. Exploring FUA's demographic diversity through this set of indicators and with the help of geostatistics techniques is crucial in order to identify spatial patterns and understand demographic disparities.

2. Study area

The FUAs in this article were defined by Śleszyński (2013), the Act on Planning and Spatial Management and the Concept of National Spatial Planning 2030. The 151 areas, of which 134 were individual towns or cities and 17 were aggregates (either urban agglomerations or conurbations) (Fig. 1). The FUAs identified in Poland covered an area of 81,700 km^2 (including 11,300 km^2 of cores, i.e. 13.8%) and had a population of 25.1 million (including 18.3 million or 73.0% in the cores). The FUAs comprised 1,148 administrative units (including urban or rural municipalities and the urban and rural portions of urban-rural municipalities). Of this number 222 towns and cities constituted the cores and 166 were included in the external areas.

3. Data and methods

3.1. Data

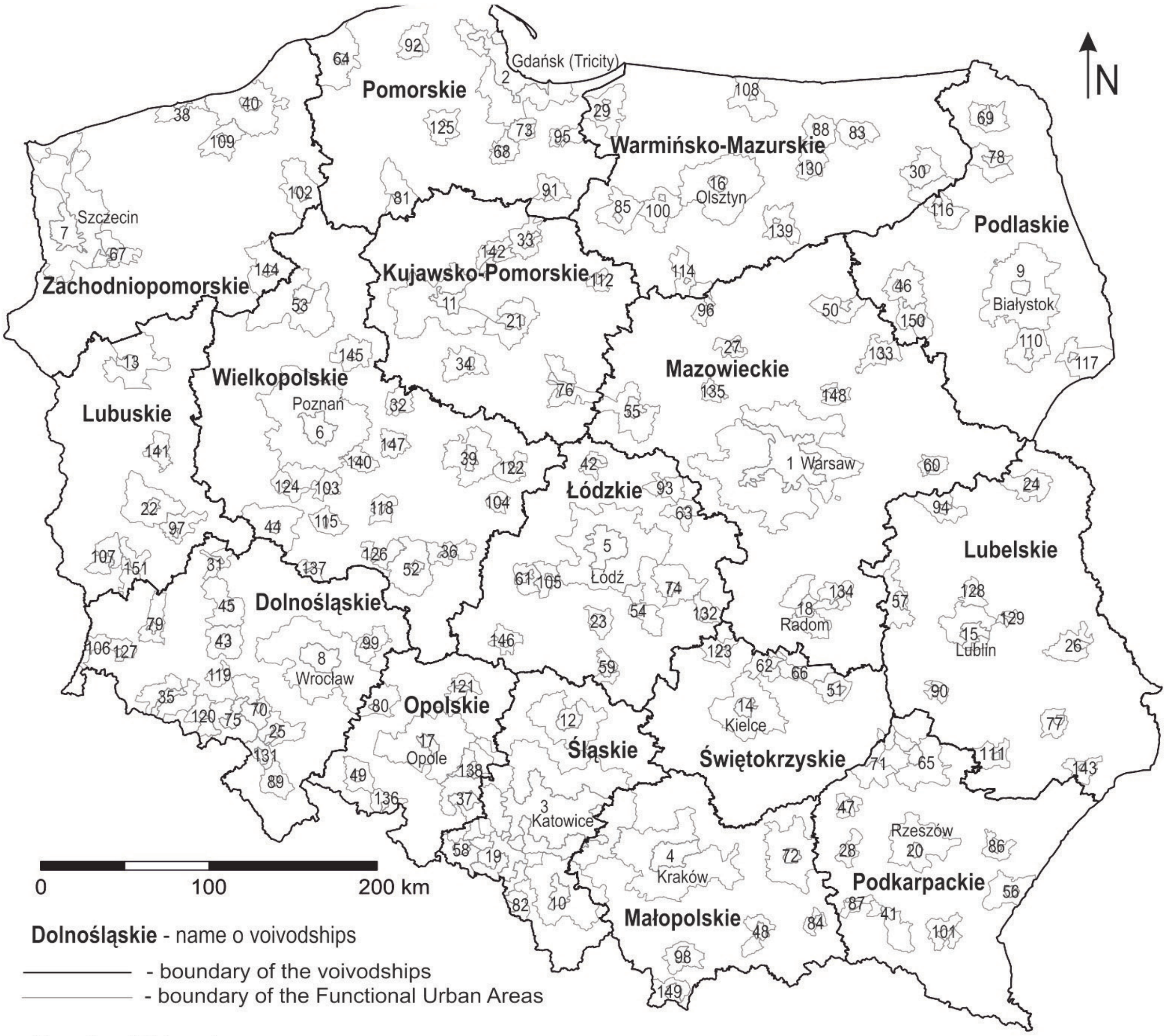
The study based on data on the population derived from the Current Population Records of the Polish Central Statistical Office (CSO), which are not published. We used data on size, age composition, natural increase, migration of population in FUAs in Poland.

Since natural and migration movement have the nature of vital events, and thus may demonstrate considerable chance variability in small administrative units in individual years, it is assumed that they will be analysed on the basis of the average values of the above ratios for three consecutive years in relation to the population for the middle year. It has been confirmed through tests that this significantly reduces the randomness of data (Yusuf et al. 2014).

The choice of the subperiods was not accidental. The starting point is 2005, which was the second year of Poland's membership of the European Union, which meant an improved economic situation for the country, an increase in building development activity, suburbanisation and a growing popularity of mortgage loans. Meanwhile, the year 2016 is illustrative of the most recent situation and the earliest years following the economic crisis, which began in Poland at the end of 2008 (Karasavvoglou & Polychronidou 2014).

3.2. Methods of spatial autocorrelation

Increase in the availability of geographic information systems has implemented developing better methods to study demographic processes across space. Global spatial autocorrelation is deter-



Functional Urban Areas:

A: 1 Warsaw

B: 2 Gdańsk (Tricity), 3 Katowice, 4 Kraków, 5 Łódź, 6 Poznań, 7 Szczecin, 8 Wrocław

C: 9 Białystok, 10 Bielsko-Biała, 11 Bydgoszcz, 12 Częstochowa, 13 Gorzów Wielkopolski 14 Kielce, 15 Lublin, 16 Olsztyn, 17 Opole, 18 Radom, 19 Rybnik, 20 Rzeszów, 21 Toruń, 22 Zielona Góra

D: 23 Bełchatów, 24 Biała Podlaska, 25 Bielawa-Dzierżoniów, 26 Chełm, 27 Ciechanów, 28 Dębica, 29 Elbląg, 30 Ełk, 31 Głogów, 32 Gniezno, 33 Grudziądz, 34 Inowrocław, 35 Jelenia Góra, 36 Kalisz, 37 Kędzierzyn-Koźle, 38 Kołobrzeg, 39 Konin, 40 Koszalin, 41 Krosno, 42 Kutno, 43 Legnica, 44 Leszno, 45 Lubin, 46 Łomża, 47 Mielec, 48 Nowy Sącz, 49 Nysa, 50 Ostrołęka, 51 Ostrowiec Świętokrzyski, 52 Ostrów Wielkopolski, 53 Piła, 54 Piotrków Trybunalski, 55 Płock, 56 Przemyśl, 57 Puławy, 58 Racibórz, 59 Radomsko, 60 Siedlce, 61 Sieradz, 62 Skarżysko-Kamienna, 63 Skierniewice, 64 Słupsk, 65 Stalowa Wola, 66 Starachowice, 67 Stargard Szczeciński, 68 Starogard Gdański, 69 Suwałki, 70 Świdnica, 71 Tarnobrzeg-Sandomierz, 72 Tarnów, 73 Tczew,, 74 Tomaszów Mazowiecki, 75 Wałbrzych, 76 Włocławek, 77 Zamość

E: 78 Augustów, 79 Bolesławiec, 80 Brzeg, 81 Chojnice, 82 Cieszyn, 83 Giżycko, 84 Gorlice, 85 Iława, 86 Jarosław, 87 Jasło, 88 Kętrzyn, 89 Kłodzko, 90 Kraśnik, 91 Kwidzyn, 92 Lębork, 93 Łowicz, 94 Łuków, 95 Malbork, 96 Mława, 97 Nowa Sól, 98 Nowy Targ, 99 Oleśnica, 100 Ostróda, 101 Sanok, 102 Szczecinek, 103 Śrem, 104 Turek, 105 Zduńska Wola, 106 Zgorzelec, 107 Żary

F: 108 Bartoszyce, 109 Białogard, 110 Bielsk Podlaski, 111 Biłgoraj, 112 Brodnica, 113 Chełmno, 114 Działdowo, 115 Gostyń, 116 Grajewo, 117 Hajnówka, 118 Jarocin, 119 Jawor, 120 Kamienna Góra, 121 Kluczbork, 122 Koło, 123 Końskie, 124 Kościan, 125 Kościerzyna, 126 Krotoszyn, 127 Lubań, 128 Lubartów, 129 Łęczna, 130 Mrągowo, 131 Nowa Ruda, 132 Opoczno, 133 Ostrów Mazowiecka, 134 Pionki, 135 Płońsk, 136 Prudnik, 137 Rawicz, 138 Strzelce Opolskie, 139 Szczytno, 140 Środa Wielkopolska, 141 Świebodzin, 142 Świecie, 143 Tomaszów Lubelski, 144 Wałcz, 145 Wągrowiec, 146 Wieluń, 147 Września, 148 Wyszków, 149 Zakopane, 150 Zambrów, 151 Żagań

Fig. 1. Functional Urban Areas in Poland
Source: own study based on Śleszyński (2013).

mined by means of Global Moran's I Index (Janc 2006, Woźniak & Sikora 2007, Pośpiech & Mastalerz-Kodzis 2015). In order to construct it, use is made of a binary weight matrix that identifies the border with each neighbouring region. The significance of the statistic in question is checked with a test where two opposing hypotheses about no spatial autocorrelation (H0) and about the existence of spatial autocorrelation on the existence thereof (H1) are verified. In the test, ZI is the test statistic which has distribution N (0.1). Values of the ZI statistic equal to zero mean no spatial autocorrelation (random distribution of the values of the variable between individual locations), a positive value means positive autocorrelation, that is, the presence of clustered values (spatial clusters), while a negative value denotes negative autocorrelation (neighbouring high and low values). The significance of the values obtained can be estimated on the basis of the p-value. With a significance level of 0.05, it is assumed that positive values of the *I* statistic are significant when the p-value is lower than 0.05, while negative values of this statistic are significant when the p-value is greater than 0.95.

In order to identify spatial systems, i.e. to determine whether a region is surrounded by neighbours with high or low values of the variable of interest, use can be made of the Local Indicators of Spatial Association (LISA) proposed by Anselin (1995). One of these is the Local Moran statistic, which can be used for identifying clusters with high or low values of the variable under study and indicates atypical locations (i.e. "outliers"). It is assumed that a significant positive value of Local Moran's I for a given area means that it is surrounded by areas with similar values of the respective feature (spatial clusters are formed, Kołodziejczak & Kossowski 2016). By contrast, a significant negative value of Local Moran's *I* for a given area means that it is surrounded by areas with different values of the same feature (it is an "outlier").

As a result of the analysis, one of the following solutions for each spatial unit can be obtained:

1. A high value unit with neighbours having a similar value (hot spot)
2. A low value unit with neighbours having a similar value (cold spot)
3. A high value unit with low-value neighbours – potential outlier
4. A low value unit with high-value neighbours – potential outlier
5. A unit with no statistically significant local autocorrelation

Another example of a local statistic is the Getis-Ord Gi* statistics (Getis & Ord 1992, Getis 2008). The results of the general Getis-Ord Gi* statistics show whether there are clusters with high or low values (so-called hot spots and cold spots). The Getis-Ord Gi* statistics can be used for detecting local concentrations of high and low values in neighbouring areas and investigating the statistical significance of this dependence.

Spatial autocorrelation methods have been widely used in research to determine the groupings that can be found in the area under analysis, including investigation of demographic processes (Oliveau, Guilmoto 2005, Matthews, Parker 2013, Lloyd 2014, Raymenr et al 2018, Sanchez-Martin et al, 2019). The Global Moran statistics, the cluster and outlier analysis (based on Anselin local Moran's I) and the hot spot analysis (based on Gi* de Getis-Ord) have been selected as they are widely documented in relevant literature (e.g Serván-Mori 2019 , Gosh, Cartone 2020).

4. Results

4.1. Global Moran statistics analysis

When analysing the results in Table 1, it can be seen that all the statistics are statistically significant throughout the entire study period. Thus, it can be concluded that there is a spatial autocorrelation (moderate or weak) in the case of the variables tested, which means that areas with similar values cluster up within the respective locations. The greatest spatial autocorrelation has been found for rate of natural increase, which is indicative of regional differences in fertility and mortality rates. The clustering of areas with similar values of rate of natural increase can be attributed to the prevailing family model (e.g. a traditionally high birth rate), the occurrence of SDT processes, which may be diffuse in nature (e.g. assimilation of patterns of low fertility rate), similarities in population age structure, etc. By contrast, the greatest dispersion in 2016 is seen for the net migration rate (negative Moran index values). This stems from the differences in population movements between the core city and suburban areas (a negative net migration rate in cities and an increase in the net migration rate in the outer zones of FUAs). A moderate negative correlation was seen for the dynamic ageing index in the first period under investigation (1990-2005). It was a period of fast population ageing in cities compared to the surrounding areas. In the next period analysed, the correlation coefficient decreased and the disparities between the cities and their fringes in terms of population ageing dynamics disappeared. A low correlation (a positive one in 2005 and a negative one in 2016) was displayed by the feature which represents demographic ageing (elderly dependency ratio), as well as for changes in the size of population (population growth rate). Considering the changes between 2005 and 2016, it should be pointed out that a relative increase in the correlation coefficient was recorded for natural increase, the decrease of negative correlation was noticed in case of the net migration rate while in the case of population growth rate and the elderly dependency ratio, the spatial correlation was reversed from positive to negative and in the case of dynamic ageing index – from negative to positive (Table 1).

The analysis presented below relies on local spatial autocorrelation statistics, namely Local Moran's *I* and Getis-Ord Gi*.

4.2. Local spatial autocorrelation statistics analysis

The values of the local Moran statistic are presented in the following figures. In order to determine whether the period 2005-2016 saw changes in the spatial features of the variables under study, a graphic is presented for the two extreme years of this period. In the case of the dynamic indicators (population growth rate and economic ageing index), two sub-periods were taken into account: 1990-2005 and 2005-2016. For the population growth rate, in the years 1990-2005, a cluster with high values of the variable (HH) was observed in the Warsaw FUA (Fig. 2). The most conspicuous clusters of low values of the rate (LL) comprise the Katowice FUA and FUAs located in the Sudetes. The FUAs located in the suburban area of Łódź (the 3rd largest city in Poland, formerly a centre of the textile industry, increasingly affected by a population decline from the beginning of the socio-economic transformation) form the clearest example of an outlier. A far greater diversity of clusters is demonstrated by the local Getis-Ord Gi* statistic, which takes into account various confidence intervals. Clusters with high population dynamics (hot spots) are located in the area of the Wielkopolskie, Kujawsko-Pomorskie, Pomorskie and partly the Mazowieckie (Warsaw FUA) Voivodships. By contrast, clusters with low population dynamics (depopulation) comprise FUAs located in the area of the former Upper Silesian Industrial District (hard

Table 1. Global Moran Statistics for variables

Measures	*POP_90_05*	*POP_05_16*	*NIR_2005*	*NIR_2016*	*NMR_2005*	*NMR_2016*	*EDR_2005*	*EDR_2016*	*DAI_9005*	*DAI_0516*
Moran's index	0,0994	-0,0943	0,3102	0,3366	-0,2179	-0,1928	0,0925	-0,0947	-0,2699	0,0995
z-score	2,5295	-2,2471	7,7582	8,3999	-5,2953	-4,6708	2,6317	-2,2503	-6,5447	2,5405
p-value	0,0114	0,0246	0,0000	0,0000	0,0000	0,0000	0,0085	0,0244	0,0000	0,0111

Source: own elaboration with the use of data from Central Statistical Office in Warsaw
POP_90_05 – population growth in 1990-2005; POP_05_16 ¬ population growth in 2005-2016
NIR_2005 – natural increase rate in 2005; NIR_2016 – natural increase rate in 2016
NMR_2005 – net migration rate in 2005; NMR_2016 – net migration rate in 2016
EDR_2005 – elderly dependency ratio in 2005; EDR_2016 – elderly dependency ratio in 2016
DAI_9005 – dynamic ageing index in 1990-2005; DAI_0516 – dynamic ageing index in 2005-2016

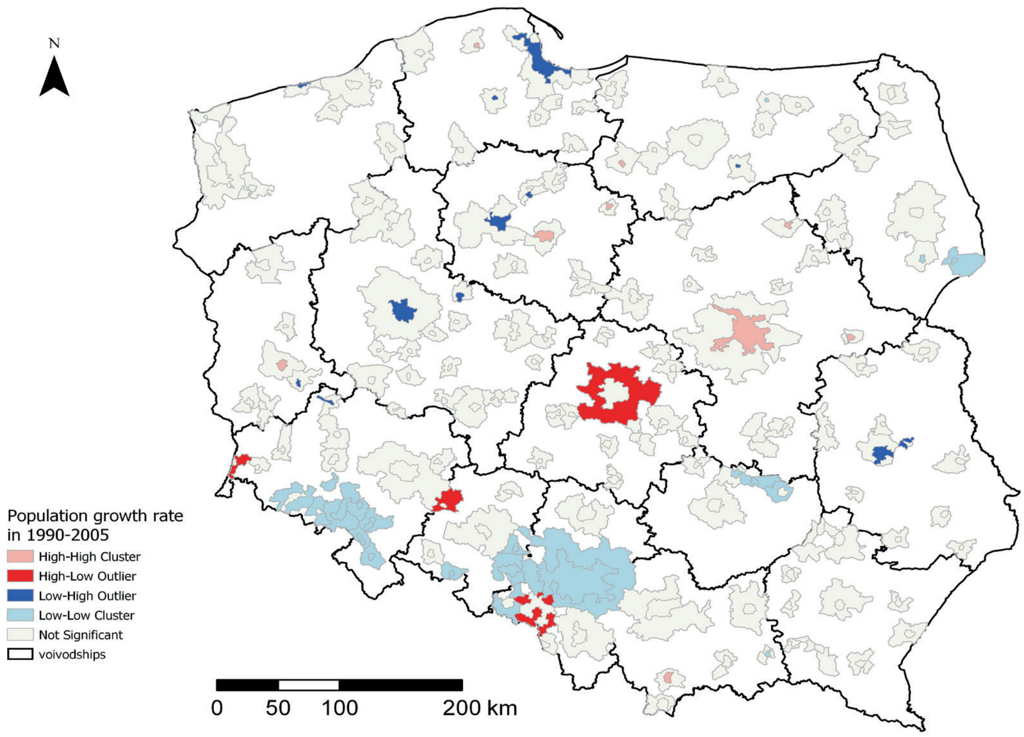


Fig. 2. Anselin Local Moran's I statistics for population growth in the years 1990-2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

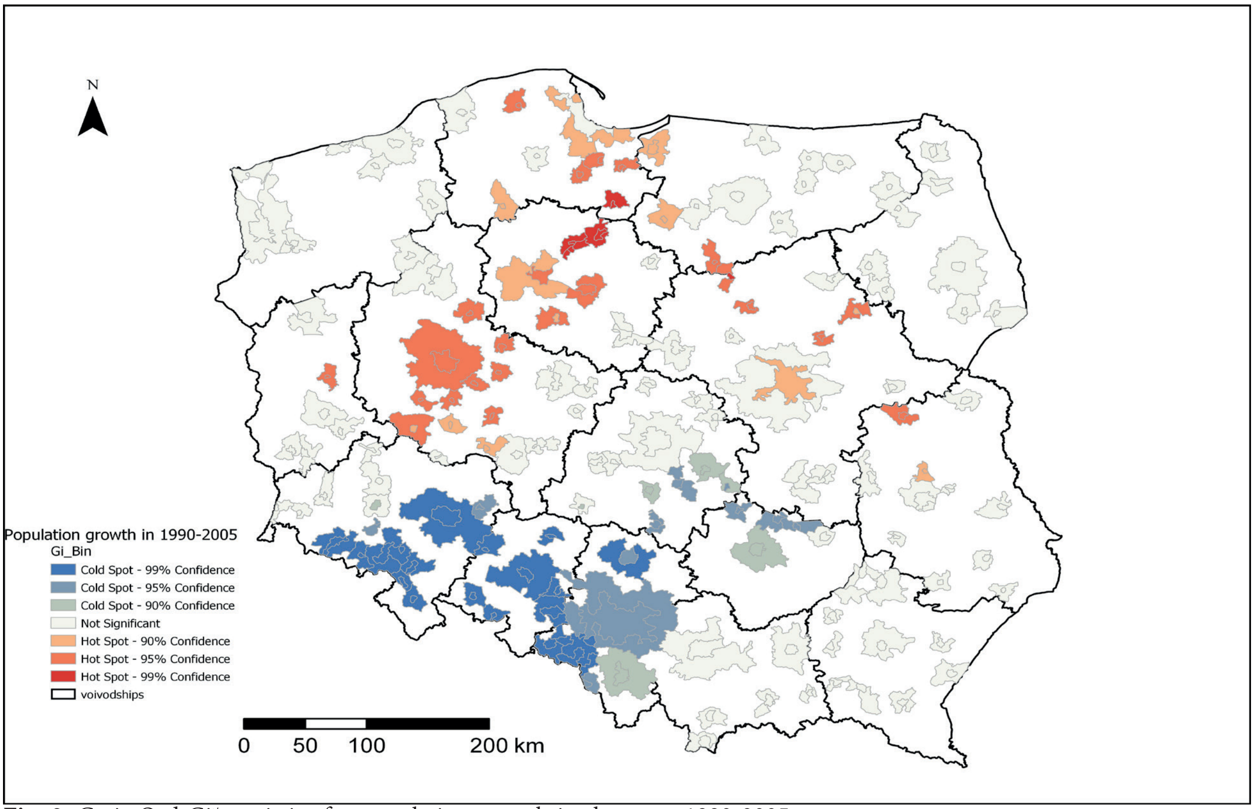


Fig. 3. Getis-Ord Gi* statistics for population growth in the years 1990-2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

coal mining), the Opolskie Voivodship, and the Sudeten region (Fig. 3).

As regards population dynamics, the years 2005–2016 saw an increase in the number of clusters and a change in their spatial distribution. A high-high (HH) cluster was no longer observed, but there was an increase in the number and range of clusters with outliers (HL), which comprised the outer zones of FUAs of various sizes located in the voivodships that underwent depopulation. Their occurrence was associated with large differences in the population dynamics between commuting zones, which were undergoing suburbanisation processes, and the demographically shrinking cores of some FUAs. The reverse situation occurred in the case of clusters of the low-high (LH) type, which were observable in areas characterised by total population growth and which comprised the cores of FUAs. They mainly concentrated in the areas of the Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie Voivodships (Tricity). Clusters with low values of population growth rate surrounded by other units with low values (LL) increased their range in relation to the previous study period, comprising not only FUAs in south-western Poland, but also some areas of the Świętokrzyskie Voivodship (former areas of the Old Polish Industrial District) and the Łódzkie Voivodship (Fig. 4). A similar spatial distribution of hot spots and cold spots is revealed by the Getis-Ord Gi* analysis, with a high concentration of high-value FUAs with the most conservative confidence interval (99%) in northern Poland, namely in the area of the Pomorskie Voivodship. They are areas also characterised by a high rate of natural increase, and in the case of the commuting zones of FUAs – by a high net migration rate (Fig. 5).

Natural growth rate clusters of the HH type concentrate in the northern part of the country, mainly in the area of the Pomorskie Voivodship. A cluster with high values surrounded by low values of natural increase is located in the commuting zone of Wroclaw (a city with a population of more than 500,000). By contrast, low-high (LH) outliers were found in the cores of large FUAs (those of Poznań, Bydgoszcz and Gdańsk). In a similar manner to the population growth rate, clusters with low values of

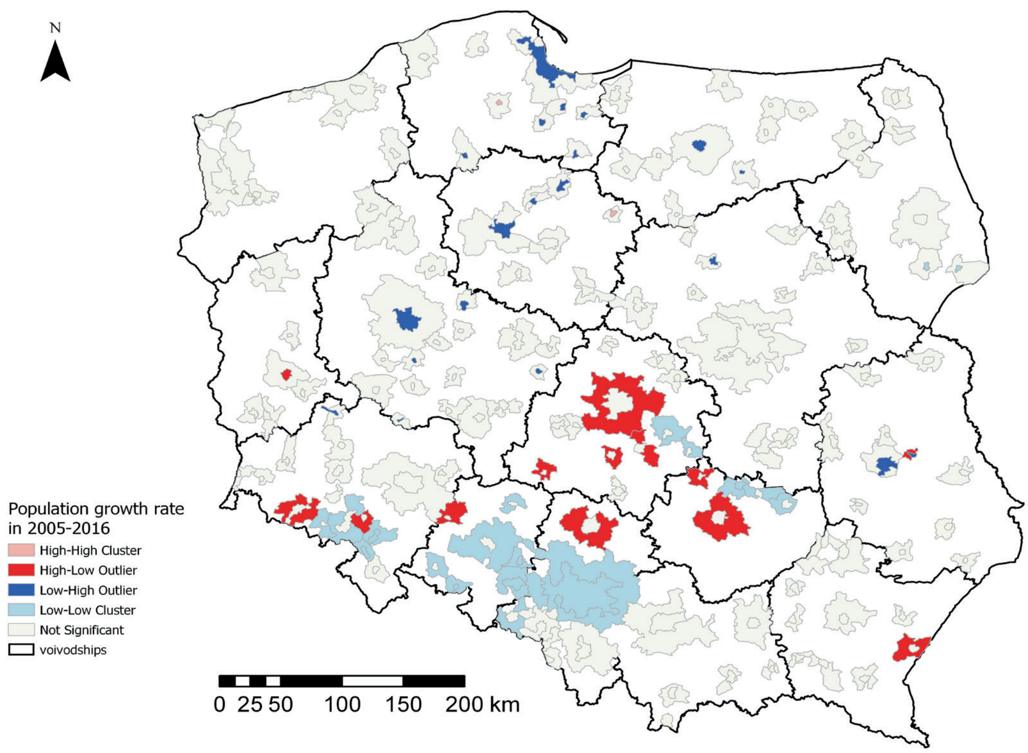


Fig. 4. Anselin Local Moran's I statistics for population growth in the years 2005-2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

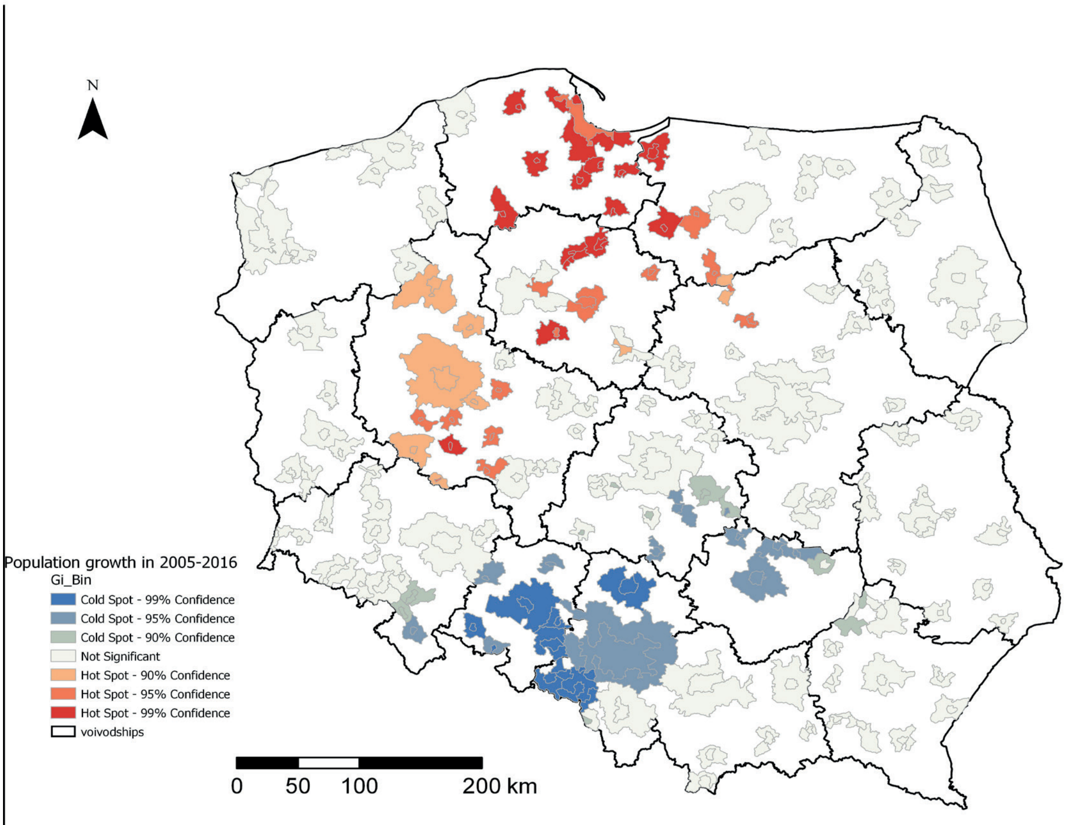


Fig. 5. Getis-Ord Gi* statistics for population growth in the years 2005-2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

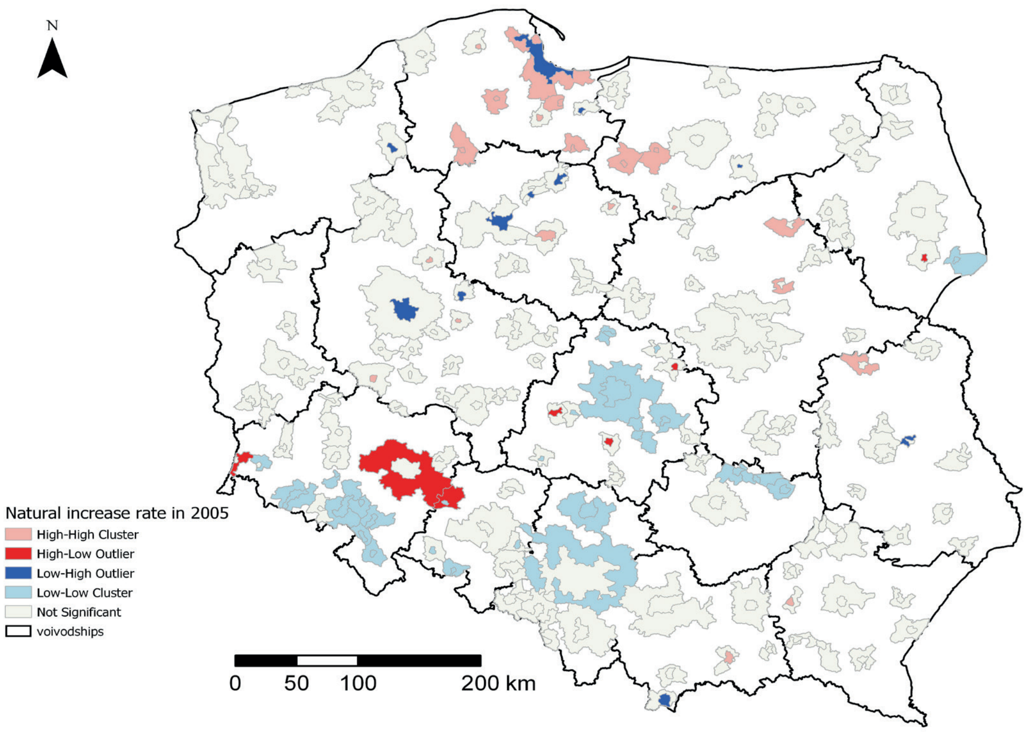


Fig. 5. Anselin Local Moran's I statistics for natural increase rate in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

rate of natural increase surrounded by units with similar values were found in the Upper and Lower Silesia regions, comprising former hard coal mining areas, in the Łódź region (former textile centre) and in the Kamienna river valley (former Old Polish Industrial District with a predominance of metallurgy and machinery industries; Fig. 6). The Getis-Ord Gi* analysis shows the hot spots and cold spots of natural increase in a clearer way. FUAs located in the Pomorskie, Warmińsko-Mazurskie, Kujawsko-Pomorskie, Wielkopolskie and partly in the Małopolskie Voivodships formed clusters with high values of rate of natural increase, while the areas of the Łódzkie, Podlaskie, Śląskie, Opolskie and Dolnośląskie Voivodships (especially the Sudeten region) formed clusters with low values of the feature concerned (Fig. 7).

When comparing local Moran's *I* calculated for the rate of natural increase for 2005 and 2016, there is an observable increase in the range of HH clusters, which, in addition to comprising the Pomorskie Voivodeship, also came to cover FUAs located in the Wielkopolskie Voivodship (including Poznań – the region's capital). On the other hand, clusters with low values of the feature concerned (LL) shrank, and their range ceased to include areas located in the Upper Silesian-Zagłębie Metropolis, where heavy industry and hard coal mining are no longer the dominant sectors of the economy (Fig. 8). This area as a whole no longer represents such negative demographic processes as depopulation, natural population decrease, migration, and population ageing. In post-industrial areas which developed higher-order services, the demographic situation diversified and suburbanisation processes, including internal suburbanisation, developed (Spórna 2018, Krzysztofik et al. 2017). As revealed by the Getis-Ord Gi* statistic, the pattern of hot spots and cold spots in both periods did not change significantly (Fig. 9).

As regards the net migration rate, based on the local Moran statistic for 2005, the greatest number of clusters were observed in the commuting zones of medium-sized FUAs, and they were high-low (HL) clusters. The clusters testify to far-reaching suburbanisation processes and differences in net migration between the cores of FUAs and their fringes. Currently, suburbanisation is the most advanced

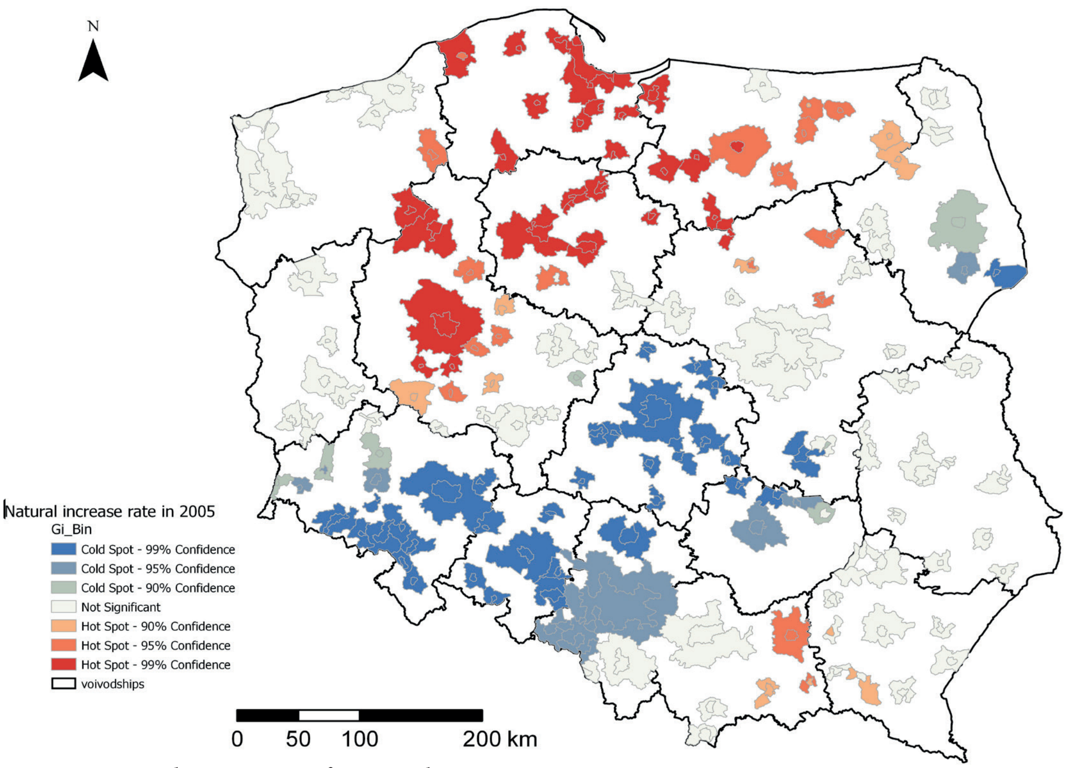


Fig. 7. Getis-Ord Gi* statistics for natural increase rate in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

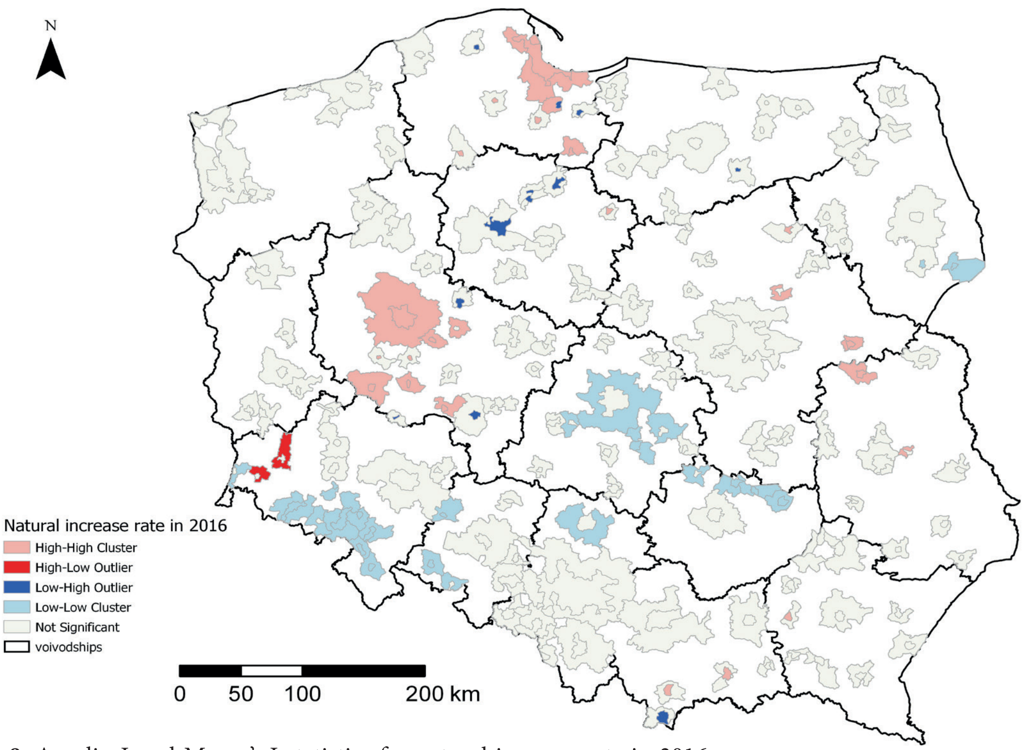


Fig. 8. Anselin Local Moran's I statistics for natural increase rate in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

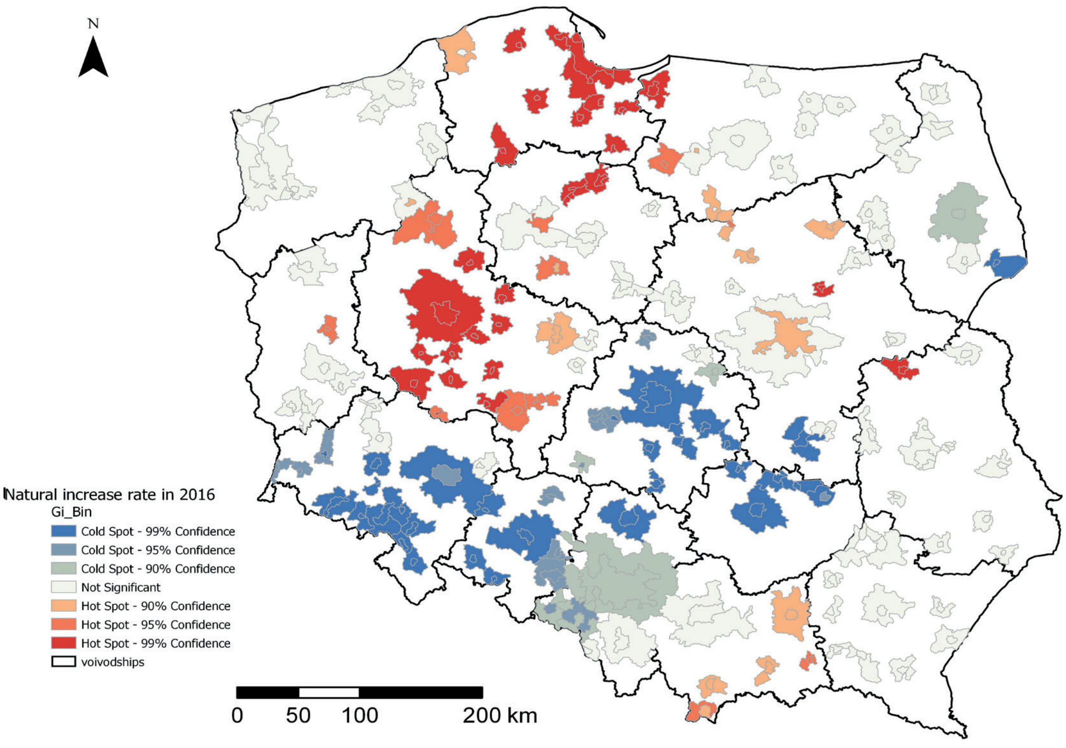


Fig. 9. Getis-Ord Gi* statistics for natural increase rate in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

in medium-sized centres (with up to 100,000 inhabitants) since the cores of the largest cities are also attractive for people coming from the outside. Therefore, these largest FUAs do not form clusters, and the differences for the net migration rate are statistically insignificant. Some large FUAs are concentrated in clusters of the LH type (e.g. Gdańsk, Poznań, Bydgoszcz, and Toruń). In 2016, an increase in the number of HL clusters and a decrease in the number of LH clusters were observed. Furthermore, high-high (HH) clusters appeared in the core of Wrocław and the Tri-City, which is indicative of high values of the balance of migration both to the cores and commuting zones. The Getis-Ord Gi* statistic shows a concentration of hot spots in the northern part of the country, in the area with favourable demographic trends (in the Pomorskie and Kujawsko-Pomorskie Voivodships). In 2016, the number of hot spot clusters decreased, but they occurred in three voivodships, including also some FUAs in the Wielkopolskie Voivodship. On the other hand, in the years 2005-2016 there was an increase in the number of cold spots in the Świętokrzyskie Voivodship (Kielce – the capital of the region and the former industrial district in the Kamienna River valley), and in the Podkarpackie Voivodship in south-eastern Poland (Fig. 10–13).

The elderly dependency ratio shows the relationship between elderly people and the workforce. Clusters of units with high values of this indicator surrounded by units with similar values in 2005 (HH) were concentrated in several formerly industrial FUAs (Łódź, Kamienna River valley, the Sudeten region) and in a peripheral FUA in north-eastern Poland (Podlaskie Voivodship). In addition, several HL clusters were also identified, mainly in the cores of large cities (Tri-City, Szczecin, Poznań, Bydgoszcz). LL clusters were found in 5 provinces. Several LH clusters were identified in the Podlaskie Voivodship, where the cores of relatively smaller FUAs with low values of the ratio were surrounded by outer zones characterised by advanced ageing

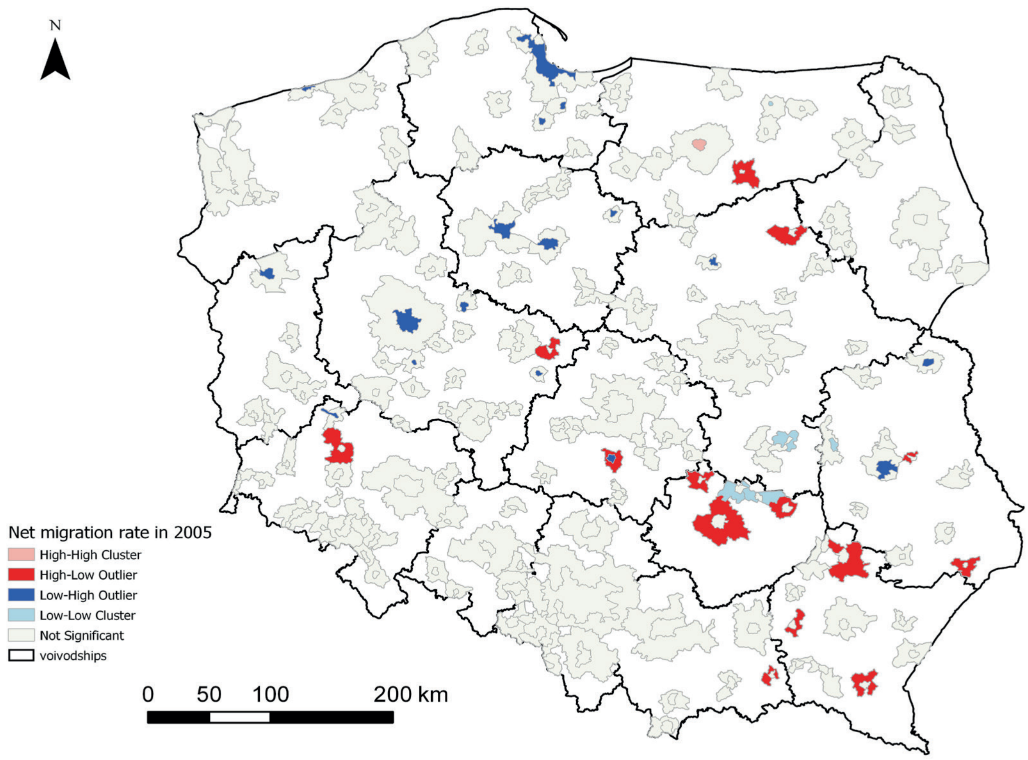


Fig. 10. Anselin Local Moran's I statistics for net migration rate in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

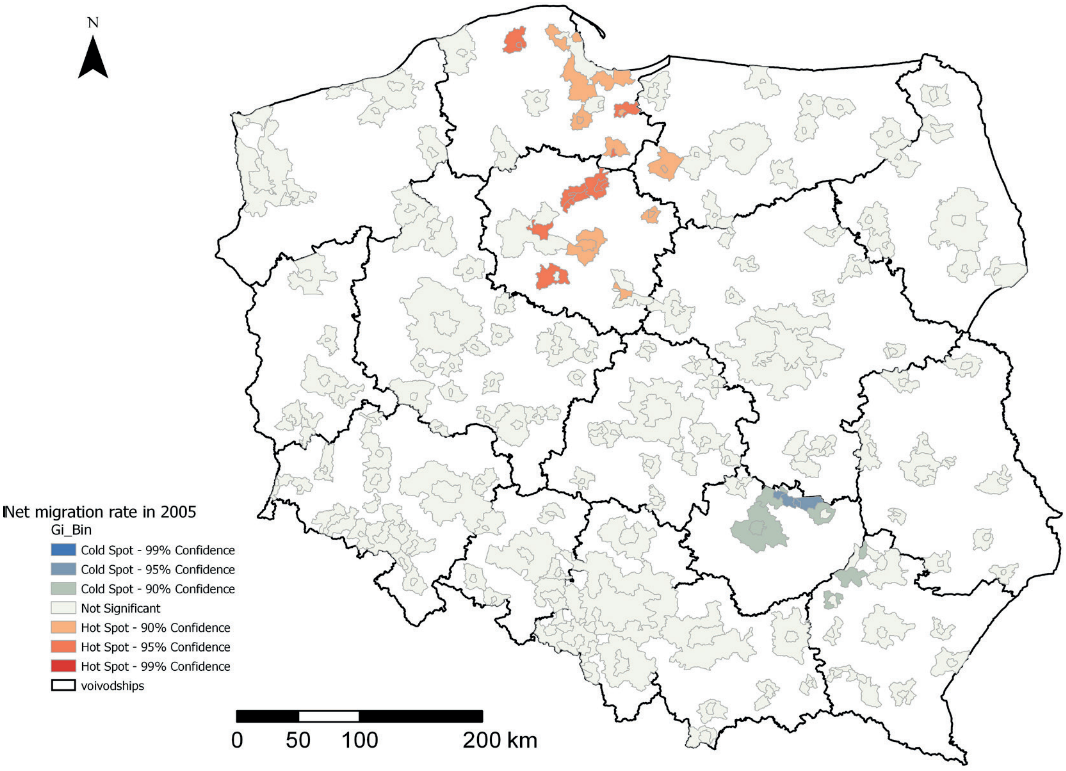


Fig. 11. Getis-Ord Gi* statistics for net migration rate in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

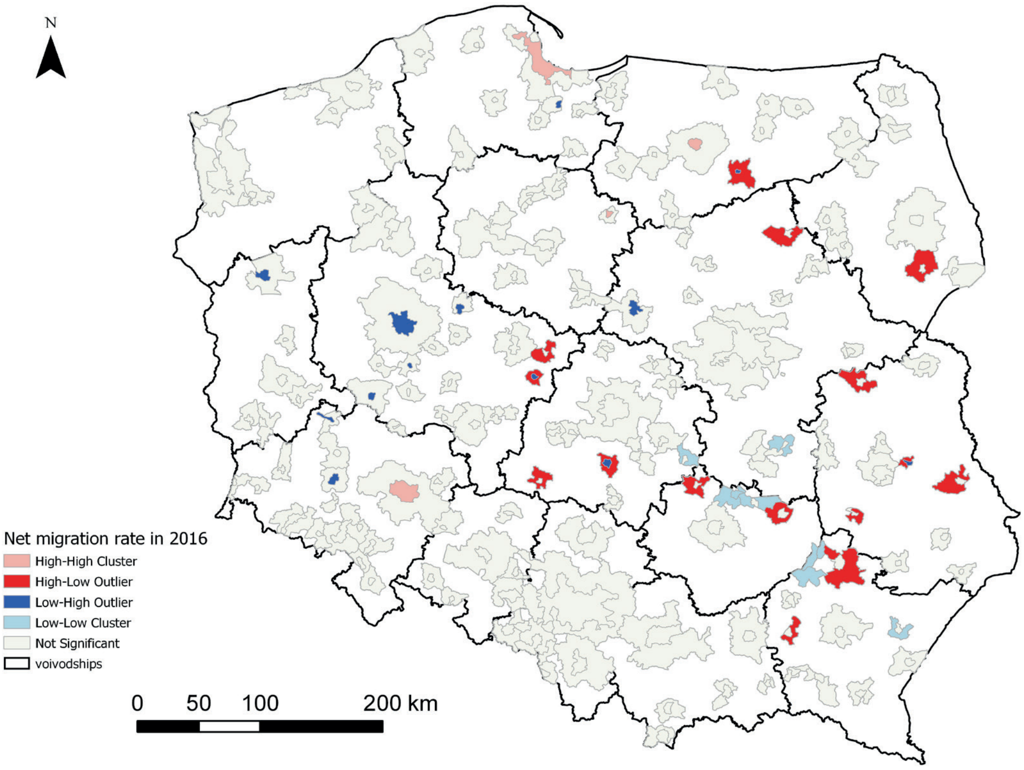


Fig. 12. Anselin Local Moran's *I* statistics for net migration rate in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

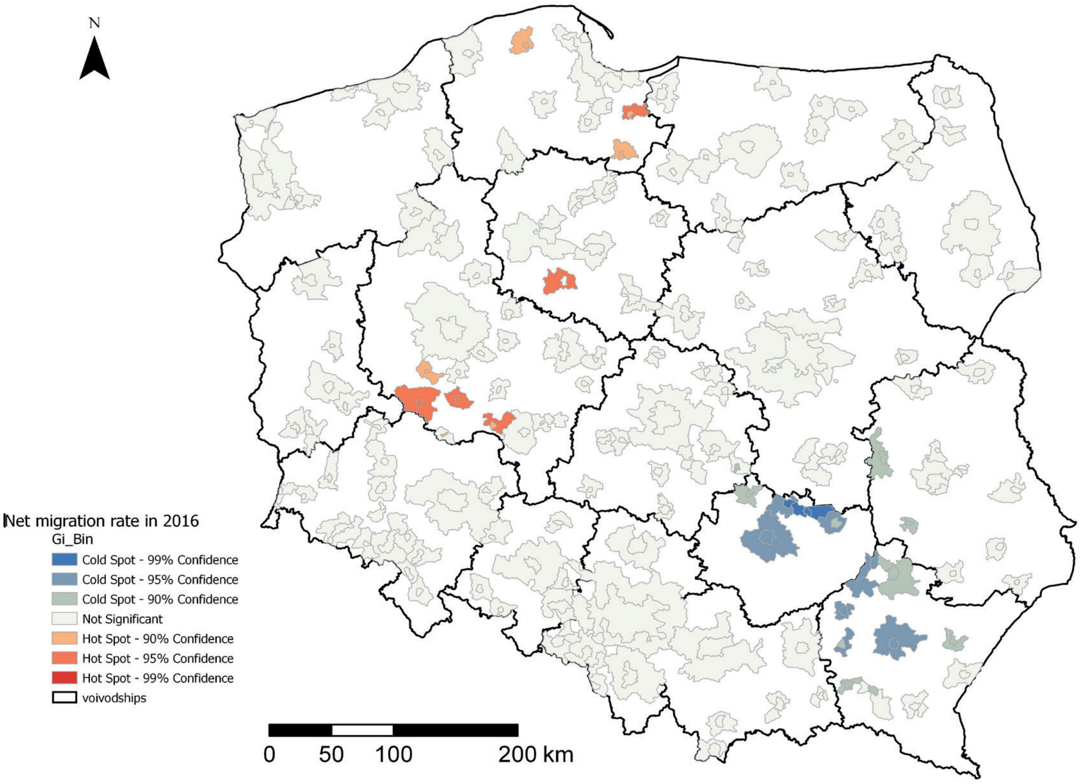


Fig. 13. Getis-Ord Gi* statistics for net migration rate in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

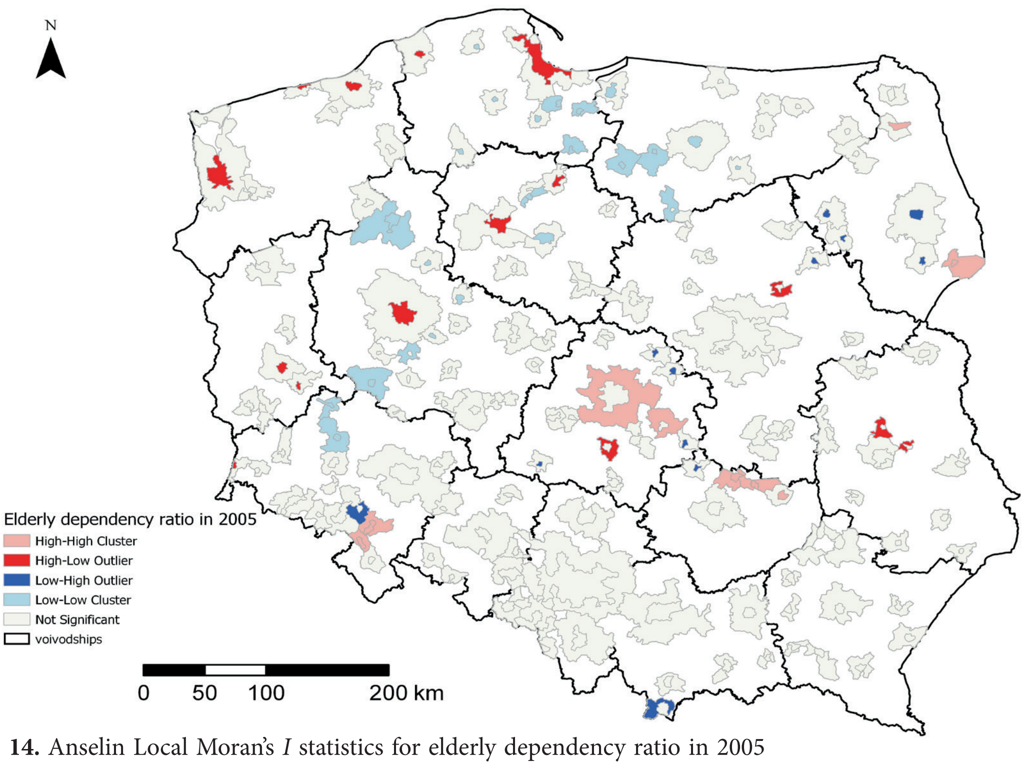


Fig. 14. Anselin Local Moran's *I* statistics for elderly dependency ratio in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

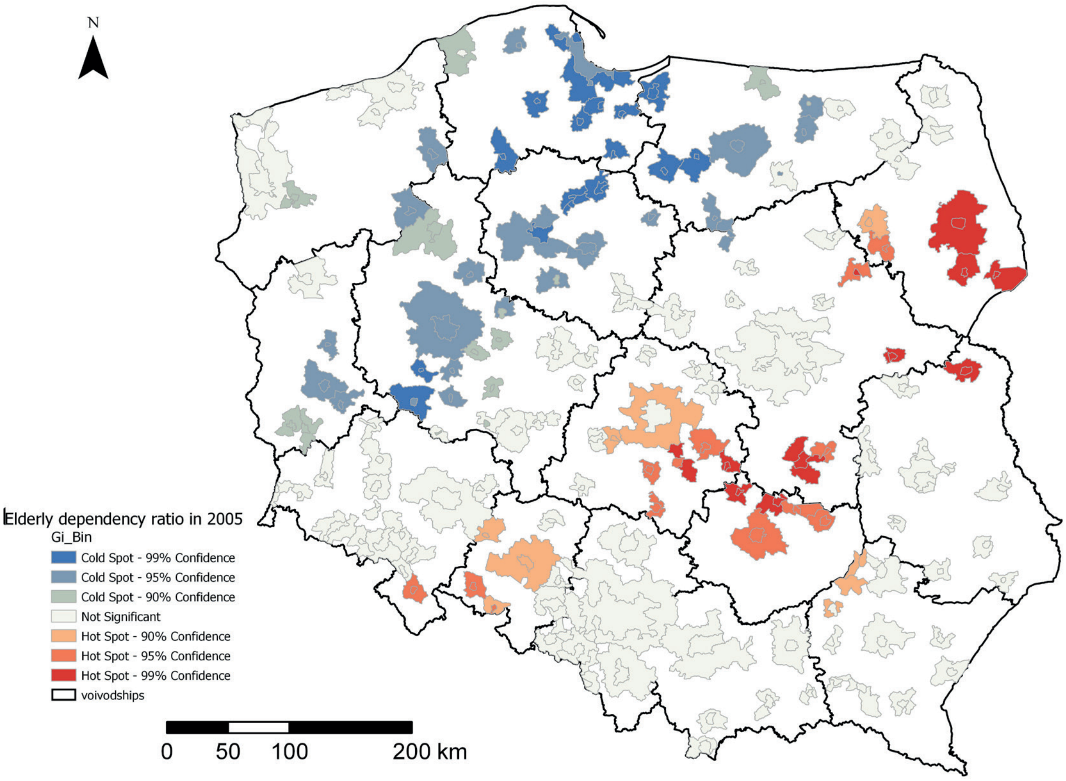


Fig. 15. Getis-Ord Gi* statistics for elderly dependency ratio in 2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

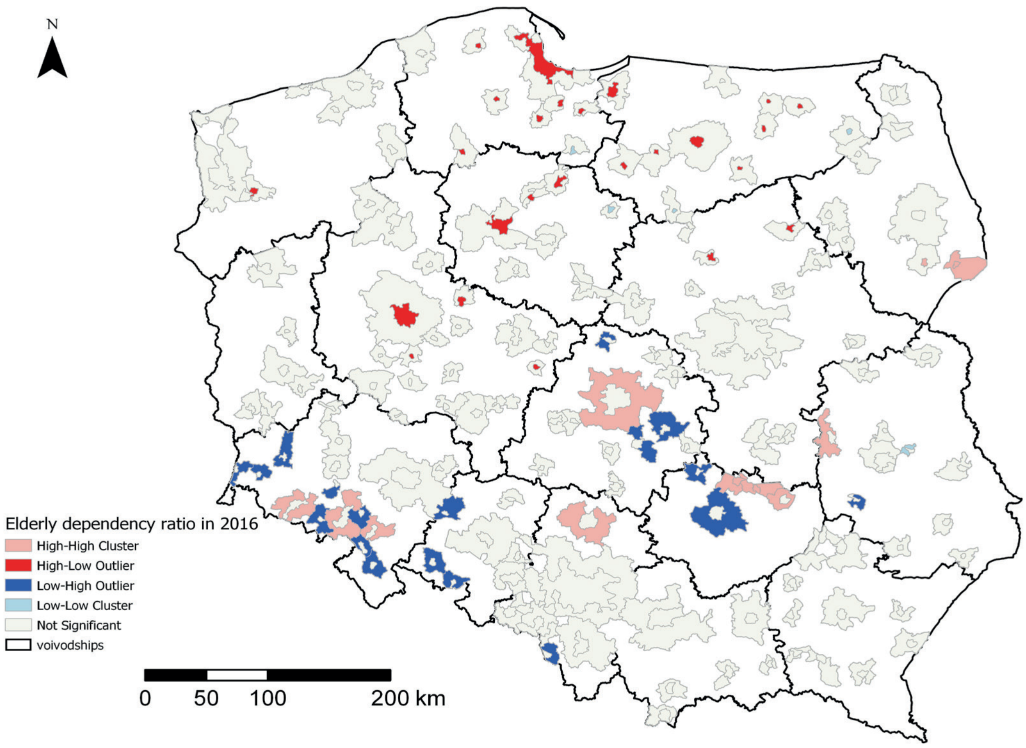


Fig. 16. Anselin Local Moran's *I* statistics for elderly dependency ratio in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

processes. In 2016, there was an expansion mainly affecting the range of LH clusters which comprised parts of the Sudeten Mountains and areas of the Świętokrzyskie and Łódzkie Voivodships, where low values were recorded in the commuting zones, while the cores were characterised by a greater elderly dependency ratio (Fig. 14, 16).

The Getis-Ord Gi* analysis reveals a noticeable split into north-western Poland, which is typically younger in demographic terms, and central, eastern and south-western Poland. In 2016, the range of cold spots with relatively younger populations shrank to northern Poland (Warmińsko-Mazurskie and Pomorskie Voivodships), while clusters with a high dependency ratio were mainly found in south-western Poland (Fig. 15 & 17).

Based on the population ageing dynamics in 1990-2005, it can be seen that sporadic HH clusters were found in north-western and south-western Poland (Zachodniopomorskie and Dolnośląskie Voivodships). Areas considered previously to be younger demographically, started to age intensively in the period of socio-economic transformation. An increase in the economic ageing index also took place in the eastern part of the country, but it was seen in the cores of smaller FUAs surrounded by areas with poor dynamics of the process being examined (HL outliers). By contrast, LH outliers were mainly located in the south-western part of the country (Fig. 18). A completely different spatial pattern was observed in the next period under investigation, namely 2005-2016. A low-low cluster (LL) was clearly noticeable in the largest FUAs (Warsaw, Łódź, Poznań, and Wrocław). As a result of the processes of suburbanisation, as well as of reurbanisation, which were most pronounced in large agglomerations, there was a decline in the rate of ageing. A growth of recentralisation processes is observed in the cores of the largest agglomerations in Western Europe (Haase et al. 2005, Kabisch and Haase 2011) and is associated with their attracting young, qualified professionals (yuppification), as well as students, to university cities (studentification). The processes of suburbanisation

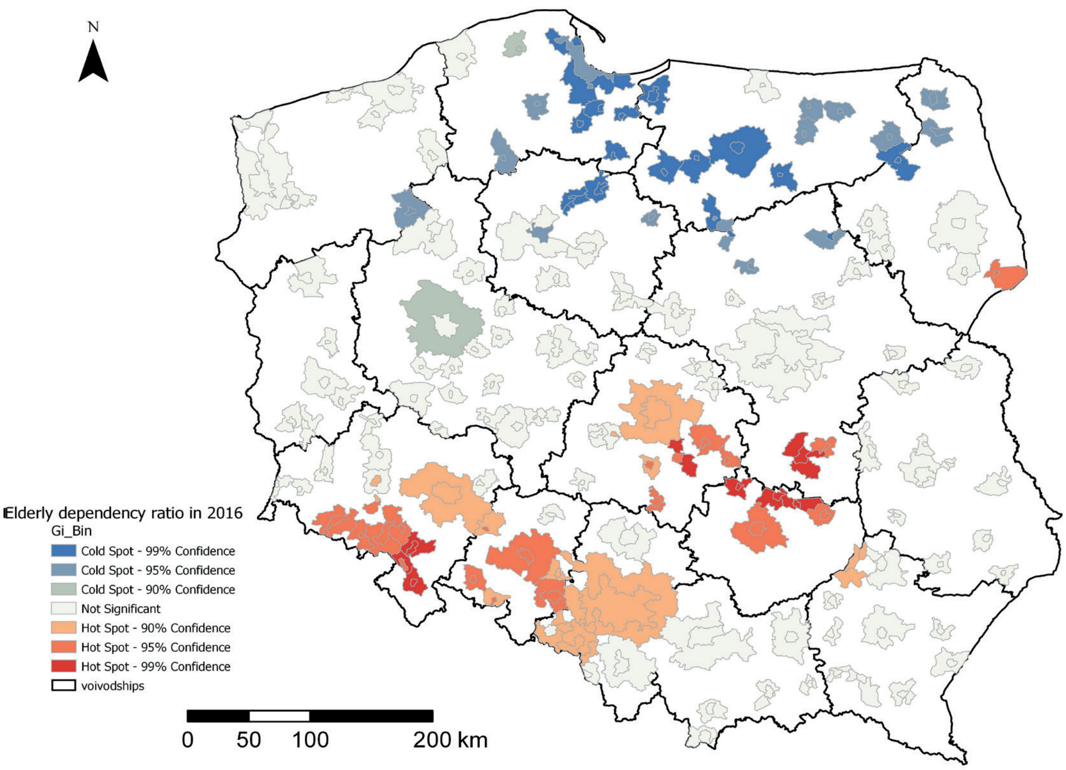


Fig. 17. Getis-Ord Gi* statistics for elderly dependency ratio in 2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

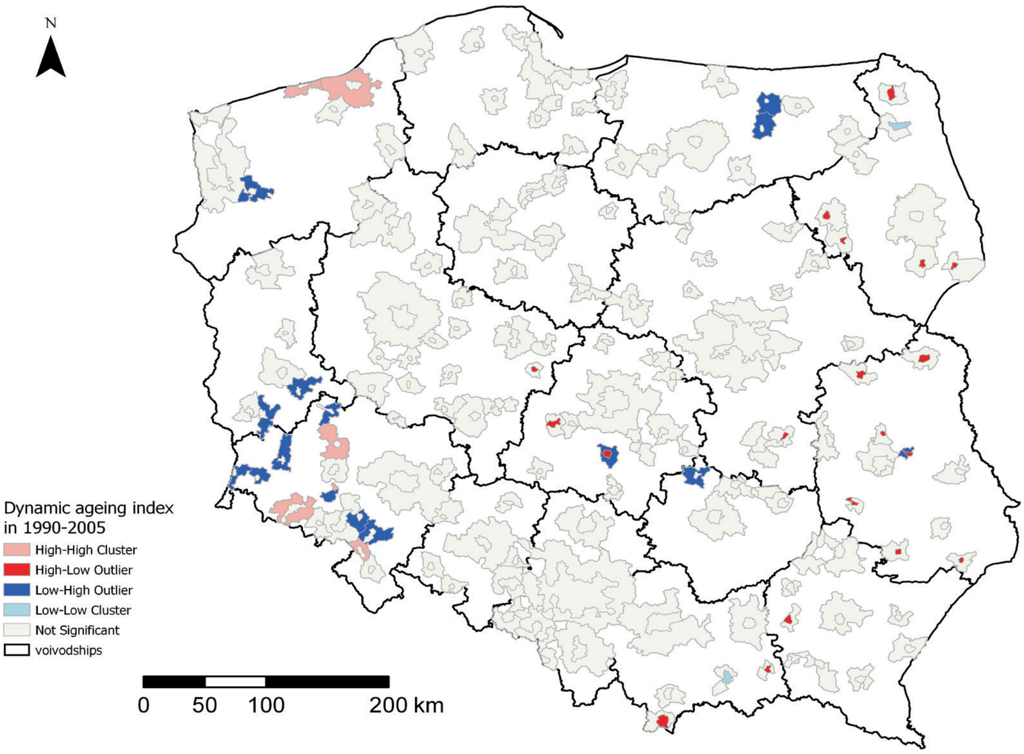


Fig. 18. Anselin Local Moran's *I* statistics for dynamic ageing index in1990-2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

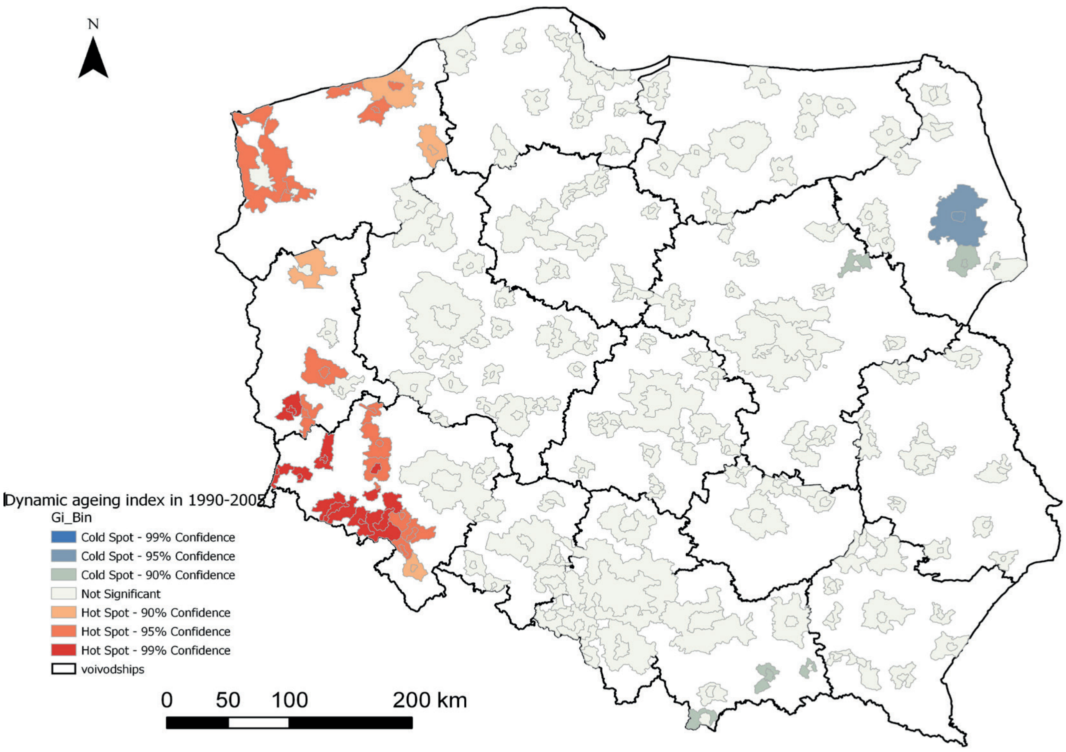


Fig. 19. Getis-Ord Gi* statistics for dynamic ageing index in 1990-2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

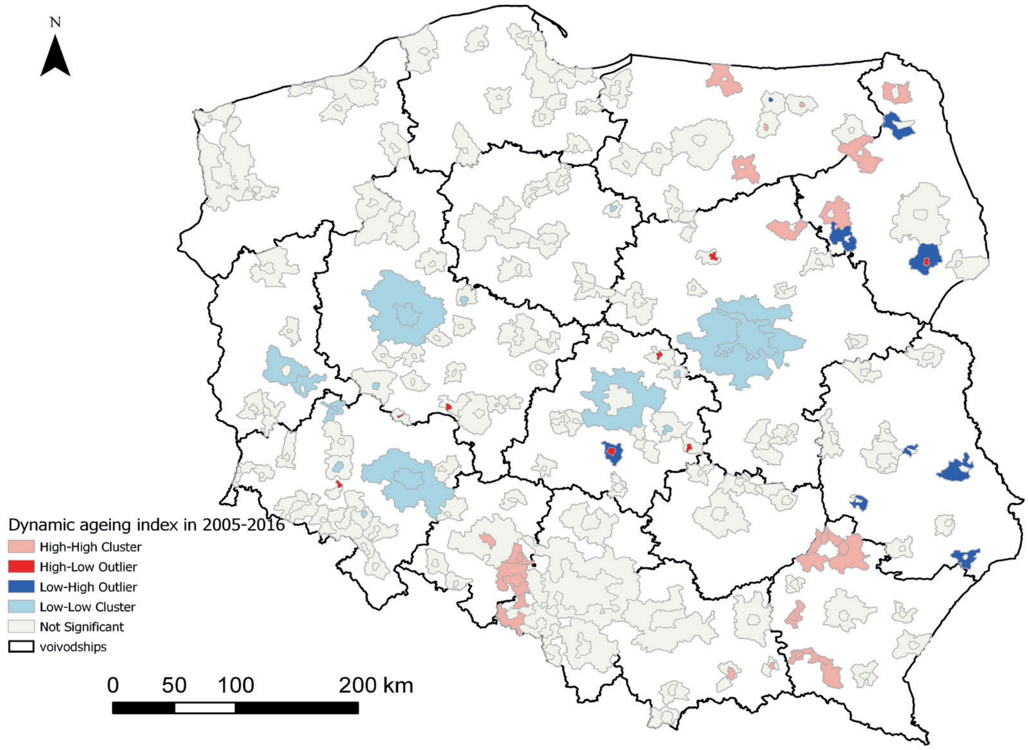


Fig. 20. Anselin Local Moran's I statistics for dynamic ageing index in 2005-2016
Source: own study on the basis of data from Central Statistical Office in Warsaw.

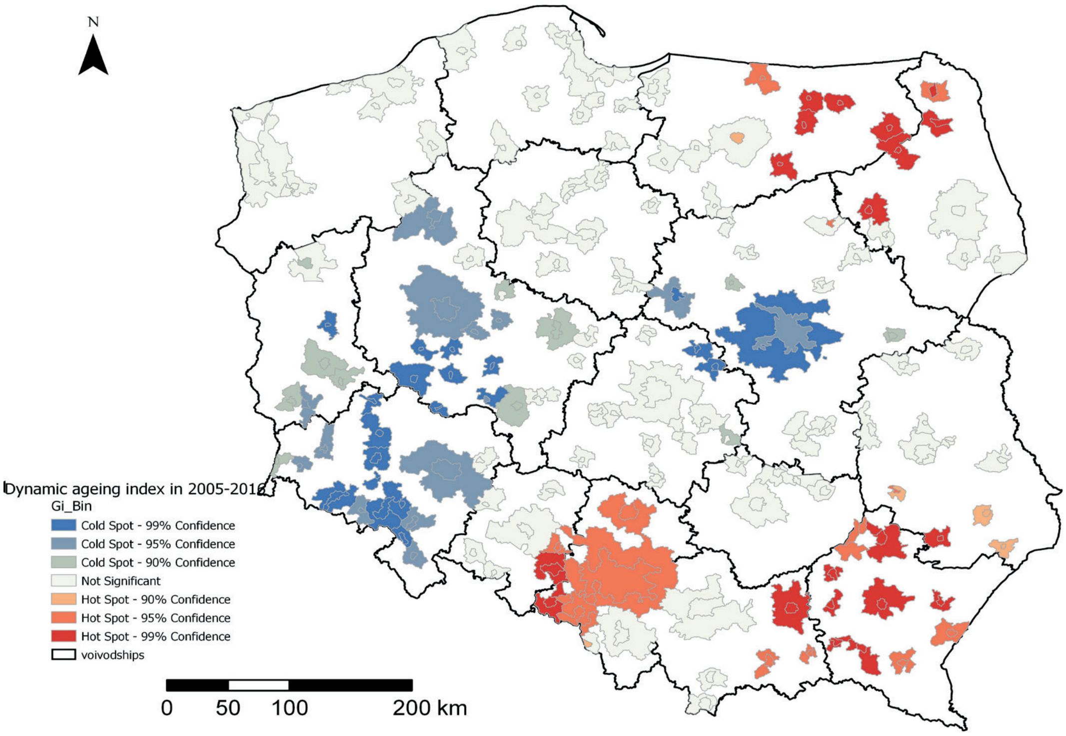


Fig. 21. Getis-Ord Gi* statistics for dynamic ageing index in 1990-2005
Source: own study on the basis of data from Central Statistical Office in Warsaw.

and reurbanisation can now occur simultaneously, disrupting the traditional urban development cycle as described by van den Berg (van den Berg et al., 1982). HH clusters were also observed in the case of smaller peripherally-located FUAs (as in the case of LH clusters; Fig. 20).

Interesting changes were also revealed by the Getis-Ord Gi* analysis. In the period 1990-2005, hot spots with high dynamics of population ageing were located in the voivodships of western Poland, while cold spots, which indicated a slowdown of this process, were observed in the Podlaskie Voivodship (north-western part of the country; Fig. 19). In the period 2005-2016, the spatial clusters with the highest ageing dynamics were identified in north-eastern and south-eastern Poland (i.e. where the economic ageing index had been low) and in Upper Silesia, where in-migration in the post-industrial areas had stopped. On the other hand, cold spots indicative of clusters with a low economic ageing index were located in the capital city region, in the Wielkopolskie Voivodship (including the Poznań FUA), as well as in the Dolnośląskie Voivodship (south-western Poland; Fig. 21).

5. Discussion and conclusions

Our findings implied that demographic processes in Functional Urban Areas in Poland, namely population growth, natural increase, net migration and population ageing showed spatial autocorrelation both globally and locally. This means that there are spatial dependencies in relation to the whole area (FUA's in total) and in relation to adjacent locations. The spatial autocorrelation methods (global and local Moran's I statistic, and the Getis-Ord Gi* method) identified the global and local spatial relationships for existing functional urban areas (FUAs) representing different demographic variables. The methods identified units with similar values (hot spots and cold spots), as well as outliers, i.e. units surrounded by FUAs (or their cores or outer zones) with different values. The Global Moran's statistics showed that all demographic indicators (including population growth, natural increase, net migration rate as well as dependency ratios and dynamic ageing indexes) were statistically significant throughout the entire study period (2005-2016) and revealed (moderate or weak) spatial autocorrelation in the case of the variables tested. Positive autocorrelation in both time periods was recorded only in case of natural increase rate while negative autocorrelation occurred both in 2005 and 2016 in case of natural migration rate. A positive character of natural increase rate means that there is a tendency to cluster municipalities with a similar indicator. Natural increase and fertility patterns are usually associated with cultural background and more spatial clusters with similar values may appear.

Migration rates, on the other hand, are more differentiated, especially between urban and rural areas as well as within metropolitan areas (between the core and the fringes) as a result of suburbanisation. In the whole period under study a relative increase in the correlation coefficient was recorded for natural increase (positive values), while the net migration recorded weakening of the negative spatial correlation. On the other hand, population growth rate and elderly dependency ratio changed its correlation from positive to negative, that is more disparities occurred in their spatial layout. Dynamic ageing index recorded the change from negative to positive values. It means that changes in the shares of young and old population are more spatially concentrated that they used to be before.

An analysis of local spatial autocorrelation statistics revealed a division into northern and north-western Poland, which is characterised by more favourable demographic trends (both in terms of overall population dynamics and its components, i.e. rate of natural increase and net migration rate) and eastern and south-western Poland, which is affected by negative demographic processes (population ageing, depopulation). In addition, there was a discernible split into cores and outer zones resulting from suburbanisation, and even reurbanisation, which is observable in the largest conurbations.

Comparing two main components of total population growth it must be said that functional urban areas by natural increase rate show much more tendency to clustering than by net migration rates. Migration rates are much more diversified, especially between the cores and fringes which results from population decentralization from the central cities to the adjacent areas. A high degree of dissimilarity is shown by elderly dependency rations which results from differences in the level of population ageing between urban, suburban and rural areas.

The study showed that spatial autocorrelation methods can be useful in an analysis of demographic variables including changes in time. Using both local methods (the hot spot analysis and cluster and outlier analysis) can be complementary as the former can establish two groups with a different level of confidence while the latter allows to detect both groupings and the areas where anomalies exist. Although there were a couple of research papers about spatial autocorrelation of socio-demographic variables in Poland (e.g. Zeug-Żebro 2014, Pośpiech, Mastalerz-Kodzis 2015, Walford, Kurek 2016, Miśkiewicz-Nawrocka, Zeug-Żebro 2017, Majdzińska 2018), none of them concerned Functional Urban Areas by municipalities. Especially, spatial autocorrelation methods can be useful in analysis of spatial clusters of areas undergoing second demographic transition, urban development (e.g. suburbanisation process) or demographic shrinkage areas (Segers et al 2020). Spatial autocorrelation can also serve as a tool of delimitation of continuity of the spatial urban landscape leading to delineate of functional economic zones of urban agglomeration based on functional interconnectivity or demographic homogeneity (Chuanglin & Danlin 2017).

This research has some limitations due to the fact that areas that are not significant span a vast zone stemming from the few number of neighbours in some cases as some FUAs are separated by rural areas which were not taken into account. On the other hand, difficulties in making homogenous groupings may be due to heterogeneous nature of variables under study and different factors may contribute to spatial clustering.

The main contribution of this study to the research on demographic processes in urban areas was an application of spatial groupings techniques not only to find out similarity and dissimilarity patterns of demographic indicators but also to apply this findings for the needs of spatial planning. Methods of spatial statistics can therefore support the identification of areas that are characterized by similar or different values of the studied variables, which allows monitoring and spatial planning of the Functional Urban Areas.

References

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

Buzar, S. Ray, H. Ogden, P.E. (2007). Beyond gentrification: the demographic reurbanisation of Bologna. *Environment and Planning A*, 39(1), 64–85. https://doi.org/10.1068/a39109.

Chuanglin, F. Danlin, Y. (2017). Urban agglomeration: An evolving concept of an emerging phenomenon, *Landscape and Urban Planning*, 162, 126–136, https://doi.org/10.1016/j.landurbplan.2017.02.014.

Serván-Mori E., Mendoza M. A., Chivardi C., Pineda-Antúnez C., Rodríguez-Franco R., Nigenda G. (2019). A spatio-temporal cluster analysis of technical efficiency in the production of outpatient maternal health services and its structural correlates in México. *The International Journal of Health Planning and Management*, 34(4): e1417-e1436. https://doi.org/10.1002/hpm.2785

Fotheringham, A. S. (2009). The problem of spatial autocorrelation and local spatial statistics. *Geographical Analysis,* 41: 398-403.

Getis, A. (2008). A history of the concept of spatial autocorrelation: a geographer's perspective. *Geographical Analysis*, 40: 297–309.

Getis, A. Ord, J.K. (1992). The analysis of spatial association by distance statistics. *Geographical Analysis,* 24(3), 189–206.

Ghosh P. Cartone A. (2020). A Spatio-temporal analysis of COVID-19 outbreak in Italy. *Regional Science Policy & Practice*, 12 (6), 1047-1062. https://doi.org/10.1111/rsp3.12376

Gil-Alonso, F. Bayona-i-Carrasco, J. and Pujadas-i-Rúbies, I. (2016). From boom to crash: Spanish urban areas in a decade of change (2001–2011). European *Urban and Regional Studies*, 23(2): 198-216.

Haase, A. Kabisch, S. & Steinführer, A. (2005). Reurbanisation of inner-city areas in European cities: Scrutinizing a concept of urban development with reference to demographic and household change. In I. Sagan, D.M. Smith (Eds.), Society, Economy, Environment – Towards the Sustainable City (pp. 75–91). Gdańsk, Poznań: Bogucki Wydawnictwo Naukowe.

Haase, A., Steinführer, A. Kabisch, S. Buzar, S. Hall, R. & Ogden, P.E. (2010). Emergent spaces of reurbanisation: exploring the demographic dimension of innercity residential change in a European setting. Population, *Space and Place*, 16(5): 443–463. https://doi.org/10.1002/psp.603.

Janc, K. (2006). The phenomenon of spatial autocorrelation on the example of I Moran's statistics and local indicators of spatial dependence (LISA) - selected methodological issues - (in Polish) In T. Komornicki, & Z. Podgórski (Eds.), Idee i praktyczny uniwersalizm geografii, *Dokumentacja Geograficzna*, 33, 76-83, Warszawa: IGiPZ PAN.

Kabisch, N. Haase, D. (2011). Diversifying European Agglomerations: Evidence of Urban Population Trends for the 21st Century. Population, *Space and Place,* 17: 236–253. https://doi.org/10.1002/psp.600.

Karasavvoglou, A. Polychronidou, P. (eds) (2014). Economic crisis in Europe and the Balkans problems and prospects. Dordrecht: Springer.

Klaassen, L.H. Scimeni, G. (1981). Theoretical Issues In Urban Dynamic. In: L.H. Klaassen, W.T.M. Molle, J.H.P. Paelinck (Eds.), Dynamic of Urban Development (pp. 8–28). Gower: Hants.

Kołodziejczak, A. Kossowski, T. (2016). Using the spatial autocorrelation method to analyse poverty in rural areas (in Polish), *Wiadomości Statystyczne* 10(665), 22-32.

Krzysztofik, R. Kantor-Pietraga, I. Runge, A. Spórna, T. (2017). Is the suburbanisation stage always important in the transformation of large urban agglomerations? The case of the Katowice conurbation. *Geographia Polonica,* 90(2,): 71-85.

Kulu, H. Boyle, P. J. (2009). High Fertility in City Suburbs: Compositional or Contextual Effects? *European Journal of Population*, 25(2), 157–174. doi: http://dx.doi.org/10.1007/s10680-008-9163-9.

Kulu, H. Boyle, P. J. Andersson, G. (2009). High suburban fertility: Evidence from four Northern European countries. *Demographic Research*, 21(31), 915–944. http://dx.doi.org/10.4054/DemRes.2009.21.31.

Kulu, H. & Washbrook, E. (2014). Residential Context, Migration and Fertility in a Modern Urban Society. *Advances in Life Course Research*, 21, 168–182. http://dx.doi.org/10.1016/j.alcr.2014.01.001.

Kurek, S. (2011a), Double transitions? Regional patterns of population ageing in Poland, *Geografiska Annaler: Series B, Human Geography*, 93 (2), 163–184.

Kurek, S. (2011b), Population Changes in Poland: A Second Demographic Transition View, Procedia - Social and Behavioral Sciences, 19, 389-396, Elsevier. The 2nd International Geography Symposium-Mediterranean Evironment 2010.

Kurek, S. Lange, M. (2013), Changes in reproductive behavior in Poland in spatial terms (in Polish), Wydawnictwo Naukowe Uniwersytetu Pedagogicznego, Kraków, ss. 160.

Kurek, S., Wójtowicz, M. (2018). Reurbanisation in a post-socialist city: spatial differentiation of the population in the Kraków Area (Poland). *Geographia Polonica,* 91(4), 449–468. https://doi.org/10.7163/GPol.0130.

Kurek, S. Gałka, J. Wójtowicz, M. (2014). The impact of suburbanization on the selected demographic structures and spatial-functional relationships in the Kraków Metropolitan Area (in Polish). Kraków: Wydawnictwo Naukowe Uniwersytetu Pedagogicznego.

Kurek, S. Wójtowicz, M. Gałka, J. (2015). The changing role of migration and natural increase in suburban population growth: The case of a non-capital post-socialist city (The Krakow Metropolitan Area, Poland), *Moravian Geographical Reports*, 23(4): 59–70. doi: 10.1515/mgr-2015-0025.

Kurek, S. Wójtowicz, M. Gałka, J. (2020). Functional Urban Areas in Poland. Demographic trends and migration patterns. The Urban Book Series. Springer, Cham; https://doi.org/10.1007/978-3-030-31527-6

Lloyd C.D. (2014). Assessing the spatial structure of population variables in England and Wales. *Transactions of the Institute of British Geographers*, 40 (1): 28-43. https://doi.org/10.1111/tran.12061

Leetmaa, K. Tammaru, T. (2007). Suburbanisation in countries in transition: Destinations of suburbanisers in the Tallinn metropolitan area. *Geografiska Annaler Series B: Human Geography*, 89(2): 127–146. http://dx-.doi.org/10.1111/j.1468-0467.2007.00244.x.

Leetmaa, K. Tammaru, T. and Anniste, K. (2009). From priority-led to market-led suburbanization in a post-communist metropolis. *Tijdschrift voor economische en sociale geografie*, 100(4): 436–453. http://dx-.doi.org/10.1111/j.1467-9663.2009.00551.x.

Lesthaeghe, R. (2010) The Unfolding Story of the Second Demographic Transition. *Population and Development Review*, 36: 211–251. doi: 10.1111/j.1728-4457.2010.00328.x.

Long, J. Robertson, C. (2017). *Comparing spatial patterns. Geography Compass*, 12: 27-41.

Majdzińska, A. (2018). Spatial measures of development in evaluating the demographic potential of Polish counties. *Statistics in Transition*, 19(3): 453-475.

Matthews, S. A. Parker, D. M. (2013). Progress in spatial demography. *Demographic Research,* 28(10): 271–312. https://doi.org/10.4054/DemRes.2013.28.10

Novák, J. Sýkora L. (2007). A city in motion: Time-space activity and mobility patterns of suburban inhabitants and the structuration of the spatial organization of the Prague metropolitan area. *Geografiska Annaler B*, 89(2): 147–167.

Oliveau, S. Guilmoto, C. (2005). Spatial correlation and demography. XXVe Congrès International de la Population.

Ouředníček, M. (2007). Differential suburban development in the Prague Urban Region. *Geografiska Annaler B*, 89(2): 111–126. http://dx.doi.org/10.1111/j.1468-0467.2007.00243.x.

Pośpiech, E. Mastalerz-Kodzis, A. (2015). Spatial dependences of selected social and economic charateristics (in Polish). *Metody ilościowe w badaniach ekonomicznych*, 16(4,): 85-94.

Raymer, J. Willekens, F. Rogers A. (2018). Spatial demography: A unifying core and agenda for further research. Population, *Space and Place*, 25(4): e2179. https://doi.org/10.1002/psp.2179

Rèrat, P. (2012). The New Demographic Growth of Cities: The Case of Reurbanisation in Switzerland. *Urban Studies*, 49(5): 1107–1125.

Sobotka, T. (2008). The diverse faces of the second demographic transition in Europe. *Demographic Research*, 19: 171–224.

Spórna, T. (2018). The suburbanisation process in a depopulation context in the Katowice conurbation, Poland. *Environmental & Socio-economic Studies*, 6(1), 57–72.

Segers, T. Devisch, O. Herssens, J. and Vanrie, J. (2020) Conceptualizing demographic shrinkage in a growing region – Creating opportunities for spatial practice. *Landscape and Urban Planning*, 195, https://doi.org/10.1016/j.landurbplan.2019.103711.

Śleszyński, P. (2013) Demographic changes in the functional urban areas in Poland, 2000–2010. *Geographia Polonica*, 86(2): 169–170. http://dx.doi.org/10.7163/GPol.2013.16

Śleszyński, P. Wiśniewski, R. and Szejgiec-Kolenda, B. (2018). Demographic processes in Poland in the years 1946-2016 and their consequences for local development: Current state and research perspectives. *Geographia Polonica* 91(3): 317-334. https://doi.org/10.7163/GPol.0123

Turok, I. Mykhnenko, V. (2006). Resurgent European cities? *GaWC Research Bulletin* 216(A).

Walford, N. Kurek, S. (2016). Outworking of the second demographic transition : national trends and regional patterns of fertility change in Poland, England and Wales 2002-2012. Population, *Space and Place*, 22(6), 508–525, DOI: 10.1002/psp.1936.

Woźniak, A. Sikora, J. (2007). Spatial autocorrelation of water supply and sewage disposal infrastructure indicators in the małopolskie province (in Polish). . *Komisja Technicznej Infrastruktury Wsi*, 4(2): 315–329, Polska Akademia Nauk, Oddział w Krakowie.

Yusuf, F. Martins, J.M. and Swanson, D.A. (2014). Methods of demographic analysis. Springer, Dordrecht.

Zborowski, A. (2007). Reterritorialization of migration in the regional and local system in South-Eastern Poland (in Polish) In: Przekształcenia regionalnych struktur funkcjonalno-przestrzennych (pp. 371–382). Wrocław: Instytut Geografii i Rozwoju Regionalnego, Uniwersytetu Wrocławskiego.

Zeug-Żebro K. (2014). Spatial analysis of aging the Polish society (in Polish) Uniwersytet Szczeciński Zeszyty Naukowe nr 811, Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania nr 36. Metody Ilościowe w Ekonomii, t. 2: 441-456