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# SPATIAL MEASURES OF DEVELOPMENT IN EVALUATING THE DEMOGRAPHIC POTENTIAL OF POLISH COUNTIES

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## ABSTRACT

The study presents a demographic potential-based typology of Polish counties created using the spatial measures of development (available in the literature and proposed by the author). The typology reveals the location of Polish areas (regions) with the highest and lowest demographic potential.The analysis was performed on data sourced from the publications of the Central Statistical Office (GUS) on the age structure and selected developments in the natural movement and migrations in counties in the years 2005 and 2016.

**Key words:** synthetic measures of development, spatial measures of development, spatial autocorrelation, demographic potential.

## 1. Introduction

This article deals with the concept of spatial measures of development. Following an overview of the different approaches to their construction discussed in the literature, the measures' modifications proposed by the author are presented. To explain their practical use, a demographic potential-based typology of Polish counties is created.

The notion of demographic potential still awaits an unambiguous definition. Among the existing ones, one describes it as the "current weight of the population, its potential ability to grow under appropriate external conditions" (Ediev, 2001, p. 291). Demographic potential is generally understood in terms of the population's size, structure and events driving demographic processes. In this article, it is meant as the demographic equivalent of human capital[2] the qualitative and quantitative interpretation of which is determined by the size and age structure of a county's population, and the structure's changes caused by fertility and mortality variations and migrations. The knowledge of the demographic potential of an area (a region or a country) has practical importance as it provides

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[2] Human capital has many definitions (see, for instance, CIPD, 2017, pp. 5-6; Dawid, 2001, p. 22; Goldin 2016, p. 56; Kotarski, 2013, pp. 10-16; Roszkowska, 2013, pp. 11-16), most of which refer to demographic characteristics (age structure, fertility, mortality rates, etc.) and social characteristics (level of education, occupational structure, stock of knowledge, etc.) (Giza-Poleszczuk and Marody, 2000). One attempt at quantifying the global stock of human capital is *The Human Capital Report 2015*.

a point of reference for adjustments to ongoing population policies, helps design new ones, prompts the intensity and direction of the necessary actions, and helps quantify the likely impacts of changes in population size and structure.

The literature offers a range of methods for evaluating and measuring demographic potential, such as a descriptive approach using several demographic variables to compare the demographic potential of territorial units (see, for instance, Pastuszka, 2017; Obrębalski, 2017), or a synthetic approach involving the construction of measures and models (e.g. Ediev, 2001; Majdzińska, 2016; Scarpaci, 1984).

It is interesting to observe that many studies analyse variables characterising the demographic potential of an area (population size, age structure, reproduction rate, etc.) without referring to "demographic potential". Most of them compare the level of some phenomenon (e.g. a demographic situation) with areas using single variables such as the mortality rate or total fertility rate.

The data on the populations' age structure and selected developments related to natural movement and migrations in the years 2005 and 2016 were sourced from the publications of the Central Statistical Office (GUS)[3].

## 2. Methodology

The study presents three approaches to constructing a spatial measure of development. The first of them refers to the concept proposed by E. Antczak (2013). The other two approaches have been derived by the author from the first one by modifying the construction of the matrix of spatial weights.

The spatial measures of development derive from the synthetic measures that take account of spatial associations between objects and the existence of spatial autocorrelation defined as "the concentration of similar values, correlations or interactions between variables relating to the geographical location of objects" (Suchecki and Olejnik 2010, pp. 102–105; see also Griffith, 2003, pp.3).

### 2.1. Spatial autocorrelation

Spatial autocorrelation is therefore defined as the degree of "correlation of the values of the observed variable between two areas", meaning that the values "determine and are determined by [the variable's] realizations in other areas" (Suchecki and Olejnik, 2010, pp. 102–105)[4].

Positive spatial autocorrelations are represented by "the contiguity of high or low values of the observed variables" and negative spatial autocorrelations by „low values […] being contiguous to high values and vice versa".

Spatial autocorrelation can be considered in global or local terms (Suchecki and Olejnik, 2010, pp. 107–109, 112–113), which respectively denote "a spatial correlation of the analysed variable across an area" or "the dependency of the analysed variable […] on its surroundings, i.e. on its values in the contiguous areas".

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[3] The numbers of counties in 2005 and 2016 are different, because in the years 2003-2012 the town of Wałbrzych was part of Wałbrzyski powiat.

[4] See also: Getis (2010, p. 256) and Griffith (2003, p. 3).

A widely used measure of the global autocorrelation is Moran's *I* statistics, which allows testing a null hypothesis that „a spatial autocorrelation is not statistically significant" (meaning that the values of the analysed variable are randomly distributed in space) against an alternative hypothesis stating otherwise. Moran's *I* statistics for a row-standardised weight matrix is written as:

$$\mathrm{I} = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m} w_{ik}(x_i-\bar{x})(x_k-\bar{x})}{\sum_{i=1}^{m}(x_i-\bar{x})^2} = \frac{z^T W z}{z^T z} \tag{1}$$

where: $x_i$ , $x_k$ - values of variable *X* in the *i*-th and *k*-th object;

$w_{ik}$ - the spatial weight between objects *i* and *k*,

$\boldsymbol{z} = [z_1, z_2, \dots, z_m]^T$ with $z_i = x_i - \bar{x}$,

$\boldsymbol{W} = [w_{ik}]$ - the $m \times m$ matrix of spatial weights $w_{ik}$.

**Moran's *I* statistics** is interpreted similarly to the Pearson's linear correlation coefficient (Pearson's product moment – see Johnson, 1984, pp. 90-91).

A useful measure of local autocorrelation is local statistics (*LISA*) identifying "the statistically significant clusters of similar values in contiguous areas" (Suchecki and Olejnik, 2010, pp. 120–125). The most popular method within *LISA* is local Moran's $I_i$,, i.e. an *i*-th component of Moran's *I* statistics (1), given by the following formula:

$$\mathrm{I_i} = \frac{(x_i-\bar{x})\sum_{k=1}^{m} w_{ik}(x_k-\bar{x})}{\sum_{i=1}^{m}(x_i-\bar{x})^2} = \frac{z_i\sum_{k=1}^{m} w_{ik} z_k}{\sum_{i=1}^{m} z_i^2} \tag{2}$$

## 2.2.Synthetic measures of development

The measure proposed by Sokołowski and Zając (Gazińska, 2003, pp. 203-204; Sokołowski and Zając, 1987, pp. 41-42) is constructed by first transforming variables into stimulants (or destimulants) and then by normalising them (a standardisation formula is usually employed to this end). Thereafter, the negative values of the normalised variables are converted to non-negative ones using the formula:

$$u_{ij} = x_{ij} - \min_i\{x_{ij}\} \tag{3}$$

where: $x_{ij}$ - the value of the *j*-th characteristic of the *i*-th object.

In the next step, after the maximum values of transformed variables $u_{ij}$ (characterising the reference model) have been determined, the measure of development is calculated as:

$$z_i = \frac{\sum_{j=1}^{p} u_{ij}}{\sum_{j=1}^{p}\max_j\{u_{ij}\}} \tag{4}$$

The measure takes values in the interval [0; 1]. Its highest value is attributed to the reference model (i.e. the unit where the level of the investigated phenomenon is the most favourable).

In the non-reference method of sums, the measure of development (Panek, 2009, p. 67 as quoted in Malina and Wanat) is constructed by transforming variables into stimulants and calculating their arithmetic average $u_i^*$ for each object. The negative values are removed using the following formula:

$$u_i^{**} = u_i^* - \min_i \{u_i^*\} \tag{5}$$

To make sure that the measure only takes values in the interval [0, 1], it is normalised using the unitarisation formula:

$$z_i = u_i^{**} - \frac{u_i^{**}}{\max_i \{u_i^{**}\}} \tag{6}$$

To construct Hellwig's synthetic measure of development (see Hellwig, 1968; Nermend, 2009, pp. 37-44), first variables are transformed into stimulants (or destimulants) and then they are normalised (in most cases a standardisation formula is used to this end). The measure utilizes the so-called reference unit $z_o$, for which all stimulant variables from all investigated objects have maximum values (or minimum values when destimulant variables are used), i.e. (see Nowak, 1990, p. 88):

$$z_{oj} = \max_i \{z_{ij}\} \quad (\text{or } z_{oj} = \min_i \{z_{ij}\}) \qquad j = 1, ..., p \tag{7}$$

Subsequently, the distance between each object and the reference unit ($z_{oj}$) is determined using the following formulas:

$$d_i = \sqrt{\sum_{j=1}^{p} (z_{ij} - z_{oj})^2}, \qquad i = 1, 2, \dots, m \tag{8}$$

Further, to make sure that the relative measure takes values in the interval [0,1] it must be transformed according to the following formula (see Nowak, 1990, pp. 88-89):

$$z_i = 1 - \frac{d_i}{d_0} \quad \text{for} \quad i = 1, 2, \dots, m \tag{9}$$

where: $$d_0 = \bar{d} + 2s_d \tag{10}$$

$d_0$ - the basis of normalisation

$\bar{d}$ - an average calculated from $d_i$ of all objects

$s_d$ - standard deviation derived from $d_i$ of all objects

The measure tends to take values in the interval [0; 1], but if the level of development or the situation of a specific object is by far worse than noted for other objects its measure may take a negative value. In order to eliminate negative values of measure $z_i$, formula (10) is modified by adopting three standard deviations (see Nowak, 1990, p. 89). The highest values of $z_i$ are assigned to the reference model (i.e. the unit where the level of the investigated phenomenon is the most favourable).

### 2.3. Spatial transformation of Indicators

The spatial measure of development as proposed in this study draws on the E. Antczak's concept (2013, pp. 39–43) referring to Hellwig's measure of development (see Hellwig, 1968)[5] and spatial autocorrelation. It is similar to it in that it also allows for autocorrelation, but differs in the underlying synthetic measure.

The methodological difference between the spatial measures of development and the synthetic (non-spatial) measures lies in the construction of the input matrix of variables $\boldsymbol{X}$. Namely, to be accepted as diagnostic variables, the values of territorial units' characteristics must vary considerably (a coefficient of variance > 0.1), be relatively weakly correlated, and show statistically significant global spatial autocorrelation. A matrix of such variables is multiplied by a matrix of spatial weights $\boldsymbol{W}$ (based on a contiguity matrix)[6] according to the following formula proposed by E. Antczak (Antczak, 2013, pp. 39-43):

$$\boldsymbol{X}^{*}_{m\times p} = \boldsymbol{W}_{m\times m}\boldsymbol{X}_{m\times p}, \tag{11}$$

where:

$\boldsymbol{W} = [w_{ik}]$ – the $m\times m$ matrix of spatial weights,

$\boldsymbol{X} = [x_{ij}]$ – the $m\times p$ data matrix,

$m$ – the number of territorial units,

$p$ – the number of diagnostic variables,

$$w_{ik} = \begin{cases} \frac{1}{m_i} & \text{when unit } k \text{ is contiguoust to unit } i, \quad i \neq k \\ 0 & \text{otherwise,} \end{cases} \tag{12}$$

$m_i$ – the number of territorial units constituting the i-th region, i.e. units contiguous to an i-th unit.

The inclusion of spatial interactions causes that different results are obtained than a classical measure would produce because the transformation of (11) shifts the focus of analysis from the specific situation of a given unit to the impacts of its interactions with the contiguous units. This effectively means that we study a situation in which the values of diagnostic variables in one unit depend on their values in the contiguous units.

[5] A description of Hellwig's method in the English language can be found, *inter alia*, in the monograph by Nermend**,** 2009 (pp. 37-44).

[6] For a discussion of different approaches to constructing a matrix of spatial weights see, for instance, Suchecki at al. (2010, pp. 26-34), Suchecki and Olejnik (2010, pp. 105-107).

In this study, the author puts forward her own modification of the concept proposed by E. Antczak, which consists in assigning to the diagonal of the weight matrix ***W*** values different from 0 for first-order contiguity[7]. Matrix *W* in formula (11) is now written as:

$$w_{ik} = \begin{cases} \frac{1}{m_i} & \text{when unit } k \text{ is contiguoust to unit } i \text{ or } i = k, \\ 0 & \text{otherwise,} \end{cases} \tag{13}$$

$m_i$ – the number of territorial units constituting the *i*-th region, i.e. units contiguous to unit *i* including that unit.

With formulas (11) and (13), we can obtain the value of the *j*-th diagnostic variable, $x_{ij}^{*}$, for the *i*-th unit, which represents the average level of the investigated phenomenon for a region consisting of the *i*-th unit and its contiguous units[8].

The above approach utilizes a first-order contiguity matrix (i.e. a matrix of contiguous units), but higher-order matrices can be used as well. A measure obtained from such obtained matrix of variables and any synthetic measure of development will be henceforth referred to as a spatial measure of development with equally weighted units (SMD-EW).

SMD-EW assumes that all territorial units contiguous to the *i*-th unit have equal weights, which hardly ever occurs in real life. The usual case is that larger units, e.g. cities, have stronger influence on the course of some phenomenon in their regions than smaller units, e.g. rural areas. To account for this disproportion, SMD-EW is modified further into a spatial measure of development with intra-regionally weighted units (SMD-IRW) by weight matrix (13) in formula (11) with a matrix $\mathbf{S}$ of intra-regional weights allowing the 'significance' of the unit in the region to be included[9]. In this paper, intra-regional weights are represented by the unit's population in relation to the total population in the region, but weights can be selected according to the purpose of research. Mathematically, the data matrix transformation can be written as:

$$\boldsymbol{X}_{m\times p}^{**} = \boldsymbol{S}_{m\times m}\boldsymbol{X}_{m\times p}, \tag{14}$$

where:

$\boldsymbol{S} = [s_{ik}]$ – the $m\times m$ matrix of intra-regional weights,

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[7] A description of this modification can also be found in the monograph by A. Majdzińska (2016, pp. 67, 173-174).

[8] The definition of a region as used in this paper is different from that typically used in the geographical or economic literature (for a review of the definitions see, for instance, the monograph by Majdzińska, 2016, pp. 11-13 or by Montello, 2008, p. 305). For the purposes of this research, a region is understood as a single entity representing the level of the analysed phenomenon in a territorial unit (a county) and the units adjacent to it. In the Polish circumstances, there can be as many regions as counties (i.e. 380). This approach excludes the similarity of the analysed phenomenon as a criterion for grouping units and requires the transformation of a contiguity matrix to account for the units' own weights (formulas 11, 13-15). It also involves a different interpretation of the results.

[9] The modification devised by the author has not been published before.

$\boldsymbol{X} = [x_{ij}]$ – the $m \times p$ matrix of diagnostic variables

$$s_{ik} = \begin{cases} \frac{L_k}{\sum_{r=1}^{m_i} L_r} & \text{when unit } k \text{ is contiguoust to unit } i \text{ or } i = k, \\ 0 & \text{otherwise,} \end{cases} \tag{15}$$

$L_k$ – the size of the *k*-th territorial unit.

$L_r$ – the size of the *r*-th region.

It is worth noting that the established weights are the same for all diagnostic variables[10].

The spatial measures of development proposed below are designed using similar aggregation methods as proposed by Sokołowski, Zając or Hellwig[11] in the non-spatial framework. They refer to the variables transformed according to formulas (11), (13) and (14), (15) and will be termed "spatial measures of development with equally weighted units" in the case of variable transformations (11), (13) or spatial measures of development with intra-regionally weighted units" in the case of transformations (14), (15). Both approaches utilize the concept of the so-called reference unit. For comparison, a spatial measure without employing a reference unit is also constructed.

## 3. Application of the spatial measures of development

In this section, the spatial measures of development are used to rank Polish counties according to their demographic potential. To prepare the rankings, four diagnostic variables were selected from a set of variables characterising the population age structure in the counties and developments relating to natural movement and migrations, namely[12]:

$x_1$ – the share of population aged 15-44 years,

$x_2$ – a total fertility rate,

$x_3$ – a standardised death rate[13],

$x_4$ – the ratio of in-migrants to out-migrants between counties.

These diagnostic variables concisely present the counties' demographic potential and its changes brought about by demographic processes. For the purposes of this analysis, variables $x_1$, $x_2$ and $x_4$ were assumed to be stimulants

[10] Another possibility is to weight variables, but this approach is not used in this study.

[11] Hellwig's measure from which E. Antczak (2013) developed her measure of spatial development is not discussed in this research. For the applications of Hellwig's taxonomic measure of development and its modification in demographic research see the monograph by A. Majdzińska (2016).

[12] Variables were selected using the statistical criteria, such as relatively high variability and weak correlations.

[13] For the purposes of standardisation, the age structure of Polish population as on 31 Dec. 2016 was taken as a standard.

and variable $x_3$ to be a destimulant (converted into a stimulant using a ratio formula[14]).

Variable $x_1$ stands for the current level of demographic potential of a county, which is basically represented by population in the mobile working age group[15]. Variable $x_2$ denotes the reproduction level (i.e. the population's ability to reproduce itself), variable $x_3$ is a measure of population loss due to deaths, and variable $x_4$ represents migrations that frequently significantly contribute to fluctuations in the size of a population.

The analysis is performed on the 2005 and 2016 data with a view to ranking counties according to their demographic potential. The rankings are first produced using the spatial measures of development based on the Sokołowski and Zając method and then the spatial measures proposed by the non-reference method of sums. The outcomes of both approaches are compared and discussed.

In the first step, the values of the synthetic measure of development are calculated for counties based on the Sokołowski and Zając method[16] (formula 4) to be used as the criterion for assigning counties to four typological groups[17].

In 2005 and 2016, the most favourable levels of demographic potential were observed in the first group of counties, most of which are contiguous to or surround large, thriving cities of Warsaw, Tri-City, Poznań, Wrocław, Kraków, Toruń and Bydgoszcz (Figures 1-2). The majority of them were receiving in-migrants and were characterised by relatively high shares of people aged 15-44 years and quite advantageous reproduction rates (due to comparatively high fertility rates and low standardized death rates), although none of the counties fully matched the reference model of development. The most similar to it in both 2005 and 2016 were Gdański, Kartuski and Poznański counties (Table 1), whereas the counties in central, eastern and south-western Poland were the most distant from it. In 2005 these were Łódzki and Kutnowski counties (Łódzkie voivodeship), Hajnowski and Siemiatycki (Podlaskie voivodeship), Wałbrzyski (Dolnośląskie voivodeship), Krasnostawski (Lubelskie voivodeship) and in 2016 and Hajnowski county (Podlaskie voivodeship), Kłodzki, Ząbkowicki and the town of Wałbrzych (Dolnośląskie voivodeships), and Ostrowiecki and Skarżyski (Świętokrzyskie voivodeship).

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[14] The ratio formula is written as (Panek, 2009, p. 36):
$x_j^S = \frac{1}{x_j^D}$ ; where: $x_j^S$ is a stymulant and a $x_j^D$ is a destimulant.

[15] According to the Polish law, the working age is 18-59 years for women and 18-64 years for men (*Ustawa z dnia 16 listopada 2016 r. …*). The mobile working age is 18-44 years (GUS, 2017b, p. 143). The age of entry into labour force as adopted by the Labour Force Survey (LFS) is 15 years (GUS, 2017a, p.16).

[16] Sokołowski and Zając define a reference unit of development as an abstract unit that has attained the highest level of development. In this study, the values of the diagnostic variables for the reference model are the following:
- 2005: $x_1 = 0.48$; $x_2 = 1.87$; $x_3 = 63.84$; $x_4 = 3.62$ (values noted for Pszczyński, Kartuski, Rzeszowski and Poznański counties);
- 2016: $x_1 = 0.46$; $x_2 = 2.03$; $x_3 = 77.78$; $x_4 = 3.76$ (Gdański, Kartuski, Tarnowski and Poznański counties).

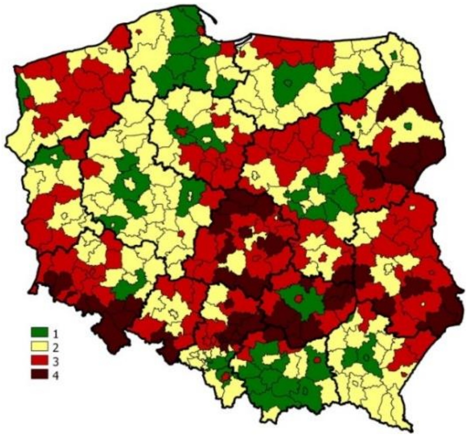
[17] Type (I) $z_i \geq \bar{z} + s_z$ ; (II) $\bar{z} + s_z > z_i \geq \bar{z}$ ; (III) $\bar{z} > z_i \geq \bar{z} - s_z$ ; (IV) $z_i < \bar{z} - s_z$ , where: $z_i$ – the value of the synthetic index for the *i*-th object, $\bar{z}$ – the arithmetic average of the synthetic measure, $s_z$ – standard deviation from the value of the synthetic measure (Nowak, 1990, p. 93; Majdzińska, 2016, pp. 32-33). If a standard deviation of 0.5 was adopted, 8 typological groups would have been produced and the results would have been more detailed.

The similarity between the counties' rankings in 2005 and 2016 was corroborated statistically by Pearson's linear correlation coefficient of 0.85 ($p<0.05$) and Spearman's rank coefficient of 0.81.

**Table 1.** Counties' rankings according to their demographic potential – the synthetic measure based on the original method by the Sokołowski and Zając method, 2005 and 2016

| counties with the lowest values of the measure | | | | counties with the highest values of the measure | | | |
|---|---|---|---|---|---|---|---|
| 2005 | | 2016 | | 2005 | | 2016 | |
| county | $z_i$ | county | $z_i$ | county | $z_i$ | County | $z_i$ |
| Łódź | 0.14 | Hajnowski | 0.13 | Kartuski | 0.76 | Poznański | 0.76 |
| Hajnowski | 0.17 | Wałbrzych | 0.14 | Poznański | 0.75 | Kartuski | 0.74 |
| Kutnowski | 0.17 | Kłodzki | 0.16 | Gdański | 0.69 | Gdański | 0.72 |
| Wałbrzyski | 0.17 | Ostrowiecki | 0.17 | Toruński | 0.68 | Wrocławski | 0.69 |
| Krasnostawski | 0.17 | Ząbkowicki | 0.17 | Bydgoski | 0.68 | Wielicki | 0.67 |
| Siemiatycki | 0.18 | Skarżyski | 0.17 | Wejherowski | 0.68 | Wołomiński | 0.65 |
| Pińczowski | 0.19 | Sosnowiec | 0.17 | Piaseczyński | 0.67 | Piaseczyński | 0.64 |
| Kazimierski | 0.20 | Głubczycki | 0.18 | Policki | 0.62 | Rzeszów | 0.58 |
| Sosnowiec | 0.20 | Piekary Śląskie | 0.18 | Pucki | 0.59 | Wejherowski | 0.58 |
| Poddębicki | 0.21 | Kutnowski | 0.18 | Wielicki | 0.59 | Bydgoski | 0.55 |
| Sopot | 0.21 | Częstochowa | 0.19 | Wrocławski | 0.58 | Legionowski | 0.55 |
| Lipski | 0.21 | Wałbrzyski | 0.20 | Nowosądecki | 0.57 | Grodziski | 0.54 |
| Łęczycki | 0.21 | Jelenia Góra | 0.20 | Myślenicki | 0.57 | Nowosądecki | 0.54 |
| Skarżyski | 0.22 | Hrubieszowski | 0.20 | Rzeszów | 0.57 | Limanowski | 0.53 |
| Zawierciański | 0.22 | Łódź | 0.20 | Warszawski Zach. | 0.56 | Rzeszowski | 0.53 |

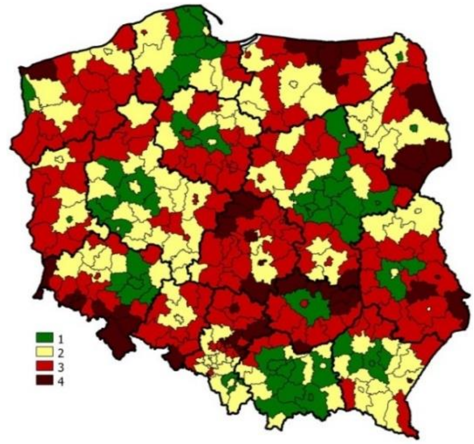
*Source*: GUS (BDL); created by the author.




$\bar{z} = 0.37,\ s_z = 0.10,\ min = 0.14,\ max = 0.76$

Source: GUS (BDL); created by the author.

**Figure 1.** Differences in regions' demographic potential in 2005 (based on the synthetic measure derived from the Sokołowski and Zając method)




$\bar{z} = 0.35,\ s_z = 0.09, min = 0.13,\ max = 0.76$

Source: GUS (BDL); created by the author.

**Figure 2.** Differences in regions' demographic potential in 2016 (based on the synthetic measure derived from the Sokołowski and Zając method)

Because the rankings characterise counties in a synthetic manner (Table 2)[18], the counties in particular typological groups have different values of the diagnostic variables, even though their distance from the reference county is similar. In almost all groups, variables $x_1$, $x_2$ and $x_3$ differ to a relatively small extent[19]).

[18] For the sake of comparison, the same set of diagnostic variables ($x_1$–$x_4$) and classical Hellwig's taxonomic measure of development (see Hellwig, 1968) were used to produce the counties' rankings for 2016. The values of Hellwig's measure and of the measure based on the Sokołowski and Zając method were similar; Pearson's linear correlation coefficient of 0.98 ($p$<0.05) and Spearman's rank correlation coefficient of 0.97 showed that the similarity was high and statistically significant.

[19] The coefficient of variance for $x_4$ was high, reaching 0.52 for the full sample (the 2016 value of this variable ranged from 0.3 to 3.8).

**Table 2.** Statistics characterising the groups of counties (the Sokołowski and Zając synthetic method, 2016).

| Typological group | Average values of variables | | | | Coefficients of variance | | | |
|---|---|---|---|---|---|---|---|---|
| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_1$ | $x_2$ | $x_3$ | $x_4$ |
| 1 | 0.43 | 1.50 | 97.5 | 1.59 | 0.03 | 0.10 | 0.07 | 0.48 |
| 2 | 0.43 | 1.37 | 102.1 | 0.91 | 0.03 | 0.08 | 0.08 | 0.31 |
| 3 | 0.42 | 1.29 | 107.1 | 0.70 | 0.03 | 0.08 | 0.07 | 0.29 |
| 4 | 0.40 | 1.18 | 111.1 | 0.67 | 0.03 | 0.08 | 0.06 | 0.31 |

*Source:* GUS (BDL); created by the author.

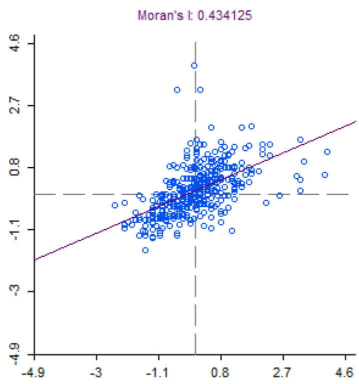
The spatial dependency of the measure derived from the Sokołowski and Zając method was tested using Moran's *I* statistics. Its 2005 and 2016 values of 0.43 and 0.45[20], respectively, show that the global spatial autocorrelation for first-order contiguity was positive, moderate and statistically significant ($p$<0.001)[21] (Figures 3 and 5).

According to local Moran's $I_i$ statistics, in 2005 the largest clusters of counties with relatively high and significant levels of demographic potential were in Pomorskie, Wielkopolskie and Małopolskie voivodeships and in 2016 also in Mazowieckie voivodeship. The majority of the regions where the levels of demographic potential were rather unfavourable were situated in central, eastern and south-western Poland (Figures 4 and 6).

The spatial autocorrelation was also evaluated for the case of second-order contiguity in 2016. The global autocorrelation turned out to be slightly weaker compared with that determined for first-order contiguity (Moran's *I* statistics 0.17; $p$<0.001).

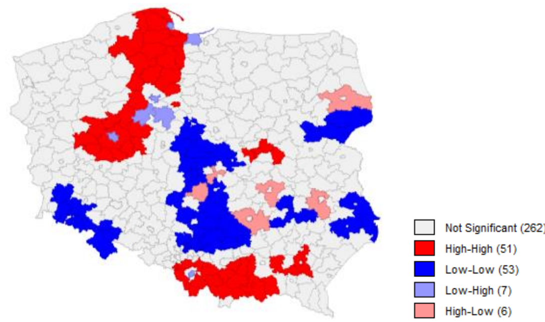
[20] Calculations were performed using the GeoDa software.

[21] The global spatial autocorrelation of the counties was determined based on a first-order row-standardised contiguity matrix. Moran's *I* statistics for the selected variables and years were the following:
2005 – $x_1$: 0.46; $x_2$: 0.45; $x_3$: 0.37; $x_4$: 0.21 ($p$<0.001);
2016 – $x_1$: 0.37; $x_2$: 0.50; $x_3$: 0.36; $x_4$: 0.24 ($p$<0.001).



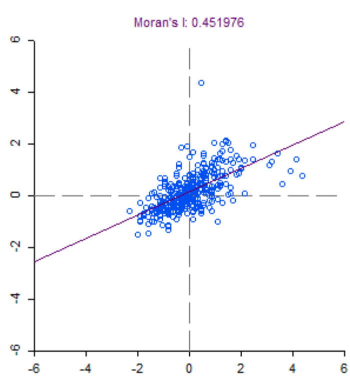

*Source:* GUS (BDL); created by the author using GeoDa software.

**Figure 3.** Global spatial autocorrelation for counties' demographic potential in 2005 (based on the Sokołowski and Zając synthetic method**;** first-order contiguity)



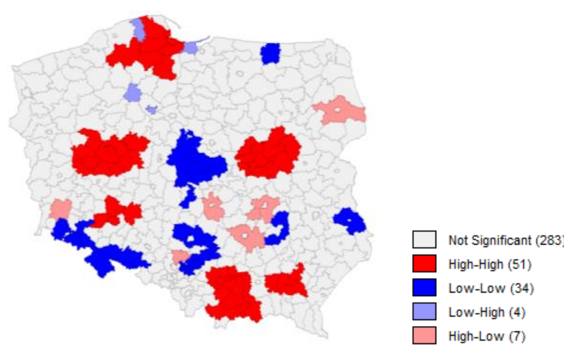

*Source:* GUS (BDL); created by the author using GeoDa software.

**Figure 4.** Local spatial autocorrelation for counties' demographic potential in 2005 (based on the Sokołowski and Zając synthetic method; first-order contiguity)




*Source:* GUS (BDL); developed by the author using GeoDa software.

**Figure 5.** Global spatial autocorrelation for counties' demographic potential in 2016 (based on the Sokołowski and Zając synthetic method; first-order contiguity)




*Source:* GUS (BDL); developed by the author using GeoDa software.

**Figure 6.** Local spatial autocorrelation for counties' demographic potential in 2016 (based on the Sokołowski and Zając synthetic method; first-order contiguity)

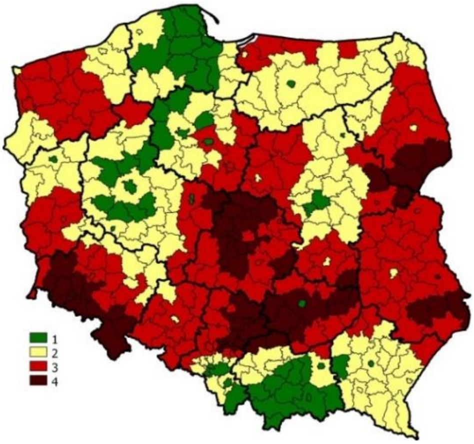
In the next step, counties were ranked and grouped using the spatial measure based on the Sokołowski and Zając method described in Section 2.2 and indicators transformed according to formulas (11)-(12). This measure accounts for the influence of intra-regional dependencies, so it produced different rankings than the classical measure did (formula 4). Some counties that had previously ranked relatively low moved up as a result of spatial interactions modifying the course of demographic processes, while others moved down because of the adjacency of counties with a relatively low levels of demographic potential (Tables 1 and 3 and Graphs 7 and 8).

Most large cities improved their rankings, because higher fertility rates and positive net migration rates in the contiguous counties strengthened their demographic potential eroded by depopulation processes.

**Table 3.** Counties' (regions) rankings according to their demographic potential – based on the spatial measure developed from the Sokołowski and Zając method, 2005 and 2016

| counties with the lowest value of the measure | | | | counties with the highest value of the measure | | | |
|---|---|---|---|---|---|---|---|
| 2005 | | 2016 | | 2005 | | 2016 | |
| county | $z_i$ | county | $z_i$ | county | $z_i$ | county | $z_i$ |
| Kłodzki | 0.15 | Kłodzki | 0.16 | Poznań | 0.85 | Poznań | 0.65 |
| Dąbrowa Górnicza | 0.20 | Jelenia Góra | 0.16 | Toruń | 0.77 | Świdwiński | 0.57 |
| Zduńskowolski | 0.20 | Kamiennogórski | 0.18 | Bydgoszcz | 0.76 | Wałbrzyski | 0.50 |
| Łęczycki | 0.20 | Wałbrzych | 0.18 | Nowy Sącz | 0.63 | Pruszkowski | 0.47 |
| Siemianowice Śląskie | 0.20 | Chorzów | 0.20 | Kościerski | 0.63 | Warszawa | 0.46 |
| Zgierski | 0.21 | Siemianowice Śląskie | 0.20 | Lęborski | 0.62 | Kościerski | 0.45 |
| Świętochłowice | 0.21 | Ząbkowicki | 0.20 | Wejherowski | 0.58 | Wrocław | 0.45 |
| Ząbkowicki | 0.21 | Świętochłowice | 0.20 | Warszawa | 0.58 | Rzeszów | 0.44 |
| Kamiennogórski | 0.22 | Dąbrowa Górnicza | 0.20 | Gdynia | 0.57 | Nowy Sącz | 0.43 |
| Chorzów | 0.22 | Jeleniogórski | 0.21 | Pucki | 0.57 | Kraków | 0.43 |
| Kielecki | 0.22 | Kielecki | 0.21 | Pruszkowski | 0.57 | Bydgoszcz | 0.43 |
| Piekary Śląskie | 0.23 | Częstochowski | 0.21 | Tatrzański | 0.57 | Lęborski | 0.43 |
| Zawierciański | 0.23 | Szydłowiecki | 0.21 | Średzki | 0.56 | Gdynia | 0.43 |
| Bielski | 0.23 | Kętrzyński | 0.21 | Limanowski | 0.55 | Grodziski | 0.42 |
| Będziński | 0.23 | Łęczycki | 0.22 | Rzeszów | 0.55 | Bocheński | 0.42 |

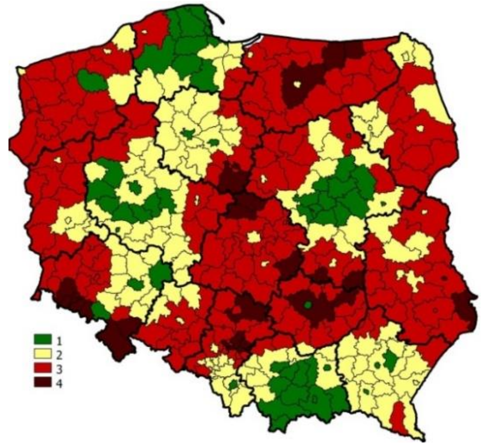
*Source: GUS* (BDL); created by the author.




$\bar{z} = 0.38, \quad s_z = 0.10, \quad min = 0.15, \quad max = 0.85$

*Source:* GUS (BDL); created by the author.

**Figure 7.** Differences in regions' demographic potential in 2005 (based on the spatial measure derived from the Sokołowski and Zając method)




$\bar{z} = 0.29, \quad s_z = 0.06, \quad min = 0.16, \quad max = 0.65$

*Source:* GUS (BDL); created by the author.

**Figure 8.** Differences in regions' demographic potential in 2016 (based on the spatial measure derived the Sokołowski and Zając method)

Subsequently, a spatial measure of development with equally weighted units (SMD-EW) (formulas 11 and 13) was calculated for counties and the areas around them (Table 4 and Figures 9 and 10). Because of their weights, some 'insular' counties in the previous classification (Graphs 7 and 8) joined areas formed by the adjacent counties, in spite of significantly different values of diagnostic variables. The results thus obtained for individual counties can be interpreted as representing the demographic potential of a region consisting of a county and the adjacent units.

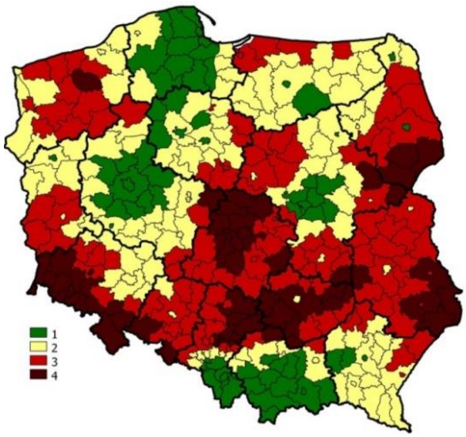
The highest levels of demographic potential in both 2005 and 2016 occurred in Pomorskie, Wielkopolskie, Małopolskie and Mazowieckie voivodeships, and the lowest in Łódzkie, Świętokrzyskie, Dolnośląskie, Podlaskie and Lubelskie voivodeships.

The highest levels of demographic potential in 2016 were determined for Poznań (its relatively low fertility rate and negative net migration were offset by high demographic potential of Poznański county) and Rzeszów (Rzeszowski county and the town of Rzeszów enjoyed a relatively good demographic situation because of low mortality rates and definitely more people seeking residence in the area than leaving it). The other end of the scale is represented by Kłodzki county (a very low fertility rate and a negative migration rate in this region were accompanied by a relatively high standardised mortality rate) and the town of Wałbrzych (its demographic potential was as low as in the county).

**Table 4.** Counties' (regions) rankings according to their demographic capital – the SMD-EW, 2005 and 2016

| counties with the lowest value of the measure | | | | counties with the highest value of the measure | | | |
|---|---|---|---|---|---|---|---|
| 2005 | | 2016 | | 2005 | | 2016 | |
| county | $z_i$ | county | $z_i$ | county | $z_i$ | county | $z_i$ |
| Wałbrzyski | 0.14 | Kłodzki | 0.12 | Bydgoszcz | 0.80 | Poznań | 0.79 |
| Świdwiński | 0.26 | Wałbrzych | 0.12 | Poznań | 0.79 | Rzeszów | 0.75 |
| Kłodzki | 0.27 | Jelenia Góra | 0.13 | Wejherowski | 0.78 | Wielicki | 0.71 |
| Ząbkowicki | 0.32 | Wałbrzyski | 0.16 | Kościerski | 0.78 | Pruszkowski | 0.71 |
| Łęczycki | 0.32 | Ząbkowicki | 0.18 | Pucki | 0.76 | Warszawa | 0.71 |
| Dąbrowa Górnicza | 0.32 | Kamiennogórski | 0.19 | Toruń | 0.76 | Kościerski | 0.70 |
| Siemianowice Śląskie | 0.33 | Chorzów | 0.19 | Nowy Sącz | 0.74 | Wrocław | 0.69 |
| Chorzów | 0.33 | Świętochłowice | 0.20 | Lęborski | 0.74 | Kraków | 0.67 |
| Świętochłowice | 0.33 | Dąbrowa Górnicza | 0.20 | Kartuski | 0.74 | Kartuski | 0.66 |
| Hajnowski | 0.34 | Siemianowice Śląskie | 0.20 | Rzeszów | 0.74 | Grodziski | 0.65 |
| Jelenia Góra | 0.34 | Sosnowiec | 0.20 | Pruszkowski | 0.73 | Wołomiński | 0.65 |
| Kamiennogórski | 0.34 | Jeleniogórski | 0.21 | Warszawa | 0.73 | Bocheński | 0.65 |
| Kutnowski | 0.34 | Hajnowski | 0.21 | Limanowski | 0.71 | Myślenicki | 0.64 |
| Piekary Śląskie | 0.35 | Głubczycki | 0.21 | Myślenicki | 0.71 | Wejherowski | 0.64 |
| Zawierciański | 0.35 | Ostrowiecki | 0.22 | Wielicki | 0.71 | Piaseczyński | 0.63 |

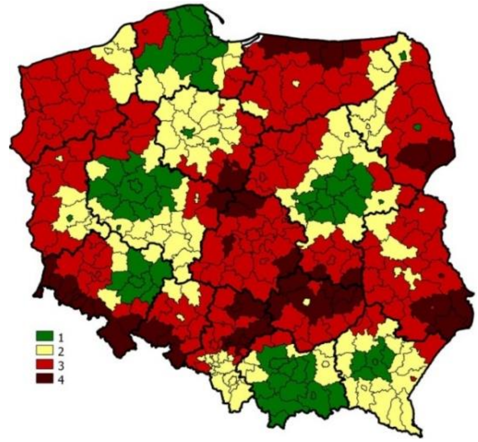
*Source:* GUS (BDL); created by the author.




$\bar{z} = 0.51, \quad s_z = 0.10, \quad min = 0.14, \quad max = 0.80$

*Source:* GUS (BDL); created by the author.

**Figure 9.** Differences in regions' demographic potential in 2005 (according to SMD-EW)




$\bar{z} = 0.39, \quad s_z = 0.12, \quad min = 0.12, \quad max = 0.79$

*Source:* GUS (BDL); created by the author.

**Figure 10.** Differences in regions' demographic potential in 2016 (according to SMD-EW)

In the next step, the spatial measure of development with intra-regionally weighted units (SMD-IRW) (formulas 14-15) was used.

The clusters of counties in Figures 11 and 12 and in Figures 9 and 10 are relatively similar, despite different rankings of their constituent counties (regions) determined from the SMD-EW and SMD-IRW methods (Tables 4 and 5).

In both 2005 and 2016, the highest average demographic potential was observed in the regions centred around Grodziski, Średzki and Kościański counties (Wielkopolskie voivodeship; Table 5), which significantly improved their positions compared with the previous ranking, having "absorbed" much of the demographic potential of Poznański county. However, the 2016 position of Poznań itself proved considerably lower (Table 4 and 5), because the intra-regional weight increased its "contribution" to the demographic potential of the city and the county[22]. The lowest levels of demographic potential occurred in counties in central and south-western Poland (in 2016 the worst situation in that respect was noted in the towns of Wałbrzych and Jelenia Góra and in Kłodzki county).

After intra-regional weights were assigned to counties, the most populous units gained slight advantage over other units in the same region (large units, especially large cities, tend to exert strong economic, social and demographic influence on the adjacent areas). The main reason for which many cities moved

[22] In 2016, Poznań accounted for 59.1% of the total population living in the city and the county (GUS, 2017b).

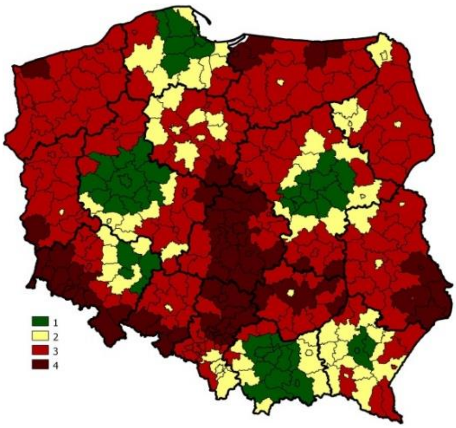
down in this ranking was relatively lower fertility rates and negative migration rates.

The relative similarity between the 2005 and 2016 rankings of the counties obtained from the SMD-IRW was confirmed by Pearson's correlation coefficient of 0.88 ($p$<0.05) and Spearman's rank coefficient of 0.86.

**Tabale 5.** Counties' (regions) rankings according to their demographic potential – the SMD-IRW, 2005 and 2016

| counties with the lowest value of the measure | | | | counties with the highest value of the measure | | | |
|---|---|---|---|---|---|---|---|
| 2005 | | 2016 | | 2005 | | 2016 | |
| county | $z_i$ | county | $z_i$ | county | $z_i$ | county | $z_i$ |
| Łódź | 0.12 | Wałbrzych | 0.09 | Średzki | 0.82 | Grodziski | 0.83 |
| Zgierski | 0.13 | Kłodzki | 0.11 | Grodziski | 0.82 | Średzki | 0.80 |
| Kłodzki | 0.15 | Jelenia Góra | 0.13 | Kościański | 0.78 | Kościański | 0.77 |
| Łódzki Wschodni | 0.15 | Wałbrzyski | 0.15 | Obornicki | 0.78 | Szamotulski | 0.76 |
| Pabianicki | 0.17 | Ząbkowicki | 0.16 | Śremski | 0.77 | Śremski | 0.76 |
| Wałbrzyski | 0.18 | Kamiennogórski | 0.18 | Lęborski | 0.77 | Obornicki | 0.73 |
| Dąbrowa Górnicza | 0.19 | Dąbrowa Górnicza | 0.18 | Szamotulski | 0.77 | Nowotomyski | 0.72 |
| Ząbkowicki | 0.19 | Sosnowiec | 0.19 | Kościerski | 0.76 | Rzeszów | 0.71 |
| Siemianowice Śląskie | 0.20 | Jeleniogórski | 0.19 | Wejherowski | 0.72 | Wrzesiński | 0.71 |
| Jelenia Góra | 0.21 | Świętochłowice | 0.20 | Nowy Sącz | 0.72 | Kościerski | 0.70 |
| Chorzów | 0.21 | Łódź | 0.20 | Gnieźnieński | 0.72 | Gnieźnieński | 0.69 |
| Łęczycki | 0.21 | Częstochowa | 0.20 | Wrzesiński | 0.71 | Poznań | 0.69 |
| Świętochłowice | 0.22 | Chorzów | 0.20 | Nowotomyski | 0.71 | Lęborski | 0.67 |
| Kamiennogórski | 0.22 | Mysłowice | 0.21 | Wągrowiecki | 0.70 | Bocheński | 0.65 |
| Kutnowski | 0.22 | Częstochowski | 0.21 | Rzeszów | 0.69 | Wielicki | 0.64 |

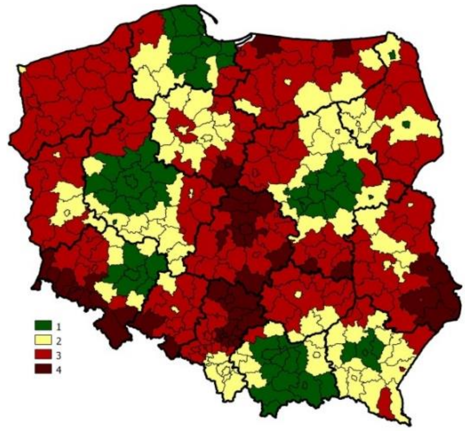
*Source:* GUS (BDL); developed by the author.




$\bar{z} = 0.43,\quad s_z = 0.13,\quad min = 0.12,\quad max = 0.82$

*Source:* GUS (BDL); created by the author.

**Figure 11.** Differences in regions' demographic potential in 2005 (according to SMD-IRW)




$\bar{z} = 0.40,\quad s_z = 0.12,\quad min = 0.09,\quad max = 0.83$

*Source:* GUS (BDL); created by the author.

**Figure 12.** Differences in regions' demographic potential in 2016 (according to SMD-IRW)

Finally, the spatial measure of development based on the non-reference method of sums was constructed, as well as its modifications allowing for counties' weights and intra-regional weights. The outcomes of these three measures will not be discussed in detail, because they are basically similar to those produced by Sokołowski and Zając method. One thing that is noteworthy, however, is that the use of intra-regional weights affected the counties' rankings (Table 5 and 6). In 2016, the most favourable levels of demographic potential were noted for Grodziski and Średzki counties in Wielkopolskie voivodeship, whereas in Tomaszowski county in Lubelskie voivodeship and in Kłodzki and Ząbkowicki counties in Dolnośląskie voivodeship the levels were the lowest (Table 6).

The different rankings of individual counties (i.e. regions) produced by both measures should be mainly attributed to the differences in their construction; in the case of the Sokołowski and Zając measure counties were compared with the reference model and in the case of the measure based on the non-reference method of sums with each other.

**Table 6.** Counties' (region) rankings according to their demographic potential – the SMD-IRW based on the non-reference method of sums, 2005 and 2016.

| counties with the lowest value of the measure | | | | counties with the highest value of the measure | | | |
|---|---|---|---|---|---|---|---|
| 2005 | | 2016 | | 2005 | | 2016 | |
| county | $z_i$ | county | $z_i$ | county | $z_i$ | county | $z_i$ |
| Głubczycki | 0.44 | Tomaszowski | 0.41 | Grodziski | 1.00 | Grodziski | 1.00 |
| Kłodzki | 0.44 | Ząbkowicki | 0.42 | Średzki | 0.99 | Średzki | 0.99 |
| Ząbkowicki | 0.45 | Kłodzki | 0.42 | Obornicki | 0.96 | Szamotulski | 0.96 |
| Kędzierzyńsko-kozielski | 0.45 | Sandomierski | 0.42 | Szamotulski | 0.96 | Obornicki | 0.95 |
| Prudnicki | 0.46 | Węgorzewski | 0.42 | Kościański | 0.94 | Śremski | 0.94 |
| Krapkowicki | 0.46 | Lubaczowski | 0.42 | Śremski | 0.94 | Kościański | 0.94 |
| Zabrze | 0.46 | Stalowowolski | 0.42 | Nowotomyski | 0.90 | Nowotomyski | 0.89 |
| Gliwice | 0.46 | Zamojski | 0.43 | Gnieźnieński | 0.88 | Wrzesiński | 0.88 |
| Wałbrzyski | 0.46 | Hrubieszowski | 0.43 | Wrzesiński | 0.88 | Gnieźnieński | 0.87 |
| Opolski | 0.47 | Tarnobrzeg | 0.43 | Wągrowiecki | 0.86 | Poznań | 0.82 |
| Strzelecki | 0.47 | Wałbrzyski | 0.43 | Grodziski | 0.85 | Wągrowiecki | 0.81 |
| Bytom | 0.47 | Braniewski | 0.44 | Chełmiński | 0.85 | Grodziski | 0.81 |
| Chorzów | 0.48 | Leski | 0.44 | Poznań | 0.81 | Warszawa | 0.79 |
| Mysłowice | 0.48 | Wałbrzych | 0.44 | Lęborski | 0.80 | Kościerski | 0.78 |
| Nyski | 0.48 | Głubczycki | 0.44 | Bocheński | 0.79 | Bocheński | 0.78 |

*Source:* GUS (BDL); created by the author.

## 4. Conclusion

Spatial measures of development allow comparing territorial units for the intensity of the selected phenomenon and evaluating the extent to which the intensity in one unit is determined by the contiguous units. The measures can be derived from any classical synthetic measure (with or without a reference unit) on condition that each variable is globally spatially autocorrelated. It is also vital to remember that the measures' results should be interpreted as allowing for the type of interactions (weights) adopted for the studied objects.

In this study, three approaches to constructing a spatial measure of development are proposed, all derived from the Sokołowski and Zając method utilising a reference unit and the non-reference method of sums. They were subsequently used to rank Polish counties according to their demographic potential in 2005 and 2016.

The first of them, based on the classical first-order contiguity matrix and the concept proposed by E. Antczak (2013), assumes that the level of the investigated phenomenon in a unit is only determined by the values of variables determining the phenomenon in the contiguous units. The situation in the first unit is thus omitted.

The second approach is the author's modification of the first one, involving the extension of the contiguity matrix to account for the territorial units' own weights. This change causes that the result obtained for a unit can be interpreted as the average level of the phenomenon under consideration in a region made up of this and the contiguous units. This modification has been called a spatial measure of development with equally weighted units (SMD-EW) and its variant (i.e. the third approach) a spatial measure of development with intra-regionally weighted units (SMD-IRW). Both measures can also be used to evaluate a territorial unit's impact on the contiguous units in terms of different criteria.

Other transformations of the measures are also possible, for instance by adopting matrices of higher orders or by assigning weights to the diagnostic variables.

A natural consequence of the three measures having different characteristics is different interpretation of their results. In the author's opinion, SMD-EW and SMD-IRW better evaluate the demographic potential of various territorial units, because, in addition to considering interactions between them, they also allow for their internal situation. In other words, they present the combined demographic potential of a unit and the units around it (i.e. of a region). The only inconvenience is that they are slightly more difficult to apply (a significant global autocorrelation of each variable is required) and the interpretation is different compared with the classical synthetic measure.

Nevertheless, spatial measures of development taking account of territorial units' weights are useful for evaluating the demographic potential of regions as defined in this article, particularly in studies investigating the demographic potential of the largest cities that lose inhabitants because of suburbanization and other processes, etc., while receiving from contiguous areas working-age people, who come every day to the city to work or study[23]. For instance, a relatively high value of a spatial measure obtained for a depopulating city indicates the demographic potential of the region made up of the city and the contiguous units (i.e. the city's capacity to take in population capital from the surrounding areas). In the case of a suburban unit that has a good demographic situation, a low value of the measure shows to what extent much the unit "supplies" the adjacent units.

[23] For more than two decades now, the majority of the largest Polish cities (in population terms) have been shrinking due to natural causes (declining fertility rates and relatively steady mortality rates) and relocation of many of their residents mainly to suburban areas.

This information is of practical importance in analysing the present and future of regional labour markets.

The created typology of Polish counties showed that the largest groupings of regions with the relatively best demographic potential are concentrated in Mazowieckie, Pomorskie, Wielkopolskie and Małopolskie voivodeships. This is probably due to the voivodeships' capital cities and suburbs being perceived favourably as in-migration areas and their fairly high fertility levels. Regions with the lowest demographic potential (resulting from low fertility rates, high shares of the elderly population and negative net migration rates) are mostly found in Łódzkie, Świętokrzyskie and Lubelskie voivodeships.

It is predicted that in the next several years the demographic potential of most regions in Poland will decline, the main reasons for which will be low fertility rates and the increasing proportion of elderly people. It seems, therefore, advisable that areas characterised by the lowest demographic potential be flagged as in need of attention from the government and of actions mitigating the negative impacts of changes in the population size and structure.

Both SMD-EW and SMD-IRW are worth considering as the tools of spatial analysis enhancing the demographic regionalisation methods and the forecasts of regions' demographic potential. At the government level, they can be used to support the creation of regional and local population policies and labour market policies.

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