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SPATIAL AUTOCORRELATION IN ASSESSMENT OF FINANCIAL SELF-SUFFICIENCY OF COMMUNES OF WIELKOPOLSKA PROVINCE

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ABSTRACT

The aim of the article was to identify the spatial effects in assessment of financial self-sufficiency of the governments of communes *(gminas)* of Wielkopolska province *(voivodship)* in 2014, employing global and local Moran I statistics. The level of the governments' self-sufficiency was examined by positional TOPSIS method. The study was based on publicly accessible databases compiled by the Ministry of Finance (*Wskaźniki do oceny sytuacji finansowej jednostek samorządu terytorialnego*) and the Central Statistical Office (*Local Data Bank*). Calculations were performed in R with packages *spdep*, *maptools* and *shapefiles*. The study demonstrated that the communes of Wielkopolska province of comparable levels of financial self-sufficiency exhibited a moderate tendency to cluster. Clusters of high levels gathered around larger urban centres, especially around Poznań, while clusters of low levels – in economically underdeveloped agricultural south-eastern and northern part of the province.

Key words: financial self-sufficiency, communes, TOPSIS method, spatial autocorrelation, Moran I statistics

1. Introduction

Communes are the lowest units of local government charged with responsibility to satisfy basic needs of local communities and to maintain favourable conditions for economic activity of local business. They are also the units that shoulder the bulk of the burden to finance local government's undertakings. They possess legal personality and can set their own financial policy. Hence, they decide on income collection, outlay proportions, budget execution and disposal of assets, described jointly as financial self-sufficiency, whose sound levels underpin sustainable local development and need satisfaction.

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Financial self-sufficiency is not only determined by demographic, social and economic factors, but also by the geographic location of a commune with its natural resources and neighbourhood interactions. The analysis of spatial effects in assessment of financial self-sufficiency may accommodate decisions of higher level administrative units regarding financial support for the communes of clustered low values because spatial autocorrelation statistics give a fuller picture of the direction and strength of spatial interactions and structures than more traditional methods [Janc 2006].

The aim of the article was to identify the spatial effects in assessment of financial self-sufficiency of communal governments of Wielkopolska province in 2014. The study was based on publicly accessible databases compiled by the Ministry of Finance (*Wskaźniki do oceny sytuacji finansowej jednostek samorządu terytorialnego* / *Indicators for assessment of the financial situation of self-governing territorial units)* and the Central Statistical Office's*Local Data Bank*). Calculations were performed in R with packages *spdep*, *maptools* and *shapefiles*.

2. Research methods

In order to identify spatial effects in assessment of financial self-sufficiency of communes of Wielkopolska province ($N = 226$), first, the synthetic evaluation of the self-sufficiency was performed using the TOPSIS positional method[3]. The procedure to create a synthetic feature is a multi-stage process with six distinctive steps. Step I consisted of selecting simple features defining analysed objects and determining their preference toward a general benchmark. Material and statistical considerations given to the selection of 6 indicators describing self-sufficiency of the communes: WDWM – own income per population (PLN *per capita*), WFIP – share of general and targeted subsidies in total income, WAP – ratio of tax income to current income, WBF – tax income per population (PLN *per capita*), and WIWO – share of investment expenditures in total expenditures [cf. Kozera, Wysocki 2015]. WFIP was considered the only destimulant in the adopted set of features and turned into a stimulant by the following transformation [Wysocki 2010]:

$$x_{ik} = a - b \cdot x_{ik}^{D}, \tag{1}$$

where: x_{ik}^{D} – value of the k^{th} feature, a destimulant $(k \in I_D)$ in the i^{th} object (i = 1,…, N),

x_{ik} – value of the k^{th} feature (k = 1, …, K) transformed into a stimulant,

a, b – arbitrary constants, here a = 0 and b = 1.

[3] It is a robust modification of the ideal method proposed by Hellwig [1968] where the synthetic index values are calculated with respect to one ideal. In TOPSIS (Hwang, Yoon 1981) a positive and negative ideals are considered. Using methods based on just one ideal can lead to erroneous results (cf. Binderman 2006, 2011).

In Step II the values of simple features were normalized with L1-median standardization[4] [Lira i in. 2002, Młodak 2006]:

$$z_{ik} = \frac{x_{ik} - \tilde{med}_k}{1.4826 \cdot \tilde{mad}_k}, \tag{2}$$

where: x_{ik} – value of the k^{th} feature in the i^{th} object,

$\tilde{med}_k$ – L1-median vector component corresponding to the k^{th} feature,

$\tilde{mad}_k = med_i \left| x_{ik} - \tilde{med}_k \right|$ – median absolute deviation of k^{th} feature values from the median component of the k^{th} feature,

1.4826 – a constant scale factor corresponding to normally distributed data, $\sigma \approx E\left(1.4826 \cdot \tilde{mad}_k (X_1, X_2, ..., X_K)\right)$,

σ – standard deviation.

The distribution of feature values standardized in this way is considered "close to the normal distribution of zero expectation and unitary standard deviation" [Młodak 2009, s. 3-21].

In Step III the coordinates of ideal and negative ideals were computed according to the following formulae [Wysocki 2010]:

$$A^+ = \left(\max_i (z_{i1}), \max_i (z_{i2}), ..., \max_i (z_{iK}) \right) = \left(z_1^+, z_2^+, ..., z_K^+ \right) \tag{3}$$

for the ideal, and:

$$A^- = \left(\min_i (z_{i1}), \min_i (z_{i2}), ..., \min_i (z_{iK}) \right) = \left(z_1^-, z_2^-, ..., z_K^- \right). \tag{4}$$

for the negative ideal. These coordinate values in Step IV yielded the distance of each object to the ideal $\left(A^+\right)$ and negative ideal $\left(A^-\right)$ using the following formula [Wysocki 2010]:

$$d_i^+ = med_k \left(\left| z_{ik} - z_k^+ \right| \right), \; d_i^- = med_k \left(\left| z_{ik} - z_k^- \right| \right), \; (i = 1, \ldots, N), \tag{5}$$

where: med_k – marginal median for the k^{th} feature.

The construction of the synthetic index in Step V followed the TOPSIS method [Hwang, Yoon 1981]:

$$S_i = \frac{d_i^-}{d_i^- + d_i^+}, \; (i = 1, \ldots, N), \tag{6}$$

where $0 \le S_i \le 1$ can be easily verified.

[4] As opposed to classical approach, using spatial (L1) median is robust against the undue influence of outliers (Młodak 2006).

The values of the synthetic index were used in Step VI to linearly arrange analysed communes in non-decreasing order. Then four typological classes were established, with cut-offs depending on the mean $(\overline{S})$ and standard deviation (s_s) of the index [Wysocki 2010]:

$$\begin{aligned}
&\text{class I (high level of financial self-sufficiency): } S_i \geq \overline{S} + s_S, \\
&\text{class II (medium high level): } \overline{S} \leq S_i < \overline{S} + s_S, \\
&\text{class III (medium low level): } \overline{S} - s_S \leq S_i < \overline{S}, \\
&\text{class IV (low level): } S_i < \overline{S} - s_S.
\end{aligned} \tag{7}$$

In the next phase of the study the strength and character of spatial autocorrelation of financial self-sufficiency were examined. The global Moran I statistic was used to find the autocorrelation overall estimate within the whole province. The local Moran I statistics were employed to identify the spatial layout of communes of Wielkopolska province, detecting clusters of similar values of financial self-sufficiency, as well as outliers.

Spatial analysis is primarily interested in the type of the effect, i.e. spatial homo- or heterogeneity. Spatial autocorrelation is usually understood as a correlation between the values of the same variable for different objects in space, and, therefore, it measures the degree of dependence of these objects set within a geographic framework [Kossowski et al. 2013]. To get a global gauge of this dependence, the global Moran I statistic is commonly employed [Bivand et al. 2008, Kopczewska 2006]:

$$I = \frac{N}{S_0} \cdot \frac{\sum_i \sum_j w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_j (x_j - \overline{x})^2}, \tag{8}$$

where: w_{ij} – spatial weight of the link between objects *i* and *j* (and element of 0-1 neighbourhood weight matrix **W** based on common border criterion[5]), where:

$$w_{ij} = \begin{cases} 1 & \text{when the } i^{\text{th}} \text{ object is a neighbour of the } j^{\text{th}} \text{ object,} \\ 0 & \text{when the } i^{\text{th}} \text{ object is not a neighbour of the } j^{\text{th}}, \\ 0 & \text{when } i = j \text{ (diagonal elements of the matrix),} \end{cases} \tag{9}$$

$$S_0 = \sum_i \sum_j w_{ij,}$$

[5] This matrix is often used in social and economic studies and theoretical explorations of spatial economics [cf. Sikora et al. 2014, Pietrzykowski 2011, Kopczewska 2006, Bivand, and Portnov 2004].

x_i – feature value for the i^{th} object,

$\bar{x}$ – feature value averaged over all objects,

N – number of all studied objects.

The statistic is a concise measure of the spatial dependence structure of studied objects (communes of Wielkopolska province) and it ranges over the [-1, 1] interval. Positive values of the statistic signal the existence of clustering effects among the objects, while negative values – checkerboard patterns [Kossowski et al., 2013].

Separately, the correlation between the feature value for a given object with the values of adjacent objects can be studied using local Moran I statistic [Kopczewska 2006]:

$$I_i = \frac{(x_i - \bar{x})\sum_{j=1}^{N} w_{ij}(x_j - \bar{x})}{\sum_{j=1}^{N}(x_j - \bar{x})^2 / N}, \qquad (10)$$

where w_{ij} are the elements of row-standardized spatial weight matrix **W**.

The local Moran I statistic is positive for an object surrounded by those of similar feature values. The autocorrelation is then said to be positive. On the other hand, negative values of local Moran I correspond to a situation when the object has diametrically different feature values to its neighbours, and to the autocorrelation being negative. More broadly, local Moran I statistic can be used to identify agglomeration effects – clusters of similar feature values and outliers, or objects that stand out from its neighbourhood.

Figure 1. Spatial dependencies between an object and its neighbourhood

	Low values in the object	High values in the object
High values in the neighbourhood	**LH** (negative spatial autocorrelation)	**HH** (positive spatial autocorrelation)
Low values in the neighbourhood	**LL** (positive spatial autocorrelation)	**HL** (negative spatial autocorrelation)

Source: own elaboration of Kopczewska [2006].

Two types of clusters can be defined (Fig.1): HH – objects of high feature values surrounded by objects of likewise high values, and LL – objects of low feature values bordering similar neighbours. Similarly, there can be two types of outliers: LH and HL. The map of agglomeration effects is based on statistically significant local Moran I values.

The calculation of global and local Moran I statistics and the maps presented in the article were executed in R using packages *spdep*, *maptools* and *shapefiles*.

Results of Phase I – Synthetic evaluation of financial self-sufficiency of communes of Wielkopolska province

The analysis was carried out by taxonomic methods described above; four typological classes of financial self-sufficiency of the communes were distinguished (Table 1), their spatial delimitation presented in Figure 2.

Class I, comprised of 23 or 10.2% of all province's communes, showed a high level of financial self-sufficiency. Nine of those were from the Poznań metropolitan area (i.e. Suchy Las, Tarnowo Podgórne, Czerwonak, Dopiewo, and Komorniki), attesting to the beneficial influence of large urban centres. On the other hand, high self-sufficiency of such communes as Przykona was a direct consequence of the existing mining industry exploiting its natural resources, or in the case of Powidz – of tourist functional type of the commune coupled with the location of an air base. Communal governments of Class I stood out for the highest level of own income per capita (WDWM – PLN 2,394), the lowest level of state intervention (WFIP 29,2%), and the highest level of fiscal wealth (WAP – PLN 1,911) (Table 1).

Class II of medium high self-sufficiency included 80 communes, or 35.4% of the total, and had above average level of own income per capita (PLN 1,715) and fiscal wealth (PLN 1,310). They were found mainly in the central west part of the province and relatively close to its capital or other large urban centres, which bolstered their residential and service-oriented character (Table 1).

Table 1. Intraclass values of the financial self-sufficiency indicators of communes of Wielkopolska province in 2014 (median for average values)

Specification	Typological class of financial self-sufficiency				Total
	I high	II medium high	III medium low	IV low	
Financial self-sufficiency indicators					
Percentage of all communes (%)	10.2	35.4	42.0	12.4	100.0
WDWM (*PLN per capita*)	2,394.1	1,715.7	1,194.3	843.4	1,399.7
WFIP (%)	29.2	43.6	59.4	69.8	52.9
WBF (*PLN per capita*)	1,910.8	1,310.4	868.2	594.2	1,020.1
WAP (%)	32.7	23.5	16.0	10.0	18.7
WIWO (%)	19.7	15.1	13.5	12.6	14.9

Table 1. Intraclass values of the financial self-sufficiency indicators of communes of Wielkopolska province in 2014 (median for average values) (cont.)

Specification	Typological class of financial self-sufficiency				Total
	I high	II medium high	III medium low	IV low	
Social and economic determinants					
Distance to urban centres (km)	29.7	31.4	36.7	37.5	34.2
Population density (inhabitant/km^2)	122.0	91.5	62.0	57.0	69.0
Net migration per 1000 inhabitants [a)]	2.6	-0.9	-1.9	-1.7	-1.1
Employed on individual farmsteads per 100 working age persons [b)]	11.3	15.9	29.0	44.4	24.4
Number of economic entities in REGON registry per 100 inhabitants	1,682.2	1,538.9	1,196.7	1,005.8	1,248.4

a) calculated for 2012-2014.

b) own calculation.

Source: own elaboration based on data from the Central Statistical Office (Local Data Bank) and the Ministry of Finance (Wskaźniki do oceny sytuacji finansowej….).

Class III of medium low level self-sufficiency was formed by 95 communes, chiefly from the north and south of the province, which represented 42.0% of the total. Their financial sufficiency indicators were all below average, and they were marked also by below average population density and below average level of economic activity (Table 1).

Class IV of financially least self-sufficient group of 28 communes (12.4% of all), located mainly in the southeast of the province, was characterized by the lowest, PLN 843.4 levels of own income per capita (which was 40% lower than the average). At the same time, these communes had the highest share of transfers in total income (WFIP = 69.8%). Low level of own income and its low shares in the communes' budgets lead to low levels of investment expenditure shares in total expenditures. These communes were agriculture-oriented with high numbers of

employed on individual farmsteads (44.4) and a low economic activity, owing largely to remoteness from urban centres, especially from Poznań, the economic centre of the province.

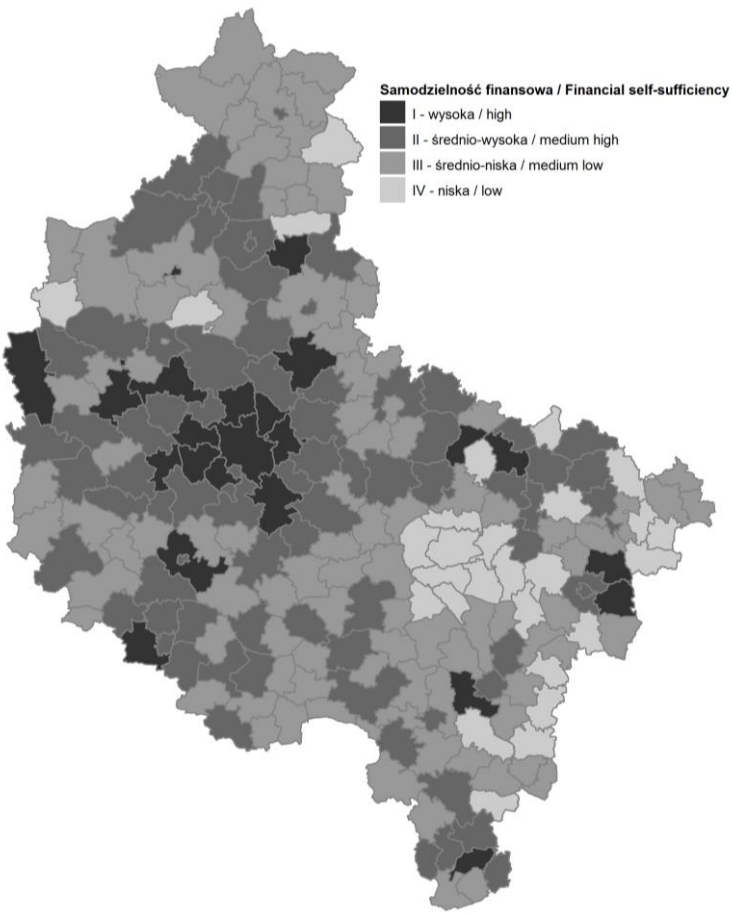

Figure 2. Spatial delimitation of financial self-sufficiency typological classes of communes of Wielkopolska province in 2014

Source: ibid.

Results of Phase I – Identification of the strength and character of financial self-sufficiency spatial autocorrelation in communes of Wielkopolska province

The strength and character of financial self-sufficiency spatial autocorrelation in communes of Wielkopolska province were identified using the global Moran I statistic, whose value reached 0.289 and proved statistically significant ($p < 0.01$). The result indicated a moderately positive spatial autocorrelation and a tendency of communes with comparable levels of financial self-sufficiency to cluster together. It should be stressed, however, that the measure does not offer an insight into the local deviations from the globally depicted pattern. In fact, in certain areas, such as the Poznań metro[6], communes display stronger connections than would have been suspected from global autocorrelation calculations only.

Thus, a more exhaustive inquiry called for employment of the local Moran I statistic, computed for every commune, which allowed for studying departures from global autocorrelation. Figure 3 shows the dispersion of local Moran I values, with standardized values of financial self-sufficiency synthetic index on the horizontal axis, and the spatial lag[7] in the index on the vertical one. Values of local Moran I statistic for selected communes are presented in Table 2. In general, they proved statistically significant for 40 communes (Figure 5), 36 of which were clustered, i.e., adjacent to communes with similar index values. Figure 4 presents the membership of the communes in Moran I scatterplot quadrants. The darkest colour denotes clusters of high financial self-sufficiency (HH), while the lightest one denotes clusters of low financial self-sufficiency (LL).

The study indicates that the communes with high financial self-sufficiency concentrate mainly in Poznań metropolitan area, producing a cluster to encompass not just the first ring around the city, but also the second and the third ones. Smaller clusters of high financial self-sufficiency were found in the north around the cities of Chodzież and Piła, and in the south around Leszno, but also in tourist districts (Powidz, Ślesin) and in mineral rich belts of eastern Wielkopolska.

The research also found low financial self-sufficiency clusters (LL): in the north, of communes heavily forested and sparsely populated, and in the southeast, of communes with agricultural character, sizable employment on individual farms, and low economic activity [cf. Kozera, Wysocki 2015].

[6] Poznań metropolitan area is the economic powerhouse of the province, situated in its center and encompassing the City of Poznań and 17 communes of the Poznań county.

[7] Spatial lag is taken for each object to be the weighted average of feature values in adjacent objects, $lag(x_i) = \sum_{j \in N_i} w_{ij} x_j$ [Kopczewska 2006].

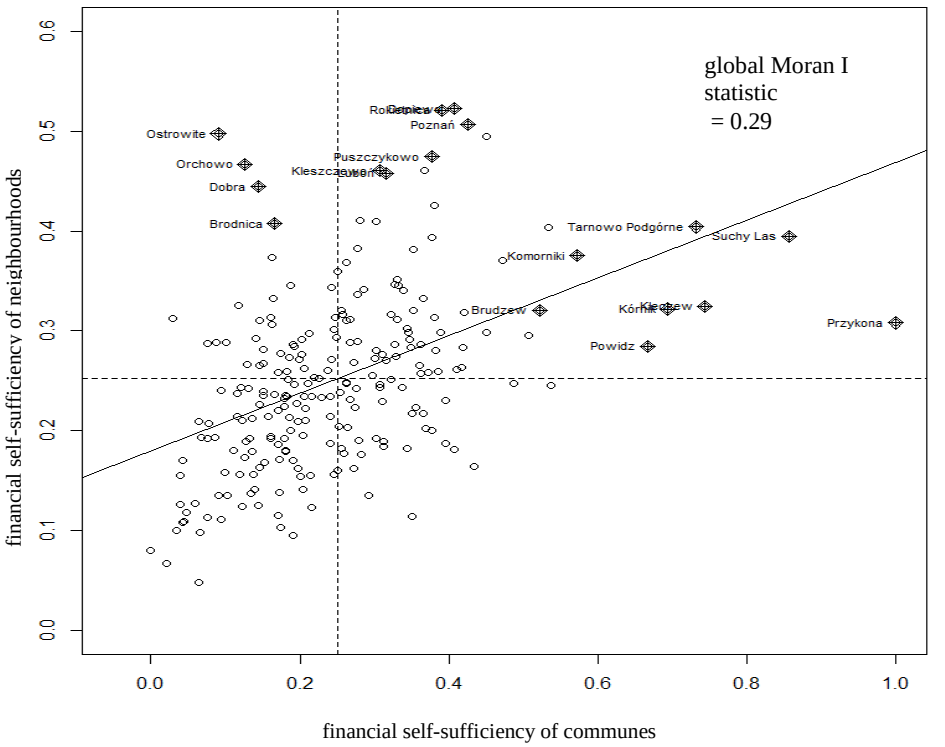

Figure 3. Dispersion of local Moran I values for the levels of communes of Wielkopolska province financial self-sufficiency in 2014

Source: ibid.

Table 2 presents examples of communes of Wielkopolska province whose local Moran I statistics proved significant: some of the HH and some of the LL clusters, as well as all outliers, i.e. communes surrounded by neighbours of diametrically different levels of financial self-sufficiency. The latter included LH (low surrounded by high) communes: Dobra of Turek county, and Orchowo and Ostrowite of Słupca county. Dobra, of medium low financial self-sufficiency, is a typically agricultural commune that borders Przykona and Turek communes with their coal mines and power plants. Similarly, Orchowo and Ostrowite, of low financial self-sufficiency and bordering tourism-oriented communes, can have their low self-sufficiency explained by a considerable distance to urban centres, bleak demographics (sparse population, low net migration), and economic relative inactivity. On the other side of the Moran diagram there was an HL outlier, Stare Miasto of Konin county. It is a residential neighbourhood of the city of Konin with double the average population density and a high number of registered economic entities (Table 2).

Table 2. Values of local Moran I statistic with respect to the level of financial self-sufficiency for selected communes of Wielkopolska province

Direction of auto-correlation		Positive						Negative			Total
Commune		Poznań	Suchy Las	Tarnowo Podgórne	Grodziec	Gizałki	Zagórów	Stare Miasto	Orchowo	Ostrowite	
Class of financial self-sufficiency		I (high)			IV (low)			II (medium high)	III (medium low)	IV (low)	
Local Moran I statistic		7.451	9.693	8.985	5.571	5.571	4.132	-1.652	-2.951	-3.880	
p-value		0.000	0.000	0.000	0.000	0.000	0.000	0.951	0.998	1.000	
Type of neighbour-hood dependency		HH			LL			HL	LH		
Socio-economic determinants	Distance to Poznań (km)	×	10.8	19.5	107	92.3	84.0	103.0	95.7	137.0	×
	Population density (km^2)	2,083	140	236	45	43	57	120	40	50	69
	Net migration per 1000 inhabitants	-4.2	17.5	18.7	-1.7	-2.8	-3.3	8.5	-5.6	0.2	-1.1
	Employed on individual farmsteads per 100 working age persons	0.7	5.7	10.7	57.2	46.3	41.2	40.2	29.0	43.4	24.4
	Number of economic entities in REGON registry per 100 inhabitants	3,153.6	3,487.0	3,251.8	1,047.4	1,291.5	1,092.8	1,628.6	1,117.4	935.1	1,248.4

Source: ibid.

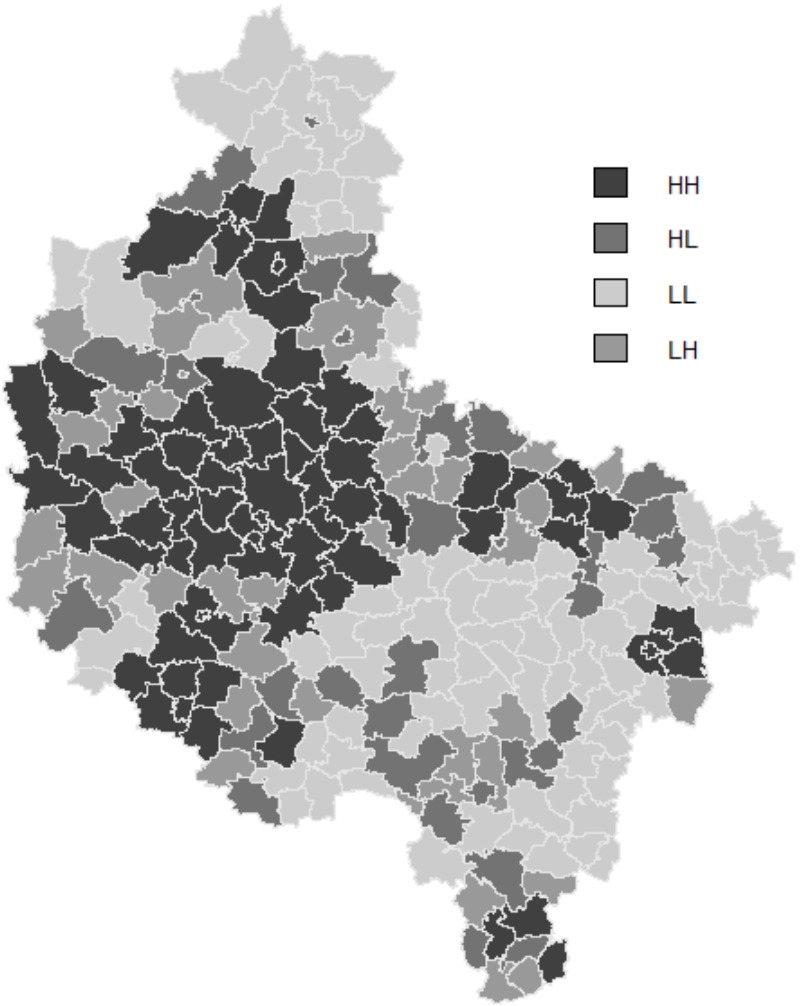

Figure 4. Membership of communes of Wielkopolska province in Moran scatterplot quadrants

Source: ibid.

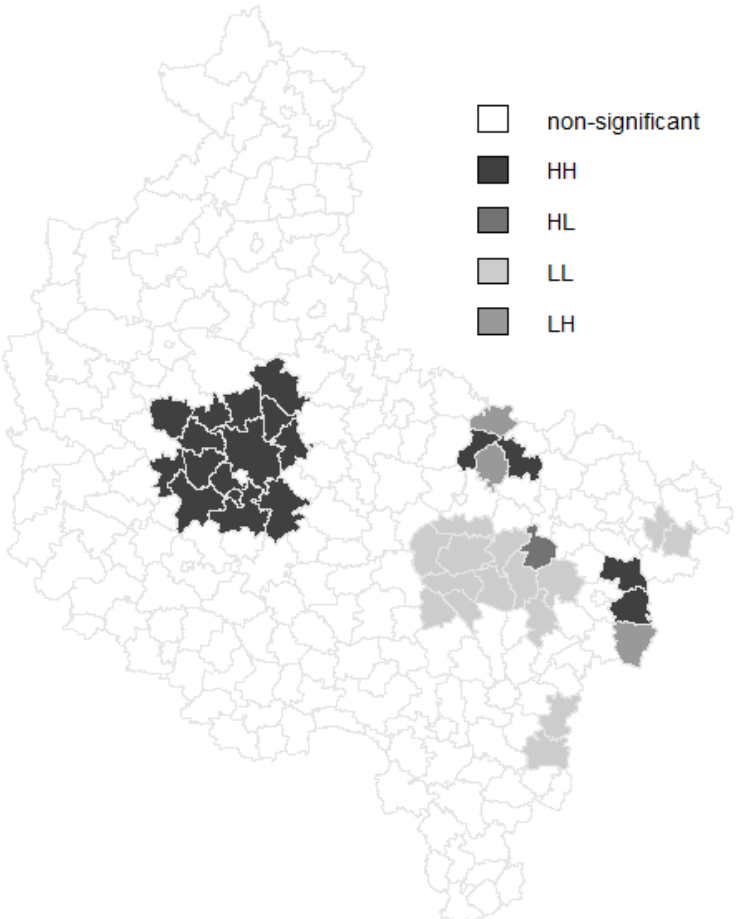

Figure 5. Significance of local Moran I statistics for communes of Wielkopolska province

Source: ibid.

3. Conclusions

Spatial methods are becoming increasingly popular in analysing not just economic, but also financial data. Autocorrelation tools may facilitate this analysis and simplify the process of revealing the underlying spatial structure of connections between local government units, also in the scope of financial self-sufficiency.

This paper studied the spatial effects in assessment of financial self-sufficiency of communes of Wielkopolska province. Computations of global

Moran I statistic showed positive spatial autocorrelation, which signified the existence of clusters of communes with similar levels of financial self-sufficiency. Local Moran I statistic assisted in finding those clusters: a high level in the Poznań metropolitan area, the product of the ongoing suburbanization of the provincial capital, and a low level in economically underdeveloped agricultural communes of northern and south-eastern parts of the province. It is difficult to speculate how the results for communes of Wielkopolska province extend to the whole country, or what is the strength that other urban centres exert on their neighbourhoods' financial self-sufficiency. Certainly, these questions warrant further research.

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