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Urban Greenery in the Greatest Polish Cities: Analysis of Spatial Concentration

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Abstract**—**Cities offer important opportunities for economic development and for expanding access to basic services, including health care and education, for large numbers of people. Moreover, green areas (as an integral part of sustainable urban development) present a major opportunity for improving urban environments, quality of lives and livelihoods. This paper examines, using spatial concentration and spatial taxonomic measures, regional diversification of greenery in the cities of Poland. The analysis includes location quotients, Lorenz curve, Locational Gini Index, and the synthetic index of greenery and spatial statistics tools: (1) To verify the occurrence of strong concentration or dispersion of the phenomenon in time and space depending on the variable category, and, (2) To study if the level of greenery depends on the spatial autocorrelation. The data includes the greatest Polish cities, categories of the urban greenery (parks, lawns, street greenery, and green areas on housing estates, cemeteries, and forests) and the time span 2004-2015. According to the obtained estimations, most of cites in Poland are already taking measures to become greener. However, in the country there are still many barriers to well-balanced urban greenery development (e.g. uncontrolled urban sprawl, poor management as well as lack of spatial urban planning systems).

Keywords**—**Greenery, urban areas, regional spatial diversification and concentration, spatial taxonomic measure.

I. Introduction

CITIES and towns are major centres for science, innovation, public services and business, fostering economic development, sense of security, and thus, also opportunity to meet the people's needs . What is more, urban areas are currently the place of residence of a large segment of the population [1]. More than half of the world's population now lives in urban areas [2]; that rate is more than 60% in Poland [3], while it reaches about 80% in many European Union countries [4]. Nevertheless, cities and towns are space of numerous disproportions and complex social, ecological and economic relations too. Urban development also entails increasing income inequalities, social polarisation and segregation, urban sprawl and deterioration of the natural environment. In consequence, the processes may lead to the impaired quality of residents' lives.

One of the possible solutions to urban problems is a sustainable (*sustainable development* shall mean such socio-economic development which integrates political, economic and social actions, while preserving the natural equilibrium and the sustainability of basic natural processes, with the aim of guaranteeing the ability of individual communities or citizens, of both the present and future generations, to satisfy their basic need, [5]) approach to cities and towns' development and the creation of space enabling and supporting urban dwellers' actions and activities [6]. Those concern, among others, green spaces in cities and towns. Urban greenery in the form of parks, lawns, and squares, as well as garden allotments, green spaces of housing estates or public forests is an extraordinarily important component of harmonious urban development [7]. It performs many functions in the everyday lives of the population, including: social and economic, recreational, holiday, touristic, technical and aesthetic ones [8]. It also beneficially affects the physical and mental health of humans [9]-[14]. On the one hand, green spaces constitute a basic element of urban tissue planning with their role increasing with urban development. On the other hand, however, contemporary urbanised areas are deficient in greenery and the current urban spatial policy does not focus on creating new green spaces but rather on their sale for building development. Moreover, there is a threat of urbanisation progress, population rise and so-called *urban sprawl* [6]. That process entails green spaces shrinking in cities and towns' centres and on their outskirts [15]. In the years 2004-2015, the average share of green spaces in the total surface areas of 66 largest Polish cities and towns (with populations exceeding 100,000) was 7.5% (with an increase of 1% in the analysed period). In 2014, green spaces accounted for 23% of the town's surface area in Chorzów (one of the "greenest" urban areas in Poland). By contrast, according to the European Commission's report, greenery covered over 60% of the surface area of the green capital city of the year (Ljubljana). In Poland, urban greenery still encounters numerous problems associated with, among others, management methods (lack of spatial development programmes, erroneous planning recommendations), management system legislation, low ecological awareness of the population, inadequate care for green spaces [16] and insufficient financial resources (from local governments' budgets) allotted to greenery maintenance. An average of PLN 21 *per capita*, which amounted to as little as USD 5.3 *per capita*, was spent on urban greenery management from own funds in the Polish greatest cities (with powiat status) in the years 2004-2015 (exchange rates, from 26.10.2016 [44]).

The creation of urban green spaces is many years' incessant process, while the planning of green spaces should be preceded by analysing the current development state. To that end, quantitative methods have been applied. Nowadays, tools related to GIS, spatial statistics and econometrics are becoming particularly cognitively important. Quantitative analyses in the scope of assessment and modelling of greenery

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resources in cities and towns are more and more commonly applied, although they have still not been popularised in the Polish specialist literature. A vast body of academic publications in Poland discusses issues of urban green spaces solely from the theoretical point of view, *i.e.* without the use of analytical methods. Nonetheless, selected strategies, local governments' surveys, current state diagnoses, experts' opinions and research studies employ, among others, green city indices [6], [8], [17], Voronoi diagram algorithms [18] or traditional statistical instruments [19], [20] to study urban greenery systems. The world specialist literature quite commonly analyses the issue of urban green spaces, applying also advanced spatial quantitative methods, such as: uni-equational econometric models [21], [22], spatial metrics estimated, GIS [23], [24], spatial autocorrelation [25], geographically weighted regression (GWR) [26] and spatial regression models [27].

The main purpose of this study is to examine changes (both in time and geographical space) in spatial diversification (concentration or dispersion) of the level of the urban greenery depending on the variable category. The spatial concentration (location quotient, Lorenz curve, Locational Gini Index) and spatial taxonomic measures are used in this empirical research. The analysis was conducted for the period 2004-2015 and the greatest Polish cities.

II. Disclosure of Inequality in the Resources of Urban Greenery

In order to measure the degree of spatial inequality, various measures of concentration are used. Inequality in the sense of concentration is understood as a non-uniform distribution of the total sum of values of a studied feature among specific units of a set and is most commonly measured with indices based on the Lorenz curve [28], [29]. Spatial analyses also employ the Gini coefficient as a synthetic measure of a phenomenon's concentration degree. In order to determine to what extent the shares of green spaces (according to space classification) were equally spread and what type of space contributed to a rise in the inequality of urban green resources (both in time and geographical space), the *LGI* (Locational Gini Index) formula was used. It had been developed by Krugman [43], and subsequently popularised by Kim et al. [30] and Ruiz-Valenzuela et al. [31]:

$$G_i^* = \frac{2}{R^2(L\overline{Q}^i)} \sum_{r=1}^{R} k_r \left| LQ_r^i - L\overline{Q}^i \right| \quad (1)$$

where R – number of regions (cities and towns), r, m – specific region (city or town), LQ – location quotient determined according to:

$$LQ_r^i = \frac{(x_r^i / \sum x_r)}{(\sum x_i / \sum x)} = \frac{p_r^i}{q_r} \quad (2)$$

for: x_r^i – value of an analysed factor, resource of variable x for the city or town (region) r (r = 1, 2, ..., R), in the i division (cross-section) criterion of the factor, resource, sector for i = 1, 2, ..., S, $\sum x_r$ – total value for the i category of an analysed cross-section, $\sum x_i$ – total value of the sum of observations according to all categories of a given cross-section of variable x for region r, $\sum x$ – sum of all observations of variable x, p_r^i – share of an individual regional observation for region r in the total value of the i cross-sectional category, q_r (weight variable) – share of the total number of observations according to all variable categories in a given r region in the sum of all variable observations (in this case: the share of surface areas of all types of green spaces in specific cities and towns in the total size of those spaces in Poland). It is worth mentioning that share values are independent of the chosen unit of measure. The Gini index is *zero* if the phenomenon structure in a given category shows distribution identical to the global (reference) structure of that variable, and is *one* if the studied variable is fully concentrated in one object (region, city, town). A detailed interpretation of spatial location quotients is also possible, which takes into account percentage values of a difference between the LQ value calculated for a given region and that for the reference region (where LQ=1 is assumed). Results below zero indicate the concentration of the phenomenon in a given region lower by a resulting percentage value than the concentration of the phenomenon in the reference area. A positive value means the concentration of the phenomenon in a given region higher than that in the reference region by the value of the difference expressed as percentage. A zero difference value means an equal distribution of a feature (similar to the reference region).

TABLE I
Summary Statistics of Selected Data of Urban Greenery and of Location Quotients for the Time Span from 2004 to 2015

	Parks	Lawns	Street Greenery	Green Areas on Housing Estate	Cemeteries	Forests
				Variables		
Mean	1.30	0.63	0.98	1.94	0.48	2.28
	(-2)	(-15)	(39)	(-7)	(4)	(-4)
Std. Dev	2.12	0.94	0.68	1.55	0.24	3.32
	(2)	(-45)	(30)	(-36)	(-2)	(-3)
Max.	16.45	6.07	2.94	10.45	1.06	14.87
	(4)	(-61)	(36)	(60)	(2)	(0)
Min.	0.04	0.04	0	0.14	0.04	0
	(-1)	(8)	(0)	(>110)	(-21)	(0)
Median	0.78	0.38	0.86	1.66	0.45	0.84
	(18)	(3)	(47)	(1)	(2)	(-5)
				LQs		
Mean	0.87	0.89	1.17	1.03	1.11	0.77
	(-3)	(10)	(-2)	(-1)	(-8)	(0)
Std. Dev	0.75	0.87	0.82	0.54	0.75	0.80
	(4)	(3)	(-9)	(-2)	(-23)	(-2)
Max.	4.15	4.71	4.33	3.29	4.99	2.69
	(12)	(4)	(-8)	(13)	(8)	(2)
Min.	0.04	0.07	0	0	0	0
	(-10)	(25)	(0)	(>100)	(66)	(0)
Median	0.76	0.63	1.01	1.06	1.06	0.59
	(-5)	(19)	(-4)	(-2)	(11)	(-10)

In parentheses are the computed changes between 2004 and 2015 to show diversity over time, values in %.

Average values of location quotients (computed for the years 2004-2015) indicated differences in the concentration of

green spaces' surface areas in specific cities and towns dependent on the green space category, as shown in Table I.

The data contained in Table I showed the over-average concentration of green spaces' surface areas in cities and towns for street green areas (*Mean LQ*=1.17) and cemeteries (*Mean LQ*=1.11). On the other hand, in the years 2004-2015, the highest deficiency of green spaces' surface areas in cities and towns concerned forests (*Mean LQ*=0.77, the concentration was as much as 23% lower than in the reference area). Furthermore, specific cities and towns could be indicated as standing out in respect to the phenomenon's concentration, i.e. where there was strong concentration and "deficiency" (concentration lower than in the reference region) of a specific urban greenery type, Fig. 1.

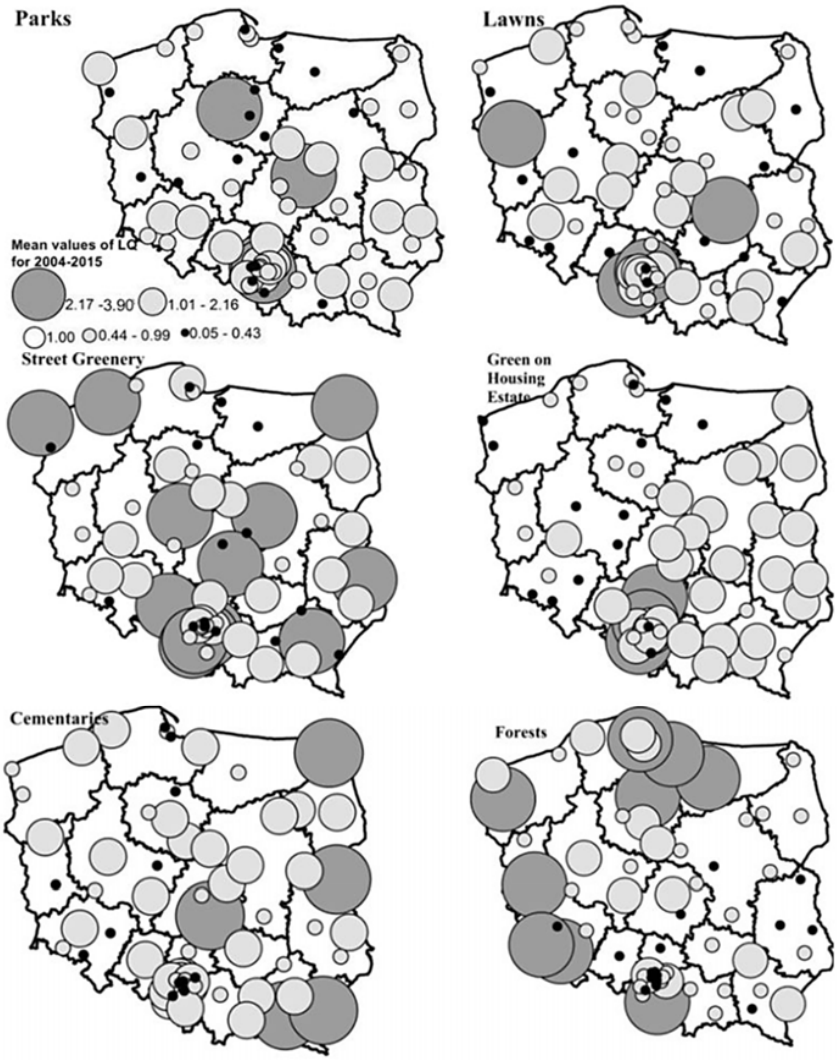

Fig. 1 The Mean Values of *LQ* calculated for the types of urban greenery areas and years 2004-2015

The greatest inequalities (diversification) in the distribution of Polish urban greenery systems' surface areas regarded forests. That was indicated by the value of the calculated spatial concentration index (*Gini*=0.53) and distance of the Lorenz curve from the main diagonal, Fig. 2. Among the analysed types of green spaces, the distribution of housing estate greenery spaces in the analysed cities and towns seemed to be the most "uniform". That was indicated by the relatively smallest deviation of the Lorenz curve from the line of equality and the Gini coefficient value (*Gini*=0.27).

Nevertheless, the phenomenon of concentration (inequality) of urban greenery resources occurred for all the studied types of spaces, with solely the degree of diversification being different and varying somewhat over the 2004-2015 period, as shown in Fig. 3. Graphs contained in Fig. 3 show a noticeable regression in cemetery surface areas' concentration strength. That may mean decreasing inequality in the sizes of those spaces, *i.e.* elimination of differences in the phenomenon's levels in cities and towns.

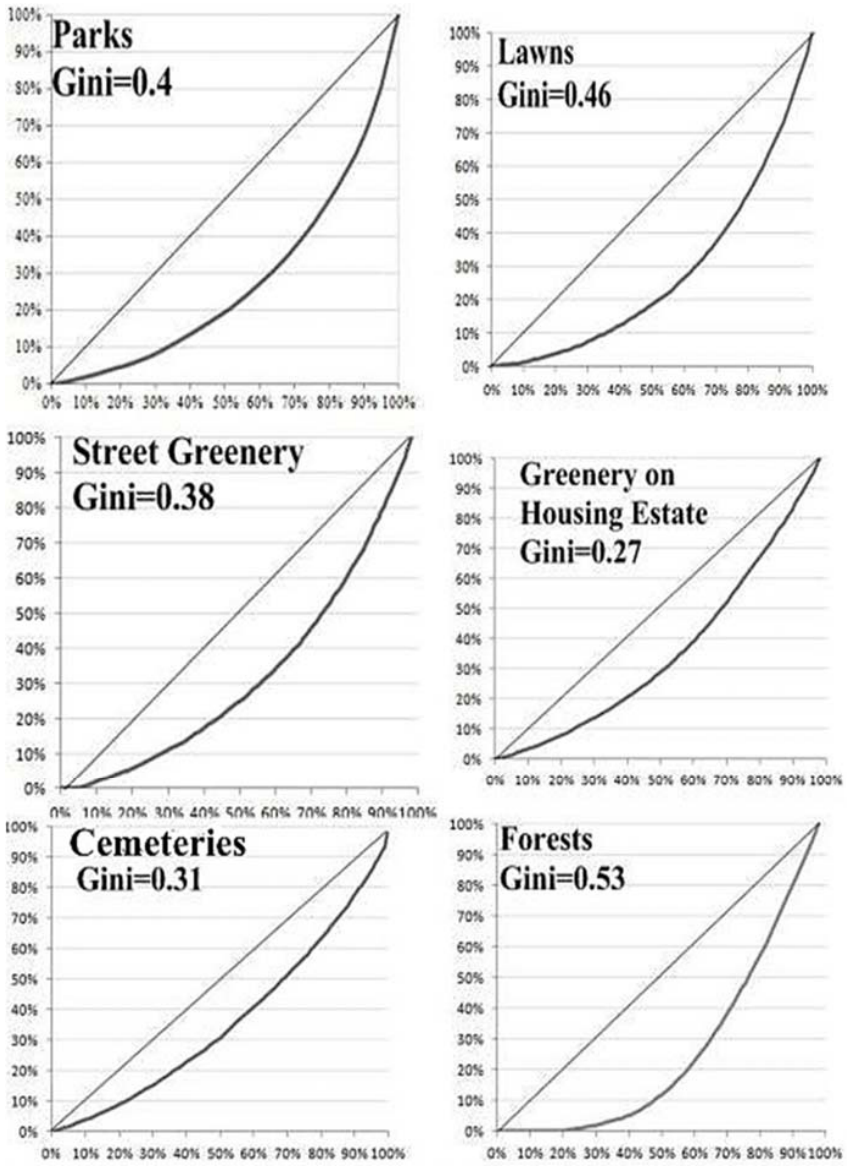

Fig. 2 Lorenz Curves and Ginis coefficients

III. Polish Cities Going Green

A. Identification of Spatial Interactions

The development of urban green spaces is a long-term process depending on many economic, social, urban planning and legislative factors, as well as spatial determinants and relationships. The location (range) of green spaces, environmental investment expenditures or supra-local cooperation of local government authorities occur in many spatial units, irrespective of artificially set administrative borders [32]. Thus, spatial relationships (spatial autocorrelation, i.e. the degree of correlation of an observed variable's value in a given location with the value of the same variable in another location) may affect surface areas of urban greenery not only in a given city or town but also in other (adjacent) locations [33], [34].

The structure of spatial interactions occurring among cities and towns was described with a nearest neighbour adjacency matrix (**W**). The matrix was built based on the criterion of distance of each city and town from its nearest neighbour. First, distances among all urban units were calculated, which was followed by finding, for each unit, a city or town (eight urban areas in this case) which was situated in the so-called nearest neighbourhood. The said matrix was selected for the analysis, keeping in mind that spatial relationships are characterised by a stronger influence among nearer located objects; the greater the distance among the units, the weaker the influence [36]. Upon transforming the adjacency matrix into a spatial weights matrix, Moran's global spatial autocorrelation *I* statistics was calculated, applying the formula [35]:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \frac{\mathbf{z}^T\mathbf{W}\mathbf{z}}{\mathbf{z}^T\mathbf{z}} \quad (3)$$

where: n – number of observations; xi, xj – values of variable x in locations i and j; $\bar{x}$ – mean observation value; x_i; w_{ij} – elements of spatial weights matrix **W**, standardised in rows to one; **z** – vector with elements from $z_1,...,z_n$, for $z_i = x_i - \bar{x}$. Elements of matrix **W** were integral and positive numbers. The value of the statistic was in the <-1,1> interval. If adjacent spatial objects were similar to one another (formed clusters), the value of the statistic was positive. If objects were different, the value of the statistic was negative. The absence of a correlation among adjacent values meant the expected I value is close to zero. In order to verify the hypotheses concerning spatial autocorrelation (H_0: observed values of the variable were randomly distributed, thus there was no spatial autocorrelation, H_1: there was spatial autocorrelation), the so-called randomisation tests were carried out [37], [38].

Data contained in Table II indicate that spatial relationships affected shares of surface areas of all types of green spaces, except for that of cemeteries, in the total urban surface area (Moran's I statistic was statistically significant).

Conclusions reached at that stage of research provided a premise for creating a synthetic measure taking into account spatial relationships (Spatial Synthetic Taxonomic Measure, SSTM) [40]. The analysis of SSTM values allowed measuring the level of green development of Polish cities and towns in the years 2004-2015, studying the concentration and diversification of units in terms of possessed green space resources and deciding whether and in which cities and towns green areas developed or were lost.

TABLE II
VALUES OF GLOBAL MORAN'S *I* STATISTICS FOR USING THE **W** MATRIX

Year/ Var.	Parks	Lawns	Street Greenery	Green Areas on Housing Estate	Cemeteries	Forests
2004	0.02	0.06**	-0.11**	0.08**	-0.02	0.31***
2005	0.02	0.07**	-0.09**	0.13***	-0.02	0.31***
2006	0.03	0.07**	-0.08**	0.13**	-0.02	0.31***
2007	0.03*	0.06**	-0.10**	-0.02	0.01	0.31***
2008	0.04*	0.07**	-0.09**	-0.02	0.01	0.31***
2009	0.04*	0.06**	-0.10**	0.06*	0.01	0.31***
2010	0.03*	-0.03	-0.10**	0.07*	0.03	0.30***
2011	0.03*	-0.06	-0.12***	0.09**	0.03	0.33***
2012	0.03*	-0.05	-0.09**	0.09**	0.03	0.33***
2013	0.03*	-0.05	-0.09**	0.08**	0.04	0.33***
2014	0.03*	-0.05	-0.04	0.08**	0.02	0.34***
2015	0.03*	-0.05	-0.07	0.09**	0.02	0.33***

Note: significance levels: α = 0.10*, 0.05 **, 0.01 ***.

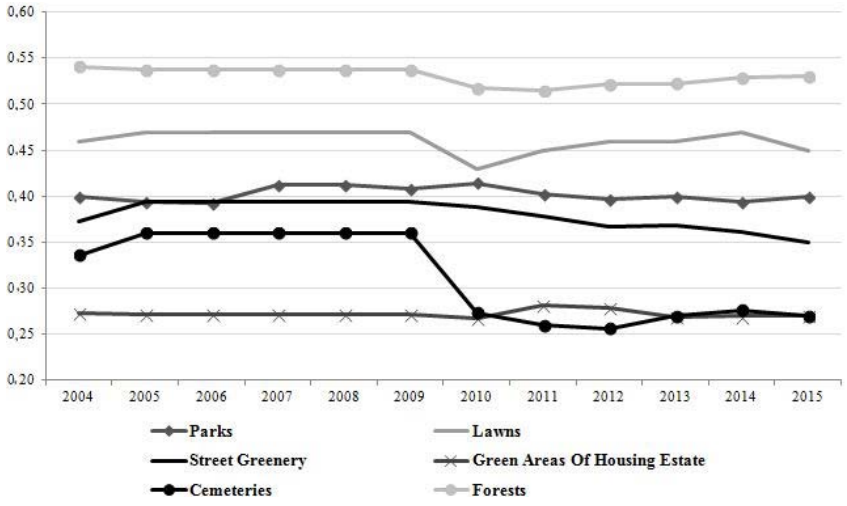

Fig. 3 Ginis indexes in the time span 2004-2015

B. Synthetic Spatial Taxonomic Measure

The Spatial Synthetic Taxonomic Measure was constructed through a modification of the commonly known Hellwig's taxonomic development measure [39]. The measure is a synthetic value, the resultant of variables considered in a study and defined as stimulants, destimulants and nominants. The set of analysed variables consists only of stimulants whose high values are beneficial from the point of view of a non-observable variable. It means that the higher the stimulant's value, the higher the level of the examined phenomenon, more in e.g. [42]. In order to be comparable, diagnostic features undergo unitarisation, normalisation or standardisation processes [41]. Variables showing statistically significant spatial autocorrelation should be standardised taking into account that property. In this article, standardisation for spatial features $x_{ij}^* = \mathbf{W}x_{ij}$ (**W** – the assumed spatial weights matrix) was performed using (4):

$$z_{ij}^* = \frac{x_{ij}^* - \bar{x}_j^*}{s_j^*} \quad (4),$$

where: *i* unit, for *i* = 1,2,..., *n*, *j* variable for *j* = 1,2,..., *m*, $\bar{x}_j^*$ – arithmetic mean, s_j^* – standard deviation.

In turn, if a synthetic measure comprises non-spatial features too (x_{ij}), standardisation for those variables is conducted as:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \tag{5}$$

where $\bar{x}_j$ – arithmetic mean, s_j – standard deviation.

Then, the target values of synthetic development measures are determined applying (6):

$$SSTM_i = 1 - \frac{d_i}{d_-} \tag{6}$$

for *i* = 1,2,..., *n*, d_- – critical distance of a given unit from the development standard:

$$d_- = \bar{d} + 2s_d \tag{7}$$

where $\bar{d}$ –arithmetic mean of vector $d = (d_1, d_2, \ldots, d_n)$, s_d – standard deviation of vector *d*, d_i – Euclidean distance of objects from pseudo-standard of development φ_j calculated depending on the character of variables. For spatial features, the following formula is used:

$$d_i = \sqrt{\sum_{j=1}^{m} (z_{ij}^* - \varphi_j)^2} \tag{8}$$

whereas for non-spatial features, (9) is applied:

$$d_i = \sqrt{\sum_{j=1}^{m} (z_{ij} - \varphi_j)^2} \tag{9}$$

z_{ij}, z_{ij}^* – standardised values, $\varphi_j = \max_{i=1,2,\ldots,n} z_{ij}$ or $\max_{i=1,2,\ldots,n} z_{ij}^*$ for stimulants, $\varphi_j = \min_{i=1,2,\ldots,n} z_{ij}$ or $\max_{i=1,2,\ldots,n} z_{ij}^*$ for destimulants.

Values of the taxonomic development measure are in the range $\langle 0;1 \rangle$. That means that the higher the value of the development measure (close or equal to "1"), the closer the object is to the standard in terms of the studied phenomenon's level.

The process of building a synthetic greenery measure took into consideration the spatial character of variables. Based on the measure values, towns and cities were ranked according to green spaces' development levels. Then, a comparative analysis was performed, and diversification of and changes in the phenomenon were assessed in the years 2004-2015, as shown in Fig. 4.

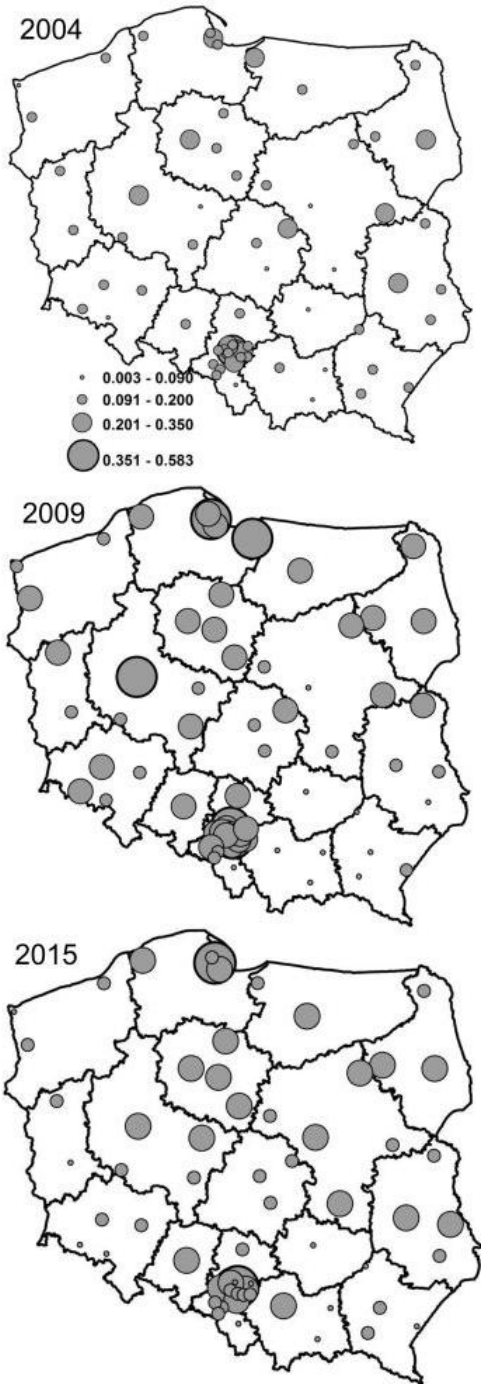

Fig. 4 Spatial synthetic taxonomic measure of urban of the selected years

Maps contained in Fig. 4 indicate an increase in the development level of urban green spaces in the years 2004-2015. In 2004, one town in the south of Poland showed high developmental potential for green spaces (the development standard), but the number of such urban areas grew by 2015 (more cities and towns in the north and south of Poland). Nonetheless, the synthetic measures' values indicated a low

general average level of "green" urban development in the analysed period and increasing diversification of that phenomenon, as shown in Table III.

TABLE III
SUMMARY STATISTICS OF TAXONOMIC MEASURE OF THE URBAN GREENERY, AVERAGE VALUES

	Values	Changes in 2004 to 2015 in %.
Mean	0.18	11
Std. Dev	0.09	12
Max.	0.50	-32
Min.	0.01	548
Median	0.17	19

IV. CONCLUSION

The article is a multidimensional analysis of green space resources' diversification in 66 cities and towns of Poland. The study covered the period from 2004 to 2015. Based on the received results, it can be concluded that:

1) The concentration (inequality) of urban greenery resources occurred for all the studied types of spaces;
2) The highest diversification (inequality of distribution) of surface areas concerned street greenery, cemeteries and forests;
3) The strength of concentration varied over the 2004-2015 period (as compared to 2004, in 2015, the biggest fall was noted for the surface areas of cemeteries: -19.7% and street greenery: -6.0%, while a rise in the strength of inequality was observed for the surface areas of parks: +0.1%);
4) Spatial relationships affected surface areas of urban greenery (except for surface areas of cemeteries) not only in a given city or town but also in other (adjacent) locations;
5) By applying values of the spatial synthetic taxonomic measure, the level of green development of Polish cities and towns in the years 2004-2015 was measured, the concentration and diversification of units in terms of possessed green space resources were studied and it was determined whether and in which cities and towns surface areas of green spaces increased or were lost;
6) As compared to 2004, the average level of green spaces' development in cities and towns increased by 11% in 2015; nonetheless, a decrease in the phenomenon occurred in 66% of urban units;
7) Values of development measures indicated a low average level of "green" urban development in the analysed period and increasing diversification of that phenomenon.

The complete assessment of urban green spaces' development diversification in cities and towns of Poland requires deeper analysis. Nevertheless, the carried out study clearly indicated the unevenness of green resources' location and the low average level of "green" urban development in the analysed period. The direction of further analyses will be to seek determinants of diversification of greenery system development in cities and towns and to model occurring relationships by means of spatial regression models.

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