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#multivariate statistical methods
#socio-economic development
#development differences
#dynamic approach

A model of the analysis of the dynamics and structure of socio-economic development (an example of the set of the largest Polish cities in the years 1998–2015)

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Abstract

The complexity of the reality studied by geographical research requires applying such methods which allow describing the state of affairs and ongoing changes in the best possible way. This study aims to present a model of research on selected aspects of the dynamics and structure of socio-economic development. The idea was to determine whether we deal with the process of reducing or widening the differences in terms of individual features. The article primarily pursues a methodological goal, and to a lesser extent an empirical one. The methodological objective of the paper was to propose and verify a multi-aspect approach to the study of development processes. The analyses carried out reveal that in terms of the features taken into account in the set of 24 of the largest Polish cities the dominating processes are those increasing differences between cities, which are unfavourable in the context of the adopted development policies aiming at reducing the existing disparities. In relation to the methodological objective, the results of the conducted research confirm the rationale of the application of the measures of dynamics and the feature variance to determine the character (dynamics and structure) of the socio-economic development process of cities. Comparatively less effective, especially for interpretation, is the application of principal component analysis and a multivariate classification, which is mainly the result of differences in the variance of particular features.

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Introduction

The complexity of the reality examined, also by geographical research, requires applying methods that allow describing the state of affairs and ongoing changes in the best possible way. The characteristic feature of geographical analysis is first of all its spatial aspect (Sack 1973; Meentemeyer 1989; Agnew 2011). Nevertheless, taking into account that a structure and a change are features of the mentioned reality, the conducted research deals with both these properties. However, priority has been given to the change, not the structure.

The subject of the research is the set of the 24 largest Polish cities, whereas its objective is to describe the changes affecting this set in 1998–2015 in the selected categories of features (six features describing the selected categories of socio-economic development). The idea to adopt the set of the 24 largest Polish cities as the research subject may raise doubts. However, it should be emphasized that the largest cities, being as assumed, generators of development and civilizational cultural progress, at the same time severely experience numerous unfavourable phenomena as well as economic and social processes occurring in the contemporary world (Jacobs 1961; Turok & McGranahan 2013; Dijkstra, Garcilazo & McCann 2013; Colenbrander 2016). They lead the way in development, but they also deal with many problems. This attitude was at least the basis for adopting an urban policy and determining its principal aims, tasks and strategies by the European Union (*European Commission* [EC] 2007; EC 2008, Parysek 2010a, 2010b; *European Union* [EU] 2011; Parysek 2013; EU 2015; EC 2016).

Polish cities and changes occurring there after 1989 have been the research subject of many authors. Unfortunately, the majority of works have been published in Polish and therefore their accessibility is limited. There are certain exceptions, although the published articles concern changes related to the political transformation rather than socio-economic development dynamics (cf. Węcławowicz 2002; Parysek 2004, 2005; Parysek & Mierzejewska 2005; Parysek 2007; Korcelli-Olejniczak 2007; Mierzejewska 2009; Parysek 2010a, 2010b; Smętkowski 2010; Steinführer et al. 2010; Korcelli-Olejniczak 2011; Haase, Grossmann & Steinführer 2012; Marcińczak, Musterd & Stępniak 2012; Mierzejewska & Parysek 2014). However, the objective of this research is different.

On the one hand, it was to determine many aspects of the dynamics and structure of socio-economic development in the set of the 24 largest Polish cities which still play a key role in the socio-economic life of the country in spite of the observable process of their depopulation. In this context it is worth determining to what extent the development processes of the largest Polish cities relate to the two contradictory hypotheses in contemporary economics, that is convergence and divergence (Nowak 2006; Malaga 2007; Kossowski 2009; Voronov & Lavrinenko 2013; Kołodziejczyk 2014; Li, Rama & Zhao 2018). At this point it should be emphasized that convergence and divergence, as a process modeled on the path of econometric formulas, is not the subject of this article. It is only a reference to the meaning of these terms. In other words, the term convergence and divergence are a kind of metaphor. Decreasing differences between the cities identified in the dimension of the particular features were interpreted as convergence, whereas the increasing differences, as divergence. It is worth remembering that these two processes are usually studied in relation to the elements constituting a specific whole, e.g. countries on a continent, regions in a given state, etc. and the set of cities is just a certain part of the city system in Poland. However, the issues of convergence and divergence were also taken in relation to cities and not only to urban systems (O'Donoghue & Townshend 2005; Markowska 2014), but also just to the set of the cities (Rodrigue, Dablanc & Giuliano 2017).

On the other hand, it was about checking a certain analytical approach to the research of the structure of the set of the objects studied and its dynamics, i.e. a multi-aspect approach to the research of development processes. Therefore, both cognitive and methodical objectives were carried out. The main role, however, is played by the methodological goal, which is to present a model of time series analysis in relation to selected features of the socio-economic development of cities. Research on the development of 24 cities is not only an example, but also a study of development, although only 24, but the largest Polish cities. It is assumed that the largest cities, despite many problems, are treated unanimously as a generators of socio-economic development (Pole`se 2005; EC 2007).

Basic research assumptions

As mentioned above, the research subject was the set of the 24 largest Polish cities during the years 1998–2015, characterised by a group of several accessible features.

When studying any set of objects, the following can be examined: (1) states of affairs, (2) events, and (3) processes. States of affairs are examined by analysing the properties of the researched objects in one selected year, e.g. in 2015 having, obviously, a specific object or a set of objects, characterised by a group of features taken into account. An event is examined by comparing two states of affairs, that is the state from the year taken as initial and the state from a different year taken as final, e.g. from the years 1998 and 2015. Whereas a process is examined

by analysing the changes in the state of affairs for consecutive years, e.g. 1998, 1999, 2000, … 2015. The subject of the research is then a set of objects characterised by a time series of a specific feature.

Development in geographical research is mostly examined and assessed by comparing two states of affairs, i.e. as an event, and this kind of approach is called comparative statistics (Kehoe 1989; Gans 1996; Athey, Milgrom & Roberts 1998; Currier 2000). However, appropriate conclusions concerning specific development can be drawn, it seems, by studying a process, that is, analysing a time series (Box & Jenkins 1970; Brockwell & Davis 1991, 1996; Shumway & Stoffer 2011). When comparing two states of affairs we lose the information about what happened in the intermediate years. Therefore, next to the traditional investigation of events (usually assessed on the basis of the computed indicators of dynamics or a growth rate), when analysing the set of the 24 largest Polish cities. The process was examined as well with the use of time series analysis. Thus, with regard to this set of cities, the feature of reality called a process was examined.

A structure is understood as a set of objects and relations between these objects. Those can be vector relations (interactions) or scalar ones. In the research whose results are presented in this article, scalar relations are taken into account. A multivariate classification is a certain type of the synthesis of structural research which can be conducted in many ways. The basis for the derivation of classes is the similarity matrix indicating the similarity relations of the objects taken into account from the point of view of the features considered (Parysek 1982). The structure of the set of the cities can also be described by interpreting the data included in the data table.

The research was carried out on the set of the 24 largest Polish cities characterized by the following features for the subsequent years (time series) of the period 1998–2015: (1) the number of inhabitants, (2) the population density, (3) the number of the employed per 10,000 inhabitants, (4) the number of economic entities per 1,000 inhabitants, (5) apartments per 1,000 inhabitants and (6) a budget income per capita. Due to the large time range, it was possible to obtain only such data. So what was possible from a reliable source, which is the Central Statistical Office (state statistics). So, we used data that could be compiled for a relatively long period of time, and not those that could better describe socio-economic development. The features taken into account seem to describe the categories, so important for its development research, as changes in: the size of a city measured by the number of inhabitants (feature 1), the population density, and at the same time spatial development and the economy (feature 2), the activity of the employed in a city in relation to the number of inhabitants (feature 3), the economic activity (feature 4), the housing standard (feature 5) and the budget income which is the financial basis for territorial self-governments (feature 6)[1]. Only for such data could a time series be arranged for a relatively long time, namely for 18 years.

Thus, there were six data tables (6 features) of the size 24x18 (24 objects and 18 subsequent measurements of the feature for the period of 1998–2015). Each of the mentioned tables was subject to identical research aiming to answer the question what the urban development process looked like in the years 1998–2015 with the features considered and how the relations were changing in the set of the 24 cities. Particular cities were analysed (the rows of the data tables), in particular the years (the columns of the data tables) and the set of the cities (the entire data table).

For particular rows, the dynamics of development was determined (a study of changes), for columns – the variance of features, whereas the entire table supplied the principal components and was a basis for a multivariate classification (a study of structures).

The arrangement of the computed coefficients of variation (a standardized measure of variance) allowed determining the general trend of changes and comparing the acquired results to the two contrasting, as already mentioned, hypotheses of contemporary macroeconomics concerning development, economic growth or the standard of life (prosperity), that is convergence (reaching the same level) and divergence (level differentiation), naturally with the full awareness of the simplification made. The correlation coefficients between the series of variation coefficients were also computed. They were calculated for the features considered which allowed determining the degree of similarity of development differences within these features.

In the conducted research a simple indicator of dynamics was applied (for the rows), as well as a coefficient of variation as a standardized measure of variance (for the columns), the principal component analysis and the method of a multivariate classification – cluster analysis (for the entire table) (Anderson 1958; Morrison 1967; Galiński 1969; Anderberg 1973; Everitt 1974; Aldenderfer & Blashfield 1985; Jolliffe 2002; Abdi & Williams 2010; Hallin, Paindaveine & Verdebout 2010). Both of the principal components and cluster analysis were conducted using classic, applied in Polish

1 The selection procedure of the features is not described here considering the availability of the literature and experience in this area. It is worth adding that each final set of features is a product of taking into account many subject-related, computational matters as well as data availability.

Cities subject to:	Cities
Development	**Rzeszów, Warszawa, Białystok, Kraków, Olsztyn, Gdańsk**, Wrocław
relative stability	Toruń, Gdynia, Szczecin, Bielsko-Biała, Lublin, Poznań, Kielce, Radom, Bydgoszcz
Depopulation	Częstochowa, Zabrze, Ruda Śląska, Łódź, Katowice, Gliwice, Sosnowiec, Bytom

in bold – positive dynamics

Table 1.
Classification of cities according to the dynamics of the changes in the population, the number in the years 1998–2015 (the size of a city)
Source: own study

geography for years, calculation procedures (Parysek & Ratajczak 1978; Parysek 1980, 1982; Maćkiewicz & Ratajczak 1993; Parysek & Ratajczak 2002). The calculations were made using the algorithm developed by A. Maćkiewicz & W. Ratajczak, published in 1993 in the journal Computers & Geosciences. In the case of principal components, the methods of principal components and cluster analysis were originally applied. Each of the features characterizing individual objects, that is the largest Polish cities, was measured for subsequent years[2]. Thus, the computed correlation coefficients between the components and the initial features (a given feature measured for subsequent years) indicated the years which were the most important for a given feature in the set of the cities. In other words the years in which the greatest differences in a particular feature took place. The classification procedure led to the distinction of the classes of the cities, similar in terms of the development process in a given category of development (a specific feature) in the years 1998–2015. Such research was conducted for each of the features put in a time series, however, in this work only some calculations are cited (due to the limited space in the article).

Socio-economic changes in the set of the examined cities

One of the more important features determining changes occurring in cities is the population number. The dynamics of the population changes in the set of the examined cities in the years 1998–2015 was highly diversified. The indicator of the dynamics varied from 83.1% in the case of Bytom to 114.7% in Rzeszów with the average of 95.01%. Hence, the cities in which the population number increased and those in which it decreased can be distinguished. An increase, however, was recorded only in the six of the 24 examined cities (Rzeszów, Warsaw, Białystok, Kraków, Olsztyn and Gdańsk), whereas the rest faced a decrease in the population. On the basis of the mean value and the standard deviation computed for the indicator of the dynamics, three groups of the cities were selected[3] (Tab. 1.).

The analysis of Table 1 shows that the cities most affected by the depopulation processes are the industrial cities of Upper Silesia (Zabrze, Ruda Śląska, Katowice, Gliwice, Sosnowiec and Bytom) and the formerly (before the year 1989) highly-industrialized ones: Częstochowa and Łódź.

The differences among the 24 cities in the changes of the number in the analysed period were relatively large and growing. This is evidenced by a coefficient of variation which in 1998 was 80.83% and in 2015 – 88.82% (the dynamics of the change in the coefficient was 109.90%). The fastest pace of the changes in this coefficient took place in 2000–2001 (the dynamics of the state in a given year in relation to the former one was 103.13%).

The changes in the population number were followed by the changes in the population density in the set of the examined cities. In 1998–2015 an increase was recorded only in four of them (Warszawa, Kraków, Olsztyn and Gdańsk), which means that in the remaining 20 the density declined. The dynamics of the changes in the population density looks slightly different than in the case of the population number. The lowest one was recorded in Rzeszów – 52.95%, a city with the largest

2 The classic pattern of the data table is in the form of *m x n*, where *m* is the number of the investigated objects and *n* – the number of features. In the conducted study *m* means the 24 cities and n – 18 the subsequent measurements of a given feature (each of the six considered).

3 Assuming the solution proposed by Hellwig, the class intervals were determined on the basis of the mean and standard deviation of each of the features considered. An intermediate interval was distinguished, differently called in relation to a specific feature (e.g. average) and two extremes. The class frames were determined by subtracting from or adding a given feature to the average ½ standard deviation. The same procedure was applied for all features.

Dynamics of changes:	Cities
High	**Warszawa, Kraków, Olsztyn, Gdańsk**, Wrocław, Toruń, Gdynia, Szczecin
Average	Bielsko-Biała, Lublin, Poznań, Kielce, Radom, Białystok, Bydgoszcz, Częstochowa, Zabrze, Ruda Śląska, Łódź, Katowice
Low	Gliwice, Sosnowiec, Bytom, Rzeszów

in bold – positive dynamics

Table 2.
Classification of the cities in terms of the dynamics of the changes in the population density in 1998–2015
Source: own study

dynamics of the population growth, and the highest one in Warszawa – 103.01% with the average of 92%. It is inevitably the evidence of the border extension of some cities including Rzeszów itself. The pace of the changes in the population density in the analysed cities was quite diverse. The classification of the cities made on the basis of the average and the standard deviation in terms of the dynamics of the changes in the population density is presented in Table 2.

The population density is a feature differentiating the analysed cities to a small degree. This differentiation, measured with the coefficient of variation, was the highest in 2001 when it amounted to 24.14%, the lowest in 2006 and 2007 – 21.16%. Taking into account the initial and final years of the analysis, generally a decreasing change (variance) in the set of the examined cities can be observed (the dynamics of the changes – 96%).

In the years analysed significant changes took part in Poland including the ones in the economy (the system transformation, accession to the European Union, the global crisis etc.), which had to leave a specific mark on the labour market, entrepreneurship among the inhabitants, housing construction and as a result on the budget the income of cities.

One of the features allowing the assessment of the economic situation in a city is the occupational activity of the inhabitants, measured by the number of the employed per 10,000 inhabitants. In the investigated period positive changes occurred in 10 out of the 24 cities analysed; the most desirable in Wrocław (the dynamics 120.85%) and Gliwice (118.68%) and the least in Bytom (58.09%), with the average dynamics of 95.44%. Generally, it can be stated that the occurring changes are not too big, yet the differentiation in the set of the examined cities is clear. The classification (into three classes) conducted on the basis of the average and the standard deviation shows that the highest dynamics of a decrease in the occupational activity of inhabitants involves the cities of Upper Silesia (except for Katowice and Gliwice) and Szczecin, Gdynia and Toruń (Tab. 3.).

In the set of the examined cities, increasing differences can be observed in terms of the occupational activity of the inhabitants, as evidenced by the coefficient of variation which in the initial year of the analysis was 18.69% and in the final one 26.80%. Thus, an increase in the value of this indicator in the examined period was quite big (the dynamics was over 143%) and was the highest in the years 1998/1999 (the dynamics in relation to the previous year of the analysis was almost 115%).

A significant feature influencing the level of economic development is entrepreneurship expressed by the number of economic entities per 1,000 inhabitants. The situation of all the examined cities in the years 1998–2015 improved in this regard. The average dynamics of changes was 142%, with the highest growth recorded in Gdynia (173.39%), Zabrze (167.96%) and Poznań (166.09%), and the lowest in Białystok (118.11%), Częstochowa (117.59%) and Radom (113.28%). On the basis of the average value and the standard deviation, three classes of cities were selected. They different in terms of the dynamics of the changes in the level of entrepreneurship (Tab. 4.).

Table 3.
Classification of the cities in terms of the dynamics of changes in the occupational activity of the inhabitants (the number of the employed per 10,000 inhabitants) of the examined cities in 1998–2015
Source: own study

Dynamics of changes:	Cities
High	**Wrocław, Gliwice, Łódź, Bielsko-Biała, Poznań, Kraków**
Average	**Gdańsk, Bydgoszcz, Katowice**, Warszawa, Lublin, Kielce, Olsztyn, Rzeszów, Częstochowa, Radom, Białystok
Low	Toruń, Gdynia, Zabrze, Sosnowiec, Szczecin, Ruda Śląska, Bytom

in bold – positive dynamics

Dynamics of changes:	Cities
high	Gdynia, Zabrze, Poznań, Warszawa, Gliwice, Gdańsk, Bytom, Kraków
average	Rzeszów, Katowice, Ruda Śląska, Wrocław, Lublin, Łódź, Szczecin
low	Bielsko-Biała, Toruń, Sosnowiec, Olsztyn, Kielce, Bydgoszcz, Białystok, Częstochowa, Radom

Table 4.
Classification of the cities in terms of the dynamics of changes in the economic activity (entrepreneurship) determined by the number of economic entities per 1,000 inhabitants in the examined cities in 1998–2015
Source: own study

The analysis of Tables 3 and 4 shows that unfavourable socio-economic changes can be observed mainly in Sosnowiec and Toruń, but also in Szczecin.

The differences in the examined cities, measured by the coefficient of variation, in terms of the level of entrepreneurship in 1998–2015 generally increased (the dynamics of changes was 116.27%). In the initial year of the analysis, these differences were at the level of 21.01%, and in the final one – 25.47%.

The population and economic changes usually influence significantly the housing situation, which is indicated by the number of apartments per 1,000 inhabitants. In all the examined cities, in the years 1998–2015 the housing situation improved, although the reasons for this improvement could be different (growth in the number of apartments or a decline in the number of inhabitants). The average dynamics of an increase in the number of apartments per 1,000 inhabitants was 128.26% with the highest ones in Wrocław (140.75%), Kraków (139.10%) and in Poznań (136.81%), and the ones in Ruda Śląska (116.95%), Zabrze (119.11%) and in Sosnowiec (121.40%). The classes of the cities in terms of the dynamics of these changes are presented in Table 5.

The differences in the set of the examined cities in terms of the changes in the housing situation were not large, however, they generally became greater in the analysed years (the dynamics of changes in the value of the variation coefficient was 114.55%). The highest growth took place in 2000/2001 (146.76%), and the largest decrease in 2002/2003 (64.93%).

In the analysed period, the budget income per capita changed considerably, with a very high growth recorded in all the considered cities. The most dynamic growth in the income was in Gliwice (the dynamics of changes was 566%), Olsztyn (465%) and Lublin (446%), whereas the least in Wrocław (301%), Zabrze (308%) and Bielsko-Biała (314%) with the average of 386%. This growth is partly due to inflation, but also to a decrease in the number of inhabitants. The classification of the cities made on the basis of the average value and the standard deviation is presented in Table 6.

Not only did the pace of changes in the budget situation of the cities vary in the investigated period, but also the differences between them, measured by the coefficient of variation. In 1998 it was 21.08%, and in 2015 – 19.48% which means that it generally decreased (the dynamics of decrease was 92.41%) which can be interpreted as eliminating the differences in the analysed cities in terms of the budget income per capita (convergence). However, taking into account the changes in differences taking place every year, the situation does not look that good. The differences were decreasing most of all in the initial years of the analysis (1998/1999, 1999/2000, 2000/2001), and in the final ones it was increasing (2010/2011, 2011/2012, 2013/2014, 2014/2015), with the largest growth in the years 2004/2005 (the dynamics of changes in the coefficient of variation counted in relation to the previous year was 112.52%) and the largest decrease in 1999/2000 (86.78%).

Taking into account all the features considered in the research, it can be stated that in 1998–2015 the differences among the cities decreased only in relation to two out of the six features accepted for the analysis: the population density and the budget income per capita. In the case of all the remaining features, the differences increased to a greater or lesser extent, the most in the case of the occupational activity of the inhabitants (Tab. 7., Fig. 1.).

Table 5.
Classification of the cities in terms of the dynamics of changes in the housing standard (the number of apartments per 1,000 inhabitants) in the examined cities in 1998–2015
Source: own study

Dynamics of changes:	Cities
high	Wrocław, Kraków, Poznań, Olsztyn, Gdańsk, Warszawa
average	Gdynia, Lublin, Kielce, Toruń, Szczecin, Rzeszów, Bydgoszcz, Bielsko-Biała, Gliwice
low	Białystok, Łódź, Katowice, Częstochowa, Bytom, Radom, Sosnowiec, Zabrze, Ruda Śląska

Dynamics of changes:	Cities
high	Gliwice, Olsztyn, Lublin, Kraków, Kielce
average	Białystok, Ruda Śląska, Łódź, Radom, Częstochowa, Szczecin, Gdynia, Katowice, Bydgoszcz, Gdańsk, Poznań
low	Bytom, Rzeszów, Toruń, Sosnowiec, Warszawa, Bielsko-Biała, Zabrze, Wrocław

Table 6.
Classification of cities in terms of the dynamics of changes in the budget situation (budget income per capita) in the examined cities in 1998–2015
Source: own study

It is difficult to state clearly which of the years analysed influenced most of the differences among the cities. In the case of entrepreneurship, the occupational activity of the inhabitants or budget incomes, the economic transformation affected Polish cities to a certain extent.

Moving to the synthetic evaluation of similarities between ongoing development processes, the following can be stated:

1) the processes of the development of the population number and occupational activity (r= 0.9083, at the significance level of 0.001) are very similar,
2) the processes of occupational activity and entrepreneurship (r= 0.6452 at the level of significance of 0.01) and the population and entrepreneurship (r= 0.5760 at the level of significance 0.01) are similar,
3) the processes of changes in the population density and housing stock (r= 0.4753 at the significance level 0.05) are more loosely connected,
4) the processes that take opposite directions are those of the population and the population density (r= -0.6533 at the level of significance 0.01), the population density and occupational activity (r= -0.5322 at the level of significance 0.01) and the housing stock and budget income (r= -0.5136 at the level of significance 0.02).

The correlation link between the other features is less strong.

Principal component analysis and the multivariate classification

As indicated in the introduction, the research was experimental and innovative both in the application of principal components and the multivariate classification applied with cluster analysis' Innovativeness consisted in the adoption in multivariate analysis of the value of only one feature measured for the subsequent years. Thus, the classification of the set of the cities was conducted taking into consideration their similarity in terms of a specific feature taking particular values in the subsequent years (the time series of a given feature for subsequent years). Although only one feature was taken into account, it was in fact the multivariate classification involving the development process in the years 1998–2015. In the research conducted, the similarity of the development process was determined: the population (also the dynamics of the population changes), entrepreneurship (economic entities per 1,000 inhabitants), occupational activity (the employed per 10,000 inhabitants) and the housing situation (apartments per 1,000 inhabitants) in the period considered. The component analysis performed was intended to show the years in which the most significant differences in a given feature in the set of the studied cities took place, that is a specific development category.

Applying data for one feature measured for subsequent years resulted in the following consequences for the analysis conducted:

1) each of the cities was described by a series of values of features with relatively small and monotonically changing differences in the subsequent years,
2) strongly correlated features were taken into account (small differences in the values of features in the subsequent years).

Table 7.
Coefficients of variation in the selected features of socio-economic development in the set of the 24 largest Polish cities in 1998 and 2015
Source: own study

Features	1998	2015	1998=100
population number	80.83	88.83	109.90
population density	23.67	22.72	96.00
employed/10,000 inhabitants	18.69	26.80	143.39
economic enitities/1,000 inhabitants	21.01	24.43	116.27
apartments/1,000 inhabitants	6.67	7.64	114.55
budget income/capita	21.08	19.48	92.41

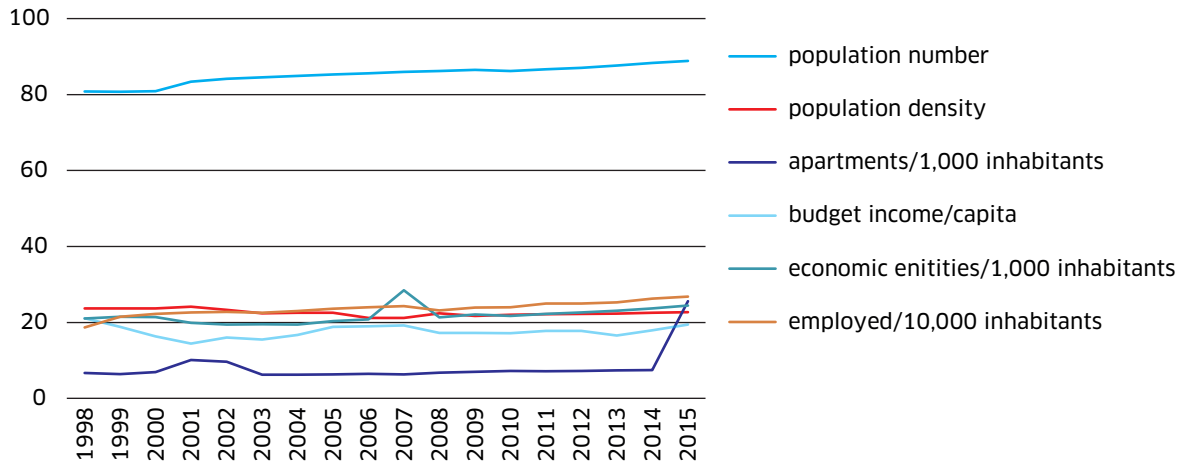

Fig. 1. Variation coefficients of the selected features of socio-economic development in the set of the 24 largest Polish cities in 1998–2015
Source: own study

The advantages of the analysis conducted are:

1) the possibility of a synthetic evaluation of development processes,
2) the identification of the similarity structure of cities, determined in relation to the ongoing process.

Multivariate classification was performed using cluster analysis. The function of similarity was the Euclidean taxonomic distance calculated in the 18-dimensional space (18 attributes - subsequent years). The generalized structure of similarity was dendrite extended in this space, which was then divided into parts (classes) eliminating the four longest connections (taxonomic distances). Therefore, it was arbitrarily decided to separate 5 classes for each of the characteristics included in the study. The statistical distribution of dendritic distances made it impossible to apply the Hellwig criterion. The variance of the features describing the individual objects was the reason for the results obtained.

Over the course of the conducted research, however, the interpretation of both principal components and the classification proved to be difficult due to the limited degree of differences in the features taken into account either in the set of the 24 largest Polish cities in a given year or in particular cities in every consecutive year.

Population number

The population number is the feature most often applied in geographical research. Contrary to some views it is an indicator, to a certain extent, synthetic in character, because there are other, correlated to the population number, features considered in geographical research (the population density, entrepreneurship among the inhabitants, their occupational activity, the level of service within different types of services etc.).

The application of principal component analysis with reference to the number of inhabitants had a certain disadvantage, namely the differences in the population number in the set of the examined cities (cities of different sizes), although both the differences in the population number and the process of ongoing changes were reflected in the classification.

In the present situation it could have been expected that the first principal component accounts for almost 100% of the variance of the features considered (specifically 99.8%) and the same amount of variance of each of the features (features for each year).

On the basis of cluster analysis it was possible to select five city classes, different from one another in terms of the changes taking place in the population number, of which four are single-component classes. It is indicative of fairly individualized features of the demographic development process in particular cities, especially in Ruda Śląska, Rzeszów, Olsztyn and Bielsko-Biała (Tab. 8.).

Dynamics of the population

Taking into account the disadvantages of the previous analysis, in the subsequent approach the population number was replaced by the dynamics of changes in the population number in each consecutive year, which enabled the determination of the similarity of the cities in terms of the dynamics of changes in the number of inhabitants.

The transformation of the features into principal components was made in such a way that

the first principal component V1 accounted for 66.86% of the variance, the second V2 – 13.4%, and the third one V3 – 8.2% of all the features considered in the research (the year-to-year dynamics of changes). Component V1 determines the differences in the dynamics of changes in the population number in 2010/2011, 2011/2012, 2012/2013, 2013/2014 and 2014/2015 (r^2 over 90%), that is in the period after 2010. The polar character of the second component (stimulating and destimulating the influence of the features: positive and negative correlation) was determined by the variance of the changes in the dynamics of the population – positive in the years: 2000/2001, 2001/2002, 2002/2003, 2004/2005 and negative in 2005/2006 and 2007/2008.

The dynamics of the demographic changes occurring in the set of the analysed cities is individual in character as well. It is evidenced by the appearance of four single-component classes out of the five selected on the basis of a cluster analysis (Tab. 8.). Ruda Śląska, Olsztyn, Białystok and Rzeszów were peculiar in this respect.

Economic entities

The transformation of those, specific in character, features took place in such a way that the first principal component V1 accounts for 91.91% of the variation of the set of 18 features (of the subsequent years of the analysis).

The analysis of correlation coefficients between the first principal component and the original variables indicates that economic entities per 1,000 inhabitants in the set of the cities were of particular importance in the years 2001–2003 and 2006–2009 (the first years of system transformation and the early years of the global crisis).

On the basis of the results of the cluster analysis conducted, five city classes were selected, different from one another in terms of the changes in the level of entrepreneurship (the number of economic entities per 1,000 inhabitants). Four of these classes are single-component ones. The separate classes are: Ruda Śląska, Zabrze, Bytom, Gliwice, that is the cities of Upper Silesia. The remaining analysed cities were included in the one, common class (*cf.* Tab. 8.).

Occupational activity

The transformation of features in the principal components took place in such a way that the first principal component V1 accounted for 89.79% of the variance of the features, and the second one V2 – 5.97%.

The first principal component maps mainly the variance of the level of occupational activity in the years 2005, 2006, 2007, 2010, 2011 and 2003, and the other component – the variance of the feature in 2009, and specifically its high level in relation to the previous and the next year.

The classification conducted on the basis of cluster analysis shows that out of the five selected classes four are single-component ones which is indicative of the specific development of Gliwice, Toruń, Częstochowa and Bydgoszcz in terms of the occupational activity of the inhabitants and minor differences in other cities in this respect (cf. Tab. 8.).

Housing situation

The transformation of the original features in the principal components took place in such a way that the first principal component accounted for 83.32% and the second one for 8.25%. The first component is correlated to the greatest extent with the number of apartments per 1,000 inhabitants in the years 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011 and 2012, and the other one negatively (at the level of significance 0.001) with the years 2001 and 2002.

The classification made on the basis of the variance of all features showed the specifics of the development of some cities in terms of the

Table 8.
Classification of the set of the 24 largest Polish cities in terms of the selected features of socio-economic development in the years 1998–2015 on the basis of a cluster analysis
Source: own study

Class	Population number	Dynamics of population	Entrepreneurship	Occupational activity	Housing situation
I	Ruda Śląska	Ruda Śląska	Ruda Śląska	Gliwice	Białystok
II	Rzeszów	Olsztyn	Zabrze	Toruń	Gliwice
III	Olsztyn	Białystok	Bytom	Częstochowa	Ruda Śląska
IV	Bielsko-Biała	Rzeszów	Gliwice	Bydgoszcz	Bytom
V	Other cities	Other cities	Other cities	Other cities	Other cities

development of housing stock per 1,000 population. Out of the five selected classes four are single-component ones and they are created by: Białystok, Gliwice, Ruda Śląska and Bytom (*cf.* Tab. 8.).

Principal component analysis shows that of particular importance for the development of the 24 largest Polish cities in the investigated period were the years 2003, 2010 and 2011, when the differences among cities were the greatest in terms of at least three features taken into account. In the year 2003, the differences occurred in terms of the level of entrepreneurship, occupational activity and the housing situation (in the set of the examined cities), and in 2010 and 2011 – in terms of the occupational activity, the housing situation and demographic changes. Thus, it can be generally stated that in the initial years of the analysis, the differences among cities in terms of the development level in the categories of features taken into account were not significant; after 2000 they grew in the case of the economic situation, whereas after 2010 the examined cities differed mainly in the demographic situation (Tab. 9.).

The classification made on the basis of a cluster analysis shows that part of the examined cities are characterized by the great individuality of development processes. This is particularly true of some cities of the industrial region of Upper Silesia (Ruda Śląska, Gliwice, Bytom, Zabrze), and also to some extent to Rzeszów, Olsztyn, Bielsko-Biała, Białystok, Bydgoszcz, Toruń or Częstochowa.

Conclusion

The conducted research, mainly due to the analysis model used, is pioneering in character. Whereas in the classical classification procedures the spatial differentiation of the set of objects is examined, the article presents the model of the study of the differentiation of objects over time. It is aimed in cognitive terms to determine many aspects of the dynamics and its structure in the set of the 24 largest Polish cities and at the same time it determines the directions of occurring changes, which can be related to the two described development tendencies called convergence and divergence (the variance of the features taken into account in the years 1998–2015) relate to the two opposing hypotheses – about convergence and divergence. Whereas the methodological aim was to test a certain analytical approach to the research of this structure and its dynamics in the set of the investigated objects.

As regards the population number, the depopulation process of 18 cities was clearly indicated and population growth was recorded only in six cities. These changes caused an increase in the differences in the population number in 1998–2015, especially after 2010.

Table 9.
Years in which the differences in the set of the 24 largest Polish cities were the greatest in terms of the features selected (on the basis of the correlation of the first principal component V1 and the years from 1998 to 2015)
Source: own study

Years	Dynamics of population	Entrepreneurship	Occupational activity	Housing situation
1998				
1999				
2000				
2001		X		
2002		X		
2003		X	X	X
2004				X
2005			X	X
2006			X	X
2007			X	
2008				X
2009		X		X
2010	X		X	X
2011	X		X	X
2012	X			X
2013	X			
2014	X			
2015	X			

It seems, however, to be mainly the suburbanization effect, but also the result of a low birth rate (Parysek & Mierzejewska 2005; Lisowski & Grochowski 2009; Kajdanek 2011; Mierzejewska & Parysek 2013; Zborowski & Raźniak 2013; Mierzejewska & Parysek 2014). On the other hand, the differences among cities in terms of population density and a budget income per capita decreased and thus, in the categories of features convergence can be mentioned. Considering the desire to level socio-economic development, the trends in the set of the examined cities in terms of the occupational activity of the inhabitants (especially in the case of Upper Silesian cities), entrepreneurship and the housing situation should be regarded as unfavourable. This assessment results from the growing differences among cities in this respect, which can be compared to divergence. It should be emphasized, however, that according to some scholars, these very differences in the socio-economic development level, thus not convergence but divergence, are a driving force for this development, at least in social terms (Szukała 2015; Niezgoda, Markiewicz & Gierczak 2016).

In the case of the methodological objective, it can be assumed that the investigated situation confirms the reasons for the application of the measures of dynamics and the variance of features to determine the character (dynamics and structure) of the process differentiating the socio-economic development of cities in the distinguished categories of the analysis and time series. Relatively less effective, especially in the sphere of interpretation, was the application the principal component analysis and the multivariate classification. Nevertheless, despite the determinants given earlier, those years in which the greatest differences in the features of the set of the investigated objects were successfully indicated and the classification in terms of the character of the development process was made. The character was determined by the values of features in particular cities in a given year and their changes in the subsequent years. In this way it was possible to make an analysis of a time series mapping the development process, a study so rarely undertaken in geographical research.

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