Map of Dynamics of Changes in Cities and Neighbouring Municipalities and Communes

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Abstract

This study analyses urban areas which comprise an urban centre, neighbouring communes and municipalities. As an administrative unit, a city is an organism full of internal and external links and it undergoes constant change at the micro- and macro-levels. A city's internal structure is modified over time as it responds to changes in the local environment and those changes often affect its neighbourhood. This article proposes a methodology for analysing the dynamics of urban spaces in five Polish cities which were surveyed in 2002–2016. The proposed method is based on an analysis of the trend and the intensity of changes concerning geolocation data. The input data were obtained from national statistical registers kept for administrative units (municipalities and communes). The method was verified for a group of municipalities and communes, creating a uniform urbanised area (a city and neighbouring municipalities and communes).

The analysis was based on the assumption that dwellings constitute the largest part of a city and that they are most susceptible to change. An observer examining the city from within will note that a critical level has been reached (an observer positioned in a rural area will report a decrease in the surface tension of the urban/rural boundary). In consequence, progressive residential development in areas adjacent to the city contributes to urban sprawl. With regard to the foregoing, a research hypothesis was proposed that the residential area per capita is the most robust indicator of economic and spatial changes in an urban area.

Keywords: urban space, dynamics, residential area, spatial structure.

1. Introduction

One of the most important documents of a strategic nature affecting the growth and development of Poland is Koncepcja Polityki Przestrzennego Zagospodarowania Kraju 2030 (National Spatial Development Policy Concept for 2030). This plan defines a spatial development policy for the country and tackles present and future challenges, including demographic ones. It entails the development of cities and rural areas based on the exploitation of the internal potential of Polish land.

Geographically, Poland is in the centre of the continent; however, from an economic perspective, in reference to European land, it is considered a delayed region when compared to Western Europe (KPZK, 2011).

The settlement system of Poland is characterised by a regular, in terms of size, distribution of cities (especially towns and medium-sized cities); a developed, multi-step hierarchical structure; and a slight advantage of the capital city of Warsaw over other regional centres when compared to other European countries.

The core constituents of the settlement system include groups of cities and conurbations aggregated according to hierarchical level and size category. The first group includes centres of fundamental importance for the country's settlement system and its economy: Warsaw, Kraków, Gdańsk-Gdynia, Wrocław, Poznań, Katowice – Upper-Silesian Agglomeration, Łódź, Szczecin, Bydgoszcz, Toruń, and Lublin. These cities (excluding Bydgoszcz, Toruń, and Lublin) are mentioned in papers drafted for purposes related to EU spatial development as so-called mega-cities, a group comprising 72 of the largest urban areas in the European Union. However, when it comes to the level of infrastructure and functions they serve, those cities are not competitive with cities of similar size in Western and Northern Europe (KPZK, 2011). From the country's point of view, they are crucial and it is expected that in the next

two decades they will be subject to the most intense growth processes, with a clear process of urbanisation and a process of development of functional urban areas defined as regions with more direct influence of a city on neighbouring areas. According to Śleszyński (2013), in Poland, the emergence of functional urban areas was largely associated with increasing commuting, characteristic of accelerated industrialisation and soaring demand for work within the city limits.

The limits are defined by urban sprawl in structural terms, in terms of urban lifestyle, as well as in terms of commuting to city centres. With regard to the foregoing, the researched cities were included in each of the said groups. Although there were attempts at identifying areas of influence, the dynamics of changes in population and the socio-economic development are still faced by new challenges which make it necessary to coordinate actions and activities, particularly those concerning the suburban zone and the city. When spatial development in one area occurs at the expense of the neighboring municipalities, usually rural, the affected areas should also experience an improvement in the standard of living. Economic growth often leads to uncontrolled urban sprawl, both in metropolitan areas and in peripheral regions. (Kurowska and Kietlińska 2017).

A city, as an administrative unit, is an organism full of internal and external links. A city is subject to never-ending micro- and macro-changes in its neighbourhood and reacts to changes over time by changes in its internal structure and often exerts an impact on adjacent areas (Kowalczyk, 2014). The spatial organisation of cities varies widely and it partly reflects the culture and economic standing of the host region. An analysis of the demographic growth of cities and urban areas over individual historical periods shows certain trends in economic development; it reflects historical events and long-term trends and it helps understand both the meaning and the background of such growth and development (Chandler, 1987).

Urban sprawl has become a characteristic feature of urban development worldwide (Zeng et al., 2015). Urbanisation is a response to specific economic, demographic or environmental conditions. Assessment and monitoring of urbanisation and other localised land transformation are exceptionally difficult on the regional and global scales (Masek et al. 2000). Therefore, it is imperative that this process be controlled with a reasonable spatial development policy and process. The analysis and modelling of urban sprawl in a spatio-temporal context is becoming a valuable research topic. Detailed understanding of landscape changes along the urban-rural gradient provides a useful tool to compare the structural and functional differences of landscape patches at different orientations. Although several case studies have been conducted confirming the efficacy of this approach, integrating temporal data with gradient analysis is still rarely used in practice. (Yu and Ng, 2007).

Urbanisation is a continuous process characterised by an increasing proportion of developed areas and continuously decreasing natural and/or semi-natural areas, such as agricultural land and forests. Urbanisation changes urban landscapes and results in ecological and environmental problems (Gong et al., 2018).

A significant aspect of urban spatial development is the problem of pressure being exerted on neighbouring areas that are incorporated into the cities (Rząd, 2005). An opposite phenomenon associated with the formation of urban areas is the fact of structures and buildings spreading beyond the city limits (Kowalczyk and Nowak, 2015).

Kurowska et al. (2017) pay attention in their research that GIS users also take advantage of demographic and economic data – a wealth of knowledge on human potential in a particular area. Deriving from various research centers, the data regard customers' demography, affluence or shopping habits.

2. Area of Research

This study involved an analysis of six urban areas of Wrocław, Kraków, Tri-City (Gdańsk, Gdynia, Sopot), Łódź, Poznań, Warsaw (the geographical location of the cities surveyed is shown in Fig. 1). The areas studied comprise the land situated within the limits of the cities and their administrative boundaries as well as within the neighbouring municipalities and communes. The objects surveyed were characterised by similar area, population, and residential area (Table 3).

Figure 1. Geographical location of the areas surveyed.

Table 1. Specification of the cities surveyed – data for 2016.

City	Administrative area (km^2)	Residential area (m^2)	Population	Residential area per capita (m^2/person)
Wrocław	293	21,743,319	637,683	34.1
Kraków	327	21,312,860	765,320	27.8
Gdańsk-Gdynia-Sopot	262 / 135 / 17	20,951,131	747,594	27.7 / 28.0 / 32.9
Łódź	293	19,137,384	696,503	27.5
Poznań	262	16,411,893	540,372	30.4
Warsaw	517	54,916,025	1,753,977	31.3

Source: own research.

3. Research

The research involved an analysis of changes in the dynamics of the processes observed in urban areas, taking into consideration their interrelations. The first part (Table 1) describes the extent of the data obtained, i.e. population, residential area, residential area per capita and number of flats. For further analyses, two variables were used: population and residential area per capita. The population indicates how much an area (municipality/commune/town/city) is burdened by human actions. In many situations, a constant population of a city is accompanied by the erection of new residential housings; it is an effect of changing standards of living as well as of moving in or out / change of residence by new generations. The second of the selected measures is a standard of living defined by residential area per capita. A development indicator was proposed as a derivative of the dynamics of population and the dynamics of residential area per capita. To define an urbanised area development indicator (d_r), the dynamics of each of the selected measures were defined to calculate the original dynamic indicators.

In statistics, an indicator is a metric or a measure which characterises a dependent variable in time or space, where an independent variable represents time. Indicators are characteristic metrics of urban dynamics and they are commonly used in surveys of social and economic well-being (Timofijuk, 2006). Indicators are relative measures which can be applied in

analyses of irregular changes. The metrics discussed are intuitive and comparable regardless of the type of the process evaluated or its magnitude (Okólski and Timofiejuk, 1987).

The first step in the analysis involved the calculation of a series of chain indicators. The term preceding the term under analysis was adopted as the base unit in a time series.

$$X_{1/0} = \frac{X_1}{X_0}; X_{2/1} = \frac{X_2}{X_1}; \ldots\ldots; X_{n/n-1} = \frac{X_n}{X_{n-1}}$$

In successive stages, the dynamics (changes in the indicator) of the variables examined were analysed in a time interval where the base period of time was the first year of observations (series of fixed base indicators). It was assumed that in the first year of the study (2002), the analysed phenomena (population, residential area per capita, total residential area) have the value of one, and in successive years of the analysis, the value of the indicator will be a product of a dimensionless quantity in a given year and the change indicator (Kowalczyk, 2014).

To calculate the dynamics of changes in the selected variables (n) (under analysis), the following formula was used:

$$d_n = \frac{X_n}{X_1}$$

where:

X_n – observation over year n

X_1 – observation over the first year

Table 2. Dynamics of changes in residential area per capita in the city of Warsaw.

	Year										
	2002	2003	2004	2005	2006	2007	….	2013	2014	2015	2016

Residential area per capita	23.6	24.1	24.5	25.0	25.5	26.1	….	30.2	30.5	30.8	31.3
Series of chain indicators	----	1.021	1.017	1.02	1.02	1.024	….	1.013	1.01	1.01	1.016
Change dynamics since 2002	1.0	1.021	1.038	1.059	1.081	1.106	….	1.280	1.292	1.305	1.326

Source: own analysis using data from the Polish Central Statistical Office.

Since the dynamics of two measures observed can have an opposite direction, a spatial development dynamics indicator (d_r) was proposed which will allow the speed of changes occurring in the areas examined to be compared. Table 3 presents three examples of sequences that may be created by a population dynamics vector $\vec{a}$ and a residential area per capita vector $\vec{b}$. For further studies, a product of the vectors was employed, where the population dynamics vector was raised to the power of 2. Increasing the importance of the population dynamics by squaring it is aimed at eliminating positive development indicators when the population dynamics indicator is negative (a population dynamics vector angle was presented as α_a and an angle of the vector of the dynamics of residential area per capita – as α_b) and the dynamics of residential area per capita is greater than 0 ($|\alpha_a| < 0$, $|\alpha_b| > 0$ and $|\alpha_a| > |\alpha_b|$).

The formula for development dynamics is as follows:

$$d_r = {d_a}^2 * d_b$$

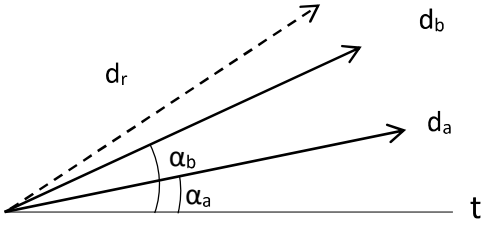
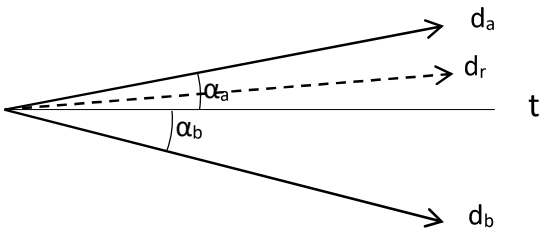
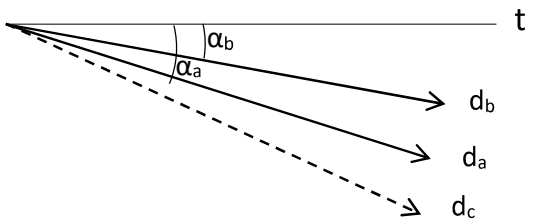
where:

d_a – dynamics of changes in the population of the municipality of n

d_b – dynamics of changes in the residential area per capita in the municipality of n.

Presenting the dynamics as a vector defined between the starting point (the year 2002 in the case under analysis) and the year 2016 for which the dynamics is being calculated, an algorithm for calculations and interpretation is shown in Table 3:

Table 3. A product of the dynamics of two phenomena presented as vectors a and b.

No.	Change directions	Product as the dynamics of the phenomena
1		$\alpha_a > 0$ and $\alpha_b > 0$ a -
2		$\alpha_a > 0$, $\alpha_b < 0$ In the urbanised area, a process of society impoverishment has begun (emergence of slums)
3		$\alpha_a < 0$, $\alpha_b < 0$ $\lvert\alpha_a\rvert > \lvert\alpha_b\rvert$ Depopulation of the city accompanied by the destruction of residential housings (occurs when cities "die")

Source: own analysis.

Table 3 presents selected results of the development dynamic calculations for the city of Warsaw and the neighbouring districts.

Table 3. Dynamics of development of Warsaw and neighbouring districts in 2016 when compared to 2002.

	Warsaw	**Wars.1**	**Wars.2**	**Wars.3**	**Wars.4**	**Wars.5**	**Wars.6**
Population Dynamics (d_a)	1.039	1.242	1.222	1.082	1.449	1.138	1.186
Dynamics of residential area per capita (d_b)	1.326	1.37	1.194	1.279	1.387	1.232	1.355
Development Dynamics ($d_r = d_a^2 * d_b$)	**1.43**	**2.11**	**1.78**	**1.50**	**2.91**	**1.60**	**1.91**

Source: own research.

The results of development dynamics over the years is presented in Figure 2, which shows the calculations for individual years from 2002 (base year) to 2016. As a result, it is clear that the development dynamics for individual districts is diverse. The highest dynamics (2.9) were noted in the district of Piaseczno. Other districts account for two ranges of development dynamics: the first range includes development dynamics ranging from 1.78 to 2.11 (Legionowo, Warszawa Zachodnia, and Wołomin), and the second range includes the development dynamics ranging from 1.43 to 1.60 (city of Warsaw, district of Otwock, and district of Pruszków). What is distinctive is that it is the central city that is characterised by the lowest dynamics in the area examined.

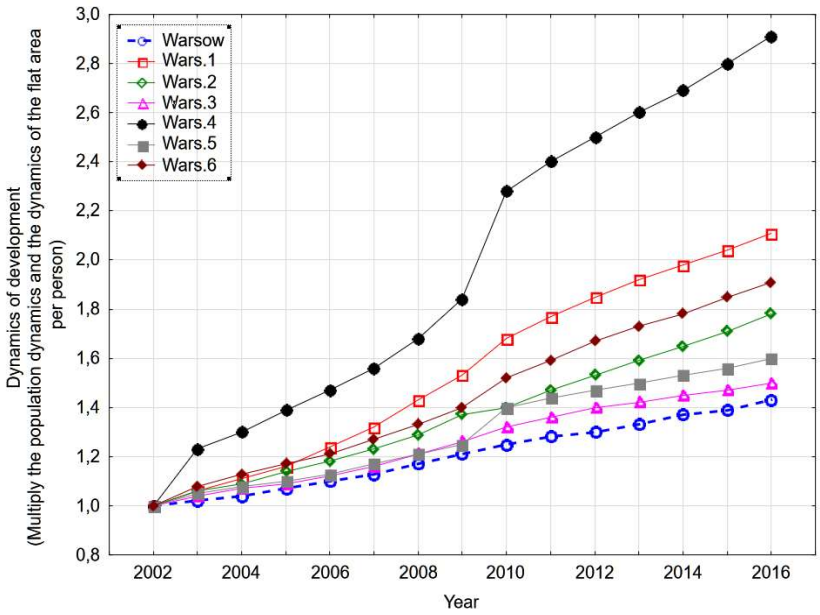


Figure 2. Development dynamics indicator for Warsaw and neighbouring districts

The regularity described in Figure 2 (the central city is characterised by the lowest development dynamics) was also noted while studying other cities.

Figure 3 provides graphs of development dynamics for cities and neighbouring municipalities and communes under analysis, taking into account their position in relation to the centre which are the city limits; the figure is called "A map of the development dynamics of cities and neighbouring municipalities and communes". To ensure clarity, results for only 2008 and 2016 when compared to 2002 are presented. The circular distribution of municipalities and communes is consistent with their actual distribution, assuming that north in Figure 3 is presented faithfully to actual north. The development indicators specified for individual neighbouring municipalities and communes around cities are very diverse. The regularity noted for the analysed cities is a development indicator for urban areas with its value between 1 and 2; whereas for the neighbouring municipalities and communes, its value reaches 6. This means that the municipalities and communes located in the immediate vicinity of the cities grow approximately 6 times quicker than areas within the administrative city limits.

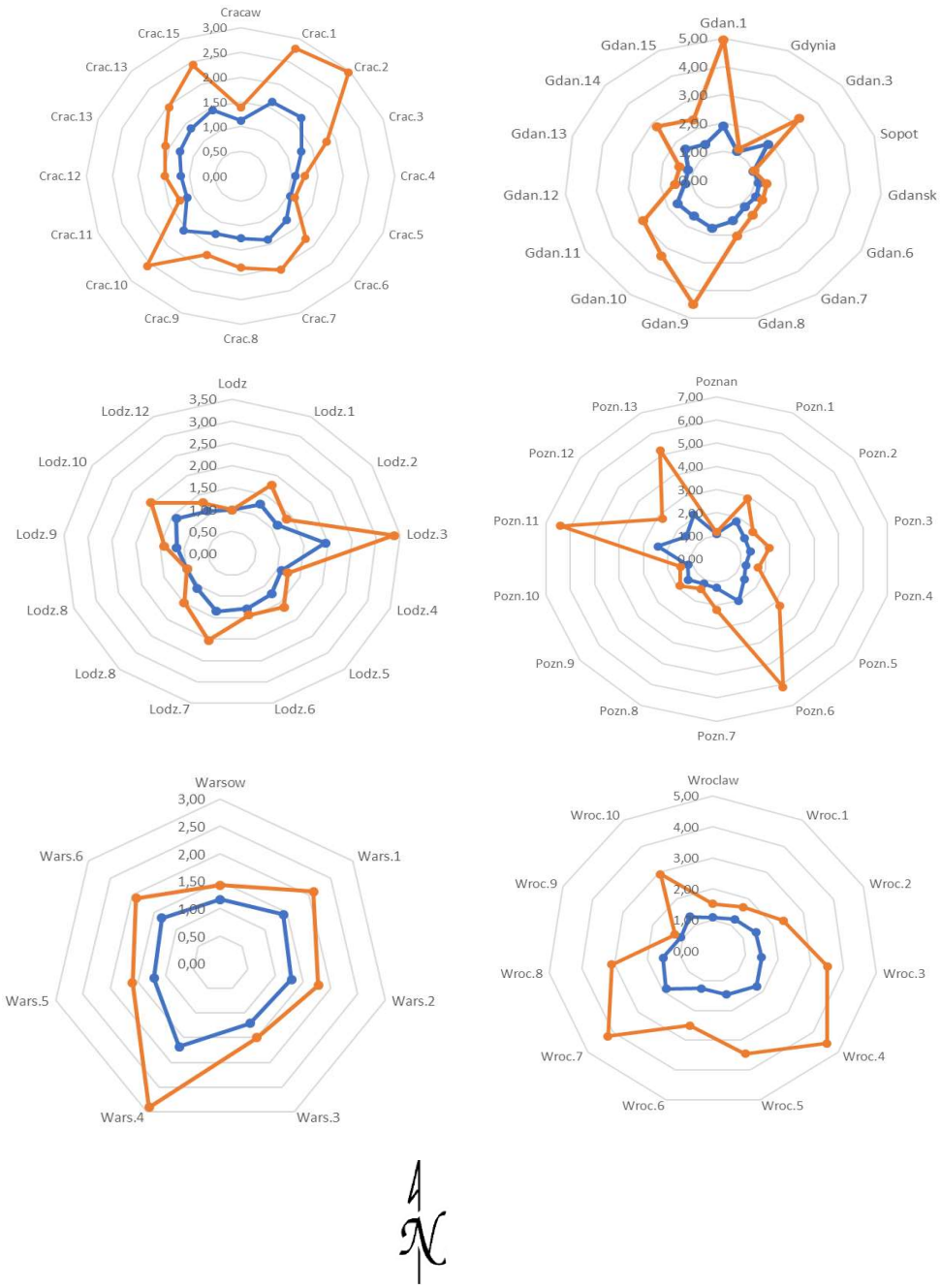


Figure 3. Map of development dynamics for cities and neighbouring municipalities and communes.

Legend for the graphs:

– dynamics of development over 2016 when compared to 2002

– dynamics of development over 2008 when compared to 2002

The regularly observed results from the greater availability of land for development (lower condensation of existing infrastructure), thus from lower investment expenditure (lower prices of land).

The studies revealed a high disparity of development dynamics between the cities and a majority of the neighbouring municipalities and communes. The defined development indicators presented in Figure 2 also indicated a high disparity between individual municipalities and communes. Only a very small number of municipalities and communes are characterised by the dynamics similar to a city: for Kraków, it is two municipalities out of fifteen; for Wrocław, it is three out of ten; for the Tri-cities, it is three out of fifteen; for Łódź, it is one out of twelve; for Poznań, it is two out of thirteen; and for Warsaw, it is two districts out of six. Figure 3 shows a histogram of development dynamics broken down by urban areas and neighbouring municipalities and communes.

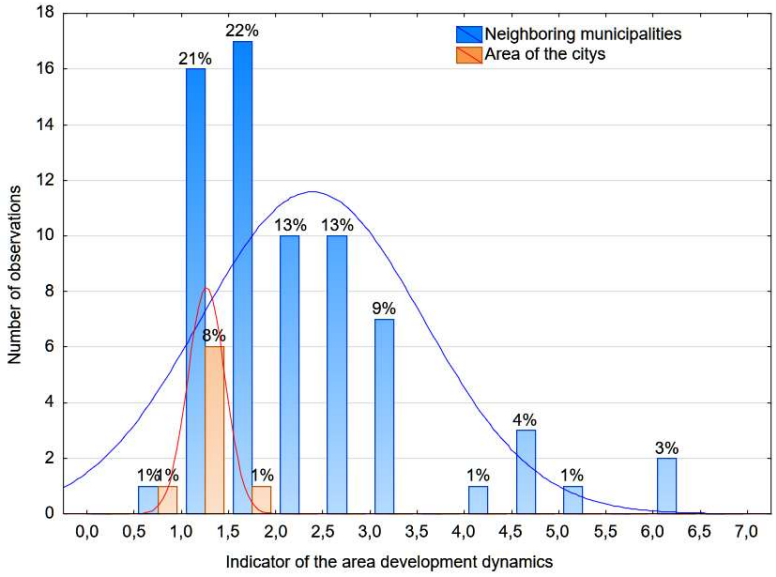


Figure 4. Histogram of dynamics indicators over 2016 broken down by urban areas and neighbouring municipalities and communes.

Over 66% of the neighbouring municipalities and communes are characterised by a higher development indicator when compared to the cities. The highest development indicator since 2002 was calculated for the city of Wrocław (1.52); for other cities, the indicators were close

to one. The highest development indicators were noted in three communes near Poznań (Komorniki, Dopiewo, and Rokietnica) where the development indicator varied from 5.1 to 6.4. Equally high development indicators (from 3.5 to 5.0) were noted in the municipalities and communes near the city of Gdańsk (Kosakowo, Pruszcz Gdański) and the city of Wrocław (Czernica, Długołęka, Siechnice, Kobierzyce).

Figure 5 presents the change in the dynamics of development of individual cities (without the neighbouring municipalities and communes). The highest dynamics were observed in Wrocław, where the largest influence on a step change that occurred over 2009–2010 was exerted by a change in residential area per capita (in 2009: 25.2m^2 per capita; and in 2010: 30.8m^2 per capita).

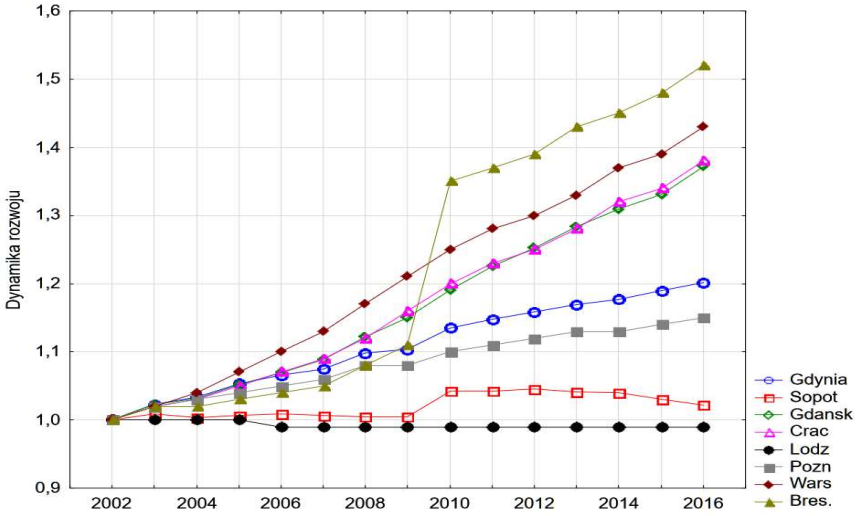


Figure 5. Development dynamics indicator for individual cities in 2016 (from 2002).

The fastest developing cities include cities whose development dynamics varied from 1.3 to 1.6 (Wrocław, Warsaw, Kraków, and Gdańsk – one of the Tri-city cities). The slowest developing cities within their administrative limits include Łódź and Sopot.

4. Discussion

In zones around large and medium-sized cities, settlement intensity increases, and the economy structure is diversified as a result of non-agricultural functions – production,

services and residential functions – due to the increasing scale of commuting. In those zones, residential housing and civil engineering infrastructure are also subject to the fastest improvements (KPZK, 2011).

The problem of urban impact on the neighbourhood is now associated especially with the processes of suburbanisation and with an increased level of social mobility (Śleszyński, 2013).

In Poland, there are numerous factors that foster the spatial concentration of population. The modelling of the city structure is affected to a great extent by internal migrations that can be both from the rural-urban system to urban-rural flows and can lead to an increase in indirect urban centres. This phenomenon occurs in various countries around the globe. Pérez-Campuzano et al. (2018) noted that during much of the twentieth century, the population of Western countries was marked by rural-urban migration and by steady and rising urbanisation. From the 1970s onward, inter-urban and urban-rural mobility increased in developed countries, including, but not limited to, in the USA (Vinning and Strauss, 1996; Berry, 1976), in Canada (Dahams and McComb, 1998), Britain and Italy (Coombes, Longa, and Raybould 1989), the Netherlands (Van Dam, Heins, and Elbersen 2002), and in developing countries (Todaro, 1976), including (but not limited to) Poland. The main trend in internal migration was rural-urban with flows mostly directed towards larger cities, which were among the main components of the marked demographic concentration towards certain metropolitan regions. Throughout the twentieth century, the population distribution in Mexico (Pérez-Campuzano et al. 2018) was typified by demographic concentration in urban locations (mainly in such large cities as Mexico City, Guadalajara and Monterrey) and a scattering of rural locations. Current urban developments are often considered outdated and static and the argument follows that they should become more adaptive (Van Karnenbeek and Janssen-Jansen, 2018).

As Chinese research suggests, population growth, as well as economic and transportation development, are still the main causes of urban sprawl (Zeng et al. 2015).

Urban sprawl in China is staggering, as the magnitude of urban land expansion in China has been much larger than the urban population growth in the past 30 years (Bai et al., 2014; Seto et al., 2012; Zhang et al., 2013).

As evidenced by Kowalczyk and Nowak (2015) using the example of a regional centre (the city of Olsztyn), the city population decreased and the neighbouring municipalities and communes noted an increase in their population. The observed trend does not point to depopulation of the city, but rather to a change in preferences in housing conditions; here, the possibility of residence in a single-family house near beautiful forests and lakes. Stachura (2012) emphasises that apart from the attractiveness of the location due to the proximity to nature, of increasing importance is the "fashion" for such locations.

Other factors include international migrations because the main migration source areas are regions away from growth centres: rural areas and towns. On the other hand, if more people come from abroad, they will largely go to cities and suburban areas (KPZK, 2011).

5. Conclusions

This article proposes a method of analysing the dynamics of cities and neighbouring municipalities and communes. There is no doubt that the development analysis cannot be limited to the administrative area of a city; it must also include neighbouring municipalities and communes. In all of the examined cases, the most important changes occur in the neighbourhood of a city. It is the impact of the central point (a city) that generates considerable changes in its neighbourhood. The proposed map of development dynamics allows this research topic to be analysed further in terms of the identification of development factors. Further studies could be based on an analysis of the correlation between the development dynamics and the variables observed in individual areas. Based on the map of

development dynamics for individual cities, one may say that Poland is presently witnessing urban sprawl, which might be caused by migrations from rural to urban areas. In general, it is expected that the process of population concentration and economic activity will continue in functional zones of large cities, towns and neighbouring rural areas. This process is associated with the globalisation of the economy.

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