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The Warsaw – Lodz *Duopolis* in the light of the changes in the urban population density

Abstract: The article presents the changes in the urban population density in the 20th c., in central Poland, in an area where the two largest Polish cities – Warsaw and Lodz are situated, within a distance of 120 km from each other. The analysis was conducted by means of a statistical method used for estimating discret distributions – the kernel function method. The conclusions served the purpose of presenting the changes which took place around these cities, as well as an academic discussion regarding the condition and the future of the *duopolis* in the light of the discussed factor.
Key words: Warsaw, Lodz, Poland, *duopolis*, population density, GIS, kernel function

Introduction

The concept of the Warsaw – Lodz *duopolis* has been debated with different intensity since the late 1990's. It was a subject widely discussed by Professor Tadeusz Markowski from the Faculty of Urban Management, University of Lodz, both in the academic context and from the local government perspective[1].The issue was also brought up by Kukliński. It can be considered on multiple planes of the interconnections between the two cities, regarding e.g. economy, infrastructure, local authority or social problems. It is certain that the inhabitants of these agglomerations have to be a part of these interconnections. The number of the population and, consequently, the population density, are among the factors determining the formation of a *duopolis*. Therefore, they underwent a spatial and temporal analysis.

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[1]The Presidents of the two cities met in 2002 and 2011; in 2001 – Wojciech Kozak and Krzysztof Panas, and in 2011 - Hanna Gronkiewicz-Waltz and Hanna Zdanowska.

In the 20th c., the population density in the majority of cities was growing all over Poland, including the Warsaw and Lodz area, along with the level of urbanization, calculated as the percentage of the urban population. It was not a continuous process, though. It stopped when the Second World War broke out, after which many cities and towns never regained the previous number of population (e.g. Brzeziny). In the communist period, the strong pressure towards industrialization caused mass migrations to cities and an increase in their population. However, this process changed at the turn of the 20th and 21st c. The direction of the migrations changed, the population growth rate decreased and the number of people inhabiting many urban centres started to shrink. Demographic processes and urbanization affected the density of urban population, which was not evenly distributed within the geographical space of Poland. This can be observed on the maps presenting the concentration of towns/cities and the urban population density in individual decades of the 20th c (Jażdżewska 2009).

The article presents the results of the analysis of the changes in the urban population density in central Poland, where the two largest Polish cities – Warsaw and Lodz – were situated 120 km apart. The author believes that it is worth observing the changes which take place around these cities and thinking whether it is possible for a *duopolis* to be formed.

The study area and data sources.

The analysis regards a fragment of Poland covering 45,000 km^2, with 147 towns and cities inhabited by the total of about 5 million people in 2010, including the Warsaw and the Lodz agglomerations (Fig.1). It is an area which belonged to the Polish state after 1918.

The author used the data established in the National Censuses in Poland, in 1931, 1950, 1960, 1970, 1978, 1988, 2002, as well as the Main Statistical Office information regarding the year 2010. The author also made use of a lattice graph of towns and cities presented as points, which were ascribed the number of inhabitants in a given census year. It was not only the number of inhabitants that was changing in the 20th c. in Poland, but also the number of towns. New towns were established, some towns were incorporated into other towns, and some lost the municipal rights (Jażdżewska 2009).This fact was taken into account for each census year and the actual number of towns was quoted.

Methods of presenting the population density

The maps of population density are prepared in many ways, and their basic task is to present this phenomenon in space in as much detail and as truthfully as possible. They were usually constructed with the use of a cartogram, where for given administrative units (e.g. *gminas, powiats*, voivodeships) the authors presented the quotient of the number of population divided by the area of the spatial unit
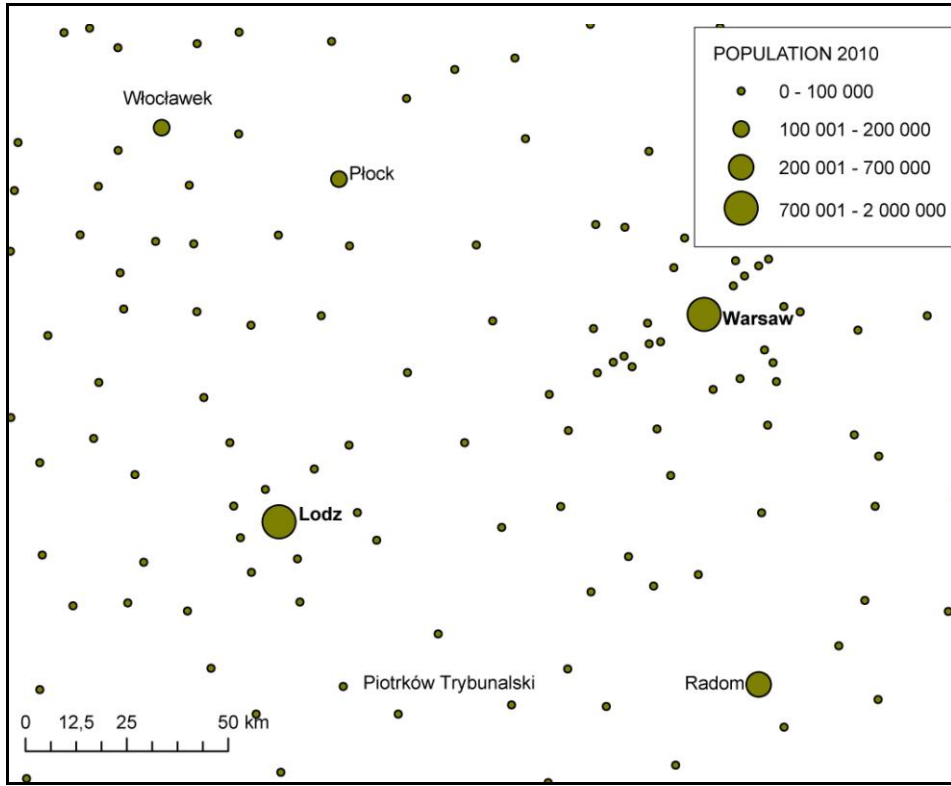
Figure. 1. Study area

Source: author's compilation

(Ratajski 1989). If an analysis comprises several census periods, the results may be presented in accordance with the administrative division valid for the census year, but comparing them with the next census year requires additional work, which involves estimating the number of population in new administrative units. In the case of Poland, we deal with frequent changes of administrative borders, both on the international (1918-1945) and national scale, such as the fluctuating number and range of voivodeships after 1945, abolishing and establishing *powiats*, establishing new *gminas*, incorporating some settlement units into cities/towns, or isolating separate towns from larger ones. The traditional method of estimating the population density seemed too sensitive to the changes of the borders of administrative units, therefore it was abandoned and replaced with a different way of presentation, called the kernel function.

The kernel function method.

The tool chosen for the analysis of the concentration of towns/cities, as well as the urban population density was an estimation method called kernel function.

Using it eliminates the problems which arise while comparing the results of cross-section studies from different periods of time, in which changes of the administrative system occurred (Longley P.A. et al. 2008, Silverman 1981). The results presented on the map do not depend on the administrative borders, but only on the number of points and the ranks ascribed to them, as well as the values of the parameters used in the method.

The kernel function method makes use of a set of points in space. Here, towns were represented by points, where one of the attributes was the number of inhabitants. This means that the data was represented by discret objects and met the requirements of the method. With this type of data, the density measurement is taken not by means of interpolation but estimation of the density distribution. It is a non-parametric method, related to kernel estimators (kernel function). The function is expressed by the following formulas:

$$\widehat{f_h}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right)$$,

where n means the size of the sample and h is the bandwidth, and $x_1, x_2, \ldots, x_n$ are the points of the n-element random sample (Peters 2011).

Where K is the kernel function of certain properties, e.g. it is symmetrical about zero or integrates to the value of 1. It usually takes the form of the Gaussian function:

$$K(x) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right)$$

Probability density function depends primarily on the value of parameter h, called the bandwidth; the higher the value the flatter the function (Longley P.A. et al. 2008, p. 344).

The method is constructed in the following way: first a lattice of squares is created for a given area (the length of the sides of each square is selected subjectively and depends on the scale of the map and the meticulousness of the study)[2]. Next, a circle of a chosen radius is delineated around each square; inside each circle the number of settlement points is counted. The important thing is to apply the appropriate length of the radius, because if it is too long, the results become overgeneralized, and if it is too short, the results become too detailed. In the present analysis of the town/city concentration, the radius r = 50 km, the length of the square side is 1 km, and in the analysis of the urban population density – r = 25 km and the length of the square side is 0.5 km.

Study results

The analysis regarded a series of maps presenting the urban population density in census years, and was carried out by means of the kernel function method.

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[2]   The author used the ArcMap 9.2 software by ESRI, Spatial Analysis module.

Each map presents the current number of towns/cities in a given census year, as well as the estimated density. The method was chosen because it disregards the changing administrative divisions in Poland during the studied period. The scales of the maps are the same and the map keys were standardized in order for the maps to be comparable.

It should be noticed that in the 20th c., in the area under study (Fig.1), the number of towns increased from 104 in 1931 to 147 in 2010. They were mainly small towns, with 2-20 thousand inhabitants. At the same time, the increase in the total number of town inhabitants in the studied area was considerable – it nearly doubled; in 1931 it did not exceed 3 million and in 2010 it was over 5 million people. In the 20th c., both, the spatial distribution of towns and the urban population density were changing (Fig.2-8). The analysis will regard first of all the changes taking place within the radius of 60 km from Warsaw and Lodz (half the distance between them).

In 1931, thirteen years after Poland regained independence, the distribution of towns in central Poland was relatively even, with the exception of the Lodz agglomeration, where there were ten towns within the distance of 25 km from the city. At that time the number of towns around Warsaw was 50 % smaller.
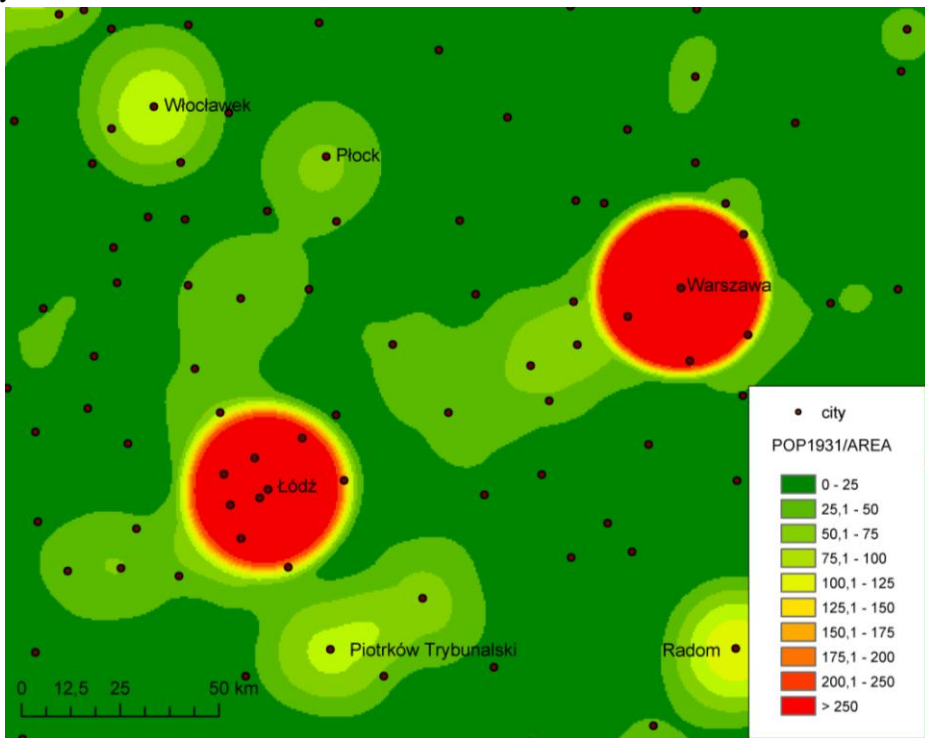

Figure. 2 Urban population density (1931)
Source: author's compilation - *kernel function*

While the distribution of towns in 1931 was quite even, the urban population was highly concentrated (Fig.2). Two agglomerations stand out in particular: the Warsaw and the Lodz agglomerations. The former one is dominated by the city of Warsaw and the urban population spreads from there to the south-west, along the railway line, through Pruszków, Grodzisk Mazowiecki, Żyrardów, Skierniewice and Łowicz. In the latter one, the urban population spreads in three directions: westwards (Zduńska Wola, Sieradz), southwards (Piotrków Trybunalski, Tomaszów Mazowiecki) and northwards (Zgierz, Ozorków, Łęczyca towards Płock). It is interesting to notice that the urban population density is not higher in the area between the Warsaw and the Lodz agglomerations. We may not talk about a *duopolis* yet.

After the Second World War, the small town of Ruda Pabianicka was joined to Lodz, new towns of Brwinów and Milanówek were founded near Warsaw, as well as Koluszki – 25 km south-east of Lodz. In 1950, only small changes in the concentration of towns and the population density could be observed near Warsaw in the direction of Lodz (Fig.3).

After ten years, we could observe changes in the concentration of towns and the urban population density in the studied area mainly near Warsaw; municipal
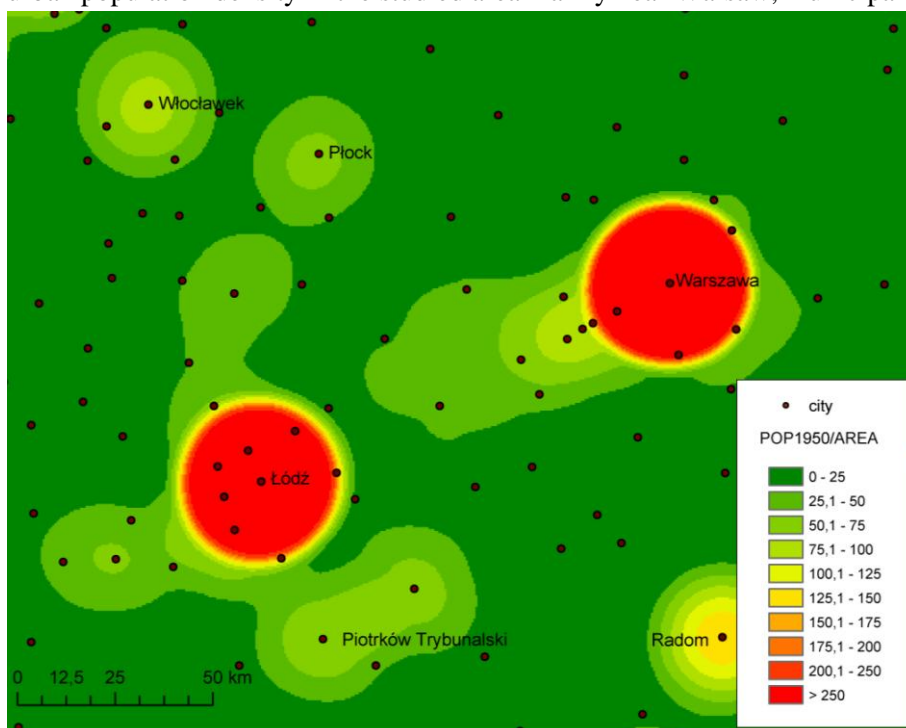

Figure. 3 Urban population density (1950)
Source: author's compilation - *kernel function*

rights were given to Karczew, Legionowo, Piastów and Zielonka; the area and urban population density of the Warsaw agglomeration increased in all directions. In the east it included Mińsk Mazowiecki, in the south – Góra Kalwaria, in the north – Serock, in the west – Sochaczew, and what is very important – it linked to the Lodz agglomeration, which did not change its basic shape in 1950-1960, but connected with Płock. The locality outside its borders which received municipal rights was Zelów (Fig.4).

In 1960-1970, the following towns were established in the Warsaw agglomeration: Podkowa Leśna, Ożarów Mazowiecki, Marki, Ząbki, Kobyłka, Sulejówek, Konstancin Jeziorna, Tłuszcz and Tarczyn. As a result the concentration of towns changed; they formed the rings of an ellipsoid, whose longer part ran along the railway line (Fig.5). In the western part of the agglomeration we could observe an increased population density; the connection with the Lodz agglomeration was getting stronger, but the Warsaw agglomeration was also spreading eastwards.

In 1970 – 1988, the process of urbanization in Poland was advancing, which can be observed on the maps of the urban population density (Fig. 6,7). Moreover, in 1975, an administrative reform was introduced, which increased the number of voivodeships to 49 and abolished the division into *powiats*.
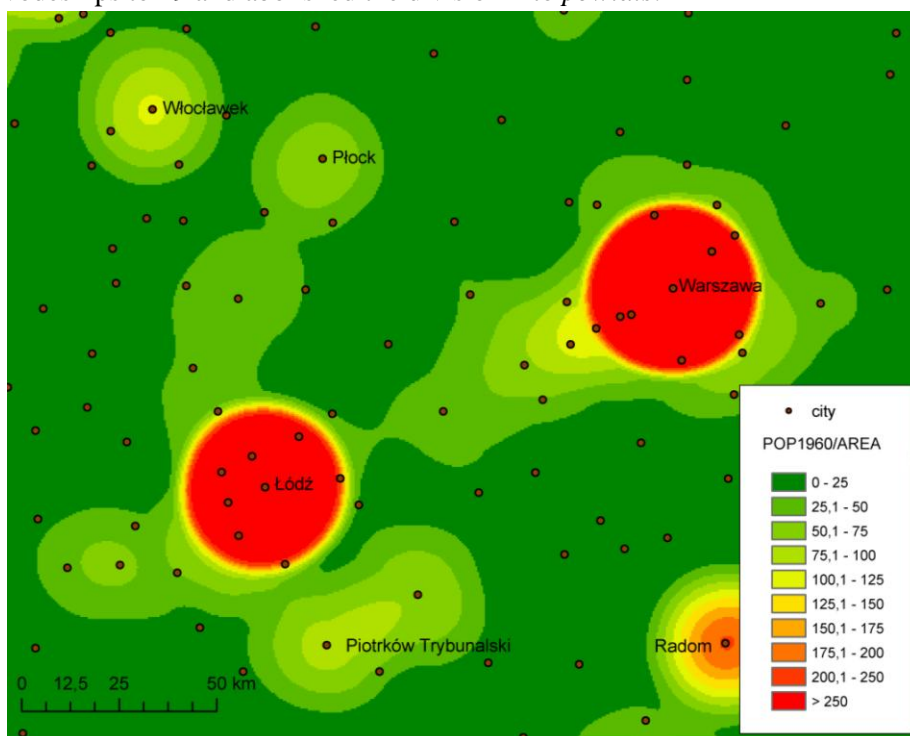

Figure. 4 Urban population density (1960)
Source: author's compilation - *kernel function*

Several medium-sized towns situated in the studied area were promoted to the rank of the voivodeship capital: Sieradz, Piotrków Trybunalski, Płock and Radom. After 1970, the sanctions regarding compulsory registration were lifted and a large number of migrants could register as the residents of Lodz and Warsaw, thus increasing the population density in these cities. This, however, did not increase the population density around them. The Warsaw agglomeration was still spreading towards Lodz, but it also incorporated Wyszków. On the other hand, the Lodz agglomeration was increasing its territory around Bełchatów. By 1988 further serious changes of the urban population density had taken place around Warsaw, whose range of influence grew considerably, not only westwards, but also to the north-east, towards Wyszków and Pułtusk. There also appeared satellite towns around this agglomeration: Józefów, Płońsk, Garwolin and Ostrów Mazowiecki. The Lodz agglomeration also increased its population density, not only near Lodz, but also around Piotrków Trybunalski and Tomaszów Mazowiecki, as well as Sieradz, Zduńska Wola and Kutno. Ciechanów and Mława form an area with elevated population density, which may link to the Warsaw agglomeration. In the south of the Lodz agglomeration, Bełchatów became an area of elevated population density, due to the investments in the brown coal mine and the power plant.
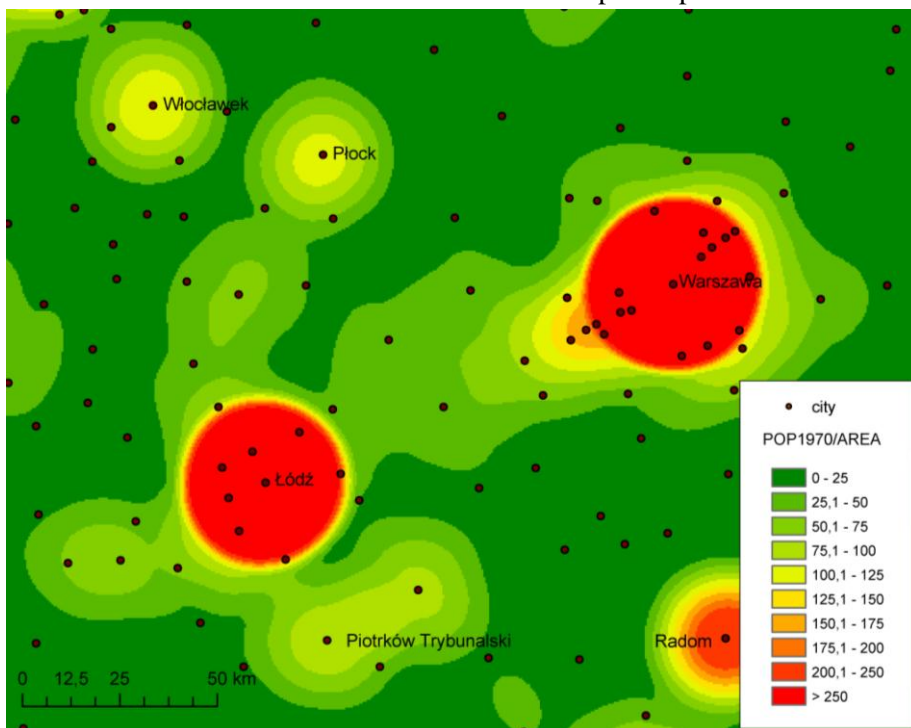

Figure. 5 Urban population density (1970)
Source: author's compilation - *kernel function*

In the south-east, Radom is increasing its zone, connecting with the Lodz agglomeration through the Opoczno region and towards Kozienice with the towns situated to the east.

Other towns established near Warsaw by 2002 included Halinów, Łomianki, Piotrków Kujawski, Skępe, Bieżuń, Pilawa, Drzewica and Glinojeck. The expansion of the Warsaw agglomeration westwards slowed down (fig. 8) or even stopped the development in towns like Żychlin, Brzeziny or Łowicz, due to the decreasing number of inhabitants. Instead, the agglomeration developed in other directions, especially northwards. The Lodz agglomeration did not significantly increase its area; only in the south Bełchatów joined Piotrków Trybunalski and Tomaszów Mazowiecki – together they form a complex of towns with an elevated urban population density. In the first decade of the 21st c., the changes in the urban population density were not so rapid as before. It may be said that it became stabilized in this part of Poland. At present, we may observe other changes approaching, antagonistic to the previous ones. The falling number of the population of the towns situated on the border of the mazowieckie and łódzkie voivodeships,
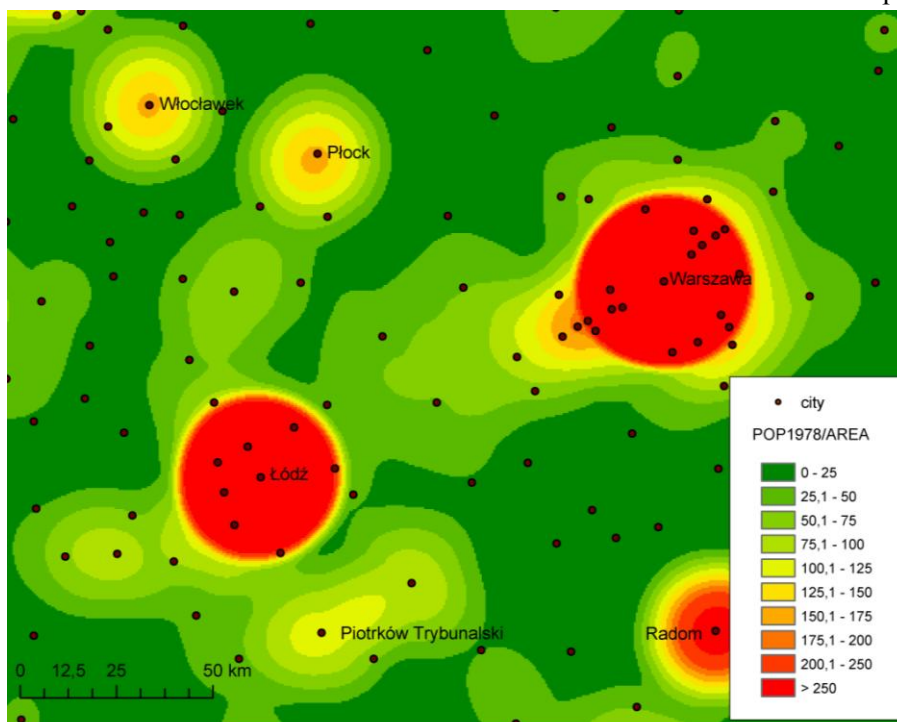

Figure. 6 Urban population density (1978)
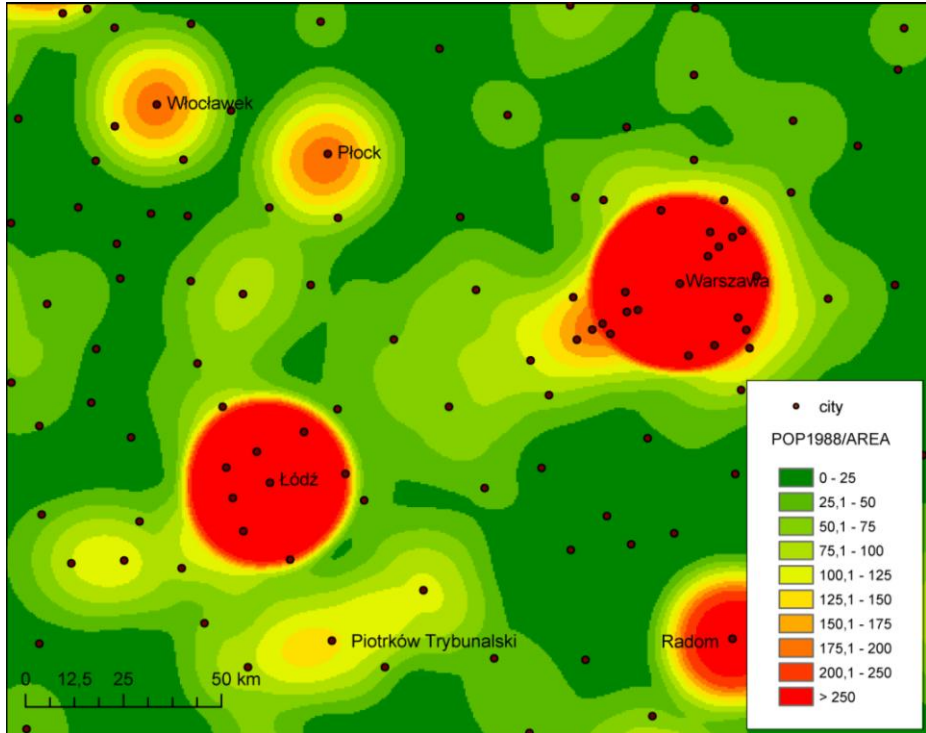Source: author's compilation - *kernel function*

Figure. 7 Urban population density (1988)
Source: author's compilation - *kernel function*

such as Brzeziny, Głowno, Łowicz or Żychlin, is the reason why the areas east of Lodz experience an urban population regression. Are there any chances for the formation of a cohesive, strong *duopolis* in this situation?

Conclusions

The 20th c. witnessed significant changes in the urban population density in central Poland. The increase in the number of the urban population from three to five million changed its spatial distribution considerably. In 1931, two agglomerations (Warsaw and Lodz) concentrated urban population, while in the larger part of the studied area the population density was low. It is interesting to observe how it has been changing around the Warsaw and the Lodz agglomerations. For many years, the Warsaw influence zone was spreading westwards, towards Lodz, but in the 1980's, it started to expand in other directions. During the studied period, municipal rights were given to 16 towns situated up to 25 km from the capital, which together with the remaining towns and the capital itself were inhabited by about 2.5 million people. On the other hand, the greatest changes in the Lodz agglomeration were recorded before 1988 and followed by regression in the next years (except
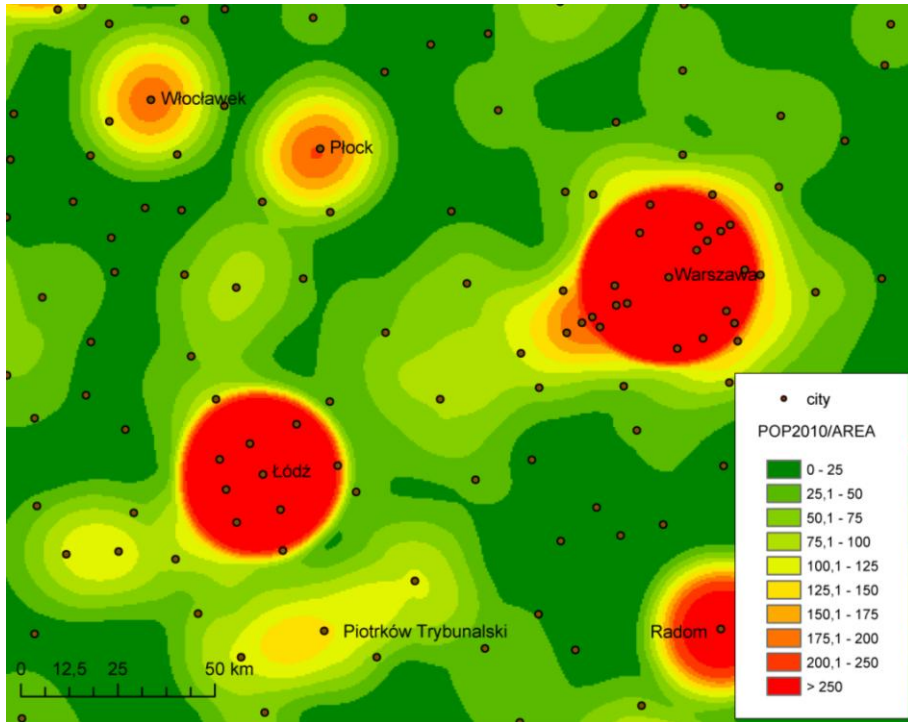
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Figure. 8 Urban population density (2010)
Source: author's compilation - *kernel function*

Bełchatów). At the beginning of the 20th c., Lodz and the towns in the agglomeration were inhabited by about 1.5 million people.

The analysis of the Warsaw agglomeration spreading along the railway line makes you wonder. Firstly, it may be assumed that the modernized railway line between the two cities will tighten the bonds between them. Secondly, the A2 motorway, running northwards, will connect them even stronger. However, for ten years, the falling number of people inhabiting the towns east of Lodz, such as Głowno, Brzeziny, Łowicz, Rawa Mazowiecka or Biała Rawska has been the reason why the area between Lodz and Warsaw does not have a chance of increasing the urban population density in the near future. Looking at the series of maps presenting the changes in the population density in the cities and in the towns between them in the 20th c., we must conclude that if the *duopolis* were to become a fact, there would have to be population changes in the towns situated east of Lodz. Despite the many discussions regarding the chances and the need for a *duopolis*, as well as the benefits both cities would enjoy, the whole issue is still highly questionable, especially as regards the studies of the urban settlement network in this region. The distinctiveness of the settlement system between the Lodz and the Warsaw

agglomerations has been observed for a long time (Jażdżewska 2008). From this point of view, one may have reservations as to the sense of creating the *duopolis* in the nearest future. (Jażdżewska 2006, p. 253). And not because of Warsaw's aversion to cooperating with Lodz, but the historical and contemporary conditions of the spatial development of the Lodz agglomeration (Jażdżewska 2002), which has been turning its back on the capital and spreading in other directions for over 100 years. Perhaps improving the accessibility by transport will change this tendency, but it is a matter of a distant future.

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