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Original article

Spatial dispersion and the concentration of buildings in an urban agglomeration – a typology proposal for the Warsaw Metropolitan Area

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ABSTRACT

The purpose of this study was to determine the state of dispersion and concentration of buildings in the Warsaw urban agglomeration. In particular, a goal was defined to develop a typology of basic administrative units due to the level and characteristics of the spatial concentration of buildings. The study was conducted based on the municipalities (urban, urban-rural and rural) of the Warsaw Metropolitan Area (delimitation of the Warsaw urban agglomeration used for the strategic and planning purposes) and districts of the capital city of Poland. Data on buildings was obtained from the topographic objects database. The share of buildings in total, as well as single-family and multi-family housing objects, was taken into account (these two categories were assumed to be the main determinants of suburbanization). Two methods were used to analyze their distribution: the density quotient factor, and the average nearest neighbour method. The spatial arrangement of buildings covers a wide spectrum of types, determined by combinations of both extreme and intermediate values of two dimensions of spatial concentration – the density of objects and the degree of their spatial dispersion (level of regularity, randomization, or clustering in their distribution). The typology allows us to indicate units for which similarly oriented spatial policy should be applied. The method of construction of the developed typology may be useful for application to research in other areas.

KEY WORDS: spatial concentration of buildings, urban sprawl, suburbs, Warsaw Metropolitan Area, typology of administrative units

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1. Introduction

This article is based on the occurrence of dispersed and concentrated buildings in the Warsaw urban agglomeration. The spatial patterns of the locations of buildings were analyzed based on topographic data for the location of all buildings. This is the first study of the examined area at such a detailed scale. In addition, the functional categories of residential buildings, which are the main determinant of urban sprawl processes, were separated for the purpose of the analysis. The capital city of Warsaw, in conjunction with the surrounding municipalities creates the only metropolitan area in Poland of the European third-order metropolis (potential MEGA type) (ESPON, 2007). It is the only monocentric agglomeration in Poland with over 2 million inhabitants. Here the processes of suburbanization and their related scatter of buildings are the most intense among the urban centres in the country and have the largest spatial coverage.

Suburbanization processes in Poland accelerated after 1989, along with the launch of market economy mechanisms. Urban agglomerations have undergone intensive transformations, as space has become an element of the market game and a commodity, and land prices have become an important indicator affecting the availability of space for development. These phenomena are referred to as "condensed evolution" and are typical of post-socialist countries (LORENS, 2005; KAJDANEK, 2012). Local governments have gained a direct impact on shaping spatial policy

and attracting investors. One effect of the changes occurring during this socio-economic transformation period was the decline of old and the emergence of new factors of segregation of urban space. This lead to the crystallization of "social space" of suburban settlements, being a manifestation of growing middle class aspirations regarding the quality of life and residence (ZBOROWSKI, 2005). As a result, spatial structures of a new type of suburbs were shaped (MANTEY & SUDRA, 2019).

The spread of built-up areas in the suburban area of Warsaw is spontaneous. It omits administrative planning control, although it is partially sanctioned by it. Urban development succession in rural areas is primarily subordinated to construction market factors (SOLAREK, 2013). It has the features of urban sprawl (GUTRY-KORYCKA, 2005), so the use of land is patchy, discontinuous and of low intensity (SQUIRES, 2002; SOULE, 2006). Buildings "drip" and "splash" along fields and thoroughfares, "spreading" to open areas (see: SOLAREK, 2013, p. 14; 2017, p. 54). This is due to the occurrence of a disordered settlement structure, with many isolated clusters of buildings not related to agriculture in rural areas and with urban-rural transition zones visible in the landscape, which are, called periurbanization zones in Europe (WEBSTER & MULLER, 2009; PIORR ET AL., 2011; HOGGART, 2012). Periurbanization is also typical for Polish metropolitan areas (IDCZAK & MROZIK, 2018), including Warsaw (GROCHOWSKI, 2011; KORCELLI ET AL., 2012).

The specific aim of the study was to develop a typology of administrative units related to the spatial concentration of buildings, which takes into account the share of single-family and multi-family housing. Spatial concentration means "the uneven distribution of specific phenomena in space" (RUNGE, 2007). The dynamics of the distribution of settlement may progress both towards clustering and dispersion, as well as towards lower or higher density. The purpose of the typology was to indicate the occurrence of areas of dispersed or concentrated buildings, and sparsely or densely distributed buildings, revealing similarities in certain groups of basic territorial units.

2. Study area

2.1. Basic information

The study area is the urban agglomeration of Warsaw. Depending on the adopted delimitation, the agglomeration borders are adopted at an average distance of 20-30 km or 40-50 km, or even at larger distances from the centre of the capital. One delimitation has been selected for the purpose of the study and that is the Warsaw Metropolitan Area according to the Mazovian Regional Planning Office, which was approved by the Management Board of the Mazowieckie Voivodeship in 2006 and is used for study and planning and strategic purposes. The area defined in such a way covers an area of 6206 km^2 and is inhabited, according to official statistics, by 3 million 147.4 thousand people, of which 1 million 754 thousand people live in Warsaw (as of December 1, 2016). The population of the Warsaw Metropolitan Area constitutes 58.7% of the population of the Mazowieckie voivodship (OBSZAR METROPOLITALNY WARSZAWY..., 2017). The metropolitan area of Warsaw consists of 72 municipalities (urban, urban-rural and rural), and covers 36 towns. Warsaw is divided into 18 districts (Fig. 1). All calculations have been made within this system of basic units – 71 municipalities (excluding Warsaw) and 18 capital districts.

Some clarifications of terminology are required at this point. The subject of the study are the buildings which occur within a monocentric urban agglomeration, understood as "a morphological unit formed by a compact set of interconnected (although separate from an administrative point of view) settlement units (a large city and its surrounding area), formed as a result of concentration processes" (MARKOWSKI & MARSZAŁ, 2006). The agglomeration consists of the major city and its suburban zone, where the intensity of land use and its multi-functionality are lower than in the city, but higher than in the countryside. It also includes a number of “satellite towns” interlinked with the central city. Metropolitan area, as a term, is a more modern concept, and is widespread in the terminology of regional policy and puts more emphasis on the functional connections of the central city with its surroundings than on the morphology and structure of the area (it is therefore a kind of functional urban area). Moreover, there are certain criteria for "metropolitan character", resulting from the socio-economic characteristics of the city and its external transnational links, which determine whether a given urban agglomeration can be defined as a metropolitan area. In this study, the two terms discussed above are used interchangeably with reference to the metropolitan settlement system of Warsaw.

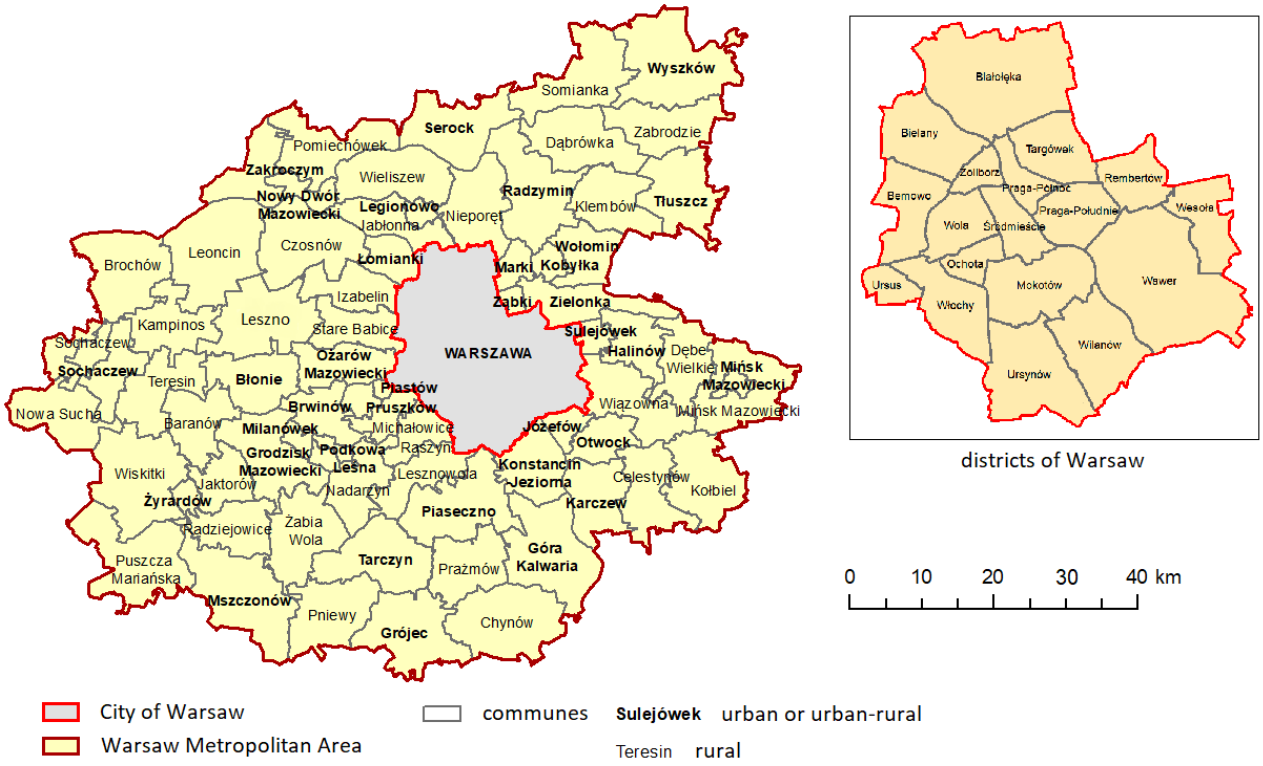

Fig. 1. Municipal division of the Warsaw Metropolitan Area. Warsaw divided by districts (in the box) (Author's own elaboration)

2.2. Settlement structure of the urban agglomeration and morphology of the suburbs

As a result of the development of the urban fabric and major elements of infrastructure, under the influence of historical, geographical and economic factors, the spatial pattern of urbanization in the Warsaw agglomeration has been shaped, and is defined as centric-radial (LISOWSKI, 2010) or band-satellite (KNAPP, 1983; SOLAREK, 2013). Its main elements are: the central agglomeration area, linear settlement bands, satellite urban centres, and rural settlement. The radial arrangement of road and rail routes has contributed to the creation of new districts within the city, followed by suburban housing estates. As a result of complex and dynamic socio-economic processes, seven basic settlement bands have developed: three located west of the River Vistula – which may be associated with some major towns there: Błonie, Grodzisk Mazowiecki / Pruszków, and Piaseczno, and four located east of the Vistula – associated with: Legionowo, Wołomin, Mińsk Mazowiecki, and Otwock (JĘDRZEJCZYK, 1992) (Fig. 2).

Most of the 20th century development visions for the Warsaw agglomeration predicted further development of the loose band-satellite system, which was supposed to promote crystallization of the settlement structure, while providing field reserves for further development (SOLAREK, 2017). In the course of urban growth, the lack of free land for development, the development of the road network and public transport, favoured the transformation of the settlement system of the suburban area as a result of the formation of secondary transverse bands (JĘDRZEJCZYK, 1992), and then their sprawling into an irregular spot (JAKÓBCZYK-GRYSZKIEWICZ, 1998). The spatial expression of these processes are urban sprawl (GUTRY-KORYCKA, 2005), chaotic settlement and scattered buildings. The specificity of agricultural land divisions on which development is planned and implemented without prior consolidation and new parceling, as well as failure to build new public roads, has caused the development to "drip" and "splash" along fields and through roads. The satellite towns of the capital city are weak settlement centres with an illegible spatial structure, which hardly stands out from the dispersed development of the zone (SOLAREK, 2013, 2017). However, a slightly increased urbanization level of rural units surrounding some county towns has been noticed, which would indicate that they are beginning to develop their own local suburban zones (DEGÓRSKA, 2017).

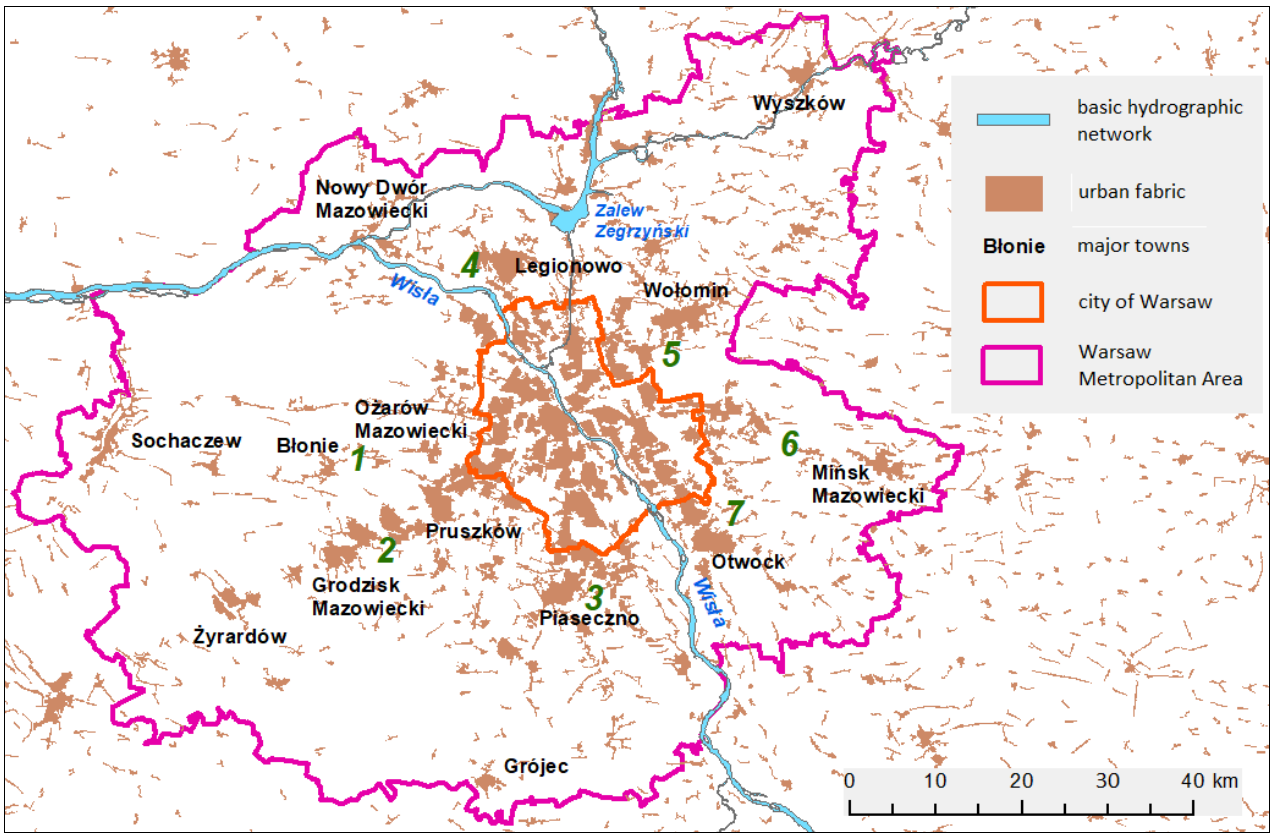

Fig. 2. Warsaw urban agglomeration and its major settlement bands, referring to the satellite towns: 1 – Błonie, 2 – Grodzisk, 3 – Piaseczno, 4 – Legionowo, 5 – Wołomin, 6 – Mińsk, 7 – Otwock. (Author's own elaboration; Source of data on built-up areas and the hydrographic network: CORINE Land Cover 2012)

Suburbia types located in the suburban zone of Warsaw are diverse and include: gated communities built by developers; open housing estates connected with the city through a street network; areas where developers' micro-investments and individual housing permeate (often with a network of cul-de-sacs) (Fig. 3A); estates developed along communication routes; housing estates, designed as contemporary "garden cities" and with a regular network of streets, but away from rail transport (Fig. 3B); former villages, currently subject to suburbanization; rural areas where investments of a "leap frogging" type are progressing (Fig. 3C). In addition to the "new suburbs", there are also "old suburbs", among them garden cities, designed before World War II, with individual housing developments on relatively large plots (e.g. Podkowa Leśna) (Fig. 3D), as well as villages with buildings located on smaller plots, more densely populated, with more urban types of land use, located along communication routes and based on a grid of streets, which developed after World War II and after 1989 which have undergone further transformations (e.g. Raszyn) (MANTEY & SUDRA, 2019).

Observation of the distribution of the bands of residential areas and suburban growth in the Warsaw agglomeration allows us to notice the leading role of the southern (Konstancin-Jeziorna, Piaseczno, Lesznowola) and south west (Michałowice, Pruszków, Grodzisk Mazowiecki) development directions, forming together with the north east band (Marki, Ząbki, Zielonka, Wołomin) an outstanding rail-road axis of the metropolitan area. In recent years, a new trend in the development of housing has been noticeable, because of the growing importance of the northern (Jabłonna, Wieliszew, Nieporęt, Serock), eastern (Wołomin, Halinów, Mińsk Mazowiecki) and southeastern (Józefów, Otwock, Karczew) development directions (DEGÓRSKA, 2012). This is due to the attractiveness of the landscape in these areas, the vicinity of forests and a large supply of cheaper land for investment.

Fig. 3. Different forms of suburbs in the suburban zone of Warsaw
(Source: orthophotomap from the national mapping service Geoportal.gov.pl)
A. Suburbanization in areas directly adjacent to the city, resulting from its territorial expansion (the effect of urban sprawl). Józefosław (Piaseczno municipality). B. Suburban estate built by one developer in the furthest part of the suburban area, isolated from compact built-up areas, Książenice (Grodzisk Mazowiecki municipality). C. Chaotic spatial development in rural areas – "leapfrog" type of urban sprawl. Kolonia Lesznowola (Lesznowola municipality). D. Podkowa Leśna – a garden city. Example of "old suburbs"

Warsaw is a city with very broad administrative borders (an "overbound city") in relation to the limits of compact urban development, like Moscow (STANILOV & SÝKORA, 2014), and unlike capitals such as Paris, or in Central-Eastern Europe such as Tallin, which in their administrative borders only contain areas of typical urban structure, morphology and physiognomy (an "underbound city")[1]. In 2000, within the city limits, covering 517 km^2, there were about 100 km^2 of unused land potentially available for development (BERTAUD & BERTAUD, 2000). Some fragments of Warsaw's districts still have a rural character (DEGÓRSKA & DEREGOWSKA, 2008). Consequently, the city is overgrowing with its suburbs and also growing within its administrative borders. The process called "inner suburbanization" is a phenomenon typical of post-socialist cities, characterized by large shares of undeveloped areas, including wastelands which require regeneration (LORENS, 2005). Examples of these in Warsaw are the districts of Białołęka (north of the city), as well as Wilanów (south of the city). They are the least populated districts, however, they are characterized by intensive development of housing construction in the last two decades.

[1] The Organization for Economic Cooperation and Development (OECD) and the European Commission have developed a common methodology for delimiting cities with more than 50,000 inhabitants, which takes into account the population density, their commuting zones and functional urban zones. The cases of overbound cities, underbound cities, and polycentric cities are included there. See: https://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:European_cities_%E2%80%93_the_EU-OECD_functionnal_urban_area_definition

3. Materials and methods

3.1. Input data and research tools

The study was conducted based on the official Topographic Objects Database (BDOT), which was made available by the Head Office of Geodesy and Cartography, and valid for the year 2013 (as for the version used in this study). It is a vector GIS database, on the basis of which topographic maps are prepared. The objects in the database are represented with an accuracy corresponding to a map at a scale of 1: 10,000. BDOT assigns a georeferenced that is connected to the geodetic flat coordinate system PUWG-1992.

The main class of objects used in the analyses was that containing buildings. Analyses were performed for the dataset representing all buildings (758 011 objects in total, belonging to 21 different categories of buildings), and separately for the following selected building categories:

1) single-family residential buildings (429 694 objects in total), and
2) multi-family residential buildings - separated as the sum of the following three categories: two apartments buildings, multi-apartment buildings and collective housing buildings (31 541 objects in total).

The dataset on buildings was processed from the polygon vector format (including the geometrical outlines of building objects) into the point vector format (a "point cloud"). The points represent building centroids. All attribute information about the objects (e.g. building type, height, etc.) has been preserved.

Research techniques and tools used in the study, from the range of geographical information systems, have allowed the processing of a large amount of spatial data in a vector format. The software used to perform the analysis included ArcGIS Desktop package (version 10): standard tools from ArcToolbox and additional plugins. The analyzes were automated in the ModelBuilder visual programming language and using the Python scripting language.

3.2. Indicators of settlement concentration

Density indicator. The density quotient factor is a classic numerical measure of the intensity of a phenomenon, expressed by the formula:

$$g = \frac{n}{p}$$

where *n* – number of objects, *p* – surface, on which the objects studied occur (RUNGE, 2007).

An example of the use of the ratio of density may be the calculation of the degree of concentration of the population of the area or the number of buildings, where the standard unit of area is 1 km^2. Various adjustments to this indicator were proposed, e.g. measures of the dispersion of rural settlement (taking into account, e.g. the number of inhabitants, the number of isolated settlements and solitary houses, the housing area and built-up area, and other factors). A synthetic comparison of these measures has been made by KOSTRUBIEC (1972), who noted that these measures do not reflect a faithful picture of the dispersion of objects, because they do not respond to the important feature of concentration, which is the change in the location of objects within the basic spatial unit under consideration.

Average nearest neighbor. The average nearest neighbor method was first used in ecological and biogeographical studies by CLARK & EVANS (1954), and shortly after in the geography of settlement and population, and studies on spatial diversity of socio-economic phenomena (DACEY, 1962; CURRY, 1964; GETIS, 1964), and also currently (LANG ET AL., 2006; JAŻDŻEWSKA, 2008; BROITMAN & CZAMANSKI, 2012; AGUILERA ET AL., 2011; LI ET AL., 2013). The indicator that this method uses is called the Clark index or Clark-Evans index. The basic assumption is to measure the average distance between each element of the set and the nearest neighbouring element. The constructed indicator allows determination of the deviation of the spatial distribution of objects (e.g. dispersion of buildings in a given area) from the theoretical, random distribution of points on the plane, in accordance with the Gaussian distribution law. The priority in its calculation is not so much the concentration as the comparison of the spread to a random pattern (see also: DACEY, 1962; BOOTS & GETIS, 1988).

The indicator is expressed as the quotient of the observed average distance to the expected distance in the case of a hypothetical random distribution, according to the formula:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E}$$

where $\bar{D}_O$ is the observed average distance value calculated, taking into account the distance between each object and its nearest neighbor, whereas $\bar{D}_E$ is the expected average value of distance.

$$\bar{D}_O = \frac{\sum_{i=1}^{n} d_i}{n}$$

$$\bar{D}_E = \frac{0{,}5}{\sqrt{\frac{n}{A}}}$$

In the above formulae d_i is the distance between the object i and the nearest object, n is the total number of objects, and A is the total area surface.

A completely random spatial arrangement occurs when $ANN = 1$. The value of measure $ANN < 1$ indicates a clustered pattern, value $ANN > 1$ indicates a trend towards dispersion. Maximum concentration occurs when all settlement points are concentrated in one place, then $ANN = 0$, maximum dispersion occurs with regular distribution of points in the hexagonal pattern, then $ANN = 2.1491$. Between these values there are spatial patterns with values more or less similar to an even distribution, theoretical random distribution, or to a cluster system.

4. Analysis of concentration and dispersion of buildings

4.1. Density of buildings

The total density of buildings in municipalities and districts (Fig. 4A) is the highest in Piastów (906 buildings/km^2). High density also occurs in other urban municipalities, such as Ząbki, Legionowo, and Mińsk Mazowiecki. The lowest density is in the Leoncin rural municipality (30 buildings/km^2) and in other municipalities of the Kampinos National Park, as well as in some other rural and urban-rural municipalities located on the outskirts of the Warsaw Metropolitan Area, especially those in the south west (within the Bolimowski Forest). The average density of building centroids in some districts of Warsaw is lower than in neighbouring satellite towns (the lowest being in Warsaw-Wilanów: 180 buildings/km^2). A high density is observed in the broad band of eastern and south eastern districts – Targówek, Praga-Południe, Wawer, Wesoła, Rembertów and in the neighbouring municipalities: from the north east – Ząbki, Marki and Kobyłka, from the east – Sulejówek and from the south east – Józefów. There is also a high-density band in the south western part of the agglomeration, along railway line no. 1 (Warsaw West - Katowice) and no. 447 (Warsaw West - Grodzisk Mazowiecki): the Warsaw-Ursus district, the towns of Piastów, Pruszków.

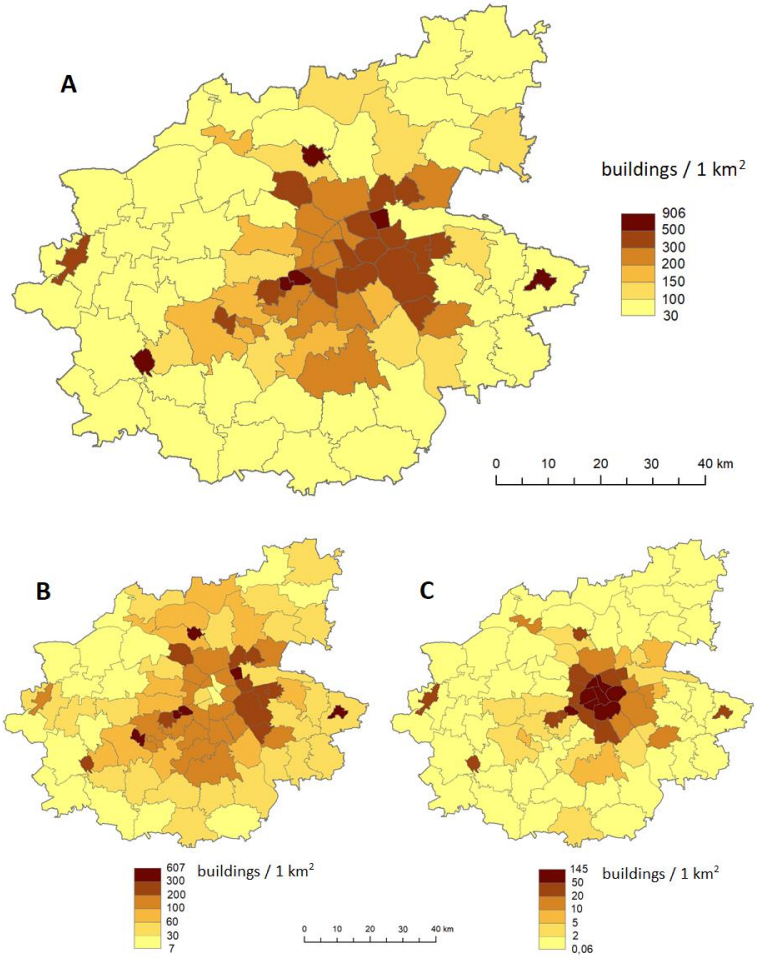

Fig. 4. The density of buildings in municipalities of the Warsaw Metropolitan Area and districts of Warsaw: A. total, B. single-family residential, C. multi-family residential (Author's own elaboration)

The density of single-family residential buildings in municipalities and districts (Fig. 4B) is the lowest in the downtown areas of Warsaw, but also in the extensively developed municipalities of the Kampinos Forest, such as Brochów and Leoncin (about 14-15 buildings/km^2), or on the southern border of the Warsaw Metropolitan Area – in the Pniewy municipality (18 buildings/km^2). In the satellite towns of Warsaw, the indicator values are high, above 200 buildings/km^2. The highest density occurs in Piastów (607 buildings/km^2). The high density of single-family housing is particularly characteristic in the extensive eastern range, covering the Wawer and Rembertów districts and the adjacent municipalities. South of Warsaw, Piaseczno is a large urban-rural municipality with a significant density of single-family houses.

The density of multi-family residential buildings in municipalities and districts (Fig. 4C) is the highest in the central districts of Warsaw, with the highest value of the indicator in Śródmieście (145 buildings/km^2). Generally, higher density occurs in districts of the left bank of the Vistula than in right-bank districts. The satellite towns which stand out are: Żyrardów, Legionowo, Pruszków (42-47 buildings/km^2) as well as: Sochaczew, Mińsk Mazowiecki and Piastów (30-33 buildings/km^2). A relatively low density of multi-family buildings occurs in such districts as Wawer, Rembertów and Wesoła and in neighbouring municipalities in the eastern suburban zone. The high density of buildings in these units in general is mainly associated with single-family housing.

4.2. Spatial dispersion of buildings

As a result of the calculations of the ANN indicator for the set of all buildings in the municipalities of the Warsaw Metropolitan Area and districts of Warsaw (Fig. 5), the highest metric values, indicating weak clustering (ANN = 0.65-0.86) were found in heavily built-up urban areas – in the central districts of Warsaw and in the urban municipalities of Piastów, Pruszków, Milanówek, Żyrardów, Ząbki, Marki, Legionowo, Sulejówek and Mińsk Mazowiecki. For some units (e.g. Piastów) these values nearly approach a relatively random order. The largest concentration (clustering) of buildings (ANN = 0.22-30) is observed in the municipalities of the Kampinos Forest, in other peripheral, agricultural municipalities of the metropolitan area – in its western part and in the north-eastern part, and in the municipality of Zielonka, which has a large forest area. The occurrence of a typically dispersed pattern, where the uniformity of the distribution of buildings is greater than for the theoretical random distribution (ANN > 0), has not been demonstrated.

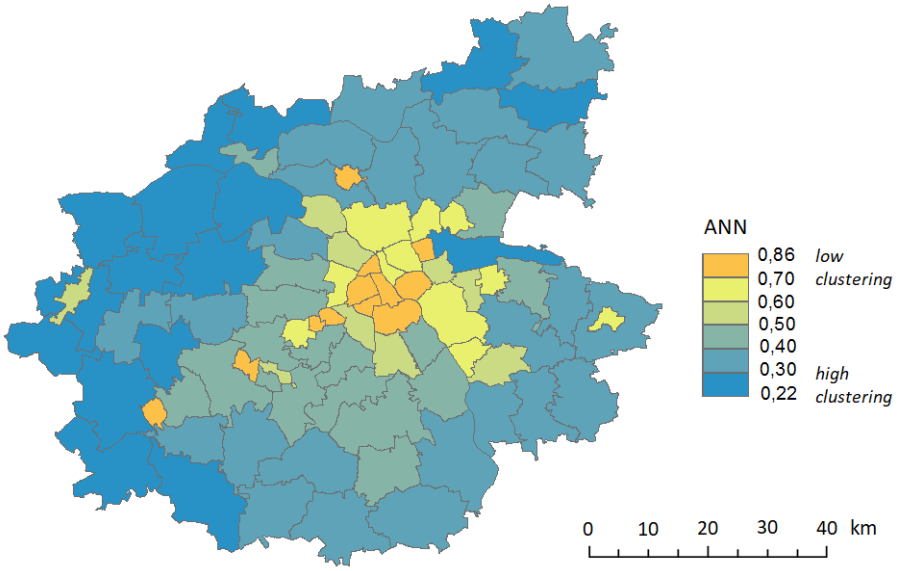

Fig. 5. Spatial distribution of values of the average nearest neighbour index (Clark-Evans index) calculated for the set of all buildings within the municipalities of the Warsaw Metropolitan Area and districts of Warsaw (Author's own elaboration)

The results of the analyses may be in conflict with the intuitive understanding of the dispersion of buildings as a pattern in which the distances between buildings, or their clusters, are so large that it is difficult to handle the development and to serve them with the technical infrastructure, public transport, etc. Such a situation usually occurs in these municipalities, where a concentration of buildings measured using the average nearest neighbor index is the largest (ANN < 0.30). Concentration in this case means, however, clustering and it is often a multi-cluster system. Individual groups of objects are located at considerable distances from each other, hence the difficulty in

seving them efficiently with the infrastructure. There may also be numerous isolated houses. They are also sparsely populated municipalities, with the dominance of extensive farming or nature protection functions. At the same time, these units are less affected by urban sprawl, associated with the successive urbanization of the peripheries (concentric spreading) than municipalities located in the close suburban zone of Warsaw, where settlement patterns are characterized by greater regularity in the arrangement of buildings, or at least lower spatial isolation of their clusters (ANN > 0.40). In this group of municipalities, the problem of infrastructure network expansion may also be significant, due to the intensity of land use, and there are problems related to landscape fragmentation, and expansion of buildings in ecological corridors, etc.

The lowest level of clustering of buildings occurs in the central districts of Warsaw and in urban municipalities (similar results may be expected in urban parts of urban-rural municipalities). These are units with large shares of residential multi-family or single-family housing, but with an orderly layout of plots. Their urban layouts often refer to a regular grid of streets and city blocks. The regularity of the arrangement of buildings is disturbed by city parks and gardens, water reservoirs, wastelands, cemeteries, railway areas, etc. In this case one can notice a certain terminological problem. It would be inappropriate to use the concept of "areas with greater dispersion of buildings" in urban areas with a high density of buildings, and the main reason is the morphology of the city, which is different from the suburban area. One should rather talk about urban areas with a "relatively uniform structure of buildings" or a more "regular, orderly structure of land use".

Therefore, the relative regularity in the arrangement of buildings should not be automatically identified with dispersion. The structure of the built-up areas and the density of the buildings are important. The municipalities of the metropolitan area, and even the outer districts of Warsaw, with a large perceived dispersion of buildings are within average coefficient values (0.40 < ANN < 0.65 or even 0.30 < ANN < 0.65). This suggests that taking the average nearest neighbour indicator as the sole measure of spatial concentration, especially without taking into account the density indicator, is not appropriate and can be misleading. This conclusion has been also been revealed following further analyses.

In Fig. 6 the spatial distribution of the standard deviation of the distances between the "nearest neighbours" for the set of all buildings within the basic territorial units has been presented. The standard deviation of these distances is the largest in the urban-rural municipalities which are extensive in area (Góra Kalwaria, Grodzisk Mazowiecki, Grójec, Piaseczno, Radzymin, Tłuszcz, Wyszków). It can be concluded that these are municipalities in which the largest morphological diversity of settlement units and heterogeneity of the local settlement network occur, and there may also be dispersed, isolated buildings. The lowest values of the distance deviation occur in the central districts of Warsaw, as well as in small urban municipalities. This confirms that the spatial structure of built-up areas in typically urban areas is the most ordered.

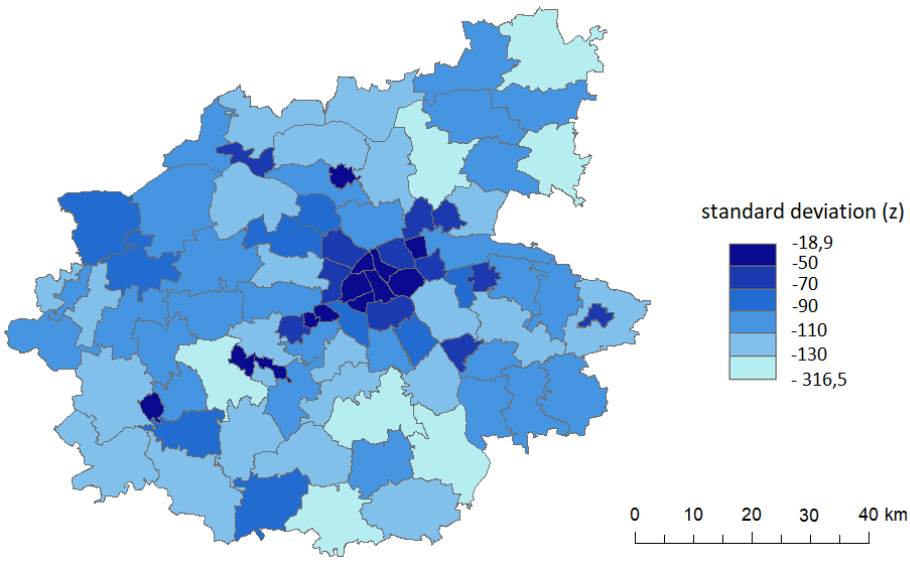

Fig. 6. Spatial distribution of the value of the standard deviation of the distance between "nearest neighbours" for a set of all buildings within the municipalities of the Warsaw Metropolitan Area and districts of Warsaw (Author's own elaboration)

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Table 1. Values of the average nearest neighbour index and parameters of statistical significance "p" and "z" and values of statistical distribution of these parameters within the municipalities of the Warsaw Metropolitan Area and districts of Warsaw (in total) (Source: BDOT topographic data (year 2013), layer of buildings)

Type of buildings	Indicator	Characteristic values of the indicator			
		Minimum	Maximum	Average	Standard deviation
Buildings in total	ANN index	0,22	0,86	0,46	0,17
	Standard deviation (z)	-316,4	-18,9	-94,6	40,0

Table 1 summarizes the characteristic values of the average nearest neighbour indicator and the standard deviation parameter (z) associated with their statistical distribution calculated in the municipalities of the Warsaw Metropolitan Area and districts of Warsaw

The average nearest neighbour indicator is very useful in determining the spatial concentration of development in selected areas, but it is not sufficient for this purpose. It is best to use it in conjunction with other indicators, especially the density quotient factor. In the search for actually dispersed buildings, one should look for such patterns where the distribution of buildings is relatively even and their density is relatively low. This leads to an attempt to juxtapose the values of the average nearest neighbour index and the density of buildings within territorial division units, and on this basis to create a typology of municipalities (and districts) with different levels of dispersion of buildings.

5. Typology of patterns of concentrated and dipersed buildings

The typology presented aims to indicate the administrative units within the Warsaw Metropolitan Area that are similar in terms of spatial development characteristics, in particular the concentration of its buildings. The typology is useful to identify units for which similarly oriented spatial policy may be required at the level of the entire metropolitan area. It reveals the differences and similarities of local settlement systems, which are affecting it, i.e. the issues of serving existing housing with infrastructure.

The classification of territorial units is based on the characteristics of the location of buildings occurring within them, interpreted as settlement points. The spatial units to which the typology refers are municipalities (71) and capital districts (18). It was assumed that the units constituting the basis of the typology should be as homogeneous as possible in terms of the characteristics of the studied phenomenon, and therefore not too large. On the other hand, the use of relatively large units allows the recognition of more complex spatial relationships within them. They should therefore not be too small either. This results in the selection of a municipal and district system.

The development of a typology required the selection and compilation of a limited number of indicators that would most accurately characterize the variability of the phenomenon, but also the features of similarity between spatial units. Two complementary measures were adopted as the basis for the classification, describing two relevant dimensions of spatial concentration:

1) density of all buildings (density quotient factor – DQF), informing what is the average number of buildings per unit area in a given territorial unit,
2) average nearest neighbour index for all buildings (ANN), informing what is the mutual configuration these buildings occur in, i.e. describing the level of dispersion.

The linear regression graph shows the correlation relationship between the values of the above mentioned indicators for all observations (Fig. 7). The estimated regression function does not quite perfectly explain the variability of the "y" variable because the coefficient of determination R^2 = 0.7666, so over 76% of observations are fitted to the regression analysis model, however, over 23% of observations do not meet this condition. This does not cause harm to the development of the typology, on the contrary, since the indicators represent different dimensions of the concentration – a perfect fit of the regression line and directly proportional relationship was not expected. However, the significance factor F is very close to zero (9.96637E-29), and therefore the results are statistically significant.

The ANN indicator increases proportionally to the density of buildings per unit of area, expressed by DQF (in buildings per 1 ha), and falls within a fairly wide range (0.2-0.9). The more unusual observations on the chart include the town of Piastów, with a very high DQF (9.06 buildings/ha), but also the highest ANN (0.863), which indicates a relatively regular placement of buildings, but standing down from the regression line. There are also other outliers, distant from the calculated linear regression plot, with a relatively large remainder. These include, for example, the Wola district – with a high ANN (0.801) at an average DQF

density (2.62 buildings/ha) and the Ochota district with very similar characteristics. On the other hand, such towns as Sochaczew, Mińsk Mazowiecki and Ząbki - have relatively low ANN values (0.501 at DQF = 3.9 buildings/ha, 0.656 at DQF = 6.16 buildings/ha, 0.731 at DQF = 6.79 buildings/ha, respectively), i.e. a significant concentration of buildings in clusters, causing these observations to stand out from the the course of the linear regression plot.

It is worth noting that all of the above-mentioned cases which are unusual relate to urbanized areas, while for rural areas, or possibly for urban-rural areas with a lower DQF, observations tend to concentrate fairly close to the regression line, although more often they occur slightly below this graph (this indicates significant clustering). An example of such a municipality is Zielonka with a low buildings' density ratio DQF (0.64 buildings/ha) and particularly high level of clustering (ANN = 0.222), resulting from the fact that the majority of the municipality area is covered by forests, and the buildings are concentrated virtually only in its very western part. Another example is the urban-rural municipality of a small town of Zakroczym (ANN = 0.237; DQF = 0.55 buildings/ha), where agricultural areas dominate.

In addition, it was observed that the correlation between the values of the DQF and ANN indicators for the set of all buildings in the municipalities of the metropolitan area and districts of Warsaw is approximated better by using the logarithmic function than by the linear regression function (Fig. 8). The determination coefficient R^2 = 0.8602, so over 86% of the observations are fitted to the logarithmic function model. This means that in the group of municipalities with low density of buildings, the ANN indicator increases rapidly (clustering decreases, dispersion increases), and for higher buildings' density values, the ANN value increases relatively slowly.

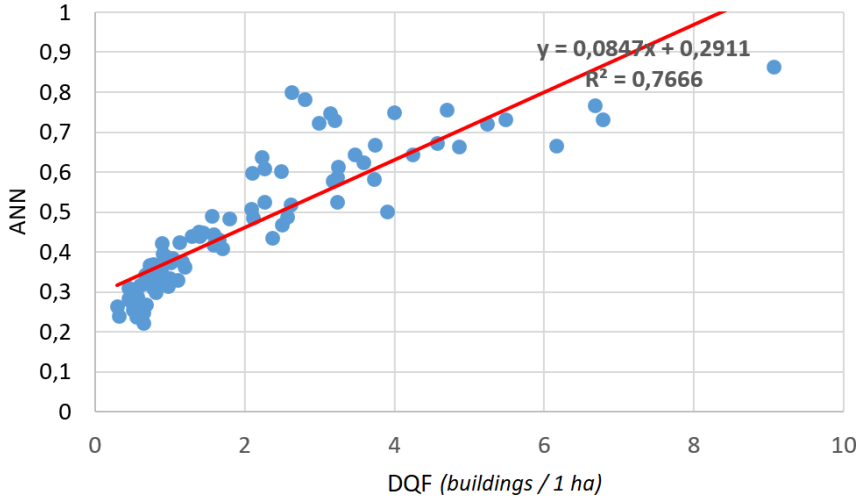

Fig. 7. Linear regression - correlation relationship between values of the density index (per 1 ha) and the average nearest neighbour index (Clark-Evans index) for a set of buildings in the municipalities of the Warsaw Metropolitan Area and districts of Warsaw. Each point is a different municipality or district (Author's own elaboration)

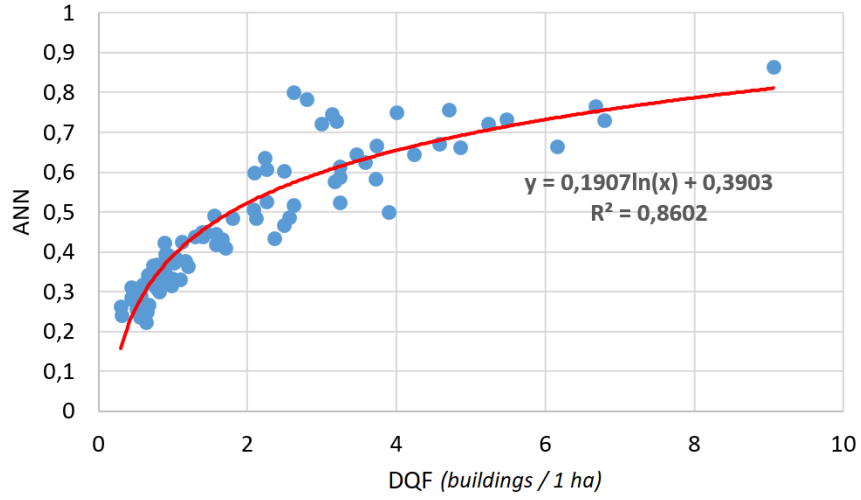

Fig. 8. Logarithmic function - correlation relationship between values of the density index (per 1 ha) and the average nearest neighbour index (Clark-Evans index) for a set of buildings in the communities of the Warsaw Metropolitan Area and districts of Warsaw. Each point is a different municipality or district (Author's own elaboration)

It has been noted that for land development it is important which categories of buildings dominate in a given area. Housing development is particularly important, as it occurs the most frequently (in rural areas also farm buildings related to agriculture are very common). The spread of housing is a phenomenon particularly noticeable in the suburban zone. For this reason, further indicators have been included in the typology, which relate to the:

3) density of single-family residential buildings,
4) density of multi-family residential buildings.

The next stage of typology development was to define the boundaries between classes of values of indicators and the number of territorial units in individual classes. Indicator values for the entire set of administrative units were divided into 5 classes, representing very high, high, medium, low or very low values. To define the boundaries between class intervals, one of the methods of cluster analysis was adopted – the method of Jenks natural breaks. It belongs to the most optimal methods for determining the boundaries between class ranges.

In consequence, 13 types and 15 subtypes of municipalities and districts were defined. They are listed in Table 2 and presented on the map (Fig. 9). Table 2 also lists the particular types, whether they include territorial units that are predominantly urban, suburban, rural or have other specific features of land use, according to the author's general interpretation. In Fig. 9 the yellow, or orange, colours in general represent rural or forest types of municipalities, red colours –peri-urban or suburban type, brown – suburban type, light violet – suburban or inner suburbs with much greenery, light blue – urban type, dark brown – inner suburbs, deep purple – city centre. However, in this respect there might be some exceptions.

The number of types may seem large, but it is a compromise between the possibly detailed characteristics of homogeneous types, and the number of types which allows them to quickly be identified and to distinguish the units assigned to them. The subtypes result from refinement of the entire classification, being usually "transitional" types for which the density or level of dispersion of buildings, or the share of single-family or multi-family housing, are larger, or smaller, than in the case of basic types. The types along with subtypes practically exhaust the possibility of classifying territorial units according to the indicators combined with each other. It can be concluded that further increasing the number of types and subtypes would be pointless.

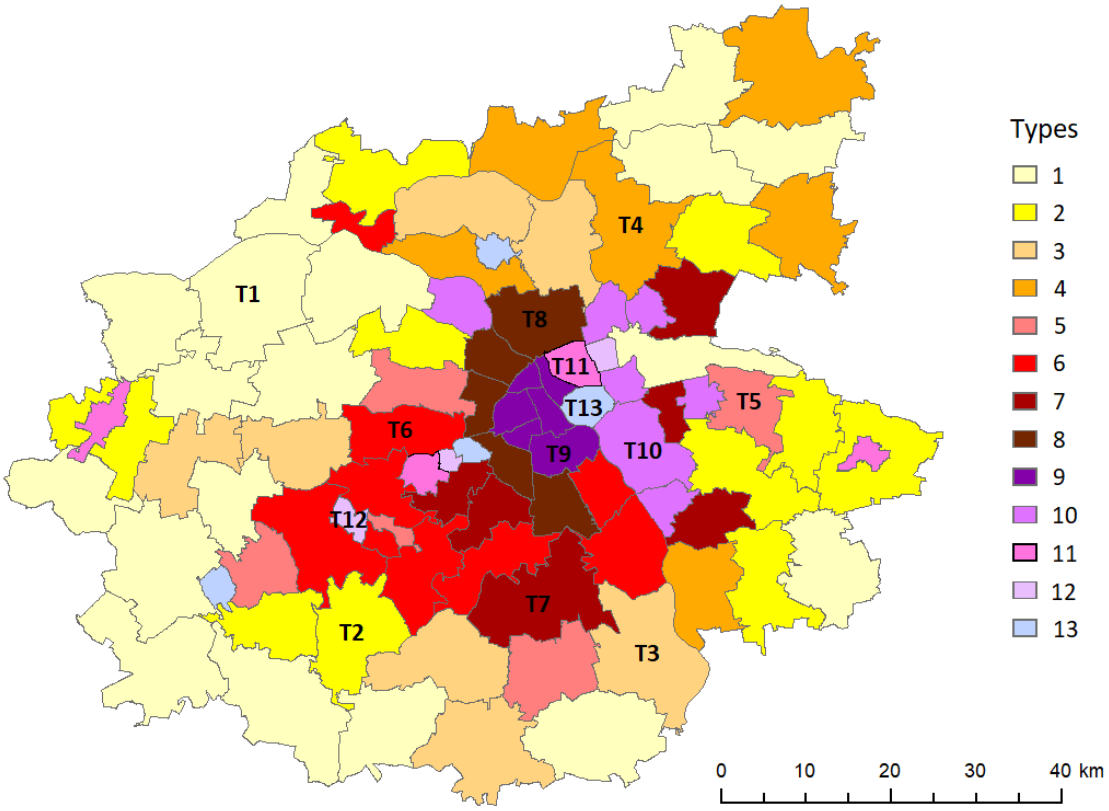

Fig. 9. Typology of the municipalities of the Warsaw Metropolitan Area and districts of Warsaw in terms of the spatial concentration of buildings (Author's own elaboration)

Table 2. Typology of the municipalities of the Warsaw Metropolitan Area and districts of Warsaw in terms of the spatial concentration of buildings

Type	Subtype	Density of buildings	Clustering of buildings	Dominating type of residential buildings	Territorial units
1		very low	very strong	single-family	Puszcza Mariańska, Somianka, Nowa Sucha, Baranów, Kampinos, Mszczonów, Leszno, Czosnów, Leoncin, Zabrodzie, Brochów, Zakroczym, Wiskitki
	1a	very low	very strong	single-family, noticeable share of multi-family	Zielonka
	1b	very low	strong	single-family	Pniewy, Kołbiel, Dąbrówka, Chynów
2		low	strong	single-family	Izabelin, Mińsk Mazowiecki (rural), Celestynów, Dębe Wielkie, Klembów, Żabia Wola, Radziejowice, Wiązowna
	2a	low	very strong	single-family	Sochaczew (rural), Pomiechówek
3		low	strong	single-family, noticeable share of multi-family	Tarczyn, Teresin, Góra Kalwaria, Nieporęt, Wieliszew
	3a	low	strong	single-family, significant share of multi-family	Grójec, Błonie
4		medium	strong	single-family, noticeable share of multi-family	Jabłonna, Wyszków, Serock, Karczew, Radzymin
	4a	medium	strong	single-family	Tłuszcz
5		medium	medium	single-family	Stare Babice, Halinów, Podkowa Leśna, Jaktorów
	5a	low	medium	single-family	Prażmów
6		medium	medium	single-family, noticeable share of multi-family	Ożarów Mazowiecki, Brwinów, Konstancin-Jeziorna, Nadarzyn
	6a	medium	medium	single-family, significant share of multi-family	Grodzisk Mazowiecki, Lesznowola, Nowy Dwór Mazowiecki, Warsaw-Wilanów
7		high	medium	single-family, noticeable share of multi-family	Otwock, Piaseczno, Warsaw-Wesoła, Wołomin
	7a	high	medium	single-family	Michałowice, Raszyn
8		high	weak	single-family and multi-family	Warsaw (whole city), Warsaw-Bielany, Warsaw-Bemowo, Warsaw-Białołęka, Warsaw-Włochy
	8a	high	medium	single-family and multi-family	Warsaw-Ursynów
9		high	very weak	multi-family	Warsaw-Śródmieście, Warsaw-Ochota, Warsaw-Wola
	9a	high	weak	multi-family	Warsaw – Praga-Północ
	9b	high	very weak	multi-family, noticeable share of single-family	Warsaw-Mokotów, Warsaw-Żoliborz
10		very high	weak	single-family, noticeable share of multi-family	Sulejówek, Józefów, Łomianki, Kobyłka
	10a	very high	weak	single-family, significant share of multi-family	Warsaw-Rembertów, Warsaw-Wawer, Marki
11		very high	weak	single-family and multi-family	Warsaw-Targówek, Pruszków, Mińsk Mazowiecki (urban)
	11a	very high	medium	single-family and multi-family	Sochaczew (urban)
12		very high	very weak	single-family, noticeable share of multi-family	Piastów, Ząbki
	12a	very high	very weak	single-family	Milanówek
13		very high	very weak	single-family and multi-family	Warsaw-Ursus, Żyrardów, Legionowo
	13a	very high	very weak	multi-family, noticeable share of single-family	Warsaw – Praga-Południe

6. Discussion

The typological diversity of municipalities (and districts) in the study area is significant. Observing the spatial distribution of the buildings' density index, it can be stated that in the Warsaw Metropolitan Area there is a group of municipalities in which buildings are sparse, well below 100 buildings per 1 km^2. These are municipalities with a significant share of forest areas (e.g. Leoncin and Kampinos in the Kampinos Forest, Puszcza Mariańska in the Bolimowski Forest) or with a predominance of extensive farming (e.g. Somianka, Zakroczym). On the other hand, there are municipalities with a very high density of settlement points, over 500 buildings per 1 km^2, especially such towns as Piastów, Pruszków, Legionowo, and Żyrardów, where there is a significant share of both single-family and multi-family housing. This density is also high in some municipalities with a clear dominance of single-family housing, like Milanówek. It is also high in many districts of Warsaw, although it is not the highest in downtown districts (city centre), despite the compact structure of built-up areas there. This is due to the fact that the calculations have been made for building centroids, without taking into account the building outlines. The height of buildings was not taken into account either. There are, however, many units with intermediate values of the buildings' density indicator, located on the spectrum between the extreme values.

A general relationship is observed where the units with the rarest buildings are also the ones in which the buildings are the most concentrated in clusters (ANN < 0.30). As a rule, such clusters are significantly isolated from each other, and agricultural or forest areas predominate in these municipalities. Areas with very little clusters of buildings (ANN > 0.75) occur in those satellite towns and districts of Warsaw that have the highest density of buildings. On the spectrum of buildings' dispersion in municipalities and districts, between extreme values, there are many units with intermediate values of this indicator. The relationship between the density and dispersion of buildings in the entire set of administrative units is close to a directly proportional correlation, although there are some exceptions (e.g. in the rural municipality of Sochaczew at very high clustering, relatively high density; while in the town of Sochaczew at very high density, barely average clustering).

However, we did not find examples of municipalities in the Warsaw Metropolitan Area, where the density of buildings would be remarkably low, and at the same time the concentration of buildings in clusters would be weak. Such a situation could occur in sparsely populated areas, without dominant urban or rural settlement centres. Such areas are rare in urban agglomerations, but theoretically they may occur – if they cover land in principle excluded from construction of buildings, or inadequate for this purpose, with only individual scattered buildings. Similarly, there are no such municipalities in the Warsaw Metropolitan Area, where the density of buildings would be very high, and at the same time concentration in clusters would be strong. This would mean the presence of one or more compact settlement centres, with a large number of buildings, surrounded by uninhabited areas. This is also a rare situation, but it cannot be ruled out that it could occur in another urban agglomeration.

7. Summary and conclusions

As a result of the study, a typology of patterns of building locations observed in individual municipalities and districts of the Warsaw Metropolitan Area was developed. The basis for constructing the typology was the density quotient factor (DQF) and the Clark index, i.e. the average nearest neighbor (ANN) method, which indicates the level of spatial dispersion of buildings. Additionally, the differences in the density of single-family and multi-family housing were taken into account. The results of empirical analyses, supported by a review of the literature, show that the above mentioned measures are complementary and are in principle sufficient to characterize the spatial concentration of buildings. The typology is therefore useful to describe the diversity of a phenomenon in a possibly complementary way. It is possible to further extend the typology, taking into account other dimensions of concentration, such as the level of centrality (degree of diffusion), or building intensity related to the height of buildings.

The diversity of municipalities and districts in terms of the values of spatial concentration indicators is significant. It was therefore possible to define a significant number of types and subtypes. However, this has been a fairly arbitrary procedure for which there are no rigid rules. It was not included in the study to compare the characteristics of the phenomenon in the Warsaw agglomeration with other areas, which makes it difficult to determine to what extent the accepted threshold values of indicators would also be appropriate for other urban agglomerations. It is uncertain whether the designated types cover the full spectrum of types of possible spatial concentration that might occur in reality. In particular, the typology does not

include units in which buildings are rare and poorly concentrated, or alternatively – dense and highly concentrated, as such units do not occur in the Warsaw agglomeration. In addition, no patterns close to random distribution have been identified, nor patterns close to a regular, uniform distribution. However, in the author's opinion, the method used for constructing this typology (and selected indicators) can be successfully used in other study areas and systems of basic spatial units.

Finally, one should comment on the consequences of the contemporary suburbanization processes taking place within the Warsaw agglomeration. As a result of these, the readability of the crystallized nodal-band settlement system gradually disappears. The problem is uncontrolled scattering of buildings, which applies to agricultural and forest areas – one of the major features of urban sprawl. This is partly sanctioned by the spatial policy of local governments. The effects are noticeable, and include: morphological and functional chaos, low economic efficiency of settlement (high service costs), imbalance on the real estate market (oversupply of investment land with low location potential), and environmental degradation. This is indicated by numerous studies, also made for the whole country, including ŚLESZYŃSKI (2018) and GIBAS & HEFFNER (2018) in the report of the KPZK PAN. They emphasize the threat of destabilization of the budgets of local self-governments by the increasing costs of serving infrastructure to dispersed housing. Regeneration of some downtown areas does not solve the problems of settlement dispersion outside the very core of the agglomeration of the Polish capital city. There is also no strategy for the concentration of settlement at the regional level.

References

Aguilera F., Valenzuela L.M., Botequilha-Leitão A. 2011. Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish metropolitan area. *Landscape and Urban Planning*, 99, 3–4: 226–238.

Bertaud A., Bertaud M.A. 2000. *The spatial development of Warsaw metropolitan area. Comments on "Warsaw Development Strategy until the year 2010"*, Report for the World Bank, Warsaw.

Boots B.N., Getis A. 1988. *Point pattern analysis*. Sage Publications, Inc., London.

Broitman D., Czamanski D. 2012. Cities in competition, characteristic time, and leapfrogging developers. *Environment and Planning B: Planning and Design*, 39, 6: 1105–1118.

Clark P.J., Evans F.C. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology*, 35, 4: 445–453.

Curry L. 1964. The random spatial economy: an exploration in settlement theory. *Annals of the Association of American Geographers*, 54, 1: 138–146.

Dacey M.F. 1962. Analysis of central place and point patterns by a nearest neighbour method. *Lund Studies in Geography, Series B, Human Geography*, 24: 55–75.

Degórska B. 2012. Spatial growth of urbanised land within the Warsaw metropolitan area in the first decade of the 21st century. *Geographia Polonica*, 85, 3: 77–95.

Degórska B. 2017. Urbanizacja przestrzenna terenów wiejskich na obszarze metropolitalnym Warszawy: kontekst ekologiczno-krajobrazowy. *Prace Geograficzne*, 262, Institute of Geography and Spatial Organization PAS, Warsaw.

Degórska B., Deręgowska A., 2008, Zmiany krajobrazu Obszaru Metropolitalnego Warszawy na przełomie XX i XXI wieku. *Atlas Warszawy*, 10, Institute of Geography and Spatial Organization PAS, Warsaw.

ESPON 1.4.3. project. *Study on urban functions*. 2007. Final Report.

Getis A. 1964. Temporal land-use pattern analysis with the use of nearest neighbor and quadrat methods. *Annals of the Association of American Geographers*, 54, 3: 391–399.

Gibas P. Heffner K. 2018. Społeczne i ekonomiczne koszty bezładu przestrzeni – osadnictwo obszarów wiejskich. [in:] A. Kowalewski, T. Markowski, P. Śleszyński (ed.) Studia nad chaosem przestrzennym. II. Koszty chaosu przestrzennego. *Studia KPZK PAN*, 182, Warsaw: 163–195.

Grochowski M. 2011. Metropolizacja a kształtowanie ładu przestrzennego układów zurbanizowanych. *Mazowsze Studia Regionalne*, 6: 167–172.

Gutry-Korycka M. (ed.). 2005. *Urban sprawl: Warsaw agglomeration: case study*. Warsaw University Press.

Hoggart K. (ed.). 2005. *The City's Hinterland: Dynamism and Divergernce in Europe's Peri-Urban Territories (Perspectives on Rural Policy and Planning)*. Ashgate Publishing Ltd.

Idczak P., Mrozik K. 2018. Periurbanisation – evidence from Polish metropolitan areas. *Economic and Environmental Studies*, 18, 1: 173–192.

Jakóbczyk-Gryszkiewicz J. 1998. *Przeobrażenia stref podmiejskich dużych miast; studium porównawcze strefy podmiejskiej Warszawy, Łodzi i Krakowa*. Łódź University Press, Łódź.

Jażdżewska I. 2008. *Przemiany miejskiej sieci osadniczej w Polsce w świetle metod matematycznych*. Łódź University Press, Łódź.

Jędrzejczyk D. 1992. Procesy osadnicze w strefie podmiejskiej Warszawy. [in:] A. Wieloński (ed.) Wpływ Warszawy na urbanizację strefy podmiejskiej. *Prace i Studia Geograficzne*, 13, Warsaw Univ. Press, Warsaw: 21–38.

Kajdanek K. 2012. *Suburbanizacja po polsku*. Zakład Wydawniczy "Nomos", Kraków.

Knapp Z. 1983. *Aglomeracja warszawska. Analiza trendów rozwoju przestrzennego Warszawy*. Institute of Urban and Spatial Planning at Warsaw University of Technology, PWN, Warsaw, Łódź.

Korcelli P., Grochowski M., Kozubek E., Korcelli-Olejniczak E., Werner P. 2012. *Development of Urban-Rural Regions: from European to Local Perspective*. Institute of Geography and Spatial Organization PAS, Warsaw.

Kostrubiec B. 1972. Analiza zjawisk koncentracji w sieci osadniczej: problemy metodyczne, *Prace Geograficzne*, 93, Institute of Geography. Polish Academy of Sciences, National Ossoliński Institute.

Lang R., Sanchez T. LeFurgy J. 2006. *Beyond Edgeless Cities: Office Geography in the New Metropolis*. Virginia Tech, National Center for Real Estate Research, Blacksburg.

Li C., Li J., Wu J. 2013. Quantifying the speed, growth modes, and landscape pattern changes of urbanization: a hierarchical patch dynamics approach. *Landscape Ecology*, 28: 1875–1888.

Lisowski A. 2010. Suburbanizacja w obszarze metropolitalnym Warszawy. [in:] S. Ciok, P. Migoń (ed.) *Przekształcenia struktur regionalnych. Aspekty społeczne, ekonomiczne*

i przyrodnicze. University of Wrocław, Institute of Geography and Regional Development: 93–108.

Lorens P. 2005. Suburbanizacja w procesie rozwoju miasta postsocjalistycznego. [in:] P. Lorens (ed.) Problem suburbanizacji. *Biblioteka Urbanisty*, 7, Urbanista, Warsaw: 33–44.

Mantey D., Sudra P. 2019, Types of suburbs in post-socialist Poland and their potential for creating public spaces. *Cities*, 88: 209–221.

Markowski T., Marszał, T. 2006. *Metropolie, obszary metropolitalne, metropolizacja: problemy i pojęcia podstawowe*. Komitet Przestrzennego Zagospodarowania Kraju PAN, Warsaw.

Obszar Metropolitalny Warszawy w 2016 r. 2017. Statistical Office in Warsaw, Mazovian Centre for Regional Surveys.

Piorr A., Ravetz J., Tosics I. 2011. *Peri-urbanisation in Europe: Towards a European policy to sustain urban--rural futures. A Synthesis Report*. PLUREL project, University of Copenhagen, Academic Books Life Sciences.

Runge J. 2007. *Metody badań w geografii społeczno-ekonomicznej – elementy metodologii, wybrane narzędzia badawcze*. The University of Silesia Press, Katowice.

Śleszyński P. 2018. Społeczno-ekonomiczne skutki chaosu przestrzennego dla osadnictwa i struktury funkcjonalnej terenów. [in:] A. Kowalewski, T. Markowski, P. Śleszyński (ed.) Studia nad chaosem przestrzennym. II. Koszty chaosu przestrzennego. *Studia KPZK PAN*, 182, Warsaw: 29–80.

Solarek K. 2013. Struktura przestrzenna strefy podmiejskiej Warszawy. Determinanty współczesnych przekształceń. *Architektura*, 13, Warsaw University of Technology Press.

Solarek K. 2017. Cechy przestrzenne suburbanizacji – Aglomeracja Warszawy a wybrane aglomeracje europejskie. *Biuletyn KPZK PAN*, 265: 36–64.

Soule D.C. (ed.). 2006. *Urban Sprawl – a Comprehensive Reference Guide*. Greenwood Press, London.

Squires G.D. (ed.). 2002. *Urban Sprawl: Causes, Consequences and Policy Responses*. Urban Institute Press, Washington D.C.

Stanilov K., Sýkora L. (ed.). 2014. *Confronting suburbanization: Urban decentralization in postsocialist Central and Eastern Europe*. Wiley-Blackwell.

Webster D., Muller L. 2009. Peri-urbanization: Zones of rural-urban transition. [in:] S. Sassen (ed.) *Human Settlement Development*. Eolss Publishers, Oxford: 280–309.

Zborowski A. 2005. *Przemiany struktury społeczno-przestrzennej regionu miejskiego w okresie realnego socjalizmu i transformacji ustrojowej (na przykładzie Krakowa)*. Institute of Geography and Spatial Management – Jagiellonian University in Kraków, Kraków.