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## **SPATIAL VARIATION IN SIZE AND SHAPE OF LAND PLOTS IN MAZOWIECKIE VOIVODSHIP**

**Abstract.** The aim of the study is to evaluate the spatial variation in the size and shape of land plots in Mazowieckie voivodship. For the purposes of the study both the shape and the compactness of the plots were measured, and the typology of communes was drawn based on this information. Subsequently, based on the two indicators related to the shape of plots, four types of communes were distinguished, depending on whether their values were higher or lower than the average (Dzieciuchowicz and Dmochowska-Dudek, 2014). In addition, the paper includes calculations for the average share of unused land in the plot surface area, the average horizontal intensity of parcel development, and an indication of the type of land coverage dominant in the plots, by commune type. Pearson's correlation coefficient was used in the analyses. It has been found that the studied area is dominated by plots characterised by small diversity in shape and high degree of compactness – mainly in the north-western part of the voivodship, as well as those where plots are highly diverse in shape and low in compactness – in the south-eastern part of the voivodship.

**Keywords:** land parcel, plot shape, plot size, Mazowieckie voivodship, GIS.

### **1. INTRODUCTION**

Research on the morphology of both rural and urban settlements has long been of interest to geographers. In particular, assessments of the shape of settlement, its genesis, and land ownership structures were carried out (Golachowski *et al.*, 1974; Koter, 1994; Jażdżewska, 1999; Wójcik, 2006; Bitner, 2010, 2011; Gawron, 2012; Gniadek and Harasimowicz, 2008; Gniadek, 2013; Dzieciuchowicz and Dmochowska-Dudek 2014). According to Koter (1979, p. 26), the morpho-

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logical structure of the city means ‘the layout and interrelations of urban space constituent units, isolated on the basis of morphological (layout) and genetic criteria’. The morphology of the city is a science of external construction (shape and physiognomy of buildings) and internal construction (spatial layout), as well as the genesis of the parts of the urban organism. Moreover, Koter (1994) noted that in literature concerning morphology there is a radical demarcation between urban morphology and rural morphology. However, he was of the opinion that both these branches should be explored in parallel, given that many cities are descended from former villages, and that many of the village settlements are former urban centres (Jażdżewska, 1999). Only the geometric data relating to land parcels of the Mazowieckie voivodship has been covered by this paper. Therefore, the morphological structure is construed as the layout of boundaries between individual plots (Bitner, 2010, 2011; Litwin *et al.*, 2000). In addition, the authors compiled the geometrical features of the plots with the land cover within their boundaries.

As a result of the political changes in Poland after 1989, there have also been significant changes in the organisation of space, which included, among others, land management. The position of the private sector, which dominated the developing land and property market, has definitely increased. Municipalities became an important market participant, especially in the early transition period. As a result of these changes, both land parcellation and consolidation of parcels was still developing (with the latter having smaller impact). As a result of the parcellation, land parcel resources grew, while consolidation had the reverse effect. Urban space transformations were significantly impacted by investments in communication and commerce, influencing not only the size, but also the shape of plots. Unfortunately, there are still few studies on these issues in our country (Dzieciuchowicz, 2011; Dzieciuchowicz and Dmochowska-Dudek, 2014).

The issues of the size and shape structure of parcels occupy an important place in the study of sustainable rural development. Excessive fragmentation can be an obstacle to optimal agricultural development and can hinder effective agricultural production (Demetriou *et al.*, 2013). Data on land use and plot size in urban areas can in turn be very useful, especially for urban planners in spatial planning (Wu *et al.*, 2009).

On the other hand, the concept of shape is extremely important in geography, because many cities or countries are recognised precisely because of their distinctive shapes. Unfortunately, shape is one of the most difficult properties of the figures to measure (Kostrubiec, 1972).

The geometric features of the land parcels were the subject of studies by MacEachren (1985); Bribiesca (1997, 2000, 2008); Fiałkowski and Bitner (2008), Bitner *et al.* (2009); Janus *et al.* (2016a, b). Therefore, the authors decided to undertake this subject, focusing on the area of the Mazowieckie voivodship, within which the capital of Poland is located. The aim of the study is to evaluate the spatial variation in the size and shape of land plots in the Mazowieckie voivodship.

## 2. RESEARCH METHODS AND DATA SOURCES

In the paper, a plot means ‘a land area limited by lands subject to different possession. It is delimited in the field and marked with a separate number’ (Jażdżewska, 1999, p. 12). Plot data used in the work were taken from the Land Parcel Identification System (LPIS). The analysed features of plots were aggregated to the municipality level, thus enabling their spatial analysis, made possible by the use of GIS tools. They were used to combine database attributes into maps. However, GIS not only provides users with a range of tools to manage and combine certain attributes with spatial data, but also includes advanced modelling, design, planning, and advanced data imaging capabilities (Mennecke, 1997). GIS is nothing more than a digital model of the reality surrounding us, with the ability to collect, store, manage, share, visualise and publish (Bobola and Sztampke, 2008).

As mentioned earlier, this paper refers only to the geometrical features of plots. Calculations included, among others, the number of plots per hectare, the median area of a plot, the parcel shape variation index, and the coefficient of plot shape compactness.

The choice of methodology is a result of the size of the analysed area, its administrative differentiation (urban, urban-rural and rural areas were analysed) and also data availability. An interesting methodology connected with plots analysis was proposed by Janus *et al.* (2016b). The authors have developed a new method of determining indicators of land fragmentation, taking into account the vicinity of plots belonging to the same owners (‘aggregated plots’). However, it was applied to the typical agricultural areas and the data included information about the owner of the property, which was not obtained for the Mazowieckie voivodship.

Therefore, the length of the borders and parcel areas were used for the measurement of the shape of parcels in the municipalities. Two measures of shape were used, developed by Dzieciuchowicz and Dmochowska-Dudek (2014).<sup>1</sup> The first one, which determines the variation in shape, is the ratio of the average length of plot boundaries ( $d_j$ ) to the average area of plot in a given municipality ( $p_j$ ):

$$K_{zj} = \frac{d_j}{p_j} \cdot 100$$

The more sections of different orientations a plot boundary has, the larger its length per unit of surface area. This indicator thus increases as a result of the increasing diversity in the shape of plots in certain territorial units.

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<sup>1</sup> J. Dzieciuchowicz referenced registration areas, however the authors decided to limit themselves to the municipality level due to the size of the research area.

In literature, the indicator proposed by Kostrubiec (1971, 1972), which shows the degree of complexity of the edgeline of a figure, is used very often to determine the shape of the parcels and is presented as:

$$S = \frac{\text{quadrat of perimeter of the figure}}{\text{area of the figure}} - 12.56$$

This indicator takes values from a set of positive real numbers: for a circle it is 0, for a square – 3,44, for a right-angled and isosceles triangles, it is 10.64. It reacts strongly to the edgeline of the figure (Bribiesca, 1997; Jażdżewska, 1999) – the more advanced it is, the higher its value. However, this indicator is good only for figures where  $0 < S < 10$ , and where length and width are not strongly differentiated, which unfortunately does not work in the case of a voivodship-level survey (Jażdżewska, 1999). Therefore, the authors decided to use its modified form, proposed by Dzieciuchowicz and Dmochowska-Dudek (2014).

The second indicator used in the work determines the ratio of the average real border length ( $d_j$ ) in a given municipality to the hypothetical length of these borders  $L_j$ , which corresponds to the circumference of the circle if it had an area equal to the average real area of the plots in this municipality:

$$K_{hj} = \frac{d_j}{L_j} \quad \text{where} \quad L_j = 2\pi r$$

for a circle with an average area of plots in municipalities  $j$ .

This indicator expresses the degree to which the real shape of the plots differs from a circle. Its values increase proportionally to the indicated difference. At the same time, this increase reflects the decrease in territorial compactness of the plots. It also determines to what extent the actual average length of the parcel boundaries in a given municipality differs from the minimum length equal to the circumference of the circle corresponding to the average area of the parcels of that municipality (Dzieciuchowicz and Dmochowska-Dudek, 2014).

Subsequently, based on the two indicators related to the shape of plots, four types of communes were distinguished, depending on whether their values were higher or lower than the average (Dzieciuchowicz and Dmochowska-Dudek, 2014).

In addition, the article also uses data from the Topographic Data Base (BDOT), obtained from the Regional Center for Geodetic and Cartographic Documentation in Warsaw. It is ‘a nationwide system for the collection and sharing of topographic data, which, in addition to data, includes an appropriate funding system, organisation, IT tools and legislation’. The normative act that defines standards of this database is the Directive of the Minister of Interior and Administration of 17 November 2011 on the database of topographic objects and databases of

general geographic objects as well as standard cartographic works.<sup>2</sup> Information concerning the location of buildings was particularly interesting. It allowed for the calculations for the average share of unused land in the plot surface area, the average horizontal intensity of parcel development, and an indication of the type of land coverage dominant in the plots, by commune type. These analyses also used one of the most popular correlation indices – the Pearson index (Hauke and Kossowski, 2011).

Subsequently, an assessment of the spatial diversity of plots in the Warsaw area was made. The authors used Getis-Ord statistics for this purpose. Local autocorrelation shows the spatial dependencies of a given variable with its neighbouring objects (Getis and Ord, 1995; Ord and Getis, 2001). Owing to the method used, it was possible to indicate areas of concentration of the examined feature in the registration areas and their immediate vicinity. High positive values of the Getis-Ord statistics mean that high values (higher than average) of the examined feature are concentrated in the area of the unit and adjacent areas. High negative values of the statistics show that the concentration of relatively low values of the analysed feature (lower than the average) is observed in the area of a given unit and neighbouring areas. The result near 0 means no visible spatial concentration.

### 3. RESULTS AND DISCUSSION

Mazowieckie voivodship is the largest voivodship in Poland, both in terms of area occupied and population. The settlement network of the region consists of 85 cities in total. The district is divided into 35 municipalities, 50 urban-rural and 229 rural ones. The largest city is Warsaw, the capital of the country, followed by Radom, Płock and Siedlce. The rural settlement network consists of more than 9 000 towns and villages.

Based on the data obtained from the LPIS system, it was concluded that there were 4 776 801 land parcels in the Mazowieckie voivodship. The highest density of plots per 1 ha can be found in Warsaw and the municipalities which are located around it (Fig. 1). The reason for this is primarily the prices of individual plots, high demand for them and, consequently, numerous housing estates operating in this area (Rosik, 2013). The density of plots in the registration areas is drastically reduced in the north-western part of the voivodship (below 0.9/1 ha). On the scale of the voivodship, these areas are peripherally located in relation to Warsaw. Such high density of plots in the central part of the voivodship also shows the high level of urbanisation of the capital. It decreases with distance from Warsaw, in rural areas.

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<sup>2</sup> <http://geoportal.infoteren.pl/Resources/Docs/BDOT10k.pdf> (4.02.2016).

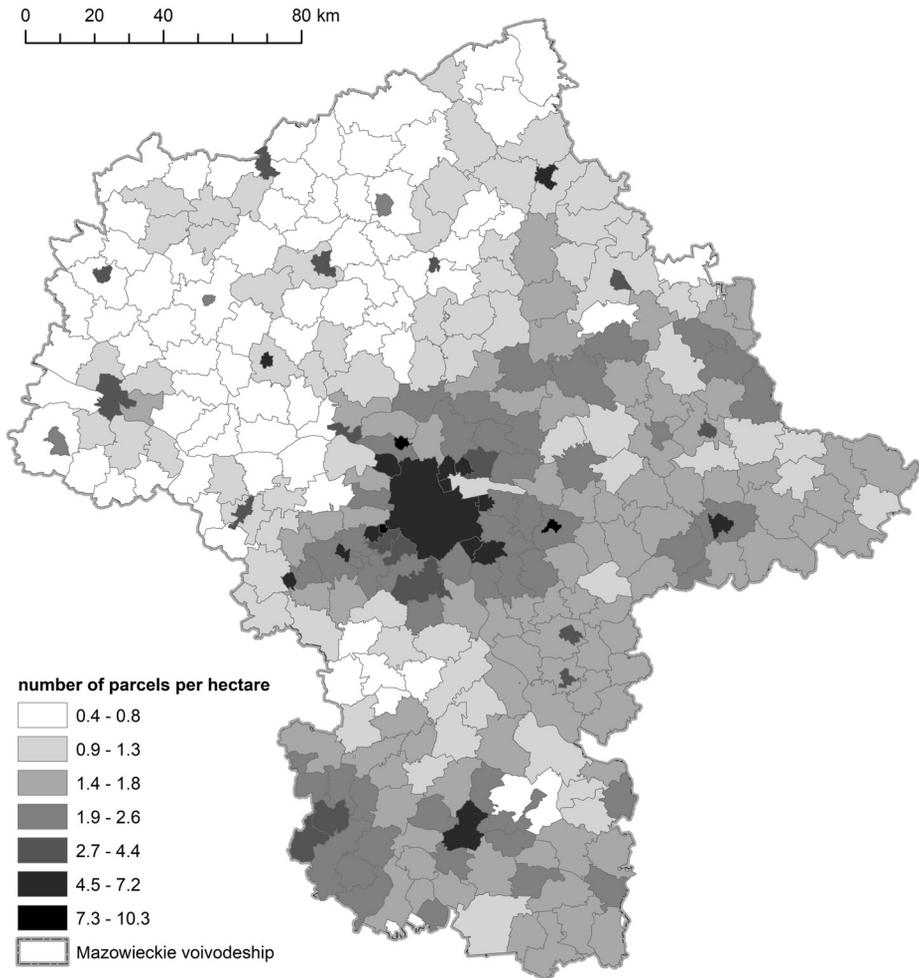


Fig. 1. Average density of plots by municipality in Mazowieckie voivodeship

Source: own study based on the LPIS data

The distribution of unused land in the scale of plots in the voivodeship is mosaic-like (Fig. 2). The largest groups of land with the largest share of unused land are the municipalities in the south-western and northern parts of the voivodeship. These are areas of low quality agricultural production, which often results from unfavourable natural soil properties. Due to their low utility values, these sites are difficult to manage and are often either forested or converted to ecological areas. In the case of non-forest and non-agricultural purposes, they can be used e.g. for development.

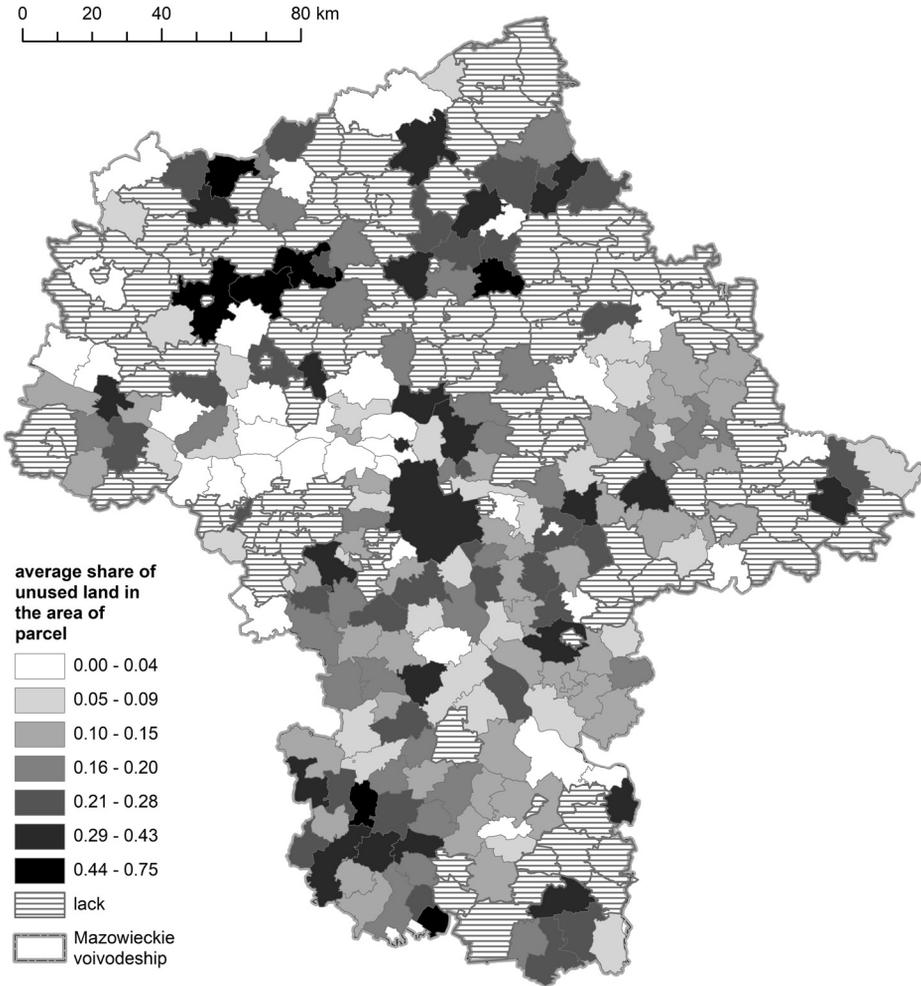


Fig. 2. Average share of unused land in the area of plots by municipality in Mazowieckie voivodship

Source: own study based on the LPIS data

The very high intensity of horizontal development of plots in the Mazowieckie voivodship can be found in urban municipalities, as well as those in the immediate vicinity of Warsaw (Fig. 3). This is due in large part to the very strong concentration of population in this area. In rural areas the intensity of horizontal development of plots is much lower.

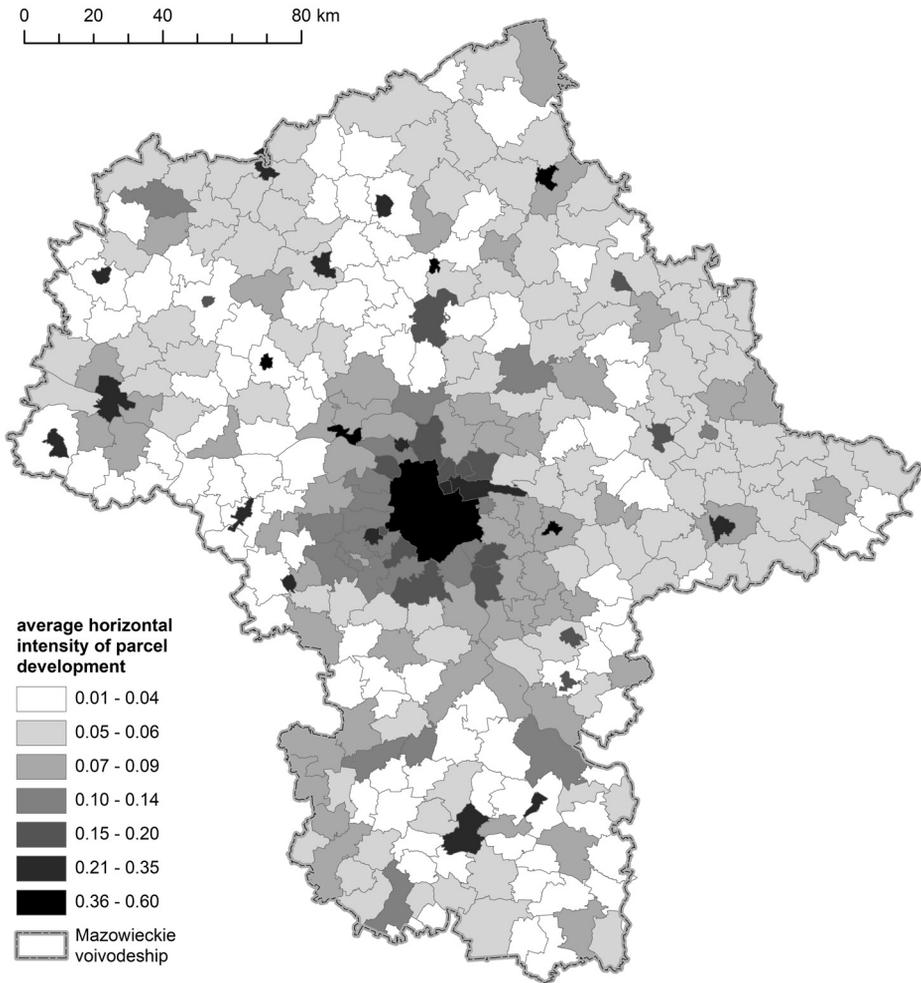


Fig. 3. Average horizontal intensity of plot development by municipality in Mazowieckie voivodeship

Source: own study based on the LPIS and BDOT data

The size of plots in the Mazowieckie voivodeship is very diverse depending on the municipality (Fig. 4). The smallest plots are located in Warsaw and other cities in the voivodeship, while the largest ones can be found in the north-western part of the voivodeship, in rural areas.

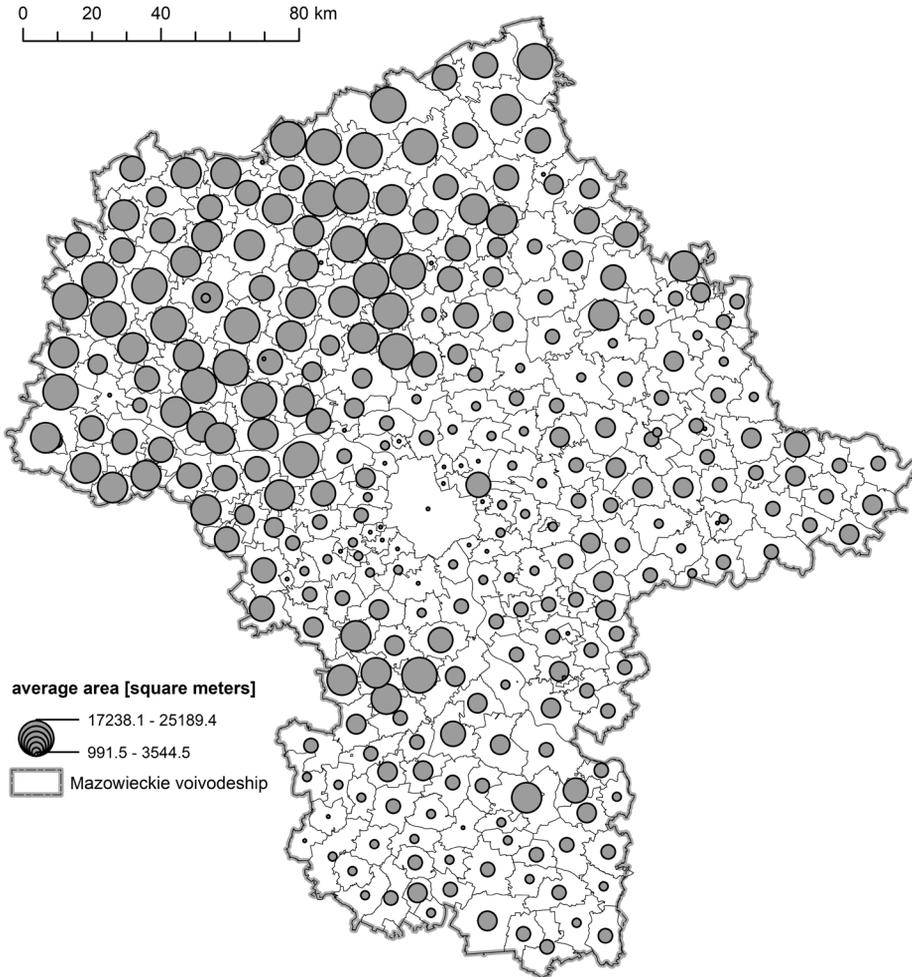


Fig. 4. Average plot size by municipality in Mazowieckie voivodship

Source: own study based on the LPIS data

In large cities, there is a tendency of increasing plot areas as they are located further away from their centres (Dzieciuchowicz and Dmochowska-Dudek, 2014). However, this phenomenon is disturbed by the occurrence of the so-called district centres (Fig. 5) around which increased competition for space can be observed, which results in fragmentation of plots (Herman, 2016). On the other hand, the largest plots are found in rural, typically agricultural municipalities, as well as in industrial areas. As far as spatial organisation is concerned, mainly in cities, high fragmentation of plots is the biggest problem. Small plots are most often created as a result of their secondary division. Very large plots, whose high price may hinder their sale, may also be a problem in terms development.

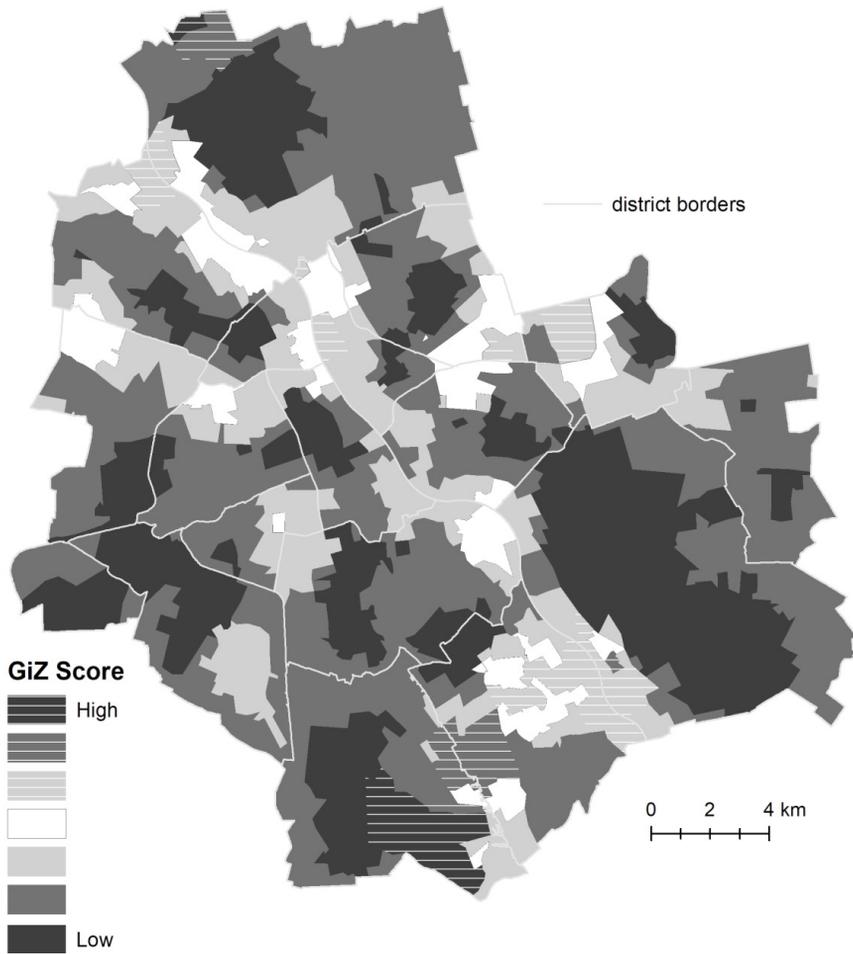


Fig. 5. Spatial concentration of plots by area in Warsaw

Source: own study based on the LPIS data

The parcel shape variation index varies from 2.4 m per 100 m<sup>2</sup> in the north-western part of the voivodship to 18.3 m per 100 m<sup>2</sup> in the south-eastern and southern parts (Fig. 6). Its values depend on the average surface area of the plots – they increase with the decrease of their surface area, and they decrease in the areas where the parcels are the largest.

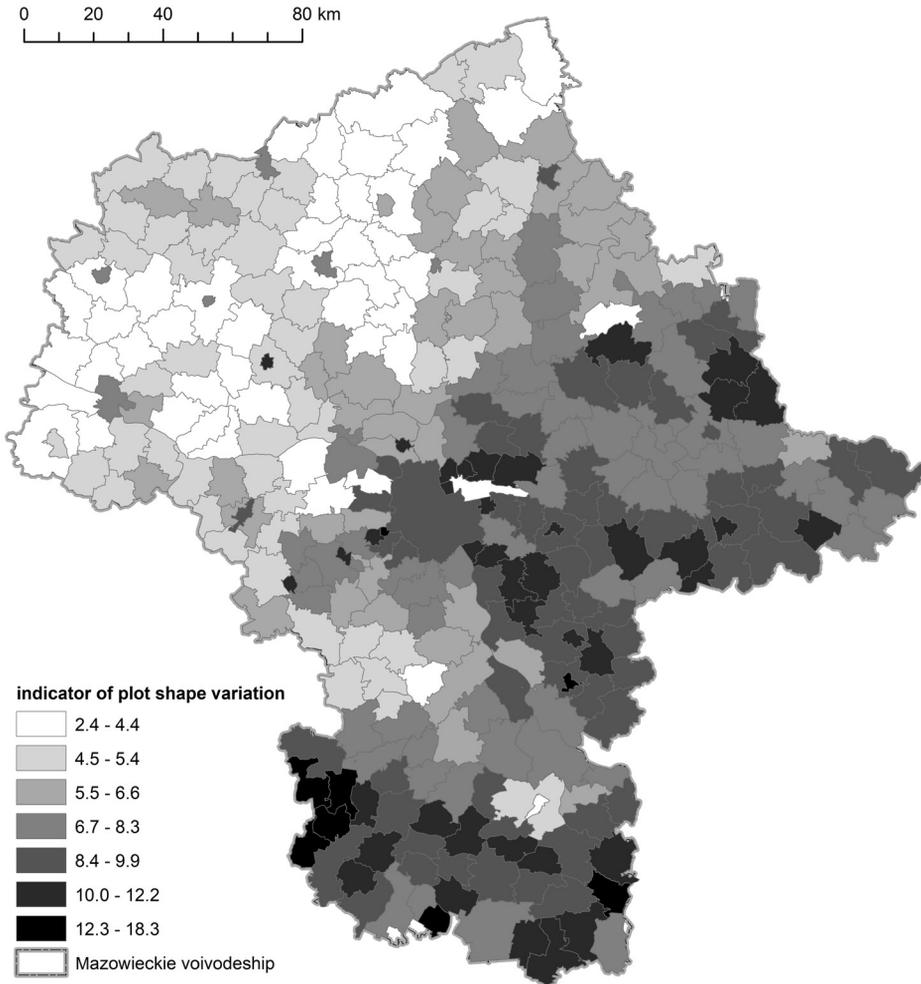


Fig. 6. Indicator of plot shape variation by municipality in Mazowieckie voivodship

Source: own study based on the LPIS data

The second parcel shape indicator used, depicting their compactness, takes values from 5 to 20.7 (Fig. 7). Low plot compactness can be found mainly in plots located in southern and south-eastern parts of the Mazowieckie voivodship. In turn, low value of this indicator, meaning high compactness, can be found in the north-western part.

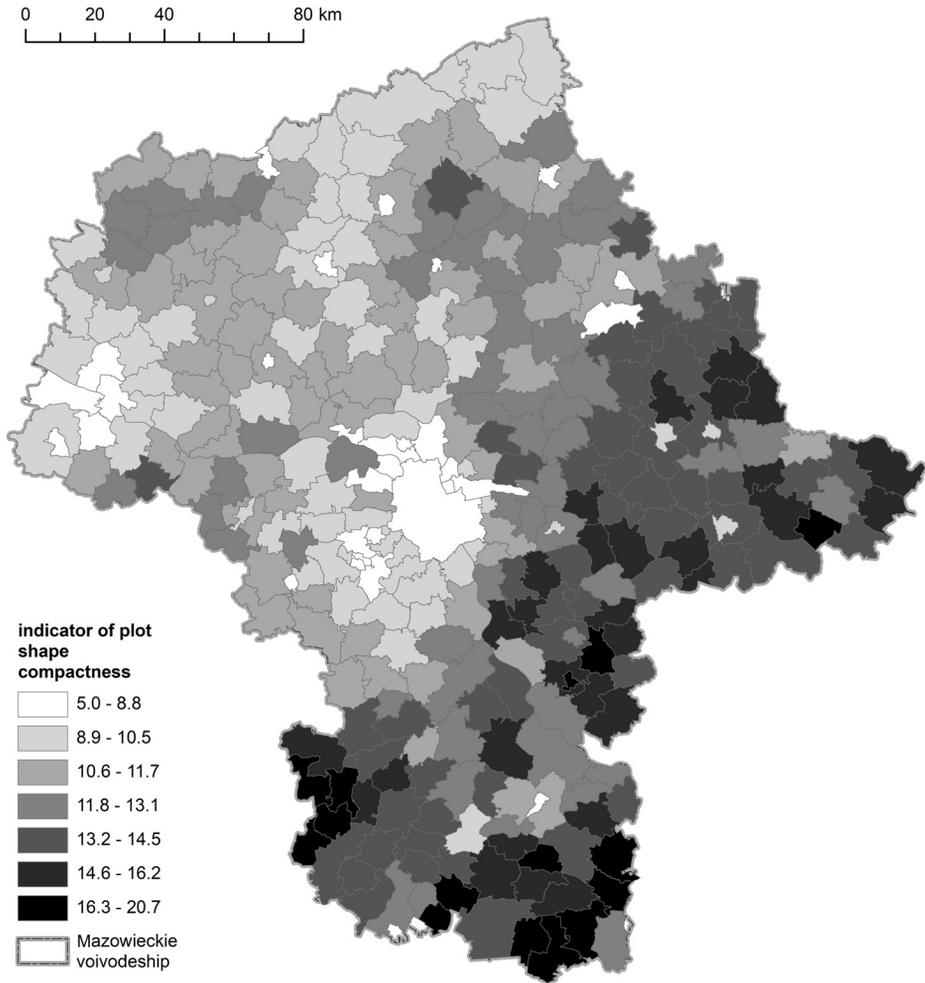
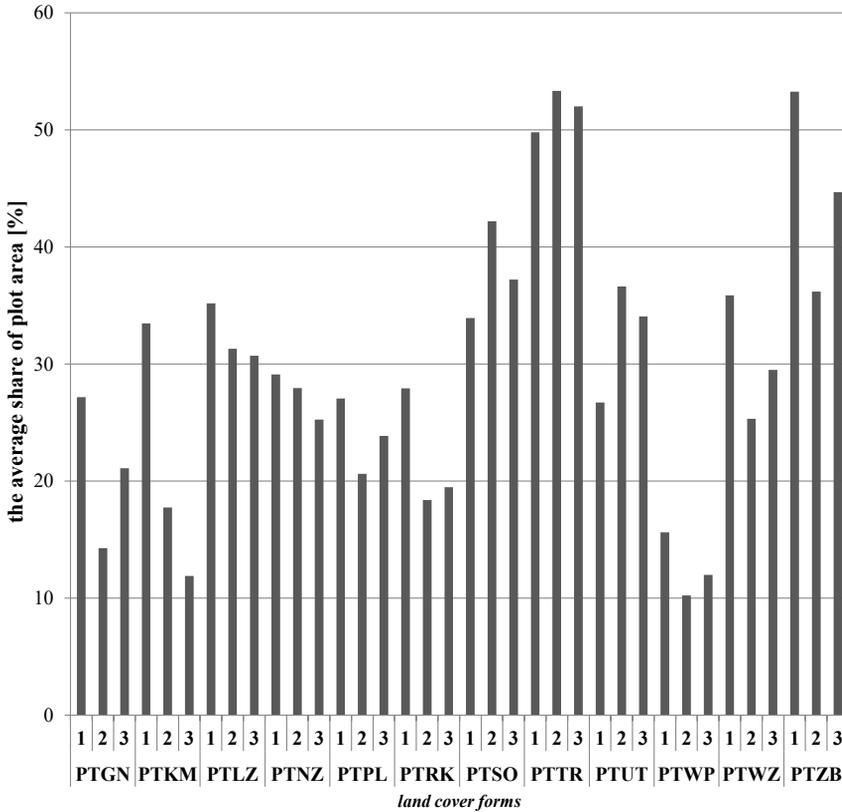


Fig. 7. Indicator of plot shape compactness by municipality in Mazowieckie voivodship

Source: own study based on the LPIS data

Land coverage of plots differs widely regardless of the type of municipality. The highest percentage of coverage in the Mazowieckie voivodship is taken up by grassland and agricultural land (approx. 50%) (Fig. 8).

The simple correlations between land cover and plot features such as their area, shape and compactness were also analysed using the Pearson linear correlation coefficient. The diagnosed absolute values ranged from 0.02 to 0.56. It can therefore be concluded that there are no simple correlations between the variables tested. Plots in urban municipalities are characterised by the highest average percentage of development, reaching over 25% of their area (Tab. 1).



1 - urban municipality, 2 - rural municipality, 3 - urban-rural municipality

PTGN - unused land; PTKM - the area under the roads, railways and airports; PTLZ - forest and wooded area; PTNZ - remaining undeveloped area; PTPL - square; PTRK - shrub vegetation; PTSO - landfill site; PTRR - grass vegetation and agriculture; PTUT - permanent crop; PTWP - surface water; PTWZ - excavation and mudflat; PTZB - development

Fig. 8. Average share of land cover forms by municipality type in Mazowieckie voivodship

Source: own study based on the LPIS and BDOT data

By analysing the values lower and higher than average for both parcel shape indicators, four types of municipalities were distinguished. The first one is characterised by a slight variation in the shape of the plots and their high compactness. It mainly covers municipalities located in the north-western part of the Mazowieckie voivodship (Fig. 9). These areas are predominantly covered by large plots with an average area of 12 306 m<sup>2</sup>, and an average border length of 570 m.

Table 1. Average share of development in the area of plots by type of municipality in Mazowieckie voivodship

Type of municipality	Number of plots	Average development share	Standard deviation of the share of development
Urban	425 900	25.2%	0.54
Rural	1 248 400	4.4%	0.14
Urban-rural	475 704	8.7%	0.39

Source: own study based on the LPIS and BDOT data.

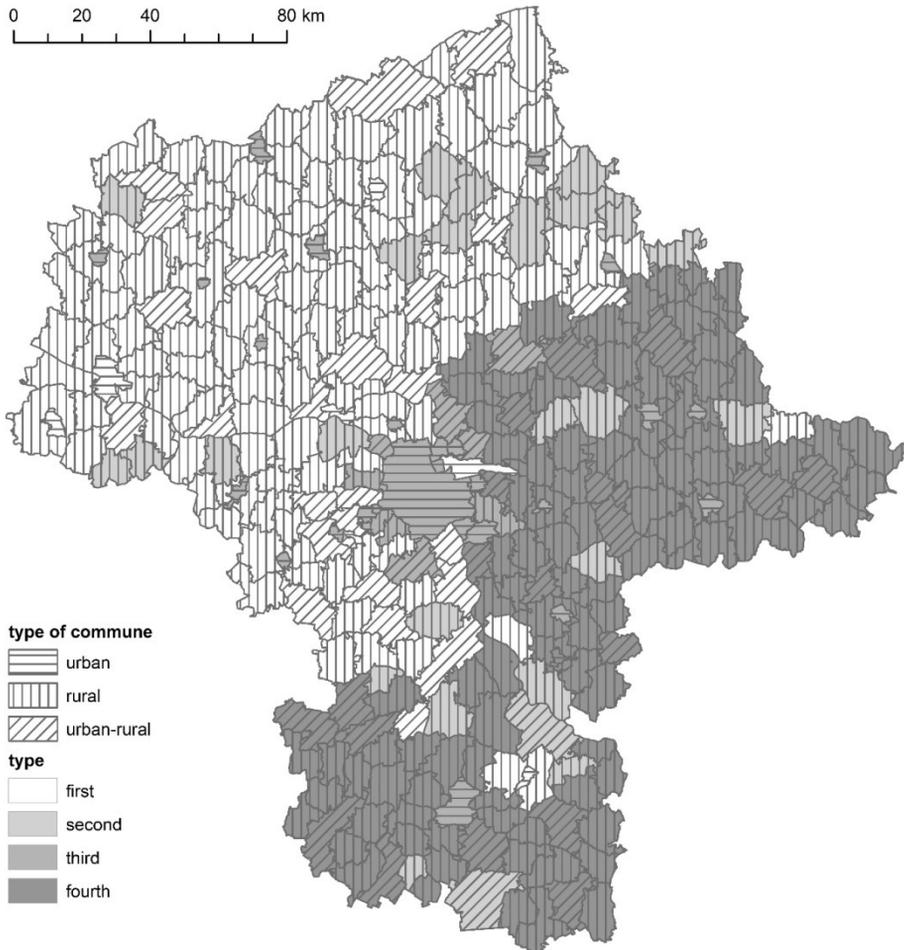


Fig. 9. Typology of municipalities in Mazowieckie voivodship according to the shape and compactness of plots against the background of the types of municipality

Source: own study based on the LPIS and BDOT data

The second one includes municipalities where plots are characterised by small variations in shape and low compactness (Fig. 9). This type includes only 26 municipalities. The average plot size of the second type is 11 459 m<sup>2</sup> and the border length is 670 m on average.

The third type are municipalities where plots of small shape variation and high compactness are distinguished. It is the second smallest group in terms of the number of municipalities that it belong to it. It covers Warsaw itself and municipalities located mostly in its immediate vicinity. In total there are 35 municipalities. These are usually small plots of approx. 2549 m<sup>2</sup> and average boundary length of 237 m (Fig. 5 and 9).

The last distinguishable type includes municipalities with large shape variability and low compactness. Altogether, 115 municipalities were classified in this type. They are located mainly in the south-eastern and eastern parts of the Mazowieckie voivodship (Fig. 9). Their average area is around 6216 m<sup>2</sup> (average border length is 569 m).

#### 4. CONCLUSION

Elements of the natural environment have a great influence on the ongoing urbanisation processes, which affects the boundaries of land plots (Bitner, 2010). Mazowieckie voivodship is largely agricultural (Rosik, 2013; Nalej, 2016), which is why the analysis of the coverage of individual plots showed that in all municipalities agricultural use predominates – these areas are largely used as grassland and for agricultural crops, as well as permanent crops. The highest horizontal intensity of development can be found in plots located in Warsaw itself and neighbouring municipalities.

Taking into account the types of municipalities in Mazowieckie voivodship that have been distinguished on the basis of the shape and compactness of the plots, it is important to note that there is a dominance of plots with slight variation in shape and large compactness, mainly in the north-western part of the voivodship, as well as those with high shape variability and low compactness, in the south-eastern part of the studied area. One positive fact is that plots located in rural municipalities in the north-western part of Mazowieckie voivodship are characterised by a rather large area (as compared to the rest of the voivodship) per plot – an average of 1.2 ha, making it possible to increase the productivity of farms in these areas (Markuszevska, 2013).

The study presented in this article is an initial stage of the analysis of spatial variation in the size and shape of plots. Further work should focus on identifying the factors that determine these characteristics and the impact they have on them.

For the purpose of this study, an attempt was made to select such factors (taking into account, among other things, the dominant form of land cover and the history of administrative boundaries). However, the dependency tests did not show significant results. It should be stressed here that the availability of data (potential factors) at such a large scale of research (regional) is severely limited. Therefore, it is advisable to transfer further research to a lower spatial level of analysis, which will make it possible to take into account data of greater detail (e.g. form of land ownership). Obtaining such data for the entire region exceeds the possibilities of the authors.

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