ACTA Scientiarum Polonorum
Acta Sci. Pol.,
Geodesia et Descriptio Terrarum 12 (2) 2013, 29-40
ISSN 1644–0668 (print) ISSN 2083–8662 (on-line)

MAPPING SPATIAL DISTRIBUTION OF CHOSEN ENVIRONMENTAL CHARACTERISTICS FOR AGRICULTURAL USE IN LOWER SILESIA

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Abstract. Spatial statistics allows to assess geographic distribution of phenomena – its concentration, magnitude and orientation of dispersion as well regularity or trends in occurrence within a space. The paper presents adaptation of point-based methods to measure spatial distribution of areal phenomena that concern agriculture: area of agricultural land, area of fertile agricultural land and soil pH. The source data in a form of chorochromatic maps (e.g. a vector soil map) are processed to 1 x 1 km grid data with use of the algorithm created in Model Builder.

The research area – Lower Silesia – characterizes various environmental conditions that results in changeability of agricultural land productivity. Spatial statistics performed for a whole region would bring only global information on spatial distribution. Hence the Authors propose to conduct analysis within subareas that depict local changeability of studied phenomena. As the research is conducted in agricultural context, the subareas of similar agricultural land areas are created regarding the administrative units. Spatial distribution is described by: mean centre, standard distance and standard deviational ellipse. All three measures are weighted by a variable (i.e. the intensity of the phenomenon) as spatial distribution is not only about location, but the value of the phenomenon in particular location is important.

Measures of spatial distribution drawn on a map yields clear and usually easy to interpret information on spatial character of a phenomenon. In some cases it may be useful to present these qualitative characteristics complemented with another type of cartographic visualization (e.g. a choropleth map. This paper presents maps about the application of spatial distribution measures into assessment of agricultural land productivity in the research.

Key words: spatial distribution, centrographic method, mean centre, standard distance, standard deviational ellipse

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INTRODUCTION

The visual analysis of phenomena presented on maps allow for general assessment of geographic distribution. To discover patterns in spatial relationships and local characteristics of phenomenon intensity one requires quantitative measures. Implementation of statistical analysis of spatial data in GIS software allow – besides calculating the measures – to visualize the outcomes. Various spatial statistics techniques to assess geographic distribution of phenomena are available in the literature [Anselin 1999, Cliff and Ord 1981, 1992, Earickson and Harlin 1994, Ebdon 1985, Jażdżewska 2003, Magnuszewski 1999, Miller 2004, Urbański 2008]. However, the majority of them is used for distribution measurements of point data [Longley et al. 2006]. The paper presents adaptation of point-based methods to measure spatial distribution of areal phenomena connected with agriculture. The research area – Lower Silesia region (Fig. 1) – characterizes various environmental conditions that results in changeability of agricultural land productivity. It is located in south-western Poland and comprises of lowlands of high potential agricultural use as well as mountainous areas representing less-favoured areas for agricultural production. The relief variability translates also on soil, water and climate conditions.

Spatial statistics analysis for a whole region would bring only global information on geographic distribution. Hence it is proposed to conduct analysis within subareas that depict local changeability of studied phenomena. As the research is conducted in agricultural context, the subareas of similar agricultural land areas are proposed (Fig. 1). The boundaries are created regarding the administrative borders of the counties.

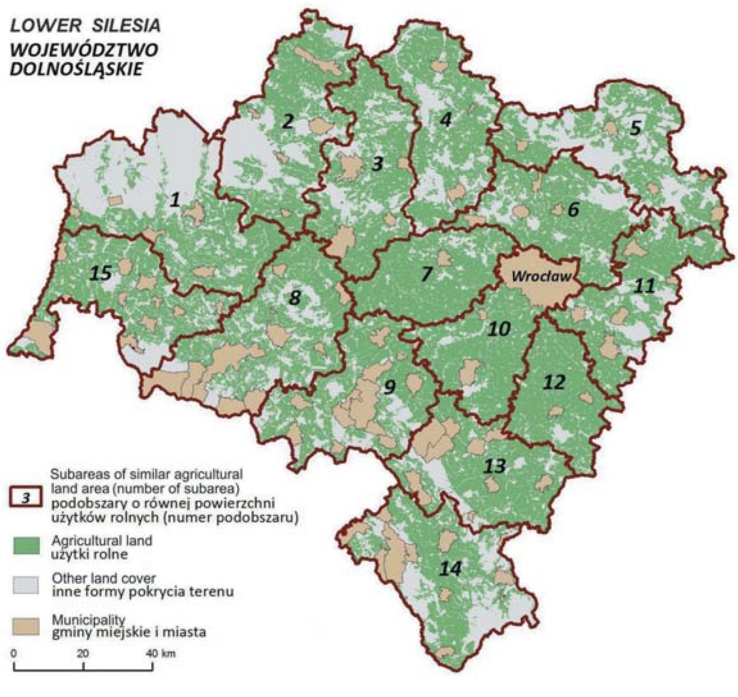

Fig. 1. Subareas of similar agricultural land area against the background of agricultural land
Rys. 1. Podobszary o zbliżonej powierzchni użytków rolnych na tle użytków rolnych

SOURCE DATA AND ITS PROCESSING

In this study chosen phenomena that affects agricultural productivity are taken under consideration: area of agricultural land, area of fertile agricultural land and soil pH. The agricultural land are extracted from vector soil map of Lower Silesia in a scale of 1 : 25 000 (source: Regional Centre of Geodetic and Cartographic Documentation (WODGIK)). The map contains also information on land potential productivity discerned as 13 types on arable lands and 3 types on meadow and grass-land. Determination of the types is based on soil type, its physical and chemical parameters, relief, climate and water conditions [Witek 1993]. The index of quality and agricultural productivity of land describes each type and ranges from 18 to 94 points within arable lands and from 20 to 80 points within meadows and grasslands [Stuczyński et al. 2007]. The fertile agricultural land are determined based on the index values and detailed description of each type [Stuczyński et al. 2007]: over 64 points for arable lands and 80 points for meadows and grasslands. The distribution of fertile land on against the agricultural land is presented in Figure 2.

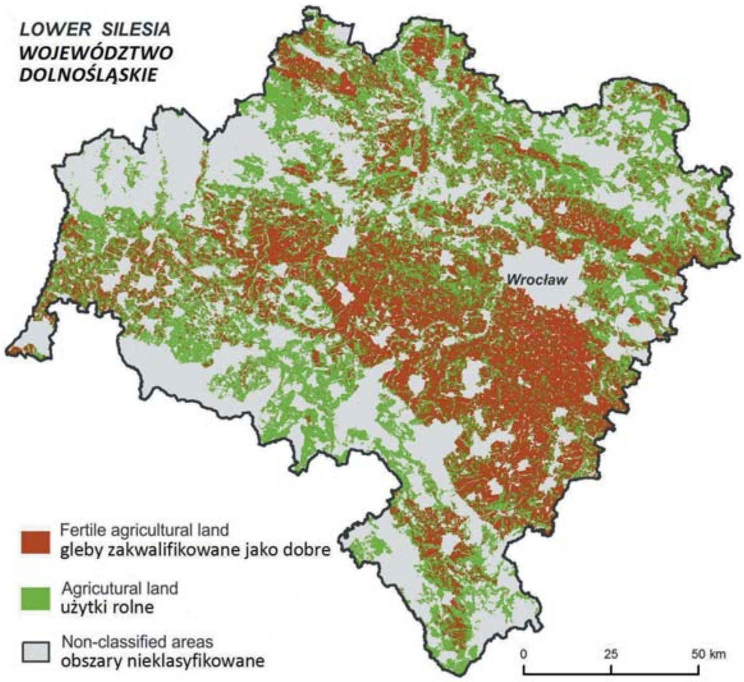

Fig. 2. Distribution of high fertile agricultural land on the background of agricultural land
Fig. 2. Rozmieszczenie gleb zakwalifikowanych jako dobre na tle użytków rolnych

Information on soil pH is derived from the map presenting physical and chemical parameters of agriculturally used soils in the scale of 1 : 25 000 [Stuczyński et al. 2007]. Figure 3 shows the distribution of soil pH within the research area. pH of soil, which is optimal for crop production (5.5–7.2) is under consideration in the further research.

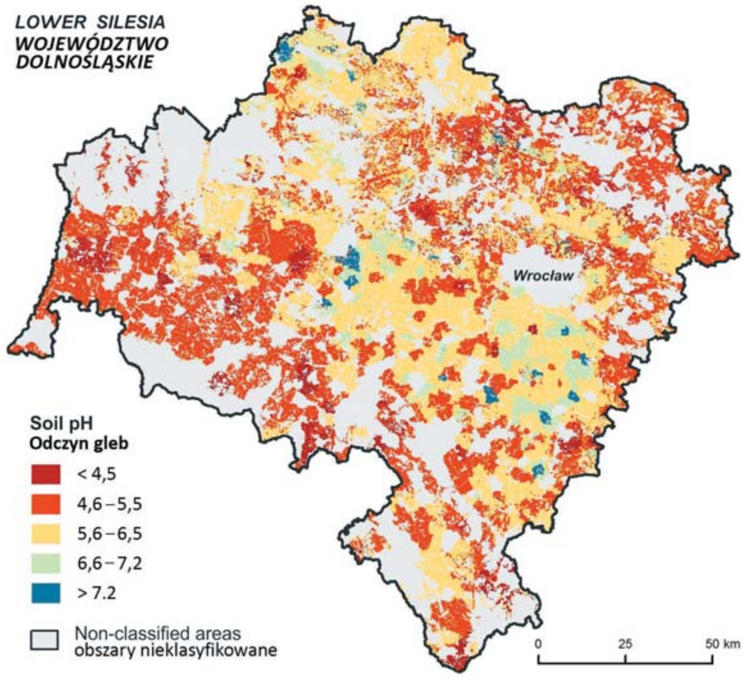

Fig. 3. Distribution of soil pH
Rys. 3. Rozmieszczenie odczynu gleby

Measuring spatial distribution requires transformation from qualitative approach (nominal scale) to quantitative scale. The continuous or semi-continuous phenomena (e.g. agricultural land; soil pH) are changed into discrete data using grid of 1 x 1 km. The geometric reference units are created according to division of Poland in TEMKART system [Podlacha 1986]. The size of grid is adopted to the study area and impacts on the accuracy of analysis that has been an issue in the separate research [Klimczak at el. 2006]. The constructed algorithm of data geoprocessing has been created in ModelBuilder in ArcGIS (Fig. 4). It enables automatic conversion of qualitative data presented on chorochromatic map (e.g. a soil map) into a database composed of grid units with qualitative attributes. The model has several parameters (letter *p* in a scheme) that make it useful for any source data, any study area and any reference unit.

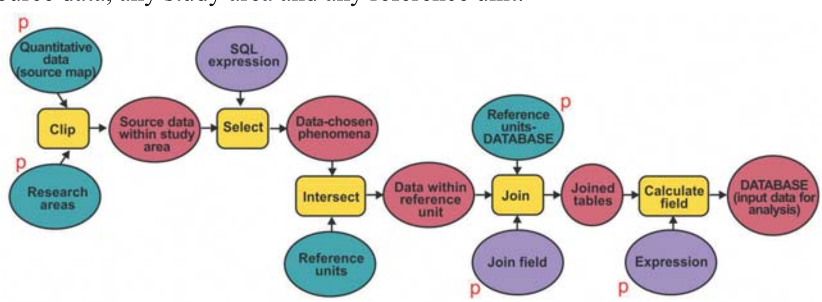

Fig. 4. Algorithm of data processing from qualitative to quantitative approach
Fig. 4. Algorytm przetwarzania danych wyrażonych w skali jakościowej na ilościową

The Lower Silesia covers 20 936 reference units of size 1 x 1 km (i.e. database features). The three characteristics calculated as the result of geoprocessing (see Fig. 4) are the percentage share of: agricultural land areas, high fertile agricultural land areas, optimal soil pH areas in the reference unit. The number of features considered in the analysis varies depending on a phenomena: 14 705 (agricultural land), 12 306 (high fertile agricultural land areas), 10 659 (optimal soil pH areas).

Methodology

Spatial distribution is not only about location, but the intensity of the phenomenon in particular location is important. The spatial measure that regards the attributes' values of the features is weighted mean centre. The weighted mean centre called also a geographic centre is two-dimensional average weighted by a variable and it is calculated according to the following formula [Magnuszewski 1999]:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad \bar{y} = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

where $\bar{x}$, $\bar{y}$ – centre (centroid), w_i – value of a variable (attribute value) x_i, y_i – coordinates of a feature, n – number of features.

The measure basically relates to the concentration of points (x and y coordinates). In the paper, the centrographic method is adopted to polygon features with the assumption that the centroid's coordinates of reference units are taken into account.

The information on geographic centre of the phenomenon is complemented with measure of its dispersion from a mean centre expressed by a standard distance. It is a two-dimensional equivalent to standard deviation and is calculated as follows [Jażdżewska 2003]:

$$r = \sqrt{\frac{\sum_{i=1}^{n} w_i (x_i - \bar{x})}{\sum_{i=1}^{n} w_i} + \frac{\sum_{i=1}^{n} w_i (y_i - \bar{y})}{\sum_{i=1}^{n} w_i}} \tag{2}$$

where $\bar{x}$, $\bar{y}$ – centre (centroid), w_i – value of a variable (a phenomenon) x_i, y_i, – coordinates of a feature, n – number of features.

Determination of weighted mean centres and standard distances within subareas and their visualization on a map allow for analysing local trends in spatial distribution. Moreover, the utility of the mean centre is for comparing spatial distribution of different phenomena and may bring information on correlation between them.

The aforementioned spatial measures yields information on magnitude of dispersion, but not its directions. In order to assess the directional trends the standard deviational ellipse is used. The angle of rotation of an ellipse is given as [Ebdon 1985]:

$$\mathrm{tg}\alpha = \frac{\sum x_i'^2 - \sum y_i'^2 + \sqrt{\left(\sum x_i'^2 - \sum y_i'^2\right)^2 + 4\left(\sum x_i' y_i'\right)^2}}{2\left(\sum x_i' y_i'\right)^2} \tag{3}$$

where: $x' = x - \overline{x},\ y' = y - \overline{y}$

The axes of the ellipse are defined as the standard deviation of the x coordinates and y coordinates from the mean centre:

$$\sigma_x = \sqrt{\frac{\left(\sum x'^2\right)\cos^2\alpha - 2\left(\sum x'y'\right)\sin\alpha\cos\alpha + \left(\sum y'^2\right)\sin^2\alpha}{n}} \tag{4}$$

$$\sigma_y = \sqrt{\frac{\left(\sum x'^2\right)\sin^2\alpha - 2\left(\sum x'y'\right)\sin\alpha\cos\alpha + \left(\sum y'^2\right)\cos^2\alpha}{n}} \tag{5}$$

It should be noticed that the standard deviational ellipse may be calculated using either the locations of the features or using the locations influenced by an attribute value associated with the features (w_i). In the research, the latter one – weighted standard deviational ellipse – is used and allows to see whether the distribution of the phenomena is elongated and hence has a particular orientation.

RESULTS

Measures of spatial distribution drawn on a map yields clear and usually easy to interpret information on spatial character of a phenomenon. In some cases it may be useful to present these qualitative characteristics complemented with another type of cartographic visualization. Figure 5 shows the localization of mean centres and standard distances calculated for high fertile agricultural lands on the background of the choropleth map presenting percentage share of these lands in a reference unit. The essential concentration of high fertile agricultural lands may be noticed in eight of fifteen subareas: 6, 7, 8, 9, 10, 12, 13, 14. Whereas the biggest dispersion characterizes subareas number: 2, 3 and 5 located in the northern part of Lower Silesia. What should be stressed out that mapping spatial statistical measures delivers additional information which may be different from visual assessment of studied phenomenon based on a choropleth map. One may notice similar intensity of the high fertile agricultural lands in 2 and 8 subareas, however only the location of the mean centre shows the place where the phenomenon is concentrated and standard distance points that the fertile lands are more condensed in the 8th subarea than in the 2nd.

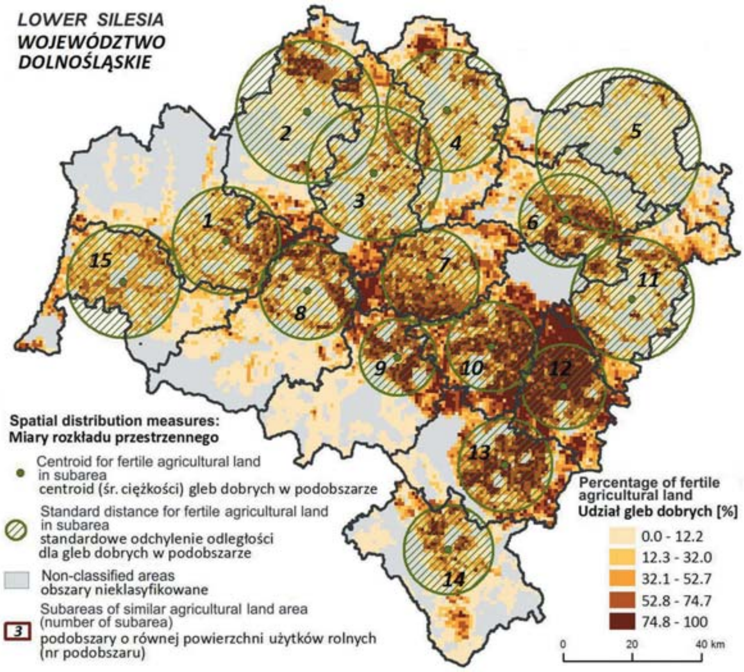

Fig. 5. Spatial distribution measures for high fertile agricultural land
Fig. 5. Miary rozkładu przestrzennego dla gleb zakwalifikowanych jako dobre

The standard distance shows the degree of dispersion of the phenomenon. In order to see the directions of dispersion which are also valuable characteristics of spatial distribution, the standard deviational ellipse is considered. The figure 6 presents the ellipses for agricultural lands calculated in subareas.

It should be stressed out that due to that fact that parameters of the standard deviational ellipses are related to the size and shape of the subareas, the better solution is to analyse the data within subareas of the similar shape and size. The example of such subareas is proposed in a form of squares of 27 x 27 km created based on the 1 x 1 km grid reference units (Fig. 8). The assumption is to cover the whole Lower Silesia not overestimating the area. However, the choice of size, shape and location of these subareas should be an issue of a further research.

The Authors notice that analysis in subareas – regardless its size and shape – is appropriate and useful for comparing a few phenomena. That is important especially in application studies such as agricultural use of land when various factors are taken into consideration. Presenting a few phenomena on one map delivers information on the possible correlation between them. In order to investigate the correlation in spatial distribution of agricultural lands and the soil conditions, the centroids and standard deviational ellipses are determined for: agricultural land, fertile agricultural land and optimal soil pH (Fig. 7).

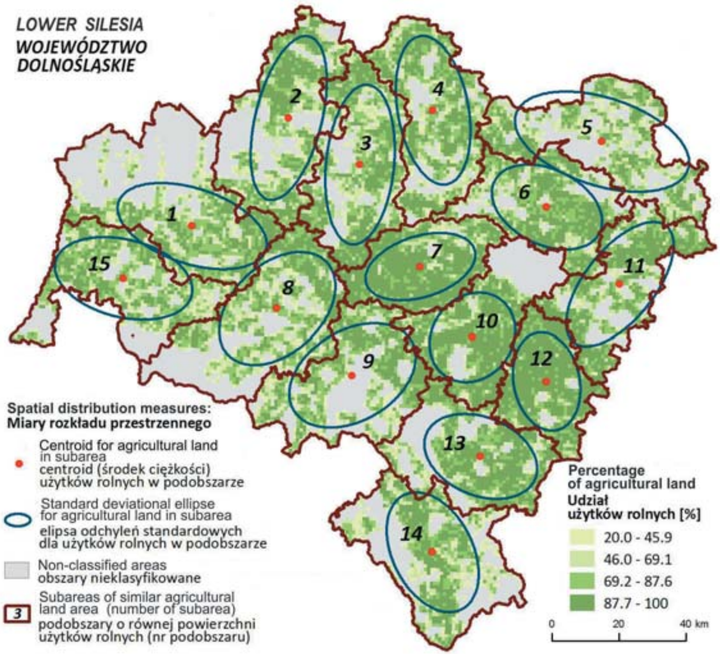

Fig. 6. Spatial distribution measures for agricultural land
Fig. 6. Miary rozkładu przestrzennego dla użytków rolnych

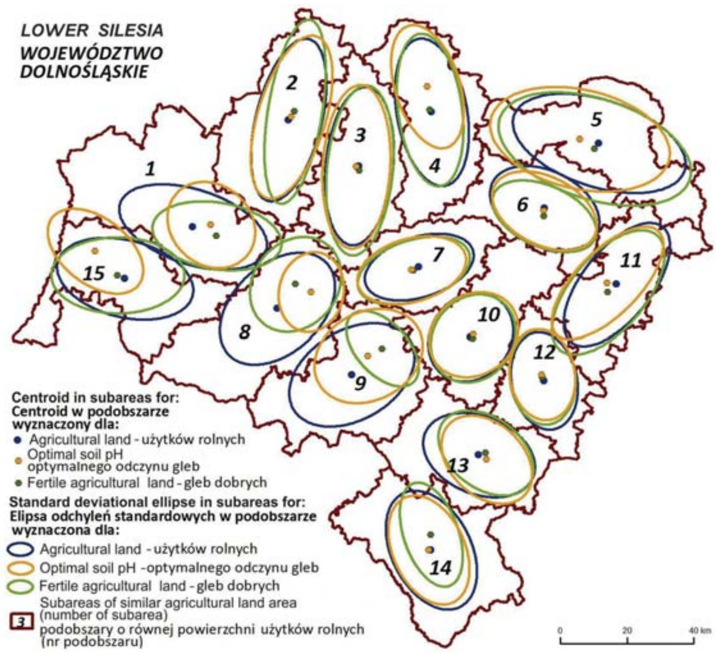

Fig. 7. Comparison of spatial distribution measures for the three phenomena
in subareas of similar agricultural land area
Rys. 7. Porównanie miar rozkładu przestrzennego trzech zjawisk
w podobszarach o zbliżonej powierzchni użytków rolnych

The visual analysis of the outcomes (Fig. 7) leads to conclusion that in some subareas (e.g. 7, 10, 12) "geographic centre" (centroid) of agricultural land and favourable conditions for agriculture are corresponding to each other, as well the dispersion and its directions are overlapping. There are also regions where the variability of phenomena within a space is bigger. For instance, 9th subarea – the agricultural land occur within the whole area, while the fertile agricultural land and soil of optimal pH are concentrated in its northern part. Moreover, the directions of dispersion are different: north-east for fertile agricultural land and south-west for optimal soil pH. Similar situation can be observed in the 8th subarea where the concentration of favourable conditions for agriculture are located in the northern part. The 15th subarea is characterized by high fertility of all agricultural land (the ellipses of agricultural land and high fertile agricultural land are nearly overlapping), but the soil conditions are located in the north-west.

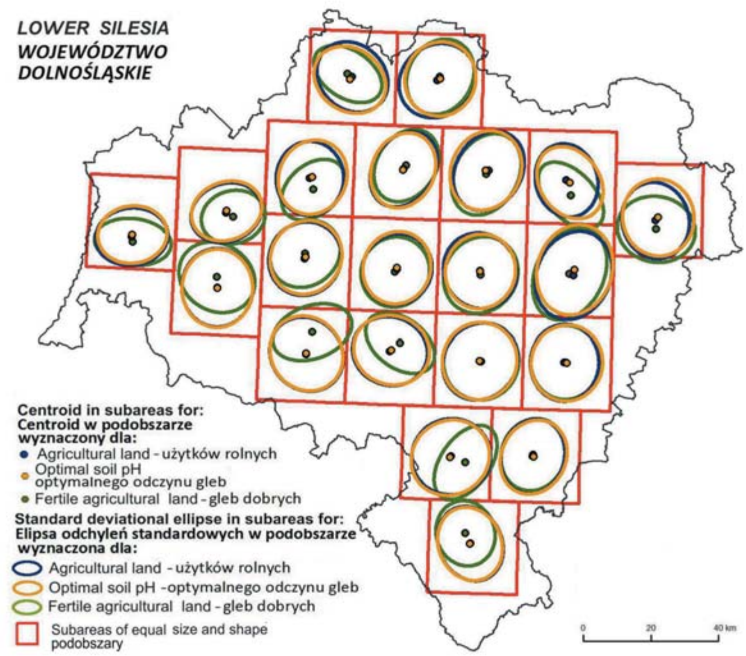

Fig. 8. Comparison of spatial distribution measures
for the three phenomena in subareas of equal size and shape
Rys. 8. Porównanie miar rozkładu przestrzennego trzech zjawisk
w podobszarach o takim samym kształcie i równej powierzchni

The analysis of the same conditions in equal subareas (Fig. 8) confirmed the observations that the most favourable conditions of agricultural land are located in the central part of Lower Silesia (the all three centroids and ellipses are overlapping). There are differences in spatial distribution in the outer subareas, mainly in direction of dispersion of high fertile agricultural land.

CONCLUSION

In analysing the spatial distribution – its concentration or dispersion and their directions – it is essential to map the outcomes. The visualization of location of the "geographic centre" and orientation of the distribution brings additional and useful information on the studied phenomena. The paper presents the application of spatial distribution measures (weighted mean centre, standard distance, deviational ellipse) into assessment of agricultural land productivity in Lower Silesia. In order to analyse the local changeability of the phenomena, the subareas of similar agricultural land area are proposed. The Authors notice that these subareas are more relevant to comparison of different phenomena within the same subarea, than to analyse a phenomenon in a global scale (within whole region). That is due to the fact that the standard deviational ellipse parameters relates to the shape and size of the subarea. The example of equal subareas is presented, however the choice of their size, shape and location should be an issue of a further research.

Mapping spatial distribution of the three factors (agricultural land, high fertile agricultural land and optimal soil pH) brings the conclusion that the central part of Lower Silesia is the most favourable region for agricultural use, especially in subareas where the standard deviational ellipses and centroids are nearly overlapping (subareas 7th, 10th, 12th) which means that the best soil conditions and fertile land are within all agricultural lands. These areas constitute nearly 20% of agricultural land in Lower Silesia and embraces most of the area within Silesian Lowlands. The research revealed also the regions where the distribution of the favourable conditions are located in a specific places of agricultural land (subarea 8th, 9^{th,} 15th). That relates to the south-western part of Lower Silesia.

WIZUALIZACJA ROZKŁADU PRZESTRZENNEGO WYBRANYCH ELEMENTÓW ŚRODOWISKA PRZYRODNICZEGO ZWIĄZANYCH Z GOSPODARKĄ ROLNĄ W WOJEWÓDZTWIE DOLNOŚLĄSKIM

Streszczenie: Statystyki przestrzenne pozwalają opisać i ocenić zjawisko pod kątem jego przestrzennych charakterystyk takich jak: koncentracja, wielkość i ukierunkowanie rozproszenia, występowanie regularności lub trendów w przestrzeni. W artykule zaprezentowano adaptację metod stosowanych dla zjawisk punktowych do oceny rozkładu przestrzennego zjawisk powierzchniowych związanych z gospodarką rolną: powierzchnia użytków rolnych, powierzchnia gleb zakwalifikowanych jako dobre, powierzchnia gleb o danym odczynie. Mapy zasięgów tych zjawisk (np. mapa glebowo-rolnicza w postaci wektorowej) jako jakościowe dane wejściowe zostały przetworzone na dane ilościowe odniesione do siatki o wymiarach 1 x 1 km za pomocą algorytmu stworzonego w środowisku Model Builder.

Obszarem badań jest województwo dolnośląskie charakteryzujące się różnorodnością warunków przyrodniczych, co wpływa na zmienność przydatności rolniczej badanego terenu. Statystyki przestrzenne wyznaczone dla całego obszaru dostarczają tylko ogólnej informacji o rozkładzie przestrzennym, stąd też w pracy przeprowadzono analizy w podobszarach, co pozwoliło na zbadanie lokalnej zmienności wybranych warunków przyrodniczych. Z uwagi na rolniczy aspekt badań zaproponowano podobszary o równej powierzchni użytków rolnych, uwzględniając granice administracyjne. Rozkład przestrzenny opisują takie miary jak: środek ciężkości, odległość standardowa, elipsa odchyleń standardowych. Uwzględniają one nie tylko lokalizację obiektu, ale również wartość zjawiska. Wizualizacja miar rozkładu przestrzennego na mapie dostarcza jasnej i zwykle łatwej w interpretacji informacji o strukturze przestrzennej badanego zjawiska. Prezentacja tych ilościowych charakterystyk na tle zjawiska przedstawionego inną metodą kartograficzną (np. metodą kartogramu) może wnosić dodatkowe informacje, w tym przypadku dotyczące przydatności warunków przyrodniczych dla gospodarki rolnej.

Słowa kluczowe: rozkład przestrzenny, metoda centrograficzna, środek ciężkości, odległość standardowa, elipsa odchyleń standardowych

REFERENCES

Anselin L., 1999. Interactive techniques and exploratory spatial data analysis [in:] Geographic Information Systems: Principles, techniques, management and applications., ed. Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W., 251–264. New York: John Wiley and Sons.

Cliff A.D., Ord J.K., 1981. Spatial Process: Models and Applications. Pion, London.

Earickson R., Harlin J., 1994. Geographic measurement and quantitative analysis. Macmillan College Paublishing Company, New York.

Ebdon D., 1985. Statistics in Geography. Basil Blackwell, Oxford.

Getis A., Ord J.K., 1992. The analysis of spatial association by the use of distance statistics. Geographical Analysis, vol. 24, 189–206.

Jażdżewska I.,2003. Statystyka dla geografów. Wydawnictwo Uniwersytetu Łódzkiego, Łódź.

Klimczak H., Galant K., Alkśnin M., 2006. Modelling of spatial structure of chosen forms of land cover using geometric reference units. Reports on Geodesy.

Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W., 2006. GIS. Teoria i praktyka. Wydawnictwo Naukowe PWN, Warszawa.

Magnuszewski A., 1999. GIS w geografii fizycznej. Wydawnictwo Naukowe PWN, Warszawa

Miller H.J., 2004. Tobler's First Law and Spatial Analysis. Annals of the Association of American Geographers, vol. 94, no. 2, 284–289.

Podlacha K., 1986. Kartograficzny system TEMKART dla komputerowego sporządzania map tematycznych. Prace IGiK, t. XXXII, z. 2, Warszawa.

Stuczyński T. (red.) i in., 2007a. Stan i zmiany właściwości gleb użytkowanych rolniczo w województwie dolnośląskim w latach 2000–2005. Urząd Marszałkowski Województwa Dolnośląskiego, Instytut Upraw Nawożenia i Gleboznawstwa, Państwowy Instytut Badawczy, Puławy – Wrocław.

Urbański J., 2008. GIS w badaniach przyrodniczych. Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk.

Witek T. i inni, 1993. Waloryzacja rolniczej przestrzeni produkcyjnej Polski według gmin. IUNG, Puławy. Seria (a) 56.

Zaakceptowano do druku – Accepted for print: 30.06.2013

For citation – Do cytowania: Kopańczyk K., Klimczak H., 2013. Mapping spatial distribution of chosen environmental characteristics for agricultural use in Lower Silesia. Acta Sci. Pol. Geod. Descr. Terr., 12 (2), 33–40.