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Izabela Basista
ORCID: 0000-0002-0820-5380

THE TOOL FOR ASSESSING THE EFFECTIVENESS OF LAND CONSOLIDATION

AGH University of Science and Technology in Krakow
basista@agh.edu.pl

Abstract

The main aim of the study was to develop a tool that automatically calculates the basic parameters describing the efficiency of land consolidation work, especially consolidation projects and analysis of the optimal location of parcels. Efficiency is usually determined by basic spatial parameters such as size, number and dispersion of plots. To calculate the spatial dispersion of parcels in a registration unit, the use of a convex envelope (convex hull) is proposed. This is one of the basic functions of a Geographical Information System (GIS). It provides a simple way to estimate the dispersion of land, taking into account its area and its belonging to a particular registration unit. The ModelBuilder application available in ArcGIS software was used to build the efficiency assessment tool. The tool was tested on three consolidation areas – Ilkowice, Rajsko-Niedzieliska-Szczurowa and Łukowa. The best results in terms of optimal distribution of plots were obtained on the Rajsko-Niedzieliska-Szczurowa site. In this case, the average area of plots increased more than threefold. The number of parcels in the entire site and in the registration units has more than threefold decreased. The average dispersion of plots in the units decreased here by almost four times. The other two sites did not score as well, but the analysis of the parameters indicates that there has been an improvement in the distribution of plots compared to the initial state. The average area of plots in Ilkowice increased by about 25% and in Lukowa by about 48%. The number of plots decreased in Ilkowice by about 25% and in Lukowa by about 48%. The average dispersion of plots in the units decreased in Ilkowice by 20% and in Lukowa by about 22%. It should be mentioned here that the Rajsko-Niedzielska-Szczurowa site consisted exclusively of agricultural plots, so it was definitely easier to achieve such good results. The Ilkowice and Łukowa sites also contained developed plots, which were not consolidated.

Keywords: land consolidation, effectiveness, Geographic Information System, convex envelope (convex hull), Poland

NARZĘDZIE DO OCENY EFEKTYWNOŚCI SCALEŃ GRUNTÓW

Abstrakt

Głównym celem artykułu było opracowanie narzędzia, które automatycznie wyznacza podstawowe parametry opisujące efektywność prac scaleniowych, w szczególności projektów scaleniowych i analizy optymalnej lokalizacji działek. Efektywność określają zwykle podstawowe parametry przestrzenne, takie jak wielkość, liczba i rozproszenie działek. Do obliczenia rozproszenia przestrzennego działek w jednostce ewidencyjnej zaproponowano wykorzystanie otoczki wypukłej. Jest to jedna z podstawowych funkcji Systemu Informacji Geograficznej (GIS). Dzięki temu w prosty sposób można oszacować rozproszenie gruntów, biorąc pod uwagę ich powierzchnię i przynależność do danej jednostki ewidencyjnej. Do budowy narzędzia do oceny efektywności wykorzystano aplikację ModelBuilder dostępną w oprogramowaniu ArcGIS. Działanie tego narzędzia sprawdzono na trzech obszarach scaleniowych – Ilkowice, Rajsko-Niedzieliska-Szczurowa oraz Łukowa. Najlepsze wyniki w zakresie optymalnego rozmieszczenia działek uzyskano na obiekcie Rajsko-Niedzielska-Szczurowa. W tym przypadku średnia powierzchnia działek wzrosła ponad trzykrotnie. Liczba działek w całym obiekcie i w jednostkach ewidencyjnych zmniejszyła się ponad trzykrotnie. Średnie rozproszenie działek w jednostkach zmniejszyło się niemal czterokrotnie. Pozostałe dwa

obiekty nie uzyskały tak dobrych wyników, ale analiza parametrów wskazuje, że nastąpiła poprawa rozkładu działek w stosunku do stanu wyjściowego. Średnia powierzchnia działek w Ilkowicach wzrosła o ok. 25%, a w Łukowej ok. 48%. Liczba działek zmalała w Ilkowicach o ok. 25%, a w Łukowej o ok. 48%. Średnie rozproszenie działek w jednostkach zmalało w Ilkowicach o 20%, a w Łukowej o ok. 22%. Należy zauważyć, że obiekt Rajsko-Niedzielska-Szczurowa składał się wyłącznie z działek rolnych, więc zdecydowanie łatwiej było osiągnąć tak dobre wyniki. Na obiektach Ilkowice i Łukowa występowały też działki zabudowane, które nie podlegały konsolidacji.

Słowa kluczowe: scalanie gruntów, efektywność, System Informacji Geograficznej, otoczka wypukła, Polska

1. INTRODUCTION

The agricultural sector is one of the main pillars of the economy, therefore its development will influence the development of the economy. Factors such as the fragmentation of agricultural land reduce agricultural productivity. Therefore, this study attempts to develop a tool that automatically calculates how much fragmentation is present in the study area.

Land consolidation and land exchange (LC) is a set of land management measures aimed at creating more favourable conditions for agriculture and forestry by improving the area structure of farms, forests and forest land, through the elimination of land fragmentation and dispersion; the rational shaping of land distributions; the adjustment of property boundaries to the system of water drainage facilities, roads or the topography of the terrain, among others [1]. After the consolidation of land the most commonly calculated values relate to the number and area of cadastral plots in an agricultural holding, in the entire consolidation object, or selected area ranges [2–5]. As studies show [6–9], a very important factor influencing the improvement of farming conditions is the distance of land from farm habitats, the so-called land distribution. Examples of calculating this parameter are based on the agricultural transport road network [10] and are usually presented for a selected group of farms [11–12]. An interesting one, due to the tools used, is the analysis of the road network on one of the consolidation sites by means of network analyses [13–14]. The authors of the work [15] also point to fragmentation as that element which strongly influences the quality of agricultural land management. Land fragmentation, i.e. the occurrence of land in many area-small contours or registration plots and additionally distant from each other (the so-called land dispersion), belonging to the same natural or legal person, hinders or completely prevents profitable agricultural production. Therefore, when analysing the fragmentation of land belonging to individual farms, it is necessary to take into account the size of individual farms and the number of parcels of land included in the farm [16].

This is confirmed by the activities carried out for many years to improve the layout, shape and quality of land cultivated by farmers [17–18]. The spatial layout of an agricultural plot has a significant impact on the production effects obtained [19–20]. It influences the reduction of the number of plots included in the farm, the minimisation of distance and travel time between the farmer's land and the elimination of uncultivated and abandoned land of lower classes [3, 21, 22]. Cultivation costs, on the other hand, are most influenced by the length of the field, slightly less by the width, with the area and perimeter of the farm plot playing an equally important role [23–25]. The distribution of farm land also takes into account the habitat plot (the farm's built-up area), the land parcels (of the farm) and the roads connecting these structures [26]. The structure of the plots on the study site, is most often characterised by the distance of the fields from the habitat plot, area, length, width, extension, regularity of the boundaries, field barriers and slope [27]. Farm layout can be assessed in different ways [4, 8, 28]. The most accurate and at the same time the most time-consuming method is to calculate the distance of cultivated fields from the habitat plot calculated along the actual roads. Most often, to simplify the calculation, a rectilinear method of determining the distance is used. Also, the reference location, the habitat, is defined in a more general way, for example as the centre of the village or the centre of gravity of the farm [29]. Using different methods to calculate the distribution can give very different results [30]. The popularity of simplified algorithms is partly due to the limited access to data that can be used to calculate distances accurately [4]. Most problematic here is the identification of the habitat plot and the determination of the correct road network [13, 31].

The main aim of the research carried out was to develop a tool to calculate the basic parameters determining the efficiency of consolidation works using existing Geographic Information System (GIS) tools. GIS systems are increasingly used for spatial analysis of objects also in issues related to the land consolidation process [32–33]. It should be highlighted that the efficiency studied relates to land consolidation projects and analysis of the optimal distribution of land parcels. It does not include economic factors. It was proposed to calculate the dispersion factor of the registered parcels in the registration units using a convex hull (convex envelope). The convex hull algorithm is implemented in any GIS software. The proposed method takes into account the spatial dispersion of land parcels within a farm and the area of these parcels. The approach does not take into account the habitat plot and the distance of the individual plots from it. But it does take into account that the parcels of a given farm may border each other. The input data is only a layer with the spatial location of the parcels and information about the belonging of each parcel to a given farm. The assumption of this method is that information about the dispersion of plots can be obtained quickly, with as few inputs as possible. Data input, calculations and the saving of results were included in a new tool using GIS. An automation tool was developed using the ModelBuilder application available in ArcGIS software.

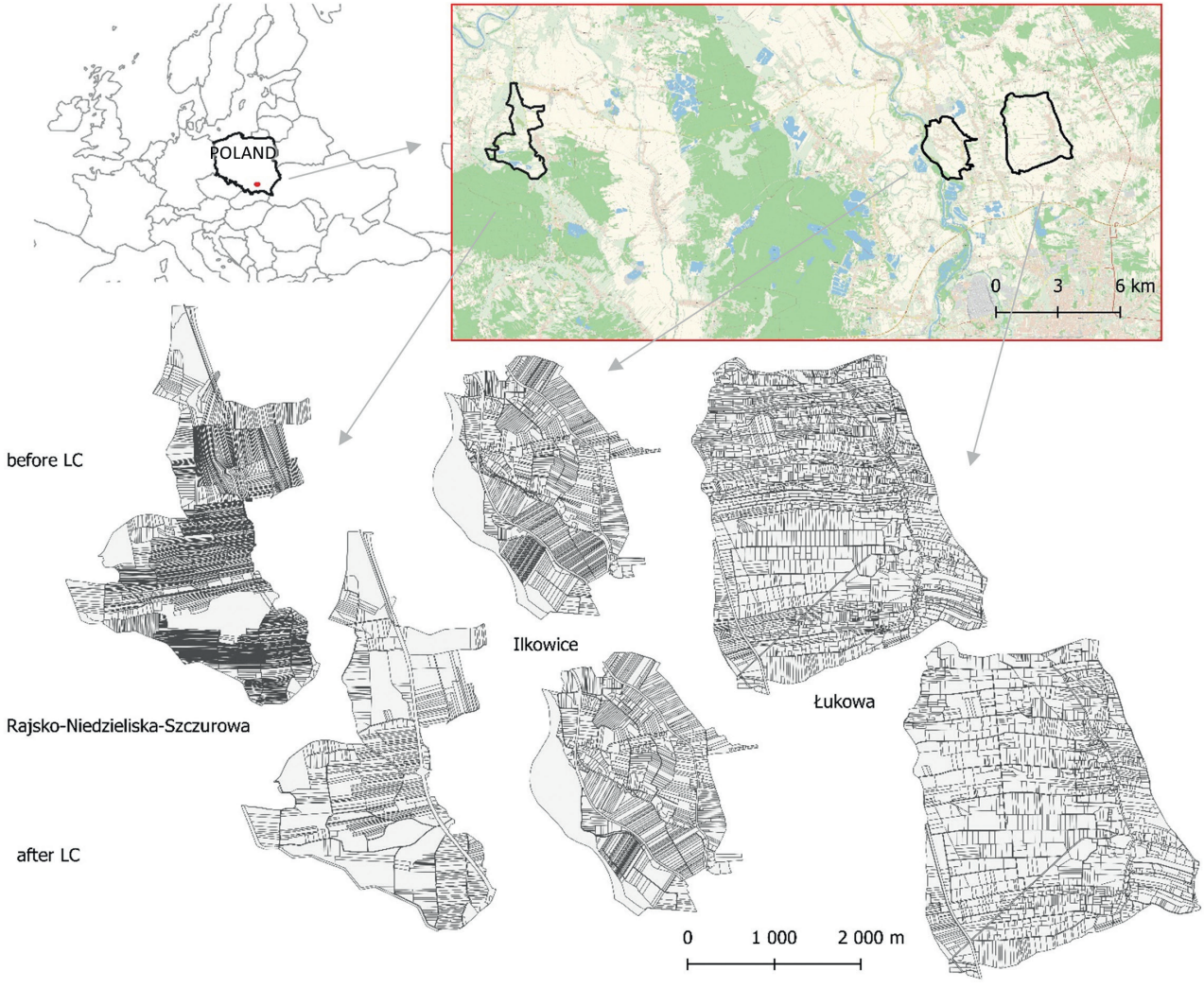

Fig. 1. Location of the analysed villages with contours of boundaries before and after LC
Ryc. 1. Lokalizacja analizowanych miejscowości wraz z granicami działek przed i po scaleniu gruntów

2. STUDY AREA

The subject of the research were three consolidation areas located in the southern part of Poland in the Lesser Poland Voivodeship (Fig. 1). The Rajsko-Niedzieliska-Szczurowa (RNS) site covers an area of approximately 590 ha and includes part of the villages of Niedzielska (41.7% of the total area of the village), Rajsko (10.2%) and Szczurowa (8.8%). The Ilkowice and Łukowa site cover whole cadastral units and have areas of 478 ha and 930 ha, respectively.

At the RNS site, the land use includes arable land covering approximately 15.5% of the site's area, grassland 71%, forests 13%. This area is practically entirely agricultural and forest. Built-up and transport-related areas are a marginal part here. In the remaining two sites, the structure of land use is more diversified. In Ilkowice, arable land occupies 66% of the unit, 12% of the total area is occupied by grassland, 4% orchards, 3% forest, 4% water, 5% residential, 3% transport and wasteland and other around 3%. In Łukowa, arable land covers 72% of the cadastral unit and it is prevalent in agricultural land. Grassland takes up 14% of the unit, orchards 2%, forest 2%, water 1%, residential 4%, transport 4% and wasteland about 1%.

Land consolidation projects were developed in 2012–2014 for the RNS site, in 2009-2011 for Ilkowice site and in 2009–2012 for Łukowa site. The land consolidation on the first two sites have been completed. On the third site, the consolidation procedure was cancelled, however, the consolidation project was developed.

3. METODOLOGY

Evaluation of the effects of consolidation works is a labour-intensive task, due to the need to take into account in the process of such an evaluation many different factors, including analysis of the road network, the area structure of farms or the shape of cadastral plots before and after the consolidation. It is worth noting that the consolidation area is usually several hundred hectares, with about a thousand land parcels assigned to several hundred registration units.

In developing the tool, the focus was on parameters which are most commonly cited in presenting the effects of scale-ups, i.e. parameters characterising the area structure of farms in a broadest sense of the term. Due to the frequent lack of information on the belonging of land register units to the relevant register group, the calculations performed by the tool will be based on register units. Another assumption is to use as little data as possible, i.e. a layer of registration parcels, in the state before and after consolidation, together with descriptive information concerning the belonging of individual parcels to a registration unit. This assumption is aimed at minimising the time and effort required to prepare the data, while at the same time generating, on their basis, as many parameters as possible to help determine the changes that have occurred. For similar reasons, land distribution, i.e. the distance of a farm's parcels form a habitat parcel, was not determined, as this would have involved collecting additional information on habitat location. A final consideration is the use of a GIS system to develop the tool.

The input data are the two layers of polygon objects mentioned earlier, showing the shape of the land parcels and their location, before and after consolidation. The attribute table contains information about the parcel number and area, as well as information on belonging to the relevant registration unit. On the basis of such data, the tool should calculate such parameters as: area of the consolidation object; number of parcels in the object; average parcel area; number of registration units; average area of registration unit and average number of parcels in a registration unit. These all values should be calculated for the state before and after consolidation.

In order to take into account a very important factor, which is the dispersion of the registered parcels belonging to one owner, based only on the geometry and location of the plots, it was proposed to calculate a kind of dispersion index (R) on the basis of the convex hull (convex envelope). The value of the R index for a given registration unit is calculated by dividing the area of the convex hull covering the parcels of that unit by the total area of those parcels. Figure 2 shows the shape of the convex hull for an example registration unit containing 10 registration parcels, and the dispersion of R for this unit is approximately 13. The smaller the value of the R index, the smaller the dispersion of the parcels. This solution takes into account the area of the registration unit. Furthermore, for units containing one plot, or several plots bordering each other, the value of the index oscillates around the value of 1 (depending on the shape of the plot(s)). Further research will aim, among other things, to eliminate these units from the calculations or to separate them.

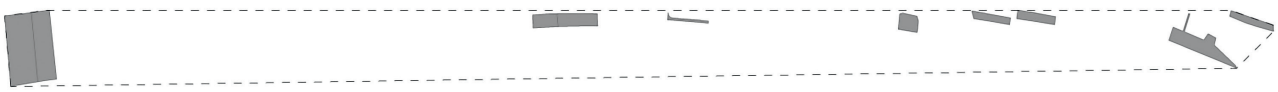

Fig. 2. Example of a convex boundary – dashed line, for registration parcels (dark grey polygons) belonging to one registration unit

Ryc. 2. Przykład wypukłej granicy – linia przerywana dla działek ewidencyjnych (ciemnoszare poligony) należących do jednej jednostki rejestrowej

The calculation of the average dispersion index of plots in the registration unit will be the latest parameter calculated by the tool. All parameters planned to be calculated are listed below:

1. Area of the consolidation object
2. Number of parcels in the object
3. Average parcel area
4. Number of registration units
5. Average area of registration unit
6. Average number of parcels in a registration unit
7. Dispersion of plots in the unit

Once the assumptions and parameters were defined, a tool was developed to automatically calculate the parameters showing the efficiency of land consolidation. The ModelBuilder application, which is part of ArcGIS software, was used for this purpose. It is used to create a model with which a sequence of processes using geoprocessing tools can be automated, documented and managed. The model is represented as a diagram of data and tools linked together, in the appropriate sequence, whereby the resulting data can be the input for subsequent tools. ModelBuilder can be thought of as a visual scripting language.

First, a model was created to which a number of geoprocessing tools were added, such as summary statistics, minimum boundary geometry, adding new fields, field joins, copying objects, joining tables, adding a geometry attribute and input data. The input data are two polygon layers with registration parcels and two values storing field names, in which information about the registration unit for the pre- and post-consolidation state is stored. The input data are processed by the subsequent tools in such a way that their intermediate results are the input data for the subsequent tools. The final result is a table with seven parameters stored in it. The user has the option of saving this result to a popular spreadsheet format (*.xls).

In developing the tool, the emphasis was on making it as versatile as possible. The user indicates only the polygon layers with the input data and the name and storage location of the resulting table. All the previously described parameters are calculated in the background.

4. RESULTS

The developed tool was tested on three consolidation site in Lesser Poland: Ilkowice, Rajsko-Niedzielska-Szczurowa (RNS) and Łukowa. The obtained efficiency parameters of the land consolidation project are presented in Table 1.

The analysis of the above values shows that the best results in terms of the optimal distribution of plots were achieved on the Rajsko-Niedzielska-Szczurowa object. In this case, the average area of plots increased more than three times. The number of plots in the entire site as well as in the registration units decreased more than three times. The average dispersion of plots in units decreased here almost four times. The other two objects did not achieve such good results, but the analysis of parameters shows that there was an improvement in the distribution of plots in relation to the initial state.

The average area of plots in Ilkowice increased from 0.35 ha to 0.47 ha (25% increase) and in Lukowa from 0.30 ha to 0.56 ha (48% increase). The number of plots decreased in Ilkowice from 1362 to 1015, a decrease of about 25%, and in Lukowa from 3156 to 1652, a decrease of about 48%. The average dispersion of plots in the units decreased by 20% in Ilkowice and by about 22% in Lukowa. It should be mentioned here that the Rajsko-Niedzielska-Szczurowa site consisted exclusively of agricultural plots, so it was definitely easier to achieve such good results. The Ilkowice and Łukowa sites also contained built-up plots which were not consolidated. This example proves that the proper assessment of the effectiveness of the developed consolidation projects must always be supported by broader knowledge about the analysed object. Nevertheless, the automatically calculated set of parameters is a great help in assessing the effectiveness of land consolidation.

Table 1. List of parameters generated by the tool
Tabela 1. Lista parametrów wygenerowanych przez narzędzie

Rajsko-Niedzielska-Szczurowa		**Before LC**	**After LC**
1	Area of the consolidation object [ha]	590,1639	590,1595
2	Number of parcels in the object	1943	575
3	Average parcel area [ha]	0,3037	1,0264
4	Number of registration units	349	341
5	Average area of registration unit [ha]	1,6910	1,7307
6	Average number of parcels in a registration unit	5,6	1,7
7	Dispersion of plots in the unit	23	6
Ilkowice			
1	Area of the consolidation object [ha]	478,1017	478,1200
2	Number of parcels in the object	1362	1015
3	Average parcel area [ha]	0,3510	0,4711
4	Number of registration units	629	620
5	Average area of registration unit [ha]	0,7601	0,7712
6	Average number of parcels in a registration unit	2,2	1,6
7	Dispersion of plots in the unit	5	4
Łukowa			
1	Area of the consolidation object [ha]	930,9463	930,9452
2	Number of parcels in the object	3156	1652
3	Average parcel area [ha]	0,2950	0,5635
4	Number of registration units	724	724
5	Average area of registration unit [ha]	1,2858	1,2858
6	Average number of parcels in a registration unit	4,4	2,3
7	Dispersion of plots in the unit	9	7

The development of the tool is an introduction to research on the use of a convex hull to calculate the dispersion of plots in a register unit. Further tests will be performed on a larger test sample and will be compared with calculations based on, among others, the road network. The tool will significantly facilitate further analyses.

5. DISCUSSION AND CONCLUSIONS

The aim of the described research was to develop a tool that calculates the parameters showing the distribution of land plots within the consolidation site. These parameters are the basis for evaluating the effectiveness of land consolidation projects. Among the most commonly calculated indices such as the average number or area of plots in a farm and in the whole consolidation area, a quick method of calculating the dispersion of plots in a farm based on the convex envelope calculation was presented. The proposed method takes into account the spatial dispersion of land parcels within a farm and the area of these parcels. For farms (units) containing one plot, or several plots bordering each other, the value of the index should be equal to 1. The smaller the value of the index, the smaller the dispersion of the plots. The task for the future is to identify those farms where the index should be equal to 1 and is not, and then improve this algorithm to take account of these cases.

This approach also does not take into account the habitat plot and the distance of individual plots from it, which is the subject of many research in this area [13, 30]. The gathering of up-to-date data of road network

and habitats of a given farm is an extremely time-consuming task. In contrast, presented method provides quickly an overall dispersal index, because the input data is only a layer with the spatial location of the parcels and information about the belonging of each parcel to a given farm. The advantage of the proposed approach is that it takes into account cases where the parcels of a given farm border each other. On the other hand, when calculating the distance between the parcels of a given farm and the habitats, the merging of neighbouring parcels must be done first [34].

The ModelBuilder application was used to implement the automation tool. This application is very user-friendly, largely intuitive and does not require knowledge of a programming language. It allows to develop a new tool that can be shared with other users. All planned calculations were successfully implemented in the tool. The correct interpretation of the obtained results remains an open question. The automatic machine calculates the dispersion of registration parcels in a register unit, based on the convex hull. This approach is easy to implementation, because any GIS system includes convex hull algorithm. Its greatest advantage is simplicity, because there is no need to specify for example the habitat parcels and road network.

This parameter can also be used to indicate objects for consolidation. The developed tool is the beginning of this research and will certainly contribute to their faster implementation.

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