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The Use of Statistical Methods for the Evaluation of Land Adjustment Proposals and Elimination of the Patchwork Pattern of Land Ownership

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Abstract. The analysis of the need for agricultural land consolidation in villages of the commune of Sławno was performed to identify villages in which adjustment interventions were needed most urgently. The factors indicative of the urgency of land adjustment were selected on the basis of a comprehensive analysis of the natural, social, economic and financial conditions characterizing the investigated villages. The analysis was carried out on the basis of data obtained from the Register of Land and Buildings of the District Office in Opoczno and the Office of the Commune of Sławno. The study allowed us to determine the surface area of land requiring urgent consolidation and exchange, thus providing grounds for applying for funds for the implementation of the proposed land adjustment scheme. Calculations were done on the basis of 19 factors (x1– x19) belonging to five groups of characteristics describing each of the investigated villages. The results expressed in the form of a synthetic measure calculated for each village allowed us to prioritize consolidation interventions. The priority ranking obtained was compared with another ranking performed using the zero unitarization method (ZUM).

Keywords: land consolidation, land exchange, land fragmentation, ranking, statistical methods.

Conference topic: Technologies of geodesy and cadaster.

Introduction

Land consolidation is one of the basic development activities in rural areas intended to comprehensively improve the organization of agricultural production space. Merging and exchange of parcels are aimed at transforming a fragmented and "checkerboarded" landscape containing excessively long fields into plots as large and regular as possible. Land consolidation decisions are based on detailed analyses of relevant parameters.

Today, comprehensive land consolidation interventions include post-consolidation land management tasks, such as improving the existing field infrastructure by building and modernizing access routes to arable land, amelioration of land, and introduction of erosion control measures (buffer strips, woodlots and roadside shrubs). Consolidation operations are regulated by the Act of 26th March 1982 on Land Consolidation and Exchange (Official Journal of Laws of 2003, No. 178, item 1749, as amended).

Properly carried out land consolidation creates an opportunity to organize agricultural holdings in an appropriate way, and, at the same time, to preserve the natural environment. Consolidation provides appropriate conditions for sustainable and multi-functional rural development by limiting the harmful influence of intensive agriculture on the natural environment. It also leads to an improvement in living and working conditions for inhabitants of rural areas (Błaż *et al.* 2010).

The analysis conducted in this study was aimed at singling out villages in the commune of Sławno in which consolidation of arable land was required most urgently. Factors describing the investigated villages were selected on the basis of a comprehensive analysis of the natural, social, economic and financial conditions found in those localities. The analysis was conducted using data obtained from the Land and Property Register of the District Office in Opoczno and data from the Office of the Commune of Sławno. The study allowed us to determine which areas required land consolidation and exchange interventions, thus becoming a basis for applying for financial resources necessary to reach the aforementioned goal.

Development of agricultural production space, as shown in numerous studies (Wójcik, Leń 2015; Leń, Mika 2016a, 2016b), has resulted in a very faulty structure of ownership of arable land in the examined area. Such an inefficient land ownership structure requires urgent intervention aimed at adjusting land use to the advanced agricultural technologies of the 21st century. However, it is impossible to perform land consolidation and exchange

in the entire commune, mostly for economic reasons. Therefore, it is necessary to create priority rankings for land consolidation and exchange projects, by using objective methods of evaluation.

A special role in empirical studies, especially comparative studies, of human activity is played by taxonomic methods, which involve linear ordering of items according to a synthetic indicator characterizing those items, which is calculated on the basis of a set of shared features. These methods are widely used in econometrics and socio-economic research to create all kinds of development rankings, based on multi-faceted data concerning the objects under analysis.

Synthetic measures allow one to order items on a scale of intensity of a multi-faceted and multi-factorial phenomenon. They are obtained by synthesizing information from a series of diagnostic variables, and are attributed to the analyzed phenomenon as one aggregated measure. In practice, there are a lot of methods of calculating synthetic measures on the basis of appropriate diagnostic variables characteristic of the examined phenomenon.

Determination of the urgency of land consolidation and land exchange interventions

Methods of multidimensional statistics are especially useful in comparative land use analyses such as those concerning the urgency of land consolidation and exchange, because they allow to determine one synthetic measure to describe the object under study (Leń *et al.* 2016).

The aim of the present study was to establish the need for land exchange and consolidation in the villages of the commune of Sławno, district of Opoczno, Łódź Voivodeship. The ranking was established using Hellwig's synthetic indicator of development (Hellwig 1968; Pluta 1968; Bartosiewicz 1976; Krakowiak-Bal 2005). The calculations were carried out using 19 factors describing each of these localities, as selected previously by Leń and Mika (2016b). The results in the form of a synthetic indicator for each village enabled us to create a ranking of priority of land consolidation and exchange interventions. They were compared with results obtained using the zero unitarization method (ZUM) (Leń, Mika 2016b).

Table 1. The list of factors that describe the desired area accepted for testing (Source: own elaboration)

1. Possession of land	2. Use of the land	3. Demographic conditions	4. Fragmentation of land	5. Plots with no road access
x1 – % the percentage of land of individual farms	x5 – % the percentage of arable land	x11 – the number of inhabitants	x13 – overall area	x18 – % of the number of plots with no road access
x2 – % the State Forests land percentage	x6 – % the percentage of medows	x12 – the number of inhabitants per 1 km^2	x14 – the total number of plots	x19 – % of the plot areas with no road access
x3 – % the percentage of the land of the Agricultural Property Agency of the Treasury	x7 – % the percentage of pastures		x15 – the number of plots in the individual sector	
x4 – % the municipal land percentage	x8 – % the percentage of forests		x16 – the average area of plots in the individual sector	
	x9 – % the percentage of communication areas		x17 – fragmentation index	
	x10 – % the percentage of building agricultural areas			

The factors listed in Table 1 represent the five groups of issues. The first two groups concerning the possession and use of land are represented by 10 factors. These are respectively factors (x1, x2, x3, x4) for the first one and factors (x5, x6, x7, x8, x9, x10) for the second mentioned group. They were calculated as a percentage of their percentage in the total area of the village, using data from a list of land acquired from cadastre.

The third group are the factors describing the demographic conditions in the villages of studied municipality x11 – number of inhabitants and x12 – number of inhabitants per square kilometer. Information on the number of inhabitants was obtained from the Sławno municipal office.

In the fourth group of factors describing land fragmentation 5 indicators were assumed. Three of them: x13 (overall area of the village), x14 (the total number of plots in the village) and x15 (number of plots in the individual

sector) also used the data from EGIB. For the elaboration the average area of parcels in the individual sector (x16) was also taken as a factor. For the refinement of the problem of fragmentation the index of fragmentation (x16) was calculated on the basis of Leń, Noga (Leń, Noga 2010).

The last group of factors was related to the percentage of plots with no road access (x18) and the percentage of the area of plots with no road access (x19). For the purposes of this part of the study the tools of GIS (Geographic Information System) were used, allowing on a transparent and fast graphical presentation of research results.

The study involved 34 survey areas located in the commune of Sławno, district of Opoczno. To calculate the synthetic measure of urgency of land consolidation and exchange, five groups of features related to the urgency of land adjustment characterizing each of the localities were studied:

- land ownership,
- land use,
- demographic conditions,
- land fragmentation,
- plots without road access.

It was assumed that all the variables were equally statistically significant and provided motivation for (stimulants) or against (destimulants) land consolidation and exchange. The calculations were done on the basis of Hellwig's synthetic indicator of development, which allows standardization of diagnostic variables by establishing a Euclidean metric, and, after that, a synthetic measure. The synthetic measure is, at the same time, a relative indicator of the urgency of land consolidation and exchange for a given survey area, in relation to a given reference object.

The algorithm below shows in what order the calculations are done:

- first, a reference object with standardized coordinates (standardized variable values) is determined on the basis of a matrix of standardized input data:

$$O_0 = \left[z_{oj} \right],\ j = 1, 2, \ldots, m; \tag{1}$$

- the coordinates of the reference object are calculated from the following formula:

$$z_{oj} = \max_i \left\{ z_{ij} \right\} \text{ – when the selected feature is a stimulant;}$$

$$z_{oj} = \min_i \left\{ z_{ij} \right\} \text{ – when the selected feature is a destimulant;}$$

$$j = 1, 2, ..., m; \tag{2}$$

- next, the distance of each object from the reference object is calculated, most frequently using a Euclidean metric in the following form:

$$d_{i0} = \left[\sum_{j=1}^{m} \left(z_{ij} - z_{0j} \right)^2 \right]^{\frac{1}{2}},\ i = 1, 2, ..., m; \tag{3}$$

- the synthetic measure is finally defined as:

$$s_i = 1 - \frac{d_{i0}}{d_0},\ i = 1, 2, ..., m, \tag{4}$$

where:

$$d_0 = \bar{d}_0 + 2S\left(d_0\right), \tag{5}$$

where:

$$\bar{d}_0 = \frac{1}{n} \sum_{i=1}^{n} d_{i0};\ S\left(d_0\right) = \left[\frac{1}{n} \sum_{i=1}^{n} \left(d_{i0} - \bar{d}_0 \right)^2 \right]^{\frac{1}{2}}. \tag{6}$$

Measure s_i usually has values in the range [0; 1]. The closer a given object is to the reference, the higher is the value of this measure. The results of the calculations are tabulated in Table 2 and presented in a graphical form in Figure 1.

Table 2. Ranking of villages based on Hellwig's synthetic indicator of development (Source: own elaboration)

Position in ranking	Village name	Synthetic indicator (si)	Position in the ZUM ranking
1	Gawrony	0.94	1
2	Kunice	0.82	3
3	Prymusowa Wola	0.77	9
4	Zachorzów	0.74	10
5	Kolonia Zachorzów	0.70	6
6	Janków Psary	0.67	2
7	Grążowice	0.62	4
8	Kamień	0.55	16
9	Ostrożna	0.53	7
10	Olszowiec	0.52	20
11	Sławno	0.52	8
12	Kozenin	0.52	15
13	Antoniówka	0.50	13
14	Antoninów	0.45	17
15	Dąbrówka	0.44	19
16	Unewal	0.42	26
17	Owadów	0.42	11
18	Dąbrowa	0.41	14
19	Grudzień Las	0.35	28
20	Bratków	0.33	21
21	Wygnanów	0.32	22
22	Wincentów	0.31	18
23	Sławno Kolonia	0.31	23
24	Kamilówka	0.31	31
25	Trojanów	0.29	32
26	Grudzeń Kolonia	0.26	24
27	Szadkowice	0.25	5
28	Józefów	0.23	12
29	Sepno Radonia	0.22	33
30	Tomaszówek	0.20	25
31	Popławy	0.17	27
32	Ludwinów	0.14	29
33	Celestynów	0.10	30
34	Olszewice	0.07	34

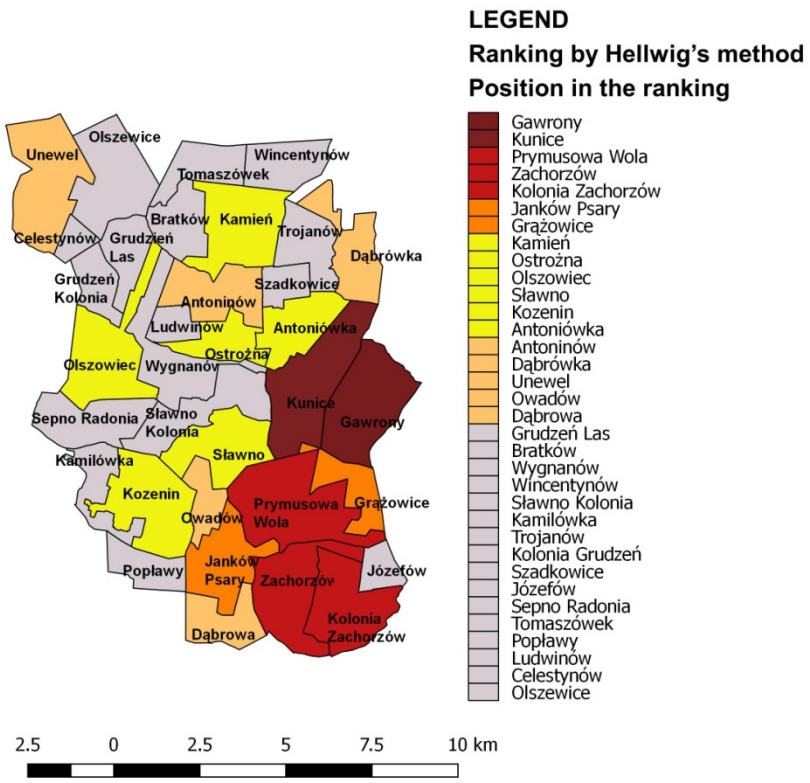

Fig. 1. A map showing the urgency of consolidation and exchange of land in the analyzed commune (Source: own elaboration)

The last column of Table 2 shows the positions of the individual villages in the ranking established for the same area and on the basis of the same features by means of the zero unitarization method. Distribution of results for that method is presented graphically in Figure 2.

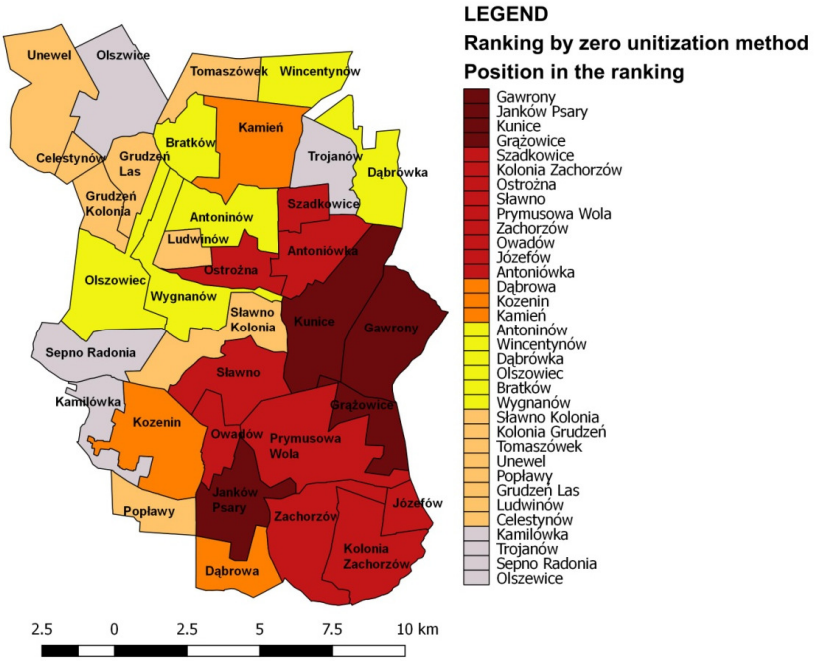

Fig. 2. A map illustrating the urgency of consolidation and exchange of land in the analyzed commune. The map was drafted using ZUM data (Source: own elaboration)

Conclusions

The results obtained in this study show that two survey areas which most urgently require consolidation are Gawrony and Kunice. They are villages with a similar cadastral area, similar land ownership and land use structures, and a similar degree of land fragmentation. At the other end of the ranking is the village of Olszewice, with the least inefficient spatial structure. These findings are confirmed by both rankings. The rankings differ by several places in the middle of the ranking scales. The differences might follow from the fact that, while the numerical values of the analyzed features for most villages in the middle positions of the ranking are similar (similar values of the metrics), the two methods have certain specific properties which become manifest during the calculation process.

The graphical representations of the results of the two rankings (Figs 1 and 2) indicate that land consolidation and exchange are most urgently needed in the south-eastern part of the commune (villages occupying the highest positions in both rankings are grouped within this area). Future studies focused on this part of the commune could use land fragmentation data to develop comprehensive land adjustment solutions for a larger area (e.g. a few cadastral areas at a time), which would allow to eliminate the checkerboard problem.

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