Methodology of Prioritization of Land Consolidation and Land Exchange Interventions

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Abstract. 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. 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. The analysis conducted in this study was aimed at singling out villages in the commune of Paradyż 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 Paradyż. 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. 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. The aim of the present study was to establish the demand for land exchange and consolidation in the villages of the commune of Paradyż, district of Opoczno, Łódź Voivodeship. The ranking was established using Hellwig's synthetic indicator of development and the zero unitarization method. The analysis allowed us to answer the questions of how different methods of aggregation of the same diagnostic variables affect the final results and whether these methods could be applied in this type of studies.

1. Introduction

The most common defects of the spatial structure of farmland belonging to privately-owned holdings in Poland are the small size (surface area) of cadastral plots, a large number of such plots in a single holding, small-sized cadastral areas, especially in terrain with diversified topography, narrow and very long plots in lowland areas, irregularly shaped plots, plots without road access, and, above all, the scattering of parcels across the village and beyond its boundaries. These problems have greatly restricted or even hindered agricultural production. Defective spatial structure is a problem that affects many countries around the world, as reported by numerous authors [17], [15], [16], [4], [19], [14], [6], [5], [1], [13], [3]. These reports provide information that makes it possible to work out ways of assessing the spatial and technical parameters of cadastral plots. It is impossible, for technical and

financial reasons, to implement land readjustment schemes that would encompass all problematic areas. Therefore, land consolidation and exchange interventions should be undertaken in those villages which most urgently need readjustment. The identification of such villages and prioritization of land readjustment projects requires assessment of the degree of defectiveness of the spatial structure of land.

The factors characterizing the investigated villages were selected on the basis of a comprehensive analysis of their spatial structure using descriptive and graphical data obtained from the Real Estate Cadastre. The study allowed us to identify areas which required urgent consolidation and exchange. Thus, becoming a basis for applying for funds for the implementation of the proposed land adjustment scheme.

2. Factors influencing the urgency of land readjustment

The study encompassed 26 cadastral communities located in the commune of Paradyż, in the Opoczno district. Based on the research conducted, 26 factors were identified in 3 groups. First group of factors provides general information about:

Gx_1 - total area,
Gx_2 - total number of parcels,
Gx_3 - total population,
Gx_4 - number of inhabitants per 1 km^2.
Gx_5 - % of privately owned parcels,
Gx_6 - % of total surface area of privately owned parcels,
For more detailed information on private farms:
Ix_2 - number of farm holdings (designated in the Polish legislation as 'register units no. 7.1),
Ix_3 - % of owners of farm holdings out of total landowners,
Ix_6 - number of parcels in the "farm holdings" category,
Ix_7 - area of parcels in the "farm holdings" category,
Ix_8 - % of parcels in the "farm holdings" category out of all privately-owned land,
Ix_9 - % of area occupied by farm holdings out of total area of privately owned land,
Ix_{10} - average number of parcels in register unit 7.1,
Ix_{11} - average area of register unit 7.1.
An important element of spatial structure analysis is land use analysis. In the present study, data on the area of agricultural land and its classes were used to calculate
Ex_1 - grassland productivity index and
Ex_2 - arable land productivity index.

Any assessment of the demand for land consolidation should necessarily contain information regarding the number of parcels in a given commune, district or province which have no road access [18]. Factors related to road access were also determined in this present study. Two factors were used:

Rx_1 - % of parcels without road access and
Rx_2 - % of parcel area without road access.

The second group of factors describes the spatial structure of the studied area. World literature lists numerous indicators of land fragmentation [8], [9], [2], [7], [10]. Some of these indicators focus on the fragmentation of entire holdings, while others describe faulty geometry of parcels. Because rural areas in Poland have a diversified spatial structure, land fragmentation factors and faulty plot geometry factors were defined separately. To determine the degree of land fragmentation, the following two factors were calculated:

Ax_1 - average area of privately owned parcels, and its more specific counterpart:
LFx_1 - the synthetic land fragmentation index.

The study showed that the parcels in the area had a very faulty geometry, which made it necessary to calculate the parcel shape factor. This factor was described as:

GPx_1 - average value of parcel shape factor and
$SGPx_1$ - synthetic parcel elongation index.

The third group of factors provides detailed information on to establish the ownership structure of the investigated land:

OSx_1 - % of land belonging to the Agricultural Property Agency of the State Treasury, and
OSx_2 - % of commune land.

These factors had to be taken into account due to the conditions imposed by the readjustment project and the need to make proper records of State Treasury land and commune land. Land consolidation projects implemented in areas with land belonging to the State Treasury produce greater project outcomes. Activities which regulate the land-ownership status of the State Treasury, simultaneously create opportunities for development of existing individual farm holdings in the area.

The outcomes of land consolidation depend on the existing conditions characterizing an area. If the area has a large number of elements that cannot be changed (so-called 'project invariants'), the potential outcomes of the project activities will be significantly poorer than for objects (areas) which do not have such constraints. This is why two additional factors which had a negative effect on the consolidation project (destimulants) were calculated:

LUx_1 - % share of orchards and

LUx_2 - % share of forests.

The choice of these two factors was dictated by the high share of these land classes in the investigated area. It should be borne in mind that for other areas, factors in this group (negative factors) may be different.

Taken together, all the above factors provided a comprehensive view of the state of the spatial structure of the examined area. It was assumed that all the variables were equally statistically significant and had a positive (stimulants) or a negative (destimulants) effect on the land consolidation and exchange activities.

3. Method

Two independent statistical methods were used to create two land consolidation urgency rankings. The first method involved the use of Hellwig's synthetic indicator of development, which enables 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 following algorithm represents the order in which 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:

$$\mathbf{O}_0 = \left[z_{oj} \right], \qquad j=1,2,...,m. \tag{1}$$

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

$z_{oj} = \max_i \{ z_{ij} \}$ - when the selected feature is a stimulant

$z_{oj} = \min_i \{ z_{ij} \}$ - when the selected feature is a destimulant $\qquad j=1,2,...,m.$ (2)

- next, the distance of each object from the reference object is calculated, most frequently using a Euclidean metric given by

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

- The synthetic measure is finally defined as:

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

where:

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

where

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

Measure s_i has usually values in the range [0; 1]. The closer a given object is to the reference, the higher is the value of this measure.

To verify the correctness of the ranking, we used another statistical approach – the zero unitarization method. The algorithm for this method has been described in detail in several papers [11], [12]. The diagnostic variables describing the investigated area can be divided into three groups:

1) Stimulants – variables whose increase in value leads to an increase in the value of a diagnostic feature of the object under consideration; in this case, standardized variables are calculated from the following formula:

$$Z = \frac{(x - x_{\min})}{(x_{\max} - x_{\min})} \tag{7}$$

2) Destimulants – variables whose increase in value leads to a decrease in the value of a diagnostic feature of the object under consideration; in this case, standardized variables are calculated from the following mathematical formula:

$$Z = \frac{(x_{\max} - x)}{(x_{\max} - x_{\min})} \tag{8}$$

3) Nominants – variables which only take on the highest rating (optimum) for a certain value or range of values; as one moves away from the optimum, the rating of the phenomenon becomes more negative; in this case, the standardized variables are calculated according to the following formula:

$$Z = \frac{(x - x_{\min})}{(x_{opt} - x_{\min})}, \text{ for } x < \text{xopt}, \tag{9}$$

$$Z = \frac{(x - x_{\max})}{(x_{opt} - x_{\max})}, \text{ for } x > \text{xopt}, \tag{10}$$

where:
z – standardized variable,
x – variable prior to standardization,
x_{max} – maximum value of a variable in a given set,
x_{min} – minimum value of a variable in a given set,
x_{opt} – optimum value of a variable in a given set.

The standardization of diagnostic features is a preliminary step, which leads to a consolidated multi-criteria evaluation of each of the objects under consideration. The consolidated evaluation of each object is obtained by aggregation. In order to obtain a synthetic measure, average values of the sets characterizing the respective features are calculated using the following formula:

$$z_i = \frac{1}{p}\sum_{j=1}^{p} x_{ij} \quad (i = 1,\ldots,m) \tag{11}$$

Standardized measures are in the range <0; 1>. Results are interpreted as the average of the optimum values achieved by each object. Accordingly, the higher the value of the synthetic measure, the higher the position of the object in the ranking.

The calculations yielded two independent rankings of urgency of land consolidation and land exchange. The ranking of villages by urgency of land consolidation and land exchange is presented in tables 1 and 2. A map showing the urgency of land consolidation and land exchange is given in figures 1 and 2.

Table 1. Ranking of urgency of land readjustment created for the villages of the commune of Paradyż on the basis of the Hellwig's synthetic indicator of development.

Position in the ranking	Synthetic measure (si)	Village	Position in the ranking	Synthetic measure (si)	Village
1	0.905	Przyłęk	14	0.268	Krasik
2	0.680	Wójcin	15	0.258	Mariampol
3	0.492	Grzymałów	16	0.243	Bogusławy
4	0.476	Kazimierzów	17	0.238	Kolonia Popławy
5	0.465	Daleszewice	18	0.220	Honoratów
6	0.431	Paradyż	19	0.220	Sylwerynów
7	0.387	Stawowice	20	0.217	Dąbrówka
8	0.356	Wójcin B	21	0.212	Stawowiczki
9	0.355	Solec	22	0.194	Podgaj
10	0.349	Alfonsów	23	0.192	Wielka Wola
11	0.310	Dorobna Wola	24	0.189	Joaniów
12	0.309	Feliksów	25	0.185	Stanisławów
13	0.285	Irenów	26	0.181	Adamów

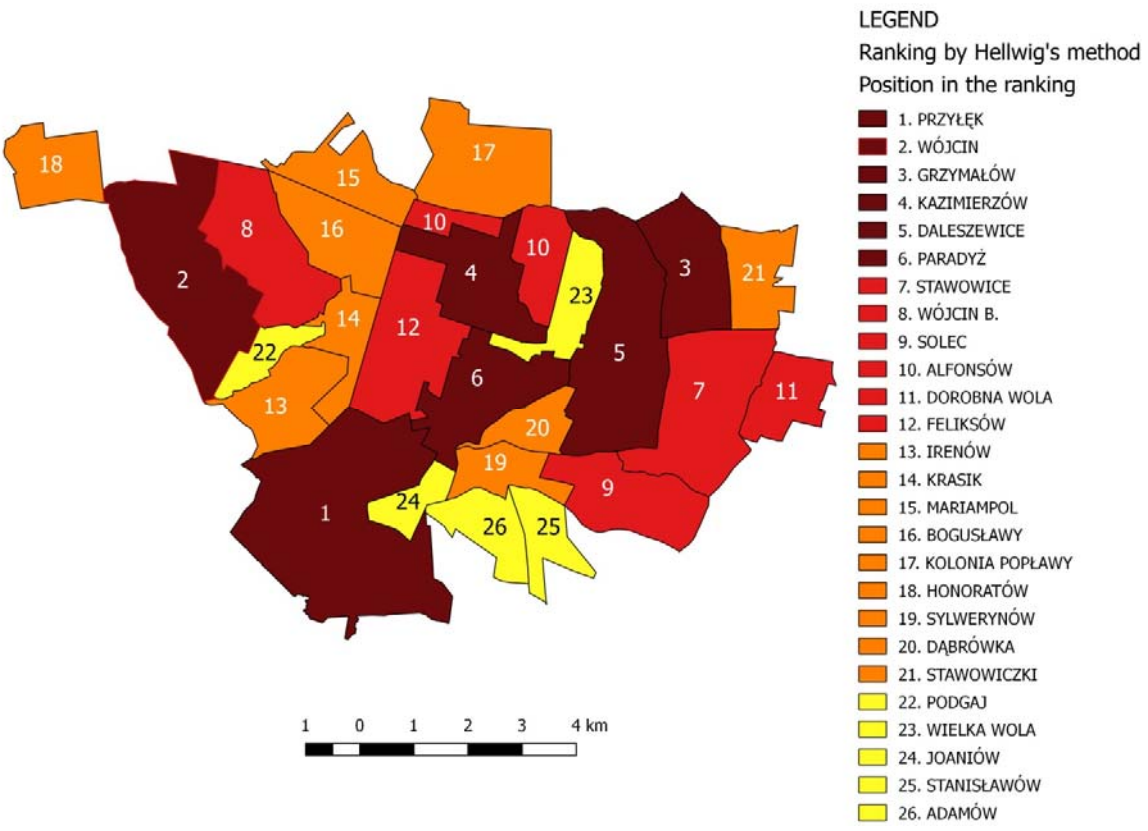

Figure 1. Spatial picture of the location of the village using the Hellwig's method

Table 2. Ranking of urgency of land readjustment created for the villages of the commune of Paradyż using the zero unitarization method (ZUM)

Position in the ZUM ranking	Synthetic measure (si)	Village	Position in the ZUM ranking	Synthetic measure (si)	Village
1	0.612	Przyłęk	14	0.420	Mariampol
2	0.586	Wójcin	15	0.415	Sylwerynów
3	0.566	Kazimierzów	16	0.408	Stanisławów
4	0.563	Grzymałów	17	0.397	Paradyż
5	0.523	Alfonsów	18	0.395	Feliksów
6	0.501	Daleszewice	19	0.395	Irenów
7	0.487	Wójcin B	20	0.394	Bogusławy
8	0.474	Stawowice	21	0.379	Stawowiczki
9	0.463	Kolonia Popławy	22	0.350	Dąbrówka
10	0.462	Solec	23	0.347	Wielka Wola
11	0.445	Krasik	24	0.339	Adamów
12	0.432	Honoratów	25	0.338	Podgaj
13	0.427	Dorobna Wola	26	0.336	Joaniów

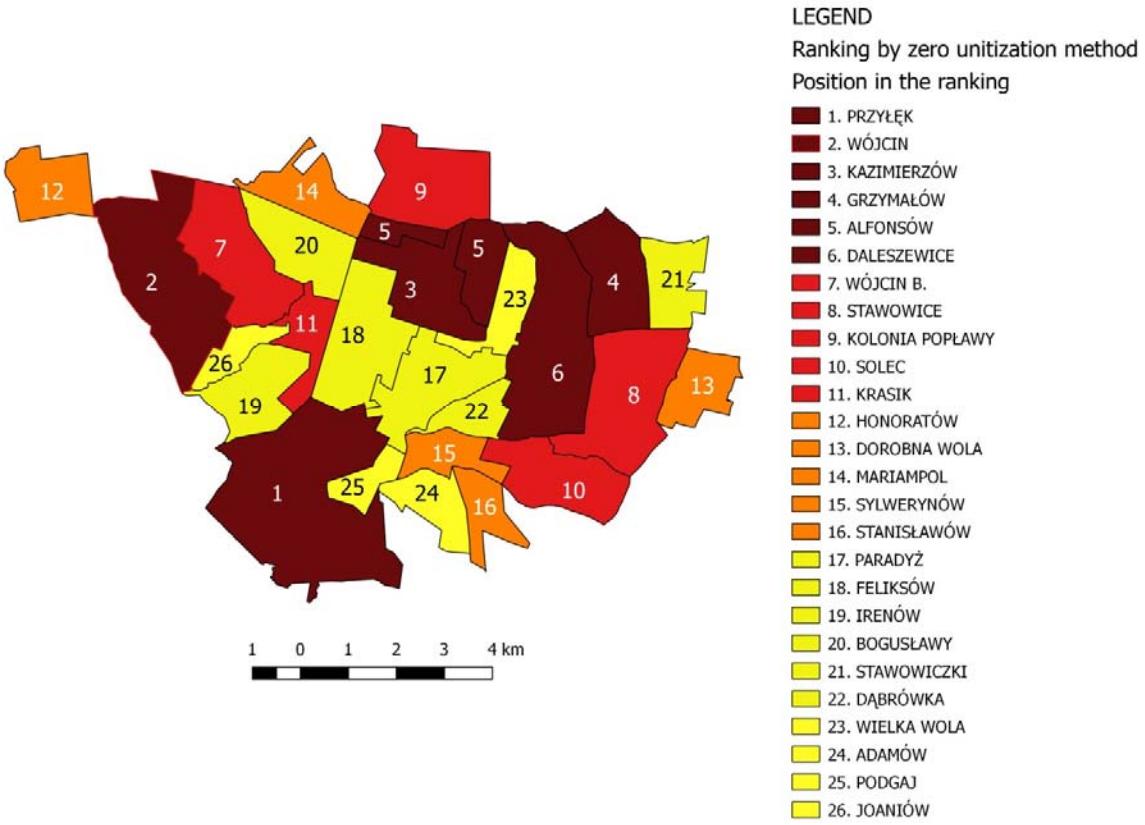

Figure 2. Spatial picture of the location of the village using the ZUM

4. Results

The results of the two independent rankings (figure 3) show that the following cadastral communities needed land consolidation most urgently: Przyłęk (1st position in the rankings), Wójcin (2nd position in the rankings) and Grzymałów (3rd and 4th positions), Kazimierz (4th and 3rd positions). At the bottom of the ranking list were the villages of Adamów and Joaniów, which had the least defective spatial structure.

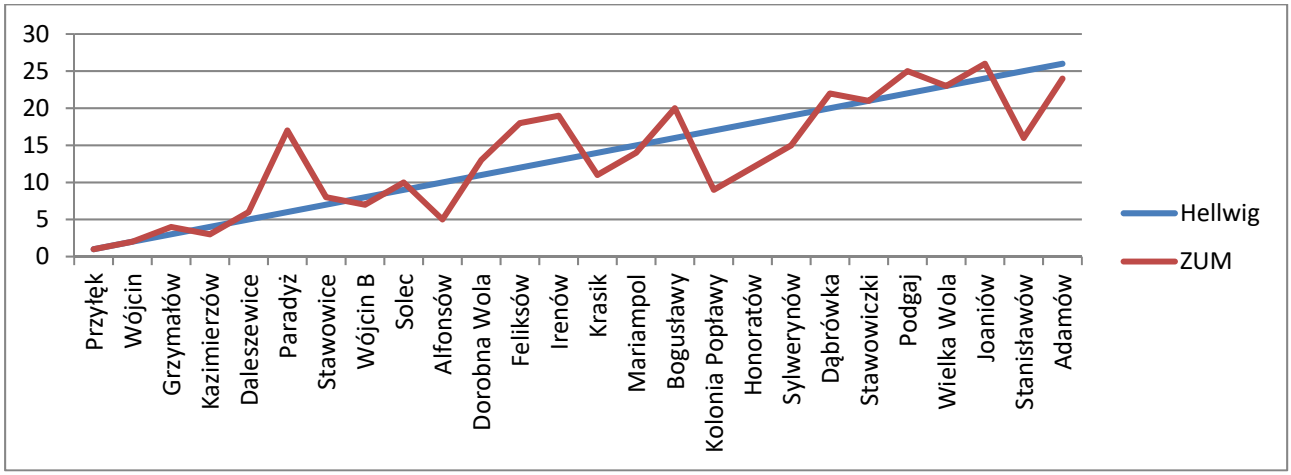

Figure 3. Comparison of results obtained using zero unitarization vs. Hellwig's method

It is worth noting that in eleven cases (42.3% of the total number of villages in the ranking), the urgency ranks of the villages differed only by one 1 position. For six villages (23.1 %), the difference was two positions. An analysis of the two rankings shows clear shifts in ranking positions among some villages in the middle of the ranking list (differences of several positions). These large differences may be due to the similarity of the numerical values of the investigated features for most of the villages in the middle of the ranking lists (similar values of the measures) and some specific characteristics of the two methods which become manifest during calculations.

5. Conclusions

This paper presents the results of two independent synthetic rankings quantifying the urgency of land consolidation and exchange interventions. The rankings were prepared for 26 cadastral communities located in the commune of Paradyż in Łódź Province. 26 factors were used to characterize each of the investigated villages. The values of the synthetic measures obtained using the two methods were compared. The study showed that synthetic measures make it possible to create land readjustment priority rankings for communes and districts. A correct and reliable classification can be achieved if it is based on detailed analyses and expert knowledge. Hellwig's data standardization method and the zero unitarization method give very similar classification results. It seems recommendable that both of these methods be used in spatial analyses carried out to determine the urgency of land consolidation and exchange. It should be remembered that a reliable ranking could only be created if appropriate factors, relevant to the structure of the investigated area are selected.

According to the prioritization rankings created in this study for the commune of Paradyż, the villages that should get into the land consolidation queue first were Przyłęk, Wójcin, Grzymałów and Kazimierzów. Villages with the least defective spatial structure were Adamów and Joaninów.

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