Application of TOPSIS Method to Hierarchization of Land Consolidation Works

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Abstract. The policy of the European Union up until 2020 to be pursued in rural areas is oriented at diversifying their functions. In EU member states, including Poland, the spatial structure of rural areas is transformed by means of the land consolidation process. The basic definition and purpose of consolidation is given in the Act of 26 March 1982 on consolidation and exchange of land where consolidation was defined as a rural management procedure aiming at transformation of the spatial arrangement of rural land in order to create more favourable management conditions by improving the territorial structure of farms, reasonable configuration of land, and aligning the limits of real properties with the system of water irrigation structures, roads and terrain. Undertaking consolidation works which contribute to improving the conditions of agricultural production in all the villages of the analyzed community (gmina) simultaneously is impossible, mostly for economic reasons but also with regard to technical and social problems. Works aiming to improve unfavourable conditions should be carried out successively in villages where they are most urgent. For the needs of analysing the urgency of consolidation works, multidimensional statistical methods can be applied. This publication attempts to apply TOPSIS – a linear ordering method. The idea behind TOPSIS is determining the distance of the analyzed objects from the ideal and anti-ideal solution. The final result of the analysis is a synthetic measure which creates the ranking of the analyzed objects. The best object is the one closest to the ideal solution and at the same time farthest from the anti-ideal solution. A number of analyses regarding the spatial structure of the analyzed gmina were necessary for the ranking purposes. The study area includes 14 villages of the gmina of Rusinów with a registered surface area of 8279.1709 ha, which accounts for 10.3% of the overall area of the powiat of Przysucha.

1. Introduction
The Rural Development Programme for the years 2014-2020 promulgates land consolidation works as geodesic works during which “new plots are formed in a configuration different from that of original plots in order to reduce the number of small, scattered plots constituting a single farm and to increase their average size. The consolidation project also includes works related to post-consolidation management of land, that is, in particular, creating a functional system of access roads to agricultural land and forestland and performing tasks affecting the regulation of the water regime in the consolidated area”.

The combination of the above-mentioned definitions and six priorities of the RDP for 2014-2020 in performing consolidation works will make it possible to follow a multi-functional and sustainable
development scheme combining the conditions of management and elements of the environment and landscape. Consolidation of land leads to restructuring of farms and contributes to improved configuration of land affected by factors such as the area of the farm, number of plots per farm, area of plots, distance of plots from the farmer’s dwelling and the circumference of plots. Also, improved layout of the network of agricultural service roads and their quality are a direct element of the management conditions. In land consolidation projects the configuration, density and width of agricultural roads are improved, thus shortening the access to fields. The quality of surface on agricultural roads to be achieved during post-consolidation management is also considerably improved [15].

The above-mentioned factors are always the elements of a land consolidation project. In addition, the structure of use of land will be also improved by transferring land from small farms to farms with an adequate development potential and designing the arrangement of agricultural plots in such farms in the process of consolidation to ensure that the farms are competitive in the market.

The improvement of the technical and social infrastructure in rural areas and the improvement of living conditions and increasing the investment attractiveness of rural areas (mainly by developing the technical and social infrastructure – including tourist infrastructure), contributes to increasing the chance of finding employment in rural areas. A chance for the development of rural areas is increased interest in those areas as the places for living and leisure. The solutions of the land consolidation project can create conditions for diversified economic activity. The development of non-agricultural activities in rural areas can accelerate structural changes. New jobs appear in connection with the development of services, catering, agritourism etc. [1]. Currently, the policy of the European Union in relation to rural areas is oriented at implementation of the idea of sustainable development. It leads to diversification of the functions of rural areas. Of course production, including mainly food production, will remain the fundamental function in connection with the global increase in food requirement forecasted by FAO. However, different functions assigned to agricultural space should take into account the following components of the equilibrium: agriculture, rural land and the natural environment. Equal treatment of the above-mentioned components is consistent with the objectives of the policies of EU member states regarding rural areas and it is reflected in the promoted idea of multi-functional and sustainable development of rural areas. According to the Act [19], the objective of land consolidation is “creating more favourable management conditions in agriculture and forestry by improving the territorial structure of farms, forests and forestland, reasonable configuration of land, aligning the limits of real properties with the system of water irrigation structures, roads and terrain”.

Consolidation and exchange of land is a technical procedure recommended for fragmented and scattered plots of individual owners. This phenomenon is presented both by Polish authors [16], [18], [5], [10] and in foreign reference literature [14], [3], [4]. Geodesic works connected with consolidation works are limited to separation of new, larger plots, altering their unfavourable geometry and reducing the number of small plots without access to roads and scattered plots situated at a considerable distance from one another or from the farmer's dwelling. These works also comprise creating a new or expanding the existing network of agricultural transport roads providing comfortable access to each of the designed plots [9], [13]. Water regime within the consolidated area must be also taken into account. Also, land owned by the Agricultural Property Agency (now the National Support Centre for Agriculture) can be used for the purposes of land consolidation and exchange. This unit plays an important role in shaping the market of land. Despite Poland has imposed statutory restrictions on trading in land, NSCA can have a considerable influence on the market, in particular in non-urbanized areas [6].

Undertaking consolidation works which contribute to improving the conditions of agricultural production in all the villages at the same time is impossible, mostly for economic reasons but also with regard to technical and social problems. Works aiming to improve unfavourable conditions should be carried out successively in villages where they are most urgent. The urgency of consolidation works is analyzed by means of multidimensional statistical methods [7], [12], [17] Here, the objective of this paper becomes evident – it is the hierarchization of land consolidation works in the villages of the
gmina of Rusinów, situated in Mazovian voivodeship, central Poland. This publication attempts to apply TOPSIS – a linear ordering method used in studies regarding the creation of different types of rankings.

2. Material and methods
For the needs of analyzing the urgency of consolidation works, multidimensional statistical methods can be applied. The studies made an attempt at using TOPSIS – a linear ordering method. The idea behind TOPSIS is determining the distance between the analyzed objects from the ideal and anti-ideal solution. The final result of the analysis is a synthetic measure which creates the ranking of the analyzed objects. The best object is the one closest to the ideal solution and at the same time farthest from the anti-ideal solution. Specific analyses of the defective spatial structure of rural areas were performed based on actual (field) data deriving from EGiB databases performing the function of real property cadastre in Poland. They made it possible to identify features describing the analyzed area. The ranking of urgency of land consolidation and exchange works was created based on features characterizing the analyzed villages. Rankings were prepared for the gmina of Rusinów. In developing the ranking, 21 features were taken into consideration:

- $x_1$ – total surface area of the village (in ha),
- $x_2$ – total number of plots,
- $x_3$ – number of residents,
- $x_4$ – number of residents per 1 km²,
- $x_5$ – percentage of cropland,
- $x_6$ – percentage of permanent meadows,
- $x_7$ – percentage of permanent pastures,
- $x_8$ – percentage of wasteland,
- $x_9$ – percentage of land planted with trees and shrubs,
- $x_{10}$ – percentage of roads,
- $x_{11}$ – productivity ratio of cropland,
- $x_{12}$ – productivity ratio of grassland,
- $x_{13}$ – percentage of the number of plots without access to roads,
- $x_{14}$ – percentage of the area of plots without access to roads,
- $x_{15}$ – average area of a plot within the precinct (in ha),
- $x_{16}$ – percentage of orchards,
- $x_{17}$ – percentage of forestland,
- $x_{18}$ – percentage of bottoms of flowing surface water,
- $x_{19}$ – fragmentation ratio,
- $x_{20}$ – average elongation ratio,
- $x_{21}$ – synthetic ratio of plot elongation for the precinct.

Features from $x_1$ to $x_{14}$ are deemed LTB (larger-the-better) characteristic, whereas $x_{15}$ to $x_{21}$ are STB (smaller-the-better) characteristics. The value of such characteristics for respective villages in the gmina of Rusinów is shown in Table 1. The first stage of the analysis is describing the value of respective variables expressed as descriptive statistics. However, the development of the ranking is preceded by initial selection of diagnostic characteristics. One of the criteria is not including variables with low level of variation (the limit is normally 20 %) [11]. For the analyzed area this relationship is not met only for two features characterizing the gmina of Rusinów (productivity ratio of cropland and productivity ratio of grassland). However, with regard to the significance of these features they were retained for further calculations.

Analysing the features one by one, be it either the structure of use, fragmentation or access of plots to roads, is very useful. However, in order to identify villages with the largest land-related problems for which consolidation is a priority, all these features must be analyzed together. Such a solution is used for creating the ranking of urgency of undertaking land consolidation and exchange works. The underlying aspect is the standardization of variables in terms of their dimension and deprivation of measures, that is, normalization of features. In selecting the method for standardizing the features, it is important that these variables fall within the range $<0;1>$. If this condition for such variables is satisfied, diagnostic features can be aggregated. The final effect is obtaining synthetic features describing the specific village in numbers and allowing their comparison [8]. The method used for the purposes of this publication is TOPSIS method proposed by C. L. Hwang and K. Yoon. This method makes use of two points of reference – ideal and anti-ideal point. The first step is the normalization of variables:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$
where:
\( x_{ij} \) – observation of the variable \( j \) for the object \( i \).

The coordinates of the ideal point are determined as follows:

\[
\text{where the maximum values are adopted for LTB variables, whereas minimum ones – for STB characteristics. The coordinates of the anti-ideal point are determined according to the formula:}
\]

\[
\text{where the minimum values are adopted for LTB variables, whereas maximum ones – for STB characteristics. For every object it is necessary to determine the distance from the ideal point:}
\]

\[
\text{and from the anti-ideal point:}
\]

| Selected features | Mean     | Median   | Min.   | Max.   | Standard deviation | Coefficient of variation |
|-------------------|----------|----------|--------|--------|--------------------|--------------------------|
| x1                | 591,37   | 570,91   | 183,96 | 1039,36| 321,99             | 0,54                     |
| x2                | 2094,64  | 1796,50  | 786,00 | 3971,00| 1146,08            | 0,55                     |
| x3                | 314,36   | 327,50   | 69,00  | 796,00 | 206,89             | 0,66                     |
| x4                | 52,69    | 44,92    | 27,90  | 102,57 | 22,78              | 0,43                     |
| x5                | 0,46     | 0,44     | 0,22   | 0,73   | 0,15               | 0,33                     |
| x6                | 0,06     | 0,07     | 0,02   | 0,12   | 0,03               | 0,54                     |
| x7                | 0,07     | 0,07     | 0,02   | 0,13   | 0,03               | 0,44                     |
| x8                | 0,00     | 0,00     | 0,00   | 0,01   | 0,00               | 0,98                     |
| x9                | 0,03     | 0,02     | 0,00   | 0,08   | 0,02               | 0,74                     |
| x10               | 0,03     | 0,03     | 0,02   | 0,03   | 0,01               | 0,21                     |
| x11               | 0,37     | 0,37     | 0,25   | 0,50   | 0,06               | 0,16                     |
| x12               | 0,35     | 0,37     | 0,18   | 0,38   | 0,05               | 0,15                     |
| x13               | 0,22     | 0,21     | 0,02   | 0,40   | 0,10               | 0,47                     |
| x14               | 0,15     | 0,14     | 0,01   | 0,28   | 0,08               | 0,52                     |
| x15               | 0,29     | 0,25     | 0,17   | 0,47   | 0,10               | 0,34                     |
| x16               | 0,03     | 0,01     | 0,01   | 0,07   | 0,02               | 0,84                     |
| x17               | 0,28     | 0,28     | 0,05   | 0,57   | 0,15               | 0,55                     |
| x18               | 0,00     | 0,00     | 0,00   | 0,02   | 0,01               | 1,52                     |
| x19               | 2,24     | 2,24     | 1,25   | 3,44   | 0,65               | 0,29                     |
| x20               | 2,47     | 2,23     | 1,44   | 3,96   | 0,80               | 0,33                     |
| x21               | 1,88     | 1,69     | 1,10   | 3,64   | 0,67               | 0,36                     |
The value of the aggregate variable is determined as follows:

\[ q_i = \frac{d_{j0}^-}{d_{j0}^- + d_{j0}^+}. \] (6)

The synthetic development measure does not exceed \( <0;1> \). The higher the value of the synthetic measure, the higher the ranking position of the specific object is [1].

3. Results and discussions

21 features listed in Table 1 were used in developing the ranking of urgency of land consolidation and exchange works. Aggregate variables were calculated by means of TOPSIS. Synthetic measures were determined. Based on the resulting measure, the ranking position was assigned to every precinct. The highest position is that of villages for which the synthetic measure reached the highest value; simultaneously, this is where land consolidation is most needed. The ranking is presented in Table 2.

| Ranking position | Name of precinct       | Value of synthetic measure |
|------------------|------------------------|----------------------------|
| 1                | Rusinów                | 0.623                      |
| 2                | Gałki                  | 0.557                      |
| 3                | Zychorzyn              | 0.555                      |
| 4                | Krzesławice            | 0.546                      |
| 5                | Brogowa                | 0.543                      |
| 6                | Bąków Kolonia          | 0.534                      |
| 7                | Klonowa                | 0.514                      |
| 8                | Wola Gałecka           | 0.512                      |
| 9                | Bąków                  | 0.504                      |
| 10               | Grabowa                | 0.500                      |
| 11               | Władysławów            | 0.484                      |
| 12               | Przystałowice Małe     | 0.481                      |
| 13               | Karczówka             | 0.475                      |
| 14               | Nieznamierowice        | 0.373                      |

The performed studies indicate that the most urgent need for land consolidation works occurs in the village of Rusinów situated in the central part of the analyzed gmina. The synthetic measure for the village was 0.623. In the following 9 villages the value of the measure ranged from 0.500 in Grabowa to 0.557 in Gałki. Władysławów, Przystałowice Małe, Karczówka and Nieznamierowice are villages characterized by the lowest need for land consolidation works. The location and the urgency of consolidation works in the analyzed gmina are illustrated in fig. 1.
4. Conclusions

The studies show that land consolidation is required in the villages situated in the gmina of Rusinów. It is impossible to consolidate land in the entire gmina at the same time for financial and technical reasons. Therefore, it was necessary to determine the hierarchy of urgency of consolidation works. In the analyzed gmina, the precincts for which consolidation should be a priority are: Rusinów, Zychorzyn, Galki, Krzesławice and Brogowa. A characteristic feature of these villages is the small average area of plots. In addition, the share of land planted with trees and shrubs is high. The synthetic elongation ratio for these villages is quite low, although in Krzesławice it has the second highest value in the gmina. The other end of the ranking is occupied by villages where no urgent need for consolidation occurs. These are: Nieznamierowice, Władysławów, Przystałowice Małe and Karczówka. They have a low ratio of productivity of grassland, except Karczówka where this ratio is the highest one in the gmina. A small problem regarding plot elongation can be also observed in these villages.

The spatial structure of the analyzed gmina pointed to its typically agricultural nature. Agricultural land accounts for 60.5% of land owned by the gmina, including cropland covering 44.5% of the area of the analyzed area. Forestland accounts for 33.1% of land in the gmina of Rusinów. In the gmina of Rusinów plots with an area up to 0.10 ha and from 0.11 to 0.30 ha account for 71.0% of all farms owned by individual farmers. The largest number of plots with the smallest area occurs in the village of Rusinów. The analysis of the network of agricultural transport roads shows a major problem with the lack of access of plots to roads in the village of Karczówka, where as many as 39.9% of plots have
no access to roads. The lack of access of plots to roads is a large problem throughout the gmina since, as shown by the surveys, every fifth plot has no direct access to a road.

With regard to the high defectiveness of the spatial structure of the analyzed villages, the technical procedure of land consolidation and exchange is recommended. As mentioned in this publication, simultaneous consolidation of land in the whole gmina is not possible. Therefore, the linear ordering method called TOPSIS was used for the purposes of establishing the hierarchy of urgency of the works. The method facilitated the ranking of villages selected for consolidation. These measures can be helpful in the allocation of funds from EU grants for the reconstruction of the spatial structure of the rural areas in Poland.

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