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PROPOSAL OF A LAND USE AND AGRICULTURAL PLANS METHODOLOGY: A CASE STUDY OF POLAND

Abstract: Land use and agricultural plans mainly realize needs related to shaping agrarian production space in Poland. These are essential tools to ensure that rural areas are correctly functional and can continue to develop. The study aimed to develop a methodology using a GIS environment to accelerate and facilitate the diagnosis of areas requiring transformation within land use and agricultural plans or land consolidation. It was assumed that the proposed methodology would allow the presentation of information about the study area in a clear and easy-to-interpret manner. The paper presents the developed analysis methodology and the results of its testing in the Cegłów municipality. The developed method comprehensively identifies problem areas in need of transformation of spatial structure and transformation of development. It focuses primarily on the most relevant issues concerning the structure of land parcels, also considering ancillary elements from the field of supplying municipalities with adequate infrastructure or services. For this reason, it is also possible to study the municipality in terms of non-agricultural forms of development. It is made to minimize the number of steps for the user, focusing only on the most relevant aspects of land use and agricultural plans. The methodology can be further developed, and further work is required to improve and develop it. In particular, it needs to enhance the visualization of problem areas, especially for infrastructure issues and services.

Keywords: land use and agricultural plans, spatial planning, development of rural areas, land consolidation

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Introduction

Land use and agricultural plans are essential for properly functioning and developing rural areas. It is crucial that rural development is recognized as a multi-level process rooted in historical traditions (Van der Ploeg et al., 2000) and that it is implemented comprehensively (Liu et.al., 2018). In Poland, the origins of land use and agricultural plans can be traced back to the medieval period (Taszakowski & Korta, 2019). Today, land use and agricultural planning processes are much more complex. Nevertheless, their main objective remains to put the rural space in order. To this end, land consolidation works, among others, consist of modifying the ownership structure of the area so that the living comfort and efficiency of the inhabitants are improved (Woch, 2008). Land use and agricultural planning are important tools in the management of rural space as they significantly affect its functionality, food production (Jónsdóttir & Gísladóttir, 2023), and attractiveness as a place to live (Bielska et al., 2024). Land use and agricultural plans are also important because of the structure of other planning documents, which, in their content, do not address many of the elements that influence the proper functioning of rural municipalities (Markuszewska, 2012).

Unfortunately, despite the apparent improvement in agricultural land distribution during the last 20 years, the demand for land consolidation work in Poland is still high. (Jadczyszyn & Woch, 2017). These problems are due to several factors, such as the pace of land consolidation work and changes in farm structure. Nevertheless, simplification of the procedure of transformation and development of rural areas as a result of land consolidation is also an important problem (Markuszewska, 2013). As rural development continues, the demand for land consolidation, land use, and agricultural works is forecast to increase, posing a challenge for local authorities and contractors (Jadczyszyn & Woch, 2017).

Similarly, as in how land use and agricultural work are carried out, we see transformations in design and survey practice today. With the development of digital technologies, the way many fields of science are viewed is changing. Previous disciplines fragment, and new, previously non-existent areas are gaining prominence. This trend is reflected in the growing use of geographic information systems (GIS). They provide the scientific community with new tools, methods, or opportunities for interdisciplinary data analysis (Werner, 2018). The use of digital methods of analysis could address the challenges that current surveyors and planners face, as described earlier. They could find application in the drafting of land use and agricultural plans. Due to the high number of spatial and statistical analyses performed, GIS is a convenient tool for their implementation. Using the software for this purpose would increase the efficiency and quality of drafting, relieve the burden on clerical staff, and accelerate the pace of transformation of the Polish countryside.

The study aimed to develop a methodology using a GIS environment to accelerate and facilitate the diagnosis of areas requiring transformation within land use and agricultural plans or land consolidation. It was assumed that the proposed methodology would allow for the presentation of information about the studied area in a clear and easy-to-interpret manner. Areas needing transformation are understood to be areas whose functionality or productivity deviates from accepted assumptions and standards, i.e., the dimensions or area of agricultural parcels.

Materials and methods

The research was carried out in 4 stages:

1. Analysis of the literature on the scope and needs for the development of land use and agricultural plans, and the possibility of using spatial analysis to improve the development of these documents.

A review of the scientific literature and selected land use and agricultural plans was conducted to identify the most important considerations whose analysis could be optimised through GIS technology. The scientific literature was then reviewed to identify tools and methods that could be used in the methodology being developed to support the development of land use and agricultural plans. A total of 4 land use and agricultural plans made for the areas of the Lower Silesian Voivodeship – 2, the Mazovian Voivodeship – 2, and the Podkarpackie Voivodeship – 1 were analysed. A land use and agricultural plans methodology was developed based on the results.

2. Proposal of a Land Use and Agricultural Planning Methodology – LUAP-M.
3. Testing of LUAP-M in the LUAP-M study area.
4. Provide recommendations and conclusions on the methodology developed.

The study area consists of selected precincts of the urban-rural municipality of Cegłów. It is a commune located in the Mazowieckie Voivodeship, Mińsk County. It is located about 50 km east of Warsaw and about 13 km from Mińsk Mazowiecki (Fig. 1). The municipality of Cegłów is mainly characterised by small farms. A level terrain with low denivelations characterises the area. The analysis area is limited to a few villages in the southwest of the municipality. The main reason for selecting the area is the spatial diversity of the ownership structure, characterized by unfavorable farm land layout. The problems concern the main elongated shape and the small area of the registered parcels.

Results and discussion

Proposal of a land use and agricultural plans methodology – LUAP-M. An analysis of the literature and exemplary (4) land use and agricultural plans showed that the existing documents coincided with the recommendations described by Woch (2008) and contain the results of analyses according to the criteria presented in Table 1. Therefore, the elements described in his article form the basis for implementing land use and agricultural plans. The designed LUAP-M methodology responds to the complex and time-consuming process of diagnosing problem areas and designing land use and agricultural plans. It is therefore characterized by a low number of analyses and their stages, as well as the simplicity of execution. LUAP-M is intended to be based on data with low subjectivity and to diagnose areas needing transformation consistently. The criteria selection was based on three important characteristics: high weighting/relevance, low complexity, and spatial reference.

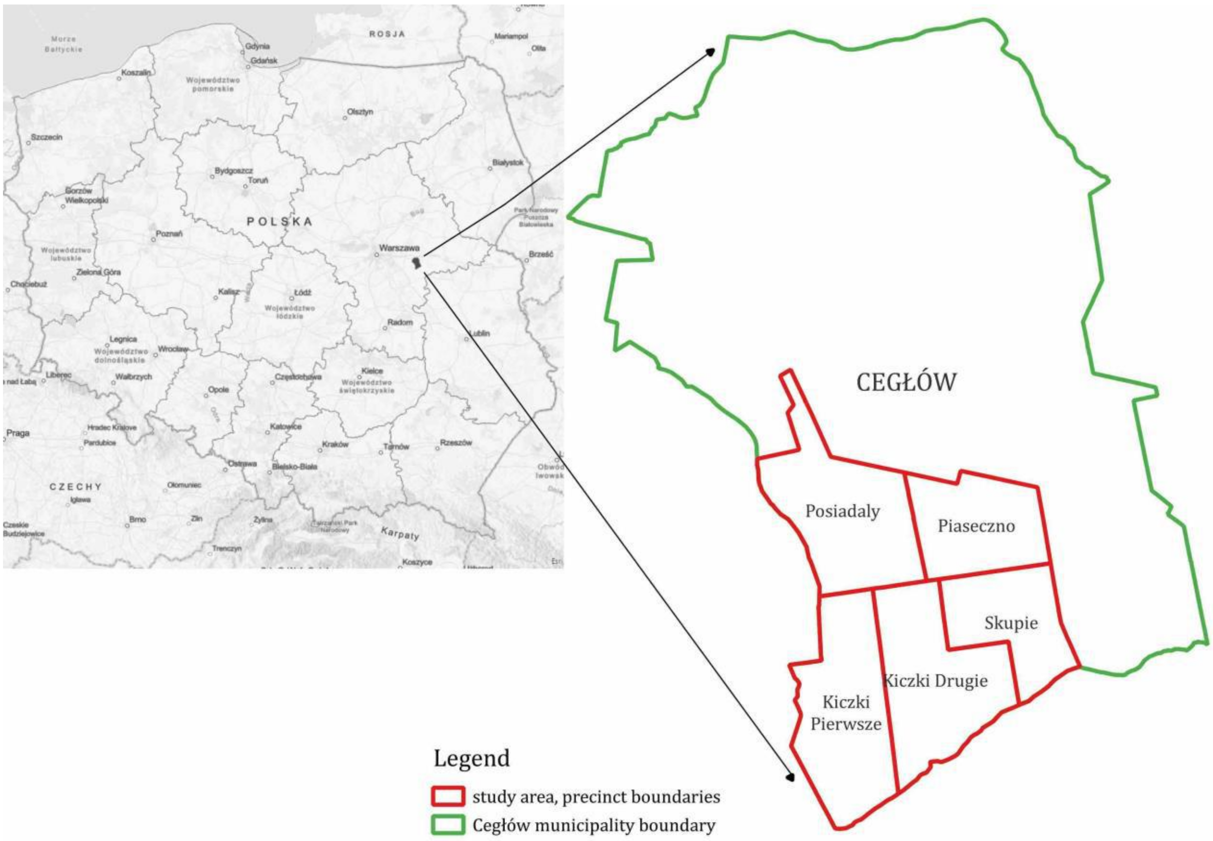

Fig. 1. Spatial scope of the analysis area
Source: own study based on databases of the State Register of Borders (PRG)

The concept of importance/relevance refers to the relevance of a criterion in diagnosing land in need of transformation. These criteria form the basis of the site's functionality and determine the course of action at the implementation stage of land use and agricultural plans. Secondary elements that provide additional information for decision-makers are omitted to simplify the methodology. Consequently, the criteria should be simple to implement and interpret. It was assumed that the analyses should have the lowest possible complexity and the lowest number of necessary steps. They should be able to be presented objectively, based on rigorous data. LUAP-M assumes the use of GIS environment tools such as ArcGIS or QGIS. In addition, the data should relate primarily to the current level of functionality of the site, supporting its diagnosis.

Following the adopted assumptions, criteria, and indicators characterizing the conditions of rural development were identified in Table 1.

Table 1. Criteria and indicators characterizing determinants of rural development

Criterion	Indicator	Data
1. Demography and employment structure	I-1.1. Population density	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Building Layer (BUBD) BUBD01 – single-family residential buildings BUBD02 – two-apartment buildings BUBD03 – three- or more-apartment buildings BUBD04 – collective housing buildings
2. Natural conditions	I-2.1. Susceptibility to water erosion	Head Office of Geodesy and Cartography (GUGiK) Digital Elevation Model (NMT) Agricultural Soil Maps – soil genus and soil species
	I-2.2. Nature conservation	General Directorate for Environmental Protection (GDOŚ) Public geospatial dataset – layers regarding location of the following subjects e.g.: • Landscape Parks • Protected Landscape Areas • Natura 2000 habitats • Nature and Landscape Complexes • Documentation Sites • Ecological Sites • Natural Monuments
3. Structure of production space	I-3.1. Plot dimensions	District Centre for Geodetic and Cartographic Documentation Powiat miński Land and Building Register (EGiB)
	I-3.2. Shape of plot	District Centre for Geodetic and Cartographic Documentation Powiat miński Land and Building Register (EGiB)
	I-3.3. Plot area	District Centre for Geodetic and Cartographic Documentation Powiat miński Land and Building Register (EGiB)
	I-3.4. Ownership structure	District Centre for Geodetic and Cartographic Documentation Powiat miński Land and Building Register (EGiB)
4. Technical infrastructure	I-4.1. Availability of roads	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Communication Network (SKDR) Land and Building Register (EGiB)
	I-4.2. Availability of utilities	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Utility Network (SU)

5. Social infrastructure	I-5.1. Availability of educational services	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Building Layer (BUBD) BUBD15 budynki szkół i instytucji badawczych
	I-5.2. Accessibility to commercial services	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Building Layer (BUBD) • BUBD08 – commercial and service buildings
	I-5.3. Accessibility of cultural services	Head Office of Geodesy and Cartography (GUGiK) Database of Topographic Objects (BDOT10k) – Building Layer (BUBD) • BUBD13 – publicly accessible cultural facilities • BUBD14 – museum and library buildings • BUBD17 – physical culture buildings Supplemented by OpenStreetMaps database

Source: own study based on Woch (2008)

Characteristics of relevant indicators in the criteria adopted for LUAP-M. Population density (I-1.1) is a valuable indicator for identifying the people affected by the problems of the area or the planned changes. It helps to determine the best location for new public service facilities or prioritize areas needing transformation. The method uses data on the housing stock of the study area. The first step is to extract the residential buildings layer (BUBD) from the Database of Topographic Objects (BDOT10k) (Geopotral, 2025). To do this, the Select by Attribute tool selects objects with codes 01 to 04. The Total Building Area was calculated based on the surface area attribute of residential buildings belonging to the BUBD layer with codes from 01 to 04. Buildings surface was multiplied by the number of floors, giving Total Building Area estimated value. This area is made in large approximation, as it is based on the general building area, not the actual usable area. The selected objects should then be exported to a new layer. A new column should be created in this layer to store the total area of each building. This area is approximate, based on the total building area and not the floor area. Before moving on to data visualization, changing the data format to point data is necessary. The reason for this is the incompatibility of the Kernel Density function with surface data. The Extract Multi Values to Points tool changes the layer to a point format. This allows the data to be reformatted while retaining the attribute table values. The layer thus created is then used in the Kernel Density tool to produce the final result.

Susceptibility to water erosion (I-2.1) – a feature that may negatively affect the quality of agricultural production space. The methodology assumes the diagnosis of the area in terms of the threat of leaching. For this purpose, erosion intensity levels were used (Józefaciuk & Józefaciuk, 1999), enabling quick and simple classification of land regarding susceptibility to water erosion. Due to the unambiguous categorization method, the methodology is suitable for automated large-area studies. The methodology also uses selected assumptions of the LUCIS (Land-Use Conflict Identification System) methodology (Carr & Zwick 2007). LUCIS aims to detect spatial conflicts between forms of development. It allows planning optimal alternatives and land use in the future (Carr & Zwick, 2007). The methodology is based on two layers of data, which contain information on the soil's granulometric composition and the terrain's slope. The layers are in vector and raster formats, respectively, which requires the selection of one standard format on which further operations will be carried out.

In contrast to the other studies, the methodology assumes that raster layers are used to implement the criterion and its visualization. The high complexity of the geometry of the terrain slope layer causes the choice of the raster format. In a vector study, it would be impractical, slowing down the tools and the overall responsiveness of the program. Before changing the format of the layer with granulometric composition, it is necessary to reclassify it. This is done in a column created for this purpose, following the division of soils (Józefaciuk & Józefaciuk, 1999). 'Very strongly susceptible' soils are assigned the value '10', while 'very weakly susceptible' soils are assigned the value '50'. The remaining categories are assigned the corresponding 20, 30, and 40 values. The layer is then transformed using the Feature to Raster tool. Similarly, the Reclassify tool is used for the slope layer, which allows changing the ranges of pixel values. The slope layer is obtained by applying the Slope tool to the digital terrain model (DTM). The values should be marked with numbers from 1 to 5. The result should be two layers categorizing individual areas into rows and columns of the table, respectively.

Despite categorizing individual layers, their connection turned out to be a relatively complicated operation, because they store information about the affiliation of areas to rows and columns, and standard methods of their connection, i.e., multiplication or summing, turned out to be ineffective. For this purpose, selected assumptions of the LUCIS methodology were used. Due to the adopted categorization of layers, it was possible to use a concept similar to that in LUCIS. In the case of the designed methodology, the digits store information about the column and row of the table to which the given pixels belong. With this assumption, both layers are summed using the Raster Calculator tool. Then, the results should be reviewed, and the Reclassify tool should be used again to assign the degree of erosion intensity. An example process is presented in Table 2.

Table 2. Example of how to perform soil categorization

L.p.	Soil susceptibility class	Slope class	Sum of layers	Degree of erosion severity
1	10	1	11	1
2	10	2	12	2
3	20	3	23	2
4	50	1	51	0
5	50	5	55	3

Source: own study based on Józefaciuk & Józefaciuk (1999)

Nature conservation (I-2.2) significantly impacts the climate and is one of today's most important challenges. From the spatial planning perspective, the boundaries of protected areas and the restrictions in force on their territory must be respected. For this reason, the LUAP-M methodology includes a study whose task is to provide information on the forms of nature conservation located in the analysis area. The study consists of loading the layers of nature conservation forms and studying their restrictions. The data is publicly available from the General Directorate for Environmental Protection (GDOŚ). Data symbols can be changed according to your preferences, but it is important to maintain the legibility of the boundaries of individual forms of protection.

Plot dimensions (I-3.1) were analyzed using multidimensional spatial analysis (Grekousis, 2020). This method was used to visualize the width and length of agricultural plots simultaneously. The visualization assumes a two-dimensional matrix in which the location depends on the values of both plot dimensions. The width of the plot determines the row in which they are located, while the length determines the column. The number of columns and rows depends on the level of accuracy we want to achieve. However, it must be borne in mind that the readability of the map made in the further stage of the analysis will decrease with increasing accuracy. A value gradient is added to the matrix made in this way, and a two-dimensional symbology is adopted. It consists of perpendicularly superimposing two two-dimensional gradients. They correspond to the values of the width and length of the dimensions of the plot. In this way, individual cells of the matrix inherit the symbology of both dimensions, which allows them to be read simultaneously.

The threshold values in the analysis are 20 to 40 meters for width and 300 to 600 meters for length of the plots (Noga, 2001). These values may vary depending on the terrain's slope or the production method. However, the analysis has no contraindications to changing the dimensions considered most appropriate for a given area. The method of calculating the dimensions of the plots is based on the assumption that the shape of the plots is close to a rectangle. Since this assumption is not always possible to choose, especially for areas of southern Poland, it is necessary to first familiarize yourself with the area being studied and assess the possibility of its application. For other areas of the country, this assumption does not significantly affect the discrepancies between the results of the analyses and the actual dimensions of the plots. Having the area and perimeter of the plot, together with the assumption described earlier, it is possible to derive a quadratic equation for one of its dimensions. After calculating one of the dimensions, the other can be calculated from the equation for the area or perimeter of a rectangle. Equation (1) for the first of the dimensions looks as follows:

$$X = \frac{\sqrt{(O^2-16*P)^2-O}}{4} \quad (1)$$

where::

X − one of the dimensions of the plot
O − plot perimeter
P − plot area

The equation derived this way should be used in the Field Calculator tool, replacing the variables with their corresponding attribute columns.

The result should be two columns storing information about the plot dimensions. However, the information in both columns is unsorted, containing plot widths and lengths. They must be sorted out before further analysis steps can be taken. This requires the creation of additional columns – one for the width of the parcel (smaller value) and one for its length (larger value). The Field Calculator tool and the min and max functions are applied to both columns. For both functions, the columns storing the unsegregated values of the plot dimensions must be selected. After running the tool, the newly created columns should contain categorized attributes.

The thus sorted data can then be visualized using the Bivariate Colors symbology. It provides the possibility to visualize two variables simultaneously, which aligns with the multidimensional spatial analyses described in the introduction to this step.

The shape of the plot (I-3.2) is an indicator of great importance in the study of the spatial structure of plots. Methods for investigating similarities or differences between objects and their correct grouping involve a number of problems depending on the target effect. In many cases, it is the complex and irregular structure of the objects or the omission of visual perception in strictly mathematical analyses. However, these methods are highly complex and geared towards scientific analysis, requiring several multi-step calculations and analyses (Fan et al., 2021; Kwinta & Gniadek, 2017). An optimal solution would be an analysis that allows the rapid and efficient extraction of plots that meet predefined criteria. For this purpose, a coefficient was designed to examine the plots' similarity to a predefined contour. It is based on a modified Path Compactness analysis. Its purpose is to test the compactness of an object by comparing its area to that of a circle of identical circumference. The equation for the Path Compactness coefficient (2) is as follows (Eastman, 2020):

$$C = \sqrt{\frac{A_p}{A_c}} \quad (2)$$

where:
C − compactness factor
A_p − area of an object
A_c − area of a circle with a common perimeter

In the projected ratio, a circle's area is replaced by a rectangle with an aspect ratio of 1:5 (Noga, 2001). Thus, instead of examining the compactness of the contours, their similarity concerning the optimum shape is examined. Equation (3) for the described method is as follows:

$$W = \frac{P_d}{P_i} \tag{3}$$

where:
W – shape factor
P_d – plot area
P_i – area of optimum plot with common perimeter

This method also assumes that the shape of the plots approximates a rectangle to a large extent. In the case of the study area, this assumption does not significantly affect the study results. Instead, it allows the area of the optimal plot to be calculated quickly. Using the coefficient assumption concerning the common perimeter, it is possible to derive the dimensions of the optimal plot. Equation (4) for the area of the optimal plot is as follows:

$$Pi = \frac{1}{12}L * \frac{5}{12}L = \frac{5}{144}L^2 \tag{4}$$

where:
P_i – area of optimum plot
L – plot perimeter

After completing equation (3), substituting the previously derived equation (4) into P_i takes the following form (5):

$$W = \frac{144\,P_d}{5 * L^2} \tag{5}$$

where:
W – shape factor
P_d – plot area
L – plot perimeter

The resulting coefficient is theoretically within the interval (0;1.8>. In some cases, due to the assumption accompanying the methodology, the value may fall outside the theoretical range. Values approaching 1 mean that the study plot has a ratio of dimensions close to optimal. Values approaching 0 mean that the plot has a high elongation. Values approaching 0 when the elongation of the plot tends towards infinity. When the shape of the plot is close to a square, the values of the coefficient will oscillate around the value of 1.8 (Fig. 2).

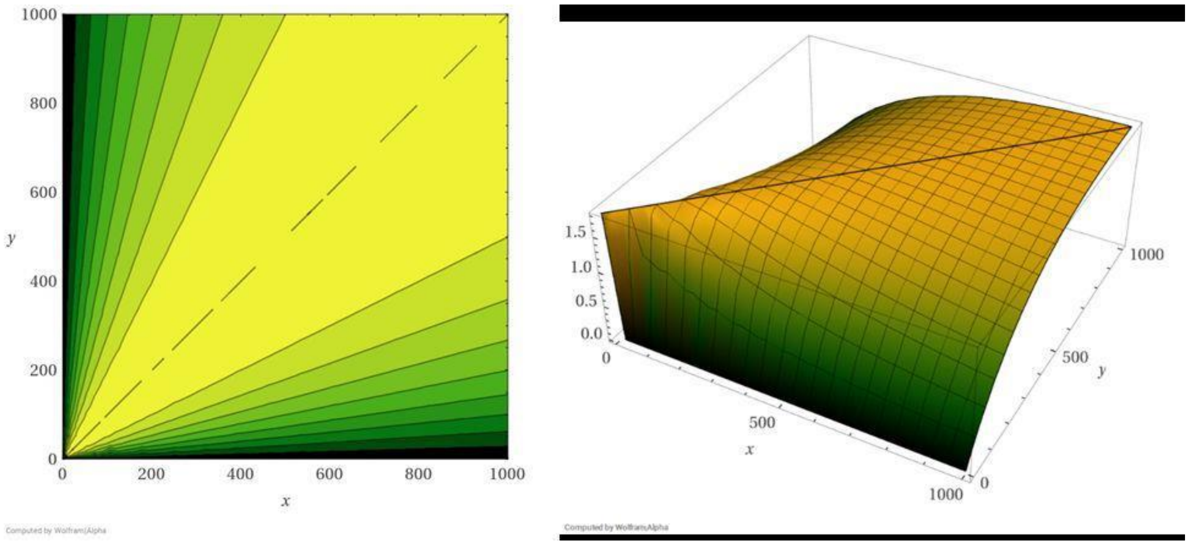

Fig. 2. Plots of the form factor function in 2D and 3D environments
Source: own study using the WolframAlpha tool

Despite the complexity of its implementation, it is relatively quick and easy to perform. It merely involves creating an additional column in the attribute table using the Field Calculator tool. This needs to be completed with the final form of the coefficient formula, replacing the variables with the corresponding columns of the attribute table.

Plot area (I-3.3) – represents one of the most important elements determining the degree of their productive efficiency. Currently, a polarization of farms in terms of area (Sulewski, 2008). For this reason, plot area analyses must be included in the designed LUAP-M methodology. It will allow for diagnosing areas characterized by small plot areas and their transformation at the project introduction stage.

The parcel area analysis is characterized by a simple implementation, consisting only of changing the Symbology of the parcel layer from the land and building register database (EGIB) to represent the area of polygons. In order to obtain more detailed data, the Summarize Attributes tool can be used, where, for example, the average surface area for individual precincts can be calculated.

Ownership structure (I-3.4) – may affect the final production efficiency of farms. In the case of a high distance of agricultural plots from farm buildings, access to them is time-consuming and fuel-intensive (Gniadek, 2012). The analysis aims to present the problem of plot fragmentation in the form of a choropleth map. In order to calculate the total number of plots in a farm, it is necessary to obtain data from the EGIB database. The layer table concerning the land ownership structure should contain a column containing the identification numbers of the registration units (JR), related to the owners of the plots. Using the Summarize tool and the Count function, it is possible to obtain the number of plots for each identifier (JR). The effect of the operation should be a separate table, which should be connected to the input layer using the Add Join tool. After connecting it to the polygon layer using the JR code, the number of plots in the farm will be assigned to each object. The data can then be visualized using a continuous gradient of values in any color. Availability of roads (I-4.1) – affects the comfort of using a given area. Its absence causes spatial chaos, as well as neighborly conflicts. Such cases are very undesirable. Therefore, it is important to detect them at the land use and agricultural works project stage. In order to obtain data on the course of roads, it is necessary to use layers from the EGIB database, later supplemented with additional data sets. Information on the type of land use (dr – road) and the area of the plot will be obtained from the EGIB data. In order to supplement the analysis, data obtained from the BDOT10k database were used, concerning the course of roads, their classes, and additional technical parameters.

The Select by Location tool was used for the analysis. Its task is to examine the relationship of objects, in this case, roads and plots, based on their mutual location in space. After selecting the appropriate layout of the two layers and setting the Intersect relationship, increasing the Search Radious value to, for example, 5 m is still necessary. The need arises from the linear format of the data. By enlarging the search area, the tool also selects objects slightly away from the roadway axis, not only those with which it intersects. When the tool is activated, the selection should include parcels most likely to have access to the road. Finally, the action described earlier using the Field Calculator tool is repeated. The result should be a layer that shows the status of road accessibility for each parcel of land. A cartogram can represent the results of the work.

Availability of utilities (I-4.2) – plays a crucial role in the proper functioning and development of rural areas (Chudy, 2011). The analysis aims to show areas of development for which access to utilities may be difficult, especially in the event of further expansion. It examines the current distance of the development from the principal axes of the networks supplying the area with utilities, presenting them as a cartogram.

The method starts with loading layers showing the selected networks' course. From these, the distance to residential buildings is measured. The distance value is obtained using the Euclidean Distance tool, which creates a distance raster about the selected object. The next step is to separate the residential development from the rest. To do this, the Select by Attrubute tool selects all objects that meet the specified condition. In the case of the BDOT10k database, these are residential buildings (BUBD) with codes 01 to 04. The resulting layer should be transformed into a point layer using Feature to Point. The resulting points should be used as the destination of the Extract Values to Points tool. This step is repeated for each network, creating separate columns for them. The layer can then be presented separately for each network. The highest values indicate the most significant distance from the existing network.

The availability of services (I-5.1, I-5.2, I-5.3) is an important element in determining rural areas' functionality and pace of development. It also affects residents' quality of life and work (Dolata, 2016). The LUAP-M methodology operates on an assumption similar to the analysis of media availability, using data on the function of the building. As a result, it presents the distance of individual households from points performing service functions. These points should be separated using the Select by Attribute tool from the layer containing building data. In the case of socio-cultural elements, it may be necessary to analyze the objects in the area and select them manually. Then, use the Euclidean Distance tool on each of the layers. The distance results should be copied to the residential development points obtained in the previous stage of the methodology. A study presenting the location of objects about the rest of the development may also be prepared for the analysis. It may be important to have a clear visualization of all objects simultaneously.

LUAP-M testing in the research area. The developed LUAP-M methodology was tested in the research area. Below, selected test results are presented and discussed. Population density (I-1.1) – Having information on population density (Fig. 3), it is possible to determine what course of action will be optimal for the most significant number of residents. The location depends primarily on the nature of the service and the level of demand for it in other villages. This is valuable information, which, on a larger scale, can also determine the place where land use and agricultural work are performed.

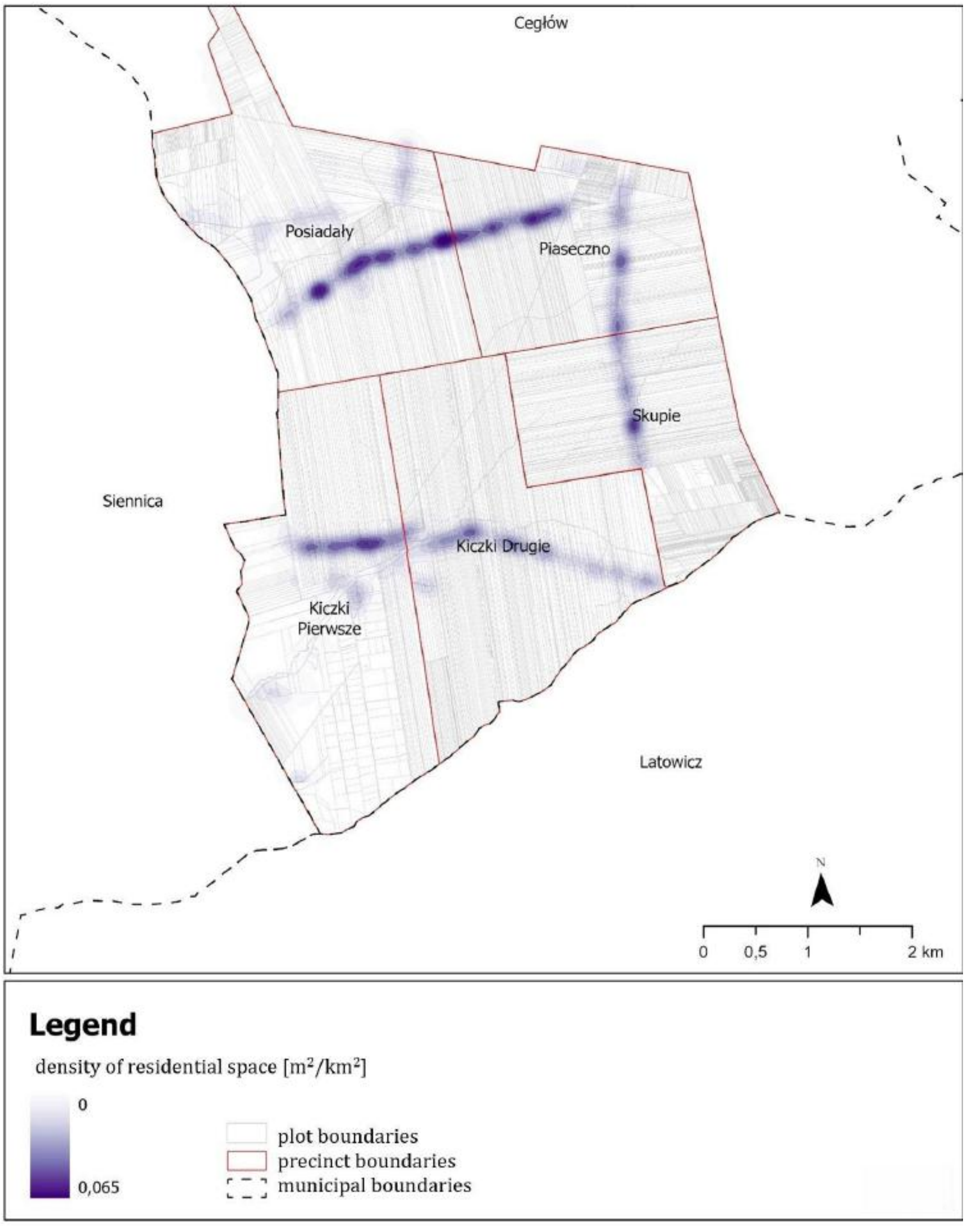

Fig. 3. Map of estimated population density for the analysis area
Source: own study based on BDOT10k, EGIB, and PRG databases

Susceptibility to water erosion (I-2.1) – Due to the flat terrain, the Cegłów commune is characterized by low water erosion intensity (Fig. 4).

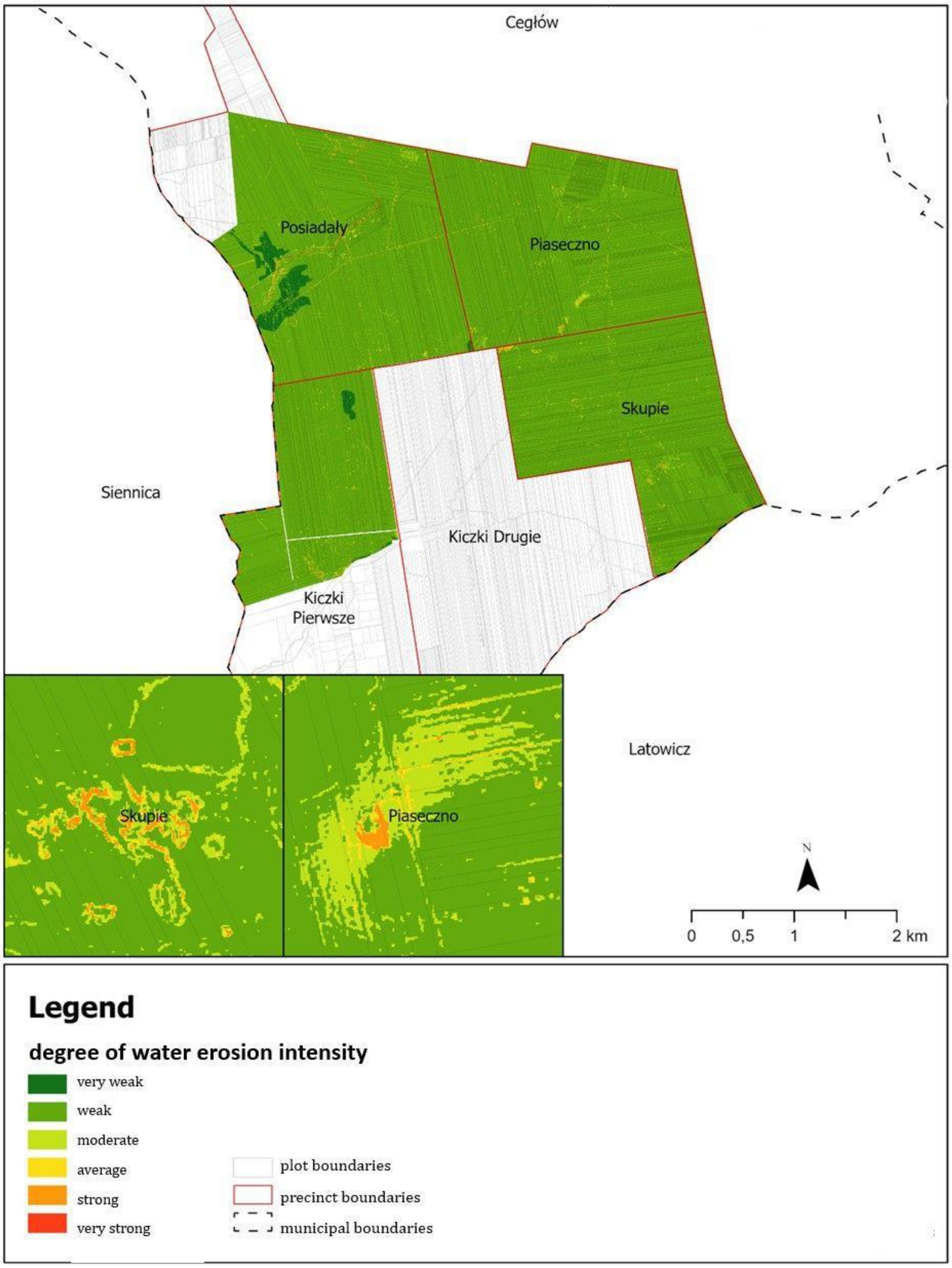

Fig. 4. Map of the degree of water erosion intensity for the analysis area
Source: own study based on Józefaciuk & Józwfaciuk (1999) and EGIB and PRG data

Nature conservation (I 2.2) – The analyzed area is located in a small part within the Mińsk Protected Landscape Area (Fig. 5).

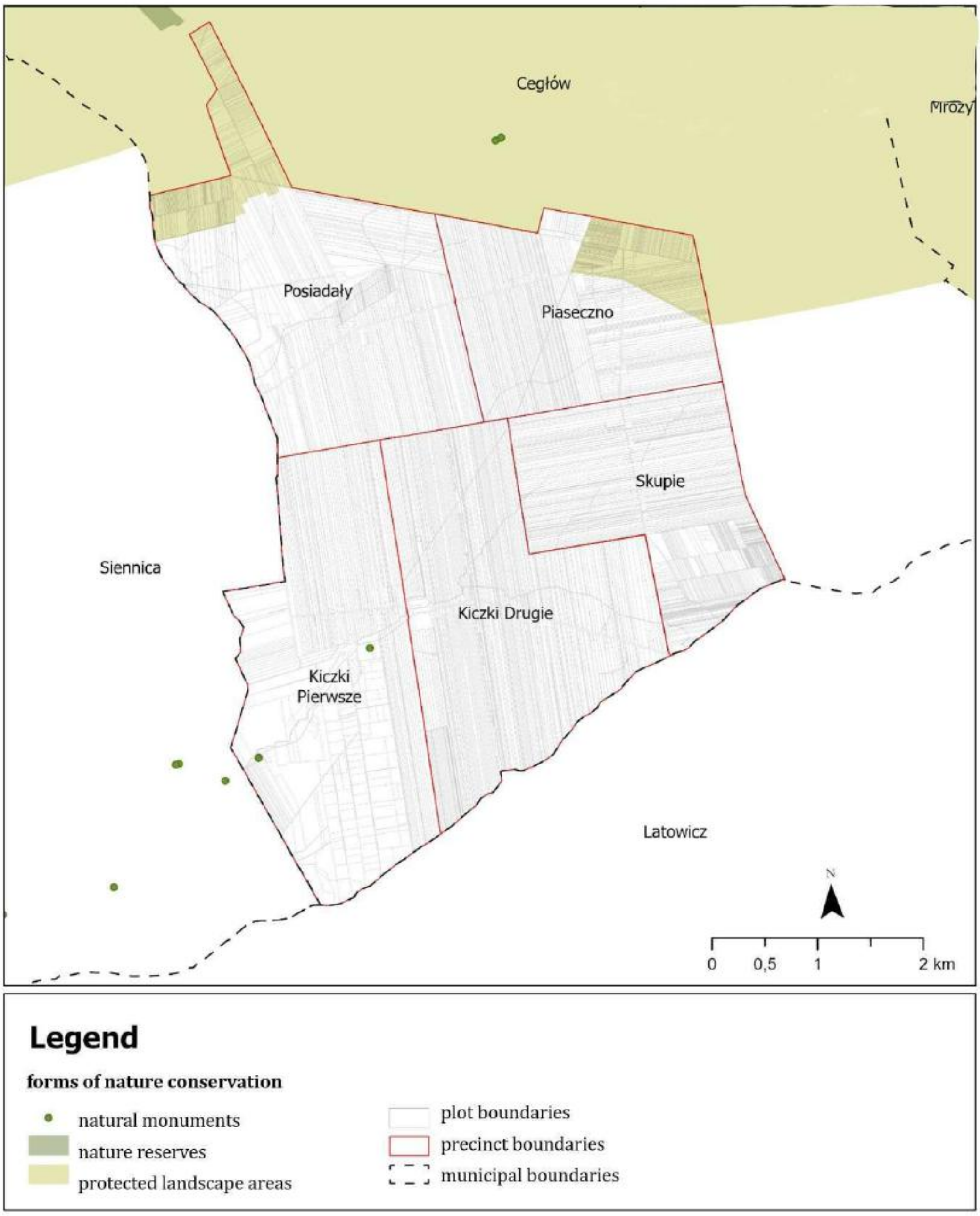

Fig. 5. Map of nature protection forms for the analysis area
Source: own study based on GDOŚ, EGIB, and PRG data

Plot dimensions (I-3.1) – Based on this analysis, one can see the trends that characterize the studied area (Fig. 6). In the case of the south- and north-western areas, plots with a high width and low length are intensified. In the process of land consolidation, it is therefore possible to propose the construction of an additional road in the central part of the study area, enabling access to the plots.

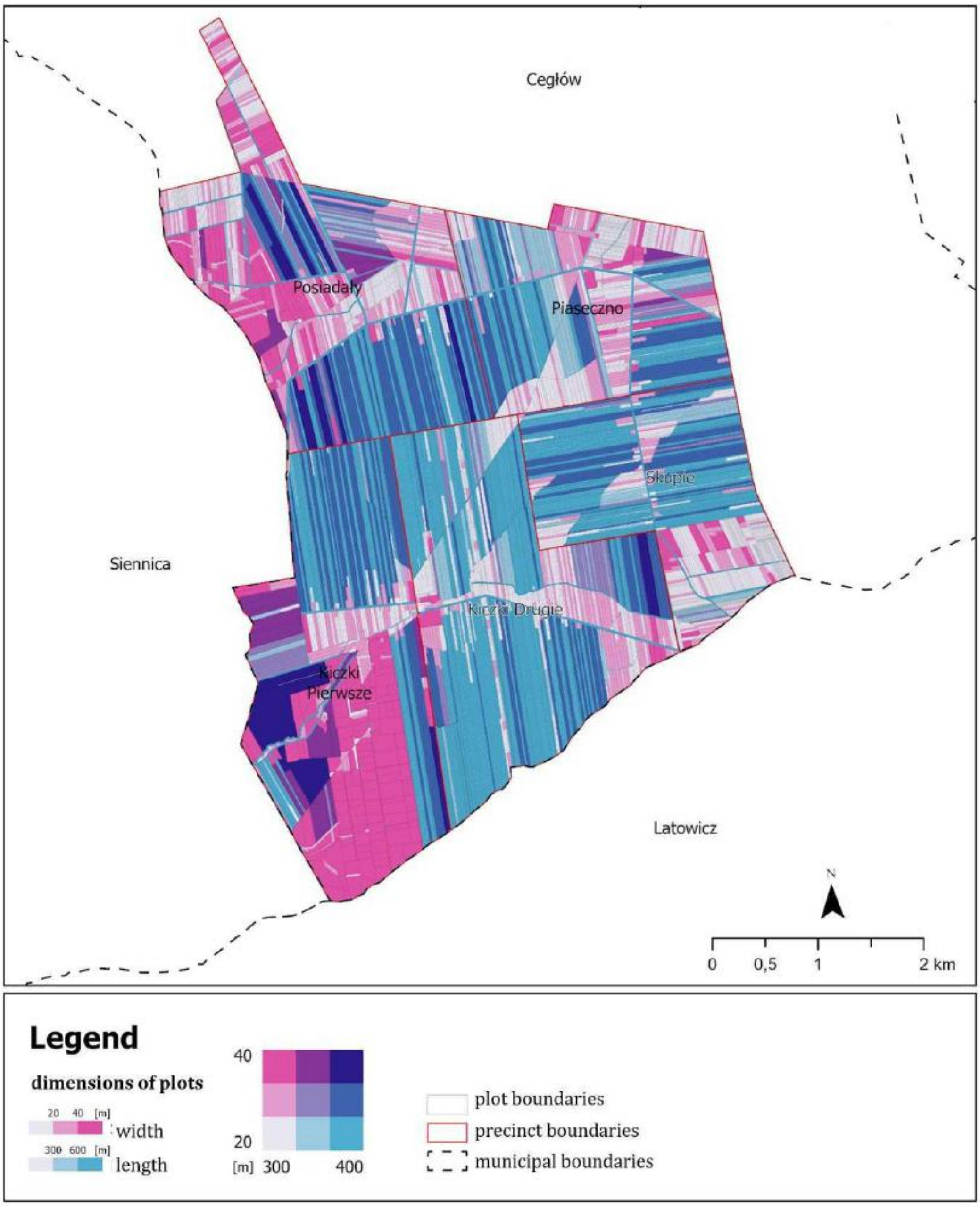

Fig. 6. Map of plot dimension ratios for the analysis area
Source: own study based on EGIB and PRG data

Shape of plot (I-3.2) – The critical degree of elongation of many plots is clear (Fig. 7). The best dimension ratio is characteristic of plots located in the village of Kiczki Pierwsze and along the main communication routes.

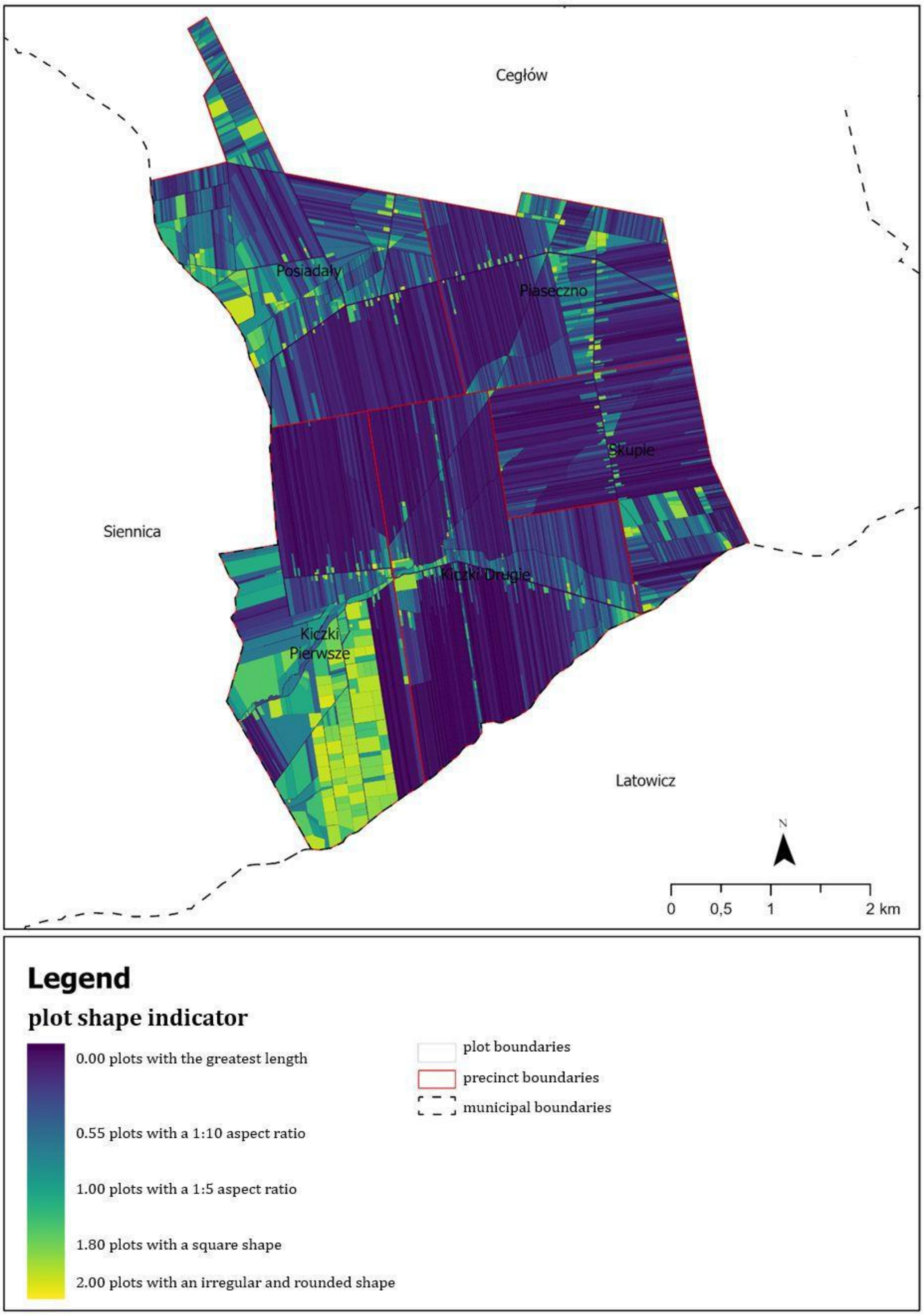

Fig. 7. Map of shape factor values for the study area
Source: own study based on EGIB and PRG data

Plot area (I-3.3) – In the example of the study area, two obvious extremes can be presented. The Kiczki Pierwsze precinct is characterised by far the most significant areas of plots, where the largest ones reach up to several hectares (Fig. 8). The average area of the plots in this precinct is 1.16 ha. In the village of Piaseczno, the trend is the opposite; the area of the plots is minimal, with an average of only 4,300 m^2. In the case of conducting land concolidations, the village of Piaseczno and Skupie would require specific changes in the ownership structure.

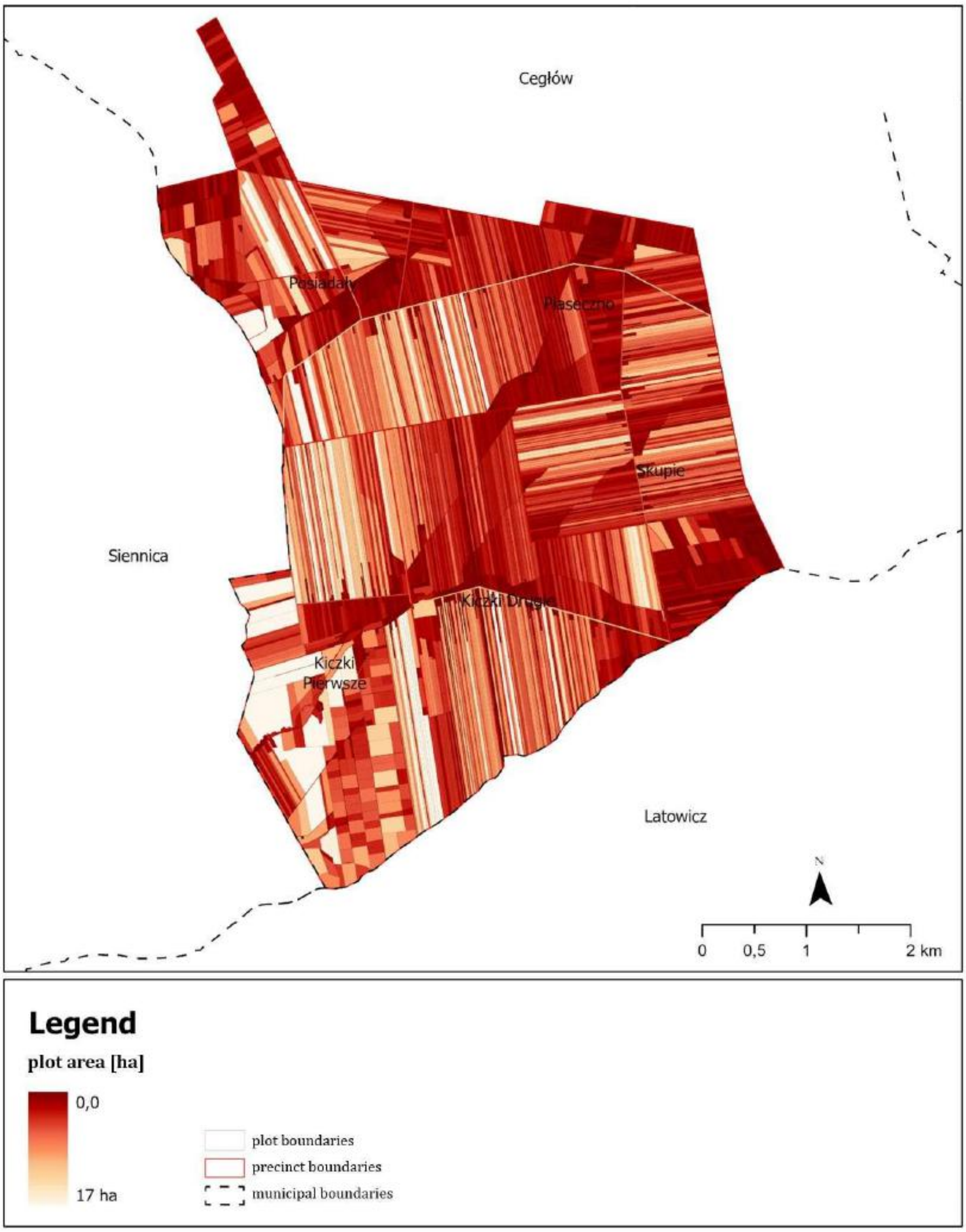

Fig. 8. Map of plot areas in the study area
Source: own study based on EGIB and PRG data

Ownership structure (I-3.4) – Analysis was conducted for the Piaseczno precinct due to limited access to data. In the case of the analysed village, farms containing plots from 1 to 5 and from 6 to 10 dominate. As can be seen, there are cases where the number of plots in one unit (JR) can reach up to 40 plots (Fig. 9), which indicates a very high degree of fragmentation of plots in farms.

Fig. 9. Map of the number of areas in the study area
Source: own elaboration based on EGIB and PRG data

Road access (I4.1) – several areas affected by the high number of plots without adequate road access can be identified. These are located in the area's center, north, and northeast (Fig. 10).

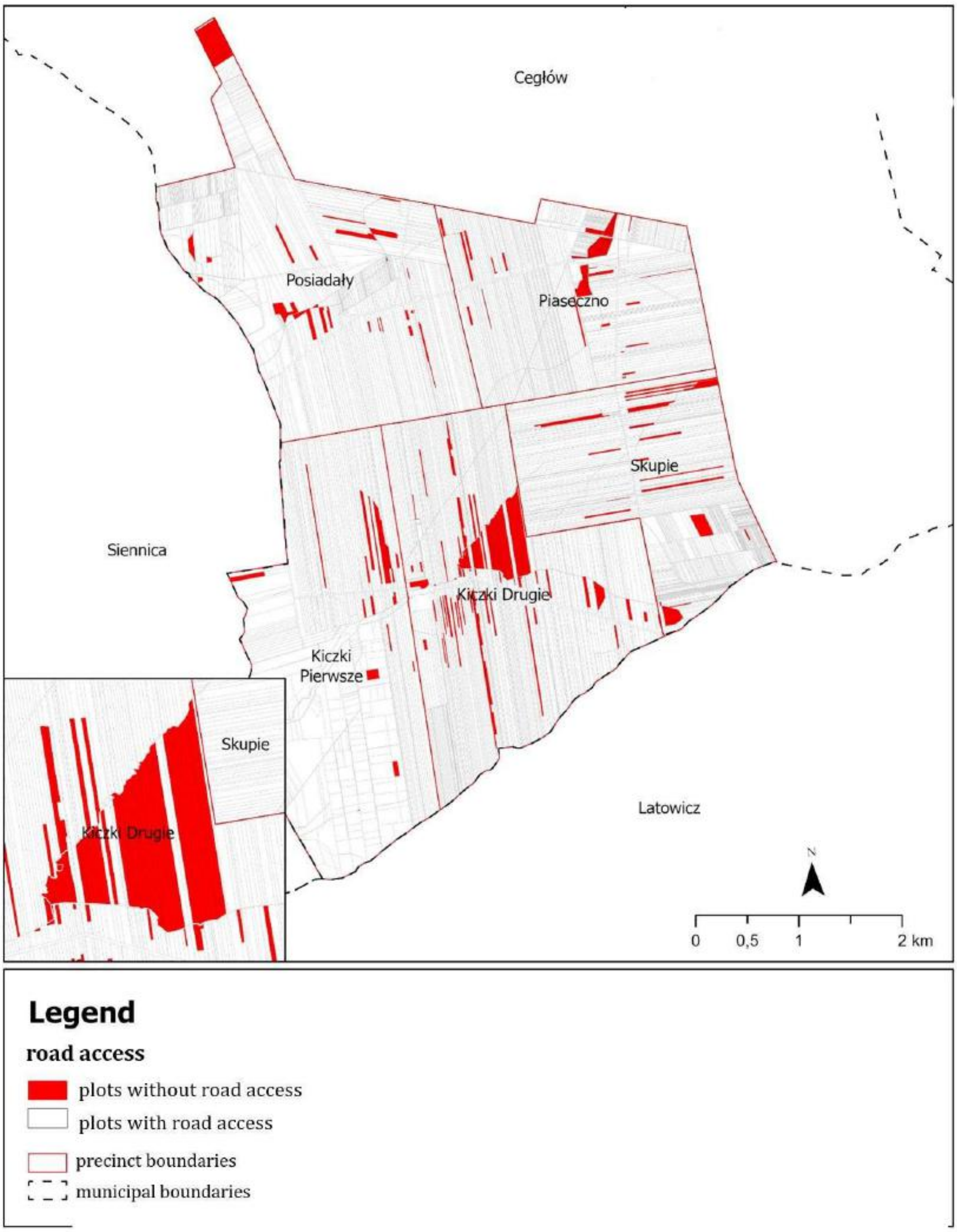

Fig. 10. Map of the state of access to roads for the analysis area
Source: own study based on EGIB, PRG, and BDOT10k data

Availability of utilities (I4.2) – Development in the study area is located primarily along the main roads. For this reason, access to the network is uniform; this applies to both the electricity and water supply networks (Fig. 11).

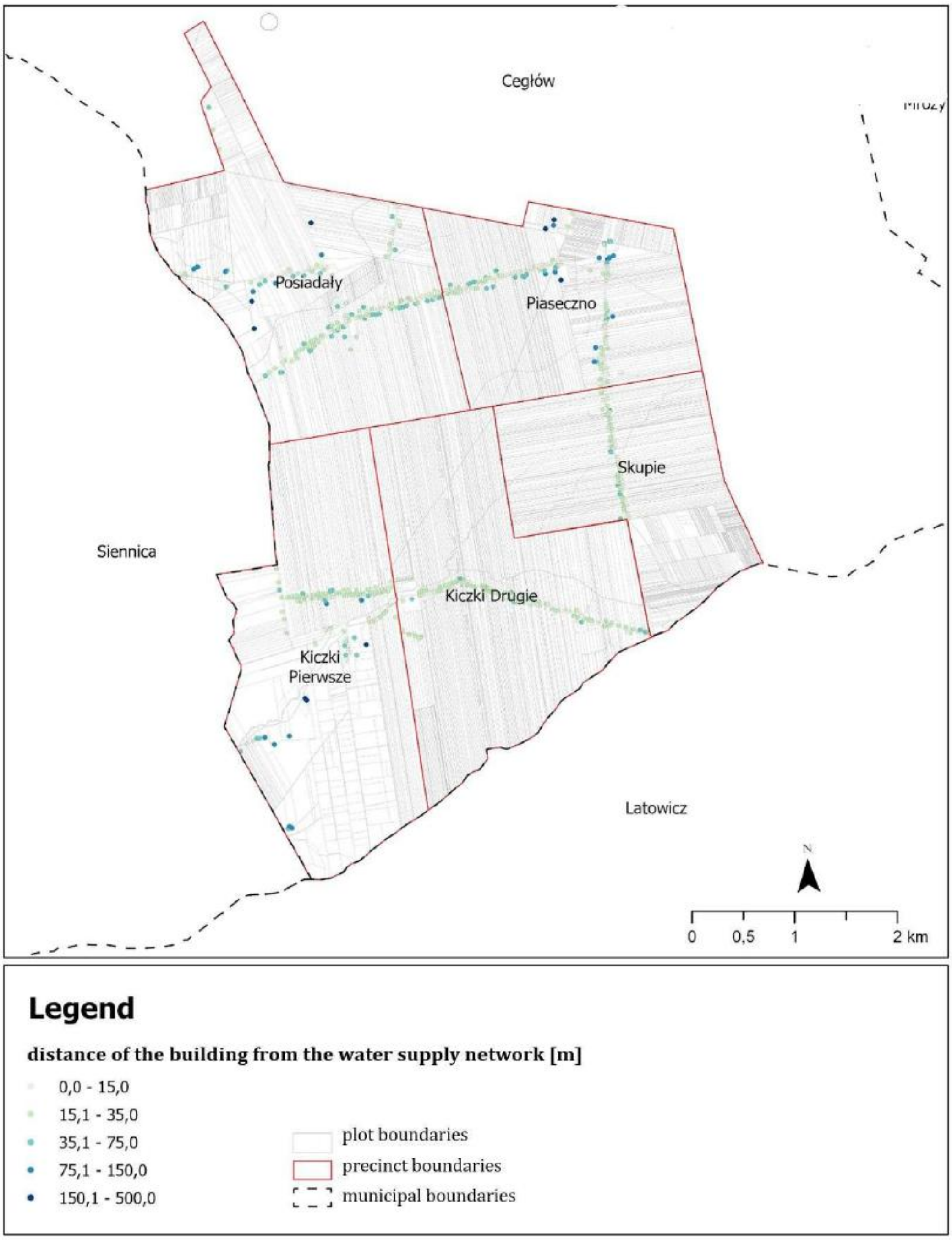

Fig. 11. Map of water supply network availability status for the study area
Source: own study based on EGIB, PRG, and GESUT data

Availability of services (I5.1, I5.2, I5.3) – The results of the accessibility analyses to commercial, educational, and cultural services are similar. Figure 12 shows accessibility to commercial services.

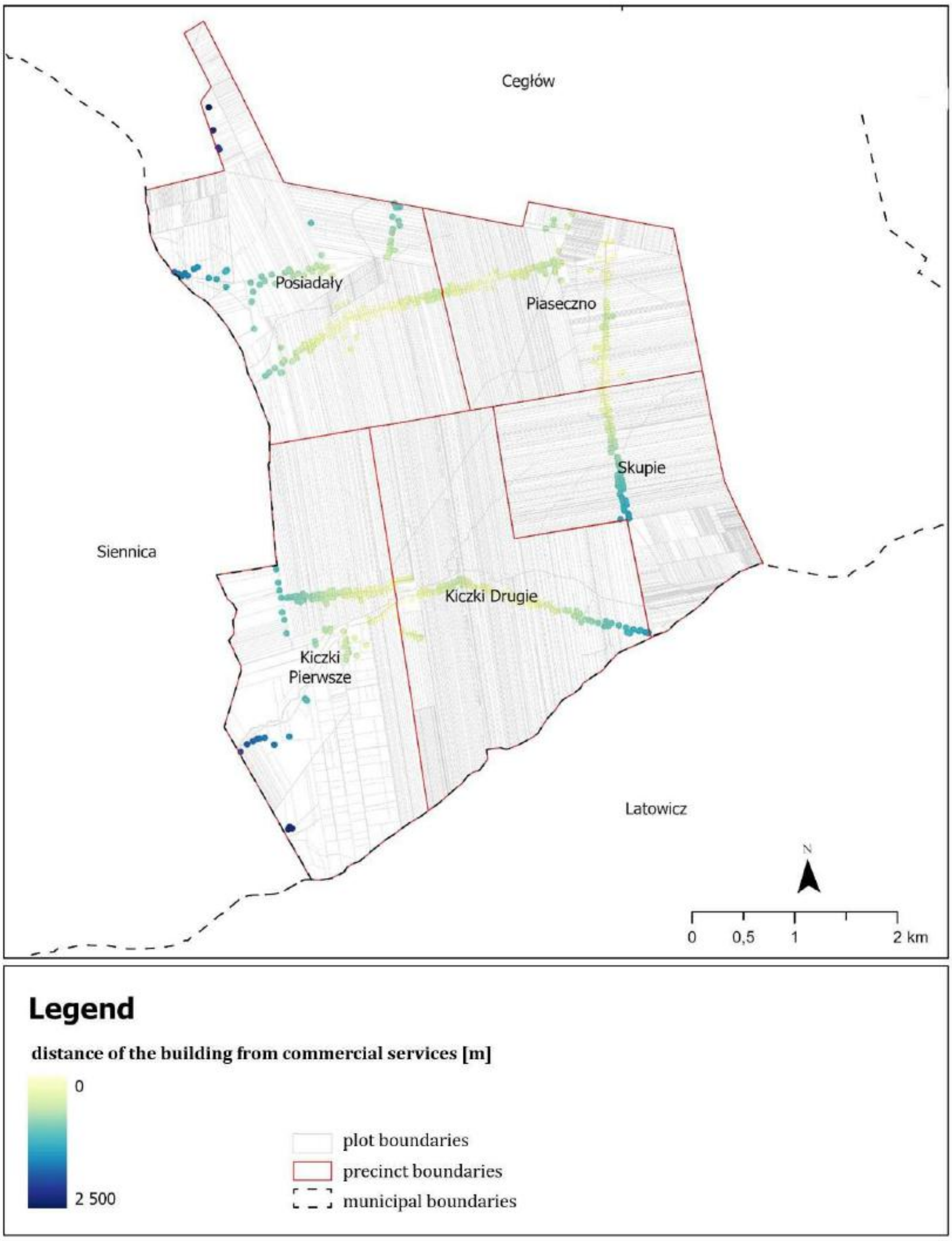

Fig. 12. Accessibility to commercial services status map for the analysis area
Source: own study based on EGIB, PRG, and BDOT10k data

According to the presented examples, the study area is struggling with several key spatial problems, the solution of which could significantly facilitate and accelerate the agricultural production process. They are primarily concerned with the land ownership structure, which negatively affects the production efficiency of farms. The main spatial problem is the excessive extension of plots and the occurrence of plots without access to public roads.

Recommendations. The method has many advantages, but unfortunately, it also has some serious disadvantages. It operates on publicly available data, so its execution does not require applying for its disclosure. The results are clear and easy to interpret, meaning they do not require additional experience from officials. The method is also characterized by simplicity and a low number of stages. A serious disadvantage of the method is its low precision. Since the results are not based on the register of residents, the population density indicator (I-1.1) may differ significantly from the actual state. Introducing additional variables, such as the area of the premises per resident, additionally increases the described discrepancies. With this in mind, the method is intended only to present the general trends of the studied area.

The analysis of susceptibility to water erosion (I-2.1) is a complex process requiring the contractor to understand its elements fully. Despite the complicated method of execution, the study results are relatively easy to interpret. They can be beneficial for areas with diversified terrain. For lowland areas with uniform relief, this stage can be omitted. Although very simple, the analysis concerning nature conservation (I-2.2) also requires a thorough study of individual forms of protection in terms of restrictions resulting from acts, regulations, and special provisions. For this reason, the analysis primarily supports the design of land use and agricultural activities.

The plot dimensions ratio (I-3.1) analysis using a choropleth map has many advantages. It allows for the transfer of a large amount of information on the dimensions of plots and the relationships between them, including the shape of the plot (I-3.2). They are also easy to interpret due to how the data is presented for people dealing with it professionally and stakeholders in the land consolidation process. Thanks to automation, this method is fast and effective. It can be used for larger areas by people without advanced experience with GIS technology. Unfortunately, the obtained results may be less reliable for plots with very irregular shapes. Nevertheless, LUAP-M can accelerate the diagnosis of areas requiring transformation, which is why it is worth further work and development.

Plot area analysis (I-3.3) plays an important role in LUAP-M, presenting one of the most important elements of land use and agricultural work. The simplicity of the analysis is undoubtedly its main advantage. It presents the general trends of the area, thanks to which it is possible to determine the area's most requiring transformation.

Ownership structure (I-3.4) requires data on ownership. The analysis used the number of registration units (JR) to indicate individual owners. However, the best results would be achieved using detailed personal data. LUAP-M presents the problem of plot fragmentation, constituting auxiliary material both in the planning process and in public consultations. The analysis of availability of roads (I-4.1) depends to a large extent on the accuracy and timeliness of the data used. This is a significant drawback, which may make the analysis insufficiently effective in the case of a lack of sufficient accuracy in both databases (EGIB and BDOT10k). In the case of a different method of recording information on the purpose of the plot, it would be necessary to modify the method or use only data from the BDOT10k database.

The analysis of availability of utilities (I-4.2) and services (I-5.1; I-5.2; I-5.3) is characterized by several drawbacks. One of them is the way of presenting the results for large areas. For this reason, it is recommended that the method be used as an auxiliary analysis that supports LUAP-M at the detailed stage. Despite the original assumption, the method does not present buildings with access to public services. The method was too complicated to perform automatically. This is due, among others, to minor inconsistencies in the databases.

Summary and conclusions

The LUAP-M methodology effectively examined elements necessary for developing land use and agricultural plans. It comprehensively identified problem areas that required changes in spatial structure and development transformation, along with accompanying features essential for land use and agricultural planning. This methodology approached the problem in a general way, which allowed it to be applied to larger areas. It primarily focused on the most critical issues related to plot structure, while also considering supporting elements related to providing municipalities with appropriate infrastructure and services. For this reason, it also enabled the analysis of municipal development in sectors other than agriculture. It was designed to minimize the user's required steps, focusing only on the most crucial aspects of land use and agricultural planning.

However, the methodology had certain drawbacks related to the issues it addressed or due to technical limitations. Some of the proposed analyses proved too labor-intensive or complex to carry out. One such element was analyzing the distance between agricultural plots and farm buildings. This analysis aimed to assess the degree of plot dispersion within a farm, based on ownership data of individual plots. During the design of LUAP-M, many solutions were considered ineffective for analyzing an entire area at once. Limitations in how data could be interpreted and visualized also affected the methodological elements.

Most of the data used came from open-access databases, which enabled the methodology to be applied relatively easily. An exception was the soil erosion susceptibility analysis, which relied on vector-based agricultural soil maps that were not publicly available. Although it was possible to use publicly available data instead, the study could not be carried out automatically using a script and required manual input, increasing the time and effort involved.

The analysis of ownership structure required more detailed data from the land and building register, which was not accessible to the public. Other studies related to the structure of production space could be performed using publicly available data.

Regarding the current methodological components, data availability limitations were most visible in the erosion susceptibility and ownership structure analyses. Due to the lack of complete data for all areas, these analyses had to be limited to several or just one cadastral district. This was a highly detrimental issue during the methodology design stage and especially during actual project implementation. The lack of data significantly complicated the selection of appropriate actions and slowed down the transformation process of problem areas.

Another equally significant obstacle was the limited data availability concerning land ownership structure. Some elements had to be omitted due to the lack of accessible data. One of these was the state of agricultural land leases. The problem stemmed from the absence of data and the way agreements were made between landowners and tenants. In Poland, such contracts were typically made orally and were not registered in any formal system. For this reason, it was impossible to describe the actual state of agricultural land leasing accurately. This was a critical aspect during planning work, but its examination would require additional field inventory.

Due to the issues described above, LUAP-M required further development and refinement. Improvements were particularly needed in visualizing problem areas, especially those concerning infrastructure and services. It was also advisable to expand on previously omitted analyses, the design of which required more time, effort, and access to specialized datasets.

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