

## Improving agricultural land structure through land consolidation: impact on cadastral parcel geometry and road network functionality

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### Summary

Land consolidation is one of the most important instruments for improving the spatial structure of agricultural areas. It reorganizes cadastral parcels, improves road accessibility, and modernizes agricultural infrastructure. The aim of this study was to evaluate the impact of land consolidation on parcel geometry and the functionality of the agricultural road network, considering the Przegonia cadastral unit in southern Poland as a case study. The analysis was based on a comparative before–after approach. Changes in parcel geometry were assessed using the elongation ratio, while road network functionality was evaluated through analyses of parcel accessibility, road conditions, planned infrastructure improvements, and the occurrence of informal farm tracks. Cadastral data, land consolidation design documents, and spatial analyses prepared during the consolidation process were used as source materials. The results demonstrated a substantial improvement in parcel geometry. The number of parcels with an elongation ratio exceeding 1:20 decreased by 64.6%, while the number of parcels with favourable proportions (1:4–1:1) increased by 66.9%. The number of parcels without access to a public road decreased from 651 to 104, which was an 84.0% reduction. In addition, more than 48 km of agricultural roads were planned for construction or reconstruction. The project also eliminated approximately 190 km of informal farm tracks, enabling the recovery of about 47.5 ha of land for agricultural production. The findings confirm that land consolidation can significantly improve cadastral parcel geometry, road accessibility, and the overall functionality of agricultural production space.

**Keywords**

spatial structure • land consolidation • elongation ratio • cadastral parcels • agricultural road network • road accessibility

**1. Introduction**

Land consolidation is one of the main instruments used to shape the spatial structure of rural areas. It enables a comprehensive reorganization of cadastral parcels, improvement of their geometric parameters, rationalization of land ownership patterns, and adaptation of agricultural road networks to the requirements of modern agriculture [Hartvigsen 2014, Janus and Ertunç 2021, Li and Song 2023]. Unlike individual infrastructure projects or land subdivision processes, land consolidation allows multiple components of agricultural space to be transformed simultaneously, leading to a long-term improvement in farming conditions [Elvestad and Sky 2019, Tunalı 2025].

One of the major constraints affecting the efficient use of agricultural land is land fragmentation [Dorož et al. 2022, Dorož et al. 2023, Božek et al. 2025]. This phenomenon occurs when numerous small parcels are spatially dispersed and owned either by multiple landowners or by a single farm operating parcels located in different parts of the cadastral unit [Tan et al. 2010]. Land fragmentation is usually the result of long-term historical processes, family divisions, inheritance practices, partial land sales, and traditional land-use patterns that have evolved over generations [Hartvigsen 2014]. In effect, it creates a spatial structure that is often incompatible with the requirements of contemporary agricultural production [Demetriou 2014, Ciaian et al. 2018, Dorož et al. 2025].

Excessive land fragmentation increases agricultural production costs [Bizimana et al. 2004, Kawasaki 2010]. Farmers are required to move machinery between numerous dispersed parcels, resulting in higher fuel consumption, longer working hours, and increased operating costs for equipment [Manjunatha et al. 2013]. Organizing field operations also becomes more difficult when parcels are small, narrow, irregularly shaped, or lack convenient road access [Rahman and Rahman 2009]. Under such conditions, even favourable soil quality and farm location do not necessarily translate into high production efficiency, as the spatial structure of the land itself acts as a limiting factor [Monchuk et al. 2010].

Agricultural suitability is not determined by parcel area alone. Parcel shape, particularly the relationship between parcel length and width, is equally important [Akkaya Aslan et al. 2007]. Parcels with regular boundaries and balanced proportions are easier to cultivate and allow for a more efficient use of agricultural machinery. They also reduce the number of turning operations required during fieldwork [Hiironen and Riekkinen 2016]. In contrast, parcels that are excessively elongated, very narrow, or irregularly shaped parcels hinder agricultural operations, increase the number of machinery movements, and result in additional time losses [Branković et al. 2015].

One of the indicators commonly used to evaluate parcel shape is the elongation ratio, defined as the relationship between parcel length and width [Akkaya Aslan et al.

2007]. This indicator can be applied to identify parcels with particularly unfavourable proportions and assess whether land consolidation has improved their functionality [Branković et al. 2015]. High elongation values indicate long and narrow parcels, which are less suitable for efficient agricultural production [Hiironen and Riekkinen 2016]. Therefore, a reduction in the number of parcels within the most unfavourable elongation classes may therefore be considered an important indicator of improvement in spatial structure [Wojewodzic et al. 2021].

However, parcel geometry should be analyzed together with its accessibility [Janus et al. 2017]. A parcel with a favourable shape cannot be considered fully functional if it lacks legal and physical access to a road [Janus et al. 2017]. Accessibility is a fundamental prerequisite for agricultural land use as it enables access for machinery, crop transportation, field operations, and day-to-day farm management activities [Taszkowski et al. 2017]. In practice, the absence of access to a public road or an agricultural access road can substantially limit the effective use of agricultural land [Janus et al. 2017].

In many rural areas, agricultural road networks have developed gradually and often without comprehensive planning [Taszkowski et al. 2017]. As a result, some roads have inadequate technical parameters, insufficient width, poor surface conditions, or an unresolved legal status [Krupowicz et al. 2017]. Many parcels are accessed via customary routes, informal farm tracks, easements, or verbal agreements between landowners [Janus et al. 2017]. Although such arrangements may be functional in the short term, they do not provide a permanent and reliable transport infrastructure [Taszkowski et al. 2017]. Moreover, they may lead to disputes, especially when land ownership or land use changes [de Vries 2022].

Land consolidation provides an opportunity to address problems related to both parcel geometry and road accessibility in a single procedure [Janus and Ertunç 2021]. This process can involve redesigning parcel boundaries, establishing new roads, widening existing roads, regulating the legal status of land occupied by roads, and reducing the number of informal access routes [Elvestad and Sky 2019]. This integrated approach is one of the key advantages of land consolidation over fragmented interventions [Hartvigsen 2014]. However, improving parcel shape without ensuring road access does not generate the full economic benefits, just as road construction alone cannot solve spatial inefficiencies if the serviced parcels remain highly fragmented or excessively elongated [Hiironen and Riekkinen 2016, Wojewodzic et al. 2021].

Another issue concerns informal farm tracks. These are access routes that exist in the field, but which are not registered as separate road parcels in the cadastral system. They are usually located along parcel boundaries or across agricultural land, and serve as access routes to fields [Janus et al. 2017]. Although they perform a practical function, they often occupy land that could otherwise be used for agricultural production, fragment cultivated areas, and contribute to an inefficient spatial layout. In the absence of legal regulation, they may also become a source of conflict [de Vries 2022].

Eliminating unnecessary informal farm tracks and replacing them with a planned road network of clearly defined legal status is an important outcome of land consolida-

tion [Taszakowski et al. 2017]. This process reduces the inefficient use of agricultural land for access routes, improves the organization of agricultural space, and allows part of the land to be returned to production [Janus and Ertunç 2021]. These benefits are particularly important in highly fragmented areas, where dense networks of informal access routes can result in considerable losses of productive land [Demetriou 2014].

The effectiveness of land consolidation should be evaluated using measurable indicators [Wojewodzic et al. 2021]. In terms of parcel geometry, relevant indicators include the number of parcels before and after consolidation, the distribution of parcels among elongation classes, and the proportion of parcels with the most unfavourable shapes [Akkaya Aslan et al. 2007, Branković et al. 2015]. Regarding the road network, important indicators include the number of parcels without road access, the length and technical condition of existing roads, the extent of planned road construction and reconstruction, as well as the scale of informal farm track removal [Janus et al. 2017, Taszakowski et al. 2017]. Such a comprehensive approach enables a more accurate assessment of whether land consolidation has genuinely improved the functionality of agricultural space [Janus and Markuszewska 2019].

Modern assessments of land consolidation increasingly rely on spatial data and Geographic Information System (GIS) tools [Tourinho et al. 2003, Branković et al. 2015]. These methods enable comparisons of pre- and post-consolidation conditions, calculation of parcel geometry indicators, assessment of transport accessibility, and visualization of spatial changes [Tourinho et al. 2001]. Consequently, they improve the objectivity of evaluation and facilitate the presentation of land consolidation outcomes to both specialists and stakeholders involved in the consolidation process.

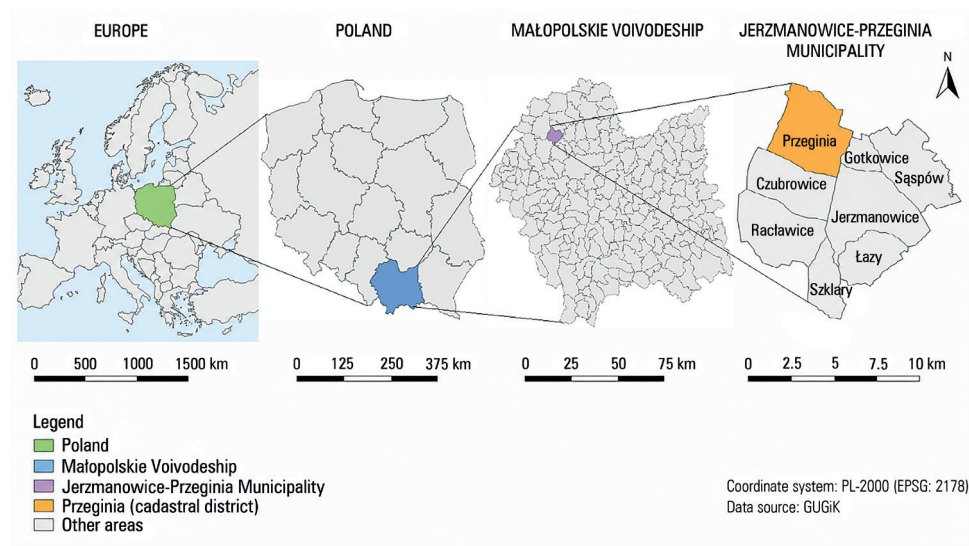
Despite the growing body of research on the outcomes of land consolidation, relatively few studies simultaneously analyze changes in parcel geometry and the functionality of agricultural road network within a single consolidation project. However, these two components are closely interconnected and play a decisive role in determining the efficiency of agricultural land use. Assessing changes in parcel structure and transport infrastructure together provides a more comprehensive understanding of the actual effectiveness of land consolidation measures [Doroż et al. 2025].

The aim of this study was to evaluate the impact of land consolidation on the improvement of parcel geometry and the functionality of agricultural road networks, considering the Przeginia cadastral unit in the Małopolskie Voivodeship, southern Poland, as a case study. The analysis focused on changes in parcel elongation structure, road accessibility, and the organization of the transport network before and after the land consolidation project was implemented.

## 2. Study area and source materials

The study was conducted in a part of Przeginia village, located in the Jerzmanowice-Przeginia municipality, Kraków county, Małopolskie voivodeship, southern Poland. The village is situated in the western part of the municipality, within the Olkusz Upland, which forms part of the Kraków-Częstochowa Upland. The study area was

selected due to its characteristic spatial problems that are typical of highly fragmented agricultural regions. These included unfavourable parcel geometry, limited road accessibility to a portion of agricultural land, and unresolved legal status of parts of the road network. Owing to these characteristics, the study area constitutes a representative case for assessing the effectiveness of land consolidation procedures.



Source: Authors' own study

**Fig. 1.** Location of the Przegonia cadastral unit within the Jerzmanowice-Przegonia municipality, Małopolskie voivodeship, Poland, and Europe

The total area of Przegonia village is 1,265.7179 ha. However, the land consolidation project did not cover the entire cadastral unit. Built-up areas located mainly along the national road were excluded from the consolidation process. Ultimately, the land consolidation project covered an area of 1 181.6220 ha, comprising 2 584 cadastral parcels before consolidation.

The source materials consisted of cadastral data, land consolidation design documents, and the results of spatial analyses carried out during the consolidation process. The study included information on the number of parcels, their distribution according to the elongation ratio, road accessibility, the technical condition of existing roads, and planned post-consolidation infrastructure measures. Particular attention was given to data enabling a comparison between the pre-consolidation situation and the conditions resulting from the land consolidation design.

The main spatial issues in the study area were a result of the historically developed parcel pattern. Many parcels were narrow and highly elongated, in some cases exceeding 2.5 km in length. Other constraints included the insufficient functionality of the road network, and the presence of informal farm tracks. A considerable number of

parcels also lacked legal access to a public road. These conditions made the study area suitable for assessing the impact of land consolidation on parcel geometry and the functionality of the agricultural transport network.

### 3. Methodology

The study employed a comparative before–after analysis. The spatial structure of the area covered by the land consolidation project was evaluated in two stages: the pre-consolidation condition, and the condition resulting from the land consolidation and the post-consolidation development design. The analysis focused on two key components that affect the functionality of agricultural spaces: parcel geometry and the accessibility provided by the agricultural road network.

Parcel geometry was assessed using the elongation ratio (ER), defined as the ratio of parcel length (L) to parcel width (W):

$$ER = \frac{L}{W} \quad (1)$$

For the purposes of this study, parcel length and width were determined using a GIS-based geometric analysis of cadastral polygons. For regular parcels, length was defined as the longest dimension of the parcel, while width was defined as the perpendicular dimension. For irregularly shaped parcels, length was determined as the longest axis of the minimum bounding rectangle fitted to the parcel geometry, whereas width was calculated as the ratio of parcel area to the determined parcel length. This approach made it possible to apply the elongation ratio consistently to both regular and irregular parcel shapes.

Based on the elongation ratio values, parcels were classified into six categories representing different levels of elongation. The distribution of parcels among these categories was then compared between the periods before and after land consolidation. Improvement in the spatial structure was assessed by a reduction in the proportion of highly elongated parcels and an increase in the number of parcels characterized by more favourable proportions for agricultural mechanization.

The functionality of the road network was evaluated by an analysis of parcel accessibility to public roads and a comparison of the existing and proposed transport systems [Janus et al. 2017, Taszakowski et al. 2017]. The assessment considered the number of parcels without access to a public road, the length and technical condition of existing roads, the extent of planned road construction and reconstruction, and the role of informal farm tracks. Particular attention was paid to whether the land consolidation project reduced the number of landlocked parcels and enabled informal access routes to be replaced with a planned, legally regulated road network.

For the purposes of this study, a parcel was considered to have road access if it had direct legal access to a public road or an agricultural access road. The assessment was based on cadastral records and the land consolidation design documentation. Easements and other forms of private legal access were not analyzed within the scope

of this study. Parcels accessible only through informal farm tracks, customary routes, or verbal agreements between neighbouring landowners were classified as lacking legal road access.

The assessment of the technical condition of agricultural roads was based on the field inventory included in the Assumptions for the Land Consolidation Project, prepared prior to the commencement of the land consolidation procedure. This inventory classified existing agricultural roads according to their surface type and technical condition. The inventory results were adopted in the present study as the basis for evaluating the condition of the agricultural road network before land consolidation.

Spatial analyses were conducted using cadastral data and planning documents prepared as part of the land consolidation project. The results were presented in tabular, cartographic, and graphical form in order to enable the assessment of the magnitude and spatial distribution of quantitative changes. This approach offered a comprehensive evaluation of the impact of land consolidation on parcel structure and the functionality of the agricultural road network [Tourinho et al. 2003, Branković et al. 2015].

## 4. Results and discussion

### 4.1. Improvement of parcel geometry

One of the most significant effects of land consolidation in the study area of Przegonia village was the improvement of cadastral parcel geometry. Before consolidation, a substantial proportion of the area consisted of long and narrow parcels that were not favourable for modern agricultural production. Excessive elongation of parcels hindered mechanized farming operations, increased the number of passes required by machinery, and reduced the efficiency of with which the agricultural equipment could be used [Akkaya Aslan et al. 2007, Hiironen and Riekkinen 2016].

The analysis of the elongation ratio revealed a clear improvement in parcel geometry. The number of parcels with an elongation ratio exceeding 1:20 dropped from 568 to 201, representing a reduction of 64.6%. At the same time, their share of the total number of parcels declined from 21.98% to 8.14%. These results indicate a substantial reduction in parcels with the most unfavourable proportions that are considered particularly problematic for agricultural mechanization and the efficient operation of farm machinery. Similar improvements in parcel shape have also been reported in other land consolidation projects [Branković et al. 2015, Janus and Markuszewska 2019].

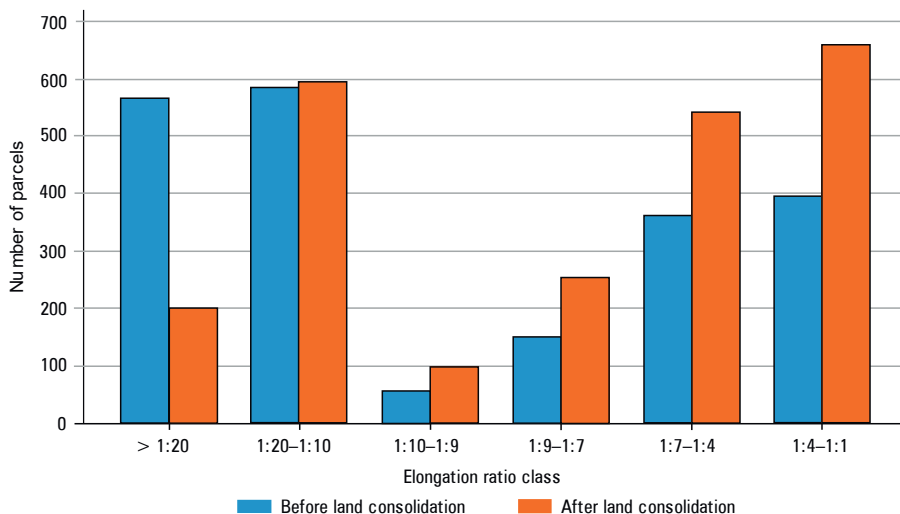
Positive changes were also observed in the group of parcels characterized by the most favourable proportions. The number of parcels within the elongation ratio class of 1:4–1:1 increased by 66.9%, rising from 396 to 661. Consequently, the share of parcels in this category rose from 15.33% to 26.76%. The increase in the number of regularly shaped parcels can be regarded as one of the most important outcomes of the land consolidation project, as it improves field operation management and makes agricultural land use more efficient.

**Table 1.** Changes in the number of parcels across elongation ratio classes

| No.          | Parcel elongation ratio class | Before land consolidation |                            | After land consolidation |                            | Change |
|--------------|-------------------------------|---------------------------|----------------------------|--------------------------|----------------------------|--------|
|              |                               | Number of parcels         | Share of total parcels (%) | Number of parcels        | Share of total parcels (%) |        |
| 1            | > 1:20                        | 568                       | 21.98                      | 201                      | 8.14                       | -367   |
| 2            | 1:20–1:10                     | 585                       | 22.64                      | 594                      | 24.05                      | +9     |
| 3            | 1:10–1:9                      | 55                        | 2.13                       | 99                       | 4.01                       | +44    |
| 4            | 1:9–1:7                       | 150                       | 5.80                       | 254                      | 10.28                      | +104   |
| 5            | 1:7–1:4                       | 360                       | 13.93                      | 540                      | 21.86                      | +180   |
| 6            | 1:4–1:1                       | 396                       | 15.33                      | 661                      | 26.76                      | +265   |
| 7            | Road parcels                  | 470                       | 18.19                      | 121                      | 4.90                       | -349   |
| <b>Total</b> |                               | 2584                      | 100.00                     | 2470                     | 100.00                     | -114   |

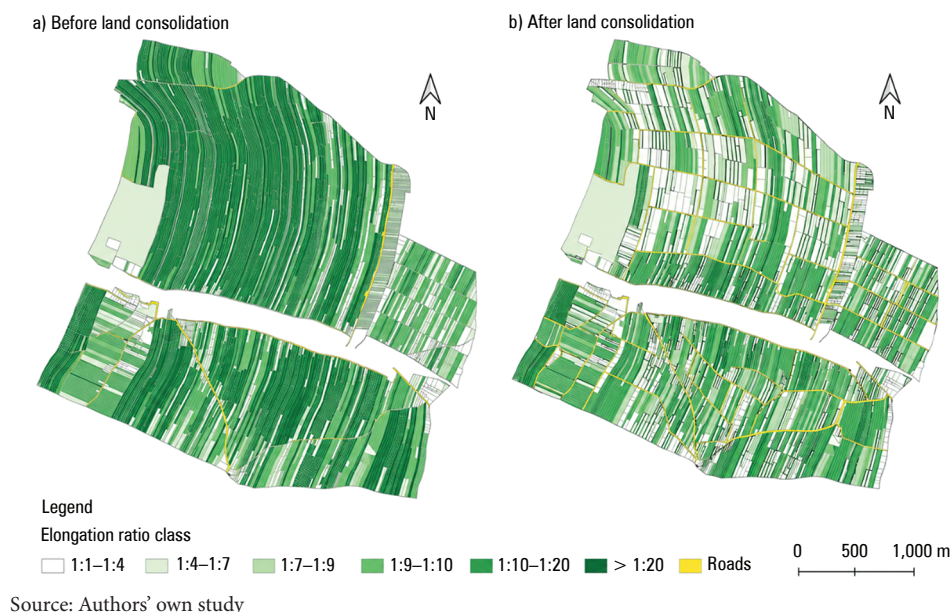
Source: Authors' own study

Road parcels were treated as a separate category because they were excluded from the parcel elongation analysis. Their inclusion in the elongation ratio classes would have biased the assessment of agricultural parcel geometry, as their function and geometry differ fundamentally from those of agricultural parcels. Therefore, they were presented separately in Table 1 to illustrate changes in the number of road parcels before and after land consolidation.



Source: Authors' own study

**Fig. 2.** Distribution of cadastral parcels among elongation ratio classes before and after land consolidation



**Fig. 3.** Spatial distribution of parcel elongation classes: a) before land consolidation, b) after land consolidation

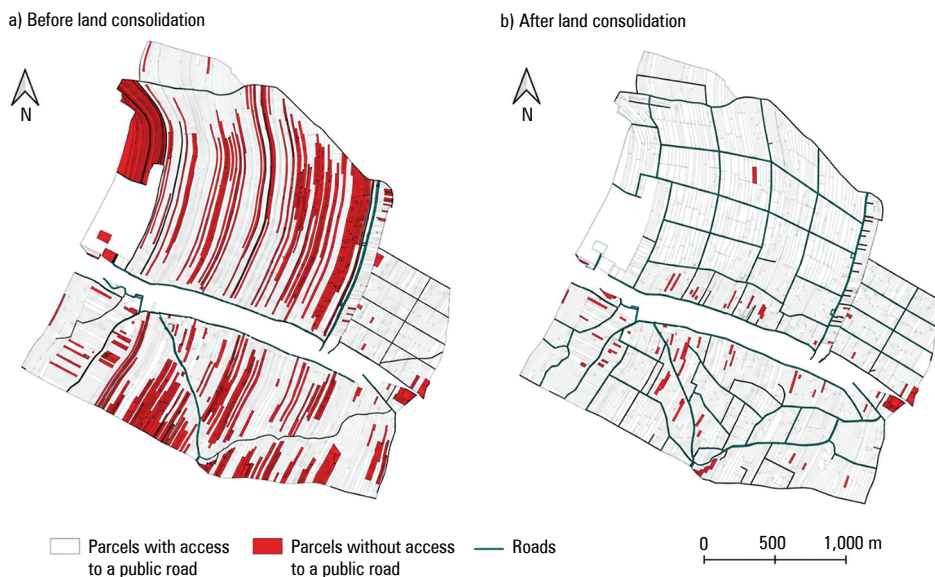
The total number of parcels classified within the two most favourable elongation ratio classes (1:7-1:4 and 1:4-1:1) increased from 756 to 1 201, representing an increase of 58.9%. At the same time, the number of parcels with an elongation ratio exceeding 1:20 decreased by 64.6%. These results confirm a substantial improvement in the spatial structure of the study area and are consistent with the findings of Janus and Markuszewska [2019], who identified improvements in parcel geometry as one of the most important outcomes of land consolidation projects.

#### 4.2. Improvement in parcel accessibility to public roads

Another important outcome of the land consolidation project was the improvement of accessibility to parcels. Prior to consolidation, a considerable proportion of parcels lacked legal access to a public road. The number of such parcels amounted to 651, representing more than one-quarter of all parcels included in the project. Access to many agricultural plots was provided through customary routes, informal farm tracks, or arrangements between neighbouring landowners [Janus et al. 2017].

The absence of legal access to a public road reduced parcel functionality and increased the risk of neighbour disputes. This issue had implications not only for transportation but also for the economic and the law [de Vries 2022]. Parcels without road access are more difficult to use and less attractive from a real estate perspective. They also render owners more dependent on relationships with neighbouring landowners.

Following the preparation of the land consolidation design, the number of parcels without direct access to a public road decreased from 651 to 104 – a reduction of 84.0%. This substantial improvement in accessibility demonstrates the effective integration of the new parcel layout with the planned agricultural road network. From a land management perspective, it reduced dependence on informal access routes, enhanced the legal security of land use, and improved the overall functionality of the agricultural spatial structure.



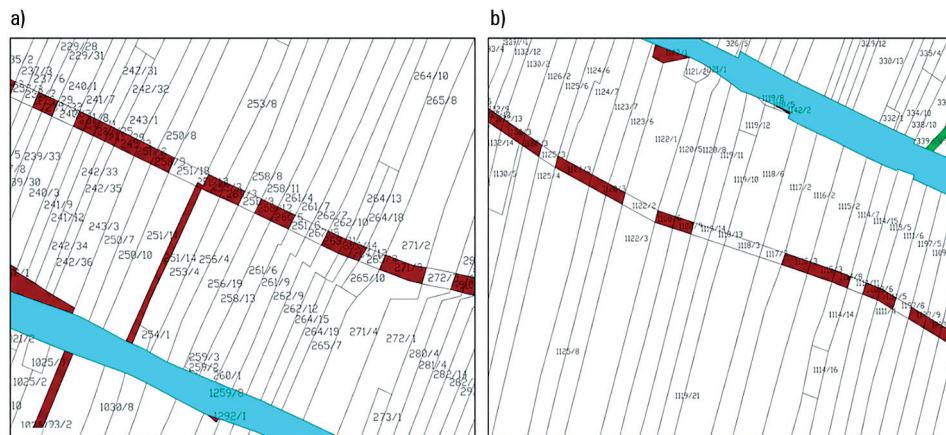
Source: Authors' own study

**Fig. 4.** Analysis of parcel access to public roads: a) before land consolidation, b) after land consolidation

The reduction in the number of parcels without access to a public road by 84.0% demonstrates that the proposed transportation solutions are highly effective. This result confirms that improved road accessibility is a key factor in the functionality of agricultural land. This is consistent with the findings reported in other land consolidation projects carried out in Poland and across Europe [Janus et al. 2017, Janus and Ertunç 2021, Doroż et al. 2022].

#### 4.3. Functionality and condition of the agricultural road network

Before land consolidation, the road system in the study area of Przegonia village was insufficient in both technical and functional terms. The road network consisted of cadastral road parcels providing legal access to agricultural land, as well as numerous informal farm tracks that functioned as access routes despite not being registered in the cadastre. In addition to the poor technical condition of many roads, a significant problem was their



Source: Authors' own study

**Fig. 5.** Examples of agricultural access roads with unresolved legal status before land consolidation: a) north of the national road, b) south of the national road

unresolved legal status, which hindered the effective management and maintenance of the agricultural transport network.

The total length of asphalt roads was 10.700 km, of which 0.651 km were considered to be in poor technical condition. Gravel roads accounted for 2.366 km, of which 0.831 km were in poor condition. The most significant issue were unpaved roads, of which there was a total length of 16.796 km. Out of this total, 14.577 km (86.8%) were classified as being in poor technical condition.

The field inventory revealed that most of the unpaved roads were in unsatisfactory technical condition. Of the total 16.796 km of unpaved roads, 14.577 km (86.8%) were considered to be in poor technical condition. This indicates that the existing agricultural road network did not provide adequate conditions for efficient agricultural transport. Such conditions were likely to hinder access to agricultural parcels during periods of increased soil moisture and to raise the operating costs of agricultural machinery.

**Table 2.** Existing roads according to the field inventory

| No. | Existing surface type         | Length (km) |
|-----|-------------------------------|-------------|
| 1   | Asphalt road – Good condition | 10.049      |
| 2   | Asphalt road – Poor condition | 0.651       |
| 3   | Gravel road – Good condition  | 1.535       |
| 4   | Gravel road – Poor condition  | 0.831       |
| 5   | Unpaved road – Good condition | 2.219       |
| 6   | Unpaved road – Poor condition | 14.577      |

Source: Krakowskie Biuro Geodezji i Terenów Rolnych (Kraków Office of Geodesy and Agricultural Land Management)



Source: Authors' own study

**Fig. 6.** Example of an agricultural access road with an unpaved surface

As part of the post-consolidation development plan, the reconstruction of the agricultural road network was proposed on a substantial scale. The project included the construction of 37.936 km of newly designed roads and an additional 1.773 km of newly designed roads equipped with drainage systems. Furthermore, 7.138 km of existing roads were scheduled for reconstruction, including 1.545 km with drainage improvements.

The total length of roads planned for construction and reconstruction amounted to 48.392 km. The scale of the proposed measures indicates that the post-consolidation development plan was comprehensive, addressing both improvements to road accessibility and the modernization of road infrastructure. The proposed solutions were designed to create an integrated transport system adapted to the requirements of modern agriculture.

**Table 3.** Changes in the agricultural road network structure

| No. | Road type                                           | Length (km) |
|-----|-----------------------------------------------------|-------------|
| 1   | Newly designed roads for construction               | 37.936      |
| 2   | Newly designed roads for construction with drainage | 1.773       |
| 3   | Roads designated for reconstruction                 | 7.138       |
| 4   | Roads designated for reconstruction with drainage   | 1.545       |

Source: Authors' own study

The proposed changes also included the regularization of the legal status of the road infrastructure. Land designated for new roads, the widening of existing road corridors, and drainage facilities was allocated for transfer to municipal ownership. This solution increases the long-term sustainability of land consolidation outcomes and provides a basis for the future maintenance and modernization of the transportation infrastructure.

The results suggest that improving the agricultural road network had a multidimensional effect. This included improved accessibility of parcel to public roads, greater technical efficiency of the road infrastructure, and the regularization of the legal status of land designated for transportation purposes. Such an approach increases the durability of land consolidation outcomes and facilitates more efficient farming operations. These findings confirm that the effectiveness of land consolidation projects should be evaluated not only in terms of both changes in parcel structure and improvements in the functioning of the entire transportation system.

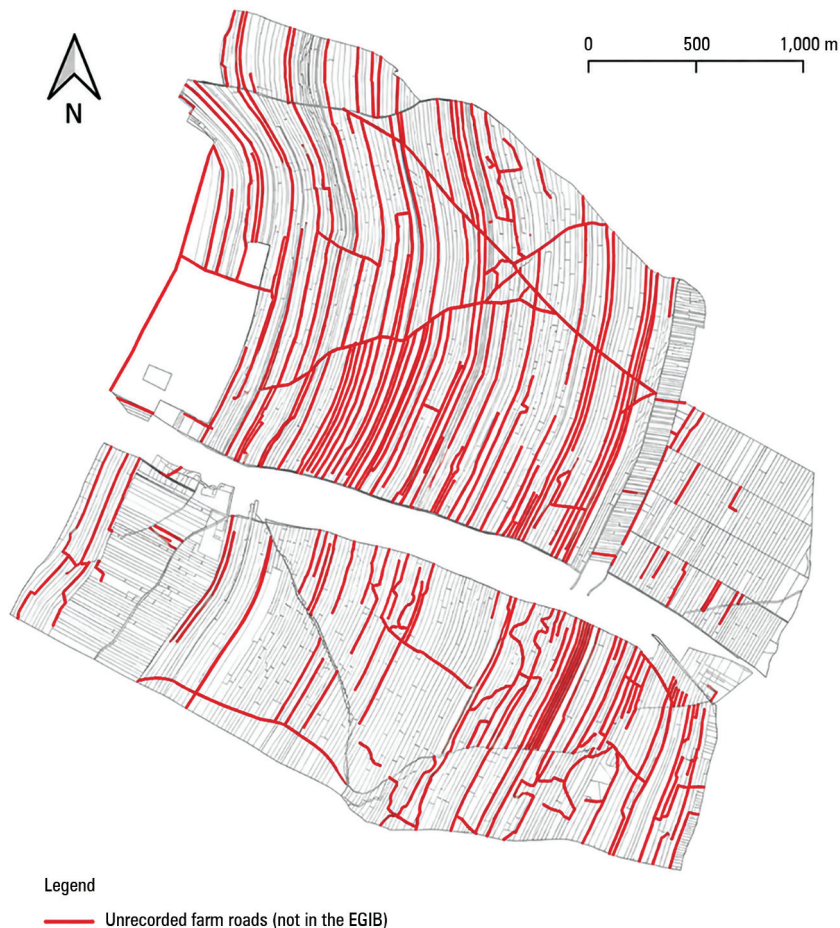
#### **4.4. Informal farm tracks and the restoration of agricultural land to production**

A significant problem prior to land consolidation was the presence of numerous informal farm tracks. These access routes were not registered in the cadastral system but functioned in practice as part of the transportation network serving agricultural land. They were usually located along parcel boundaries, had limited width, and did not meet the requirements of modern agricultural transport [Janus et al. 2017, Taszakowski et al. 2017].

Informal farm tracks were an important part of the transportation system serving agricultural land. However, their existence had several negative spatial consequences. They fragmented cultivated land, occupied agricultural land, and hindered the rational adjustment of parcel boundaries. Another problem was their lack of a clearly defined legal status, which could lead to disputes between landowners. Similar phenomena have been identified in the literature as being characteristic of highly fragmented agricultural areas [Demetriou 2014].

One of the most tangible outcomes of the land consolidation project was the removal of informal farm tracks with a total length of approximately 190 km and an area of about 47.5 ha. This created the opportunity to restore a substantial area of land to agricultural production. The results indicate that the benefits of land consolidation extend beyond improvements in parcel geometry and the construction of new roads, encompassing the recovery of land previously occupied by inefficient transport infrastructure. In practical terms, this contributes to greater continuity of cultivated land and improved organization of agricultural production space.

Eliminating informal farm tracks contributed to the rationalization of the transport system and to the recovery of a substantial area of agricultural land for production. These findings suggest that the benefits of land consolidation extend beyond improvements in parcel geometry and road accessibility, also contributing to a more efficient use of agricultural production space.



Source: Authors' own study

**Fig. 7.** Distribution of informal farm tracks not registered in the cadastre

The results should be interpreted in the context of the local characteristics of the study area. The spatial structure of agricultural land, ownership patterns, terrain conditions, and the organization of the road network in Przegonia are typical of many fragmented rural areas in southern Poland but may differ from those in other regions. Therefore, although the applied methodology can be used to evaluate the effects of land consolidation in other study areas, the quantitative results should not be directly generalized without taking local conditions into account.



Source: Authors’ own study

**Fig. 8.** Examples of informal farm tracks before land consolidation

**Table 4.** Summary of the main outcomes of the land consolidation in the study area

| Indicator                                   | Before land consolidation | After land consolidation | Change |
|---------------------------------------------|---------------------------|--------------------------|--------|
| Number of cadastral parcels                 | 2584                      | 2470                     | -4.4%  |
| Parcels with an elongation ratio > 1:20     | 568                       | 201                      | -64.6% |
| Parcels with an elongation ratio of 1:4–1:1 | 396                       | 661                      | +66.9% |
| Parcels without access to a public road     | 651                       | 104                      | -84.0% |
| Total length of informal farm tracks        | approx. 190 km            | 0 km*                    | -100%  |

\* No longer required as an element providing access to agricultural land

Source: Authors’ own study

5. Conclusions

This study confirmed that land consolidation can be an effective tool for improving the functionality of agricultural production space, particularly in areas characterized by a high degree of land fragmentation, unfavourable parcel geometry, and insufficient road accessibility [Hartvigsen 2014, Janus and Ertunç 2021]. In the analyzed study area, the positive effects of land consolidation were observed in both the structure of cadas-

tral parcels and the agricultural road network. This confirms the comprehensive nature of this instrument for rural spatial development [Elvestad and Sky 2019].

One of the most important outcomes of the land consolidation project was the improvement of parcel geometry. The number of parcels with the most unfavourable proportions, characterized by an elongation ratio exceeding 1:20, decreased from 568 to 201, while the number of parcels with favourable proportions (1:4–1:1) increased from 396 to 661. These changes indicate a substantial reduction in the parcels that hinder efficient field operations and an increase in the share of parcels better suited to modern agricultural mechanization [Akkaya Aslan et al. 2007, Hiironen and Riekkinen 2016].

Road accessibility has also been improved significantly. The number of parcels without access to a public road dropped from 651 to 104. This result demonstrates an effective integration of the new parcel layout with the planned agricultural road network that enhances the functionality of agricultural space considerably. It also confirms with findings from previous studies, which identify road accessibility as a key indicator of land consolidation effectiveness [Janus et al. 2017, Taszakowski et al. 2017].

Another important outcome was the rationalization of the transport system. The post-consolidation development plan included the construction and reconstruction of more than 48 km of agricultural roads, creating a foundation for improved accessibility and guaranteeing the long-term sustainability of the adopted infrastructure solutions. At the same time, informal farm tracks with a total length of approximately 190 km and an area of about 47.5 ha were removed. This made it possible to restore part of the land to agricultural production, improve the continuity of cultivated land blocks, and reduce problems associated with the unresolved legal status of access routes [de Vries 2022, Janus and Ertunç 2021].

The results indicate that the effectiveness of land consolidation should not be evaluated solely in terms of changes in the number of parcels. Changes in parcel geometry, road accessibility, and the degree of organization of the road infrastructure are equally important. The Przeginia study area is an example of how a properly designed land consolidation project can lead to lasting improvements in farming conditions, more efficient land use, and enhanced functionality of agricultural production spaces. The results also highlight the necessity of comprehensive assessments of land consolidation outcomes that consider both parcel geometry and the performance of agricultural road networks.

The proposed evaluation framework, which combines the assessment of parcel geometry, road accessibility, road network condition, and informal farm tracks, can also be applied in comparative assessments of other land consolidation projects, thereby supporting a more comprehensive evaluation of their effectiveness.

Future research could extend this evaluation framework by incorporating analyses of the distance between farmsteads and agricultural parcels, as well as travel time and transport costs. Such analyses would provide an additional quantitative measure of the impact of land consolidation on agricultural production efficiency and farm management.

Overall, the study demonstrates that the effectiveness of land consolidation should be evaluated using a multidimensional approach that considers not only changes in parcel structure, but also parcel geometry, road accessibility, road infrastructure, and the removal of informal farm tracks. Such an approach provides a more comprehensive assessment of improvements to the functionality of agricultural production spaces and could inform the evaluation of future land consolidation projects.

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