


The impact of land consolidation on the improvement of spatial structure and farming conditions in areas affected by highway construction

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Summary

The article discusses the process of land consolidation as a corrective measure used to minimize the negative effects of highway construction. Linear investments, such as highways, cause the fragmentation of agricultural land, leading to numerous problems related to the use of that land, and to limited transport accessibility. As a result, farmers often lose the ability to manage their plots efficiently, which affects the profitability of agricultural production and hinders the development of farms. Moreover, the lack of access to public roads increases transportation costs and reduces the competitiveness of agriculture in the given area. To mitigate these effects, the land consolidation process is applied, allowing for the reorganization of agricultural space, improvement of land structure, and ensuring access to transport infrastructure. The subject of the analysis is the land consolidation process carried out in the northwestern part of Tarnów, where the construction of the A4 highway caused significant disruption to the layout of land plots (parcels) and road network. The goal of the process was to eliminate excessive land fragmentation, improve access to public roads, and modernize the land layout to enable more efficient use in terms of farming and development. The consolidation work included, among other things, the design of a new network of access roads, the elimination of plots without infrastructure access, and the adaptation of space to the needs of local farms and enterprises. The article emphasizes that similar measures are also applied in other European countries, where land consolidation is an essential element of spatial planning.

Keywords

land consolidation • A4 highway • agricultural space

1. Introduction

The development of transport infrastructure, including the development of the highway network in particular, is an indispensable element of the economic and social progress of each country. The increasing volume of road traffic, the need to ensure a higher level of safety for road users and the intensification of trade at the national and international level require systematic modernisation and expansion of the existing road system. That notwithstanding, the implementation of linear investments, such as highways, also brings with it a number of negative effects – both environmental and spatial – especially in the context of rural areas and agricultural land [Bacior et al. 2022].

Infrastructural consolidation of land constitutes a process aimed at repairing the agricultural production space disturbed by linear investments, such as the construction of a highway [Janus 2011a, Janus et al. 2017]. Although the development of the road network is indispensable for the country's growth, its implementation may significantly violate the continuity and integrity of the agricultural space. Highways often cross complexes of cadastral plots (parcels), cutting off the ownership of part of the farmstead's land, which makes the efficacious use of that land difficult or impossible [Szafrńska 2011]. Such fragmentation leads to the disorganization of agricultural space that had been shaped over the years; its impact is long-lasting and notoriously difficult to reverse [Doroż et al. 2022].

The preeminent goal of the land infrastructure consolidation process in Poland is the rational development of the newly developed space, in particular through designing functional network of access roads to agricultural and forest land, adapted to the existing terrain. Another important element is the integration of separated cadastral plots within individual farmsteads [Doroż et al. 2022, Taszakowski et al. 2023], which directly affects the increase in the efficiency of running the agricultural business. Additionally, land consolidation allows for the elimination of the so-called 'leftovers' and optimization of the configuration of the drainage network, taking into account the design and creation of new entrances and culverts. The entire process is also geared to develop potential for improvement regarding the functionality of the production space in agriculture [Harasimowicz and Janus 2009].

Studies that addressed the impact of linear investments to date had focused on the impact of changes in the landscape structure, on increased urbanization of rural areas, as well as on the cultivation of biodiversity and obtaining landscape values. It was much less frequently that the impact of such expenditures on the continuity and integrity of agricultural space was addressed – hence, we believe, the need to search for a tool that would enable us to evaluate the impact of these investment projects, while taking into account productive functions of the land [Bacior and Prus 2018].

In contrast to the approach prevalent in Poland, the process of land consolidation in many Western European countries is an integral element of spatial planning, both in terms of land and infrastructure. For instance, in Germany [Marcinkowski 2011,

Moeller 2002] and in the Netherlands [Leenen 2021], land consolidation is determined before commencing a linear investment. Thanks to that approach, it is possible not only to secure the investment land beforehand, but also to ensure a harmonious connection of the future road system with the existing agrarian structure. This type of preventive action leads to minimizing social and economic costs, while avoiding deep fragmentation of plots and promoting the maintenance of farmsteads' continuity.

In the German model, land consolidation is one of the mechanisms of administrative action within the road investment planning procedure, in which the needs of property owners, ownership structure, and optimization of the parcel system are all taken into account. In turn, in the Netherlands, the land consolidation process is also linked with environmental aspects and landscape policies, resulting in the application of multifunctional management of rural space [Sobolewska-Mikulska and Wójcik-Leń 2012].

In Poland, however, this is not the case. The land consolidation processes are most often reactive and are launched only after the completion of the linear infrastructure investment, after the fragmentation of the agrarian structure had already occurred, when the spatial and social effects are permanent. As a result, the options for improving the spatial planning situation are severely limited, as is the effectiveness of land consolidation in terms of recovering the functionality of farmsteads. We cannot stress enough that the efficient protection of agricultural land should be integrated with investment planning process from the very beginning, while taking into account the functional and production value of that land [Dudzińska et al. 2019].

The current legal regulations in Poland do not provide for mandatory linking of land consolidation proceedings with the planning of linear investments. The provisions of the Act on land consolidation and exchange [Act 1982] allow for the implementation of land consolidation as a compensatory measure, but they do not impose the obligation to plan it in advance of the investment process. Despite attempts by scientific and expert communities to systemically integrate these procedures [Janus et al. 2017, Taszakowski et al. 2023], there are still no appropriate regulations that would allow for the treatment of land consolidation as an element of integrated spatial and investment planning.

The consequence of this state of affairs is lower spatial efficiency of investment projects and fewer opportunities for sustainable development of rural areas. Introducing the obligation to plan land consolidation in advance at the investment preparation stage could significantly improve both the quality of spatial order and the efficiency of using public funds. Western European examples show that preventively carried out land consolidation is an effective tool for minimizing social conflicts, production losses, and degradation of the spatial structure.

2. Aim and methods of the study

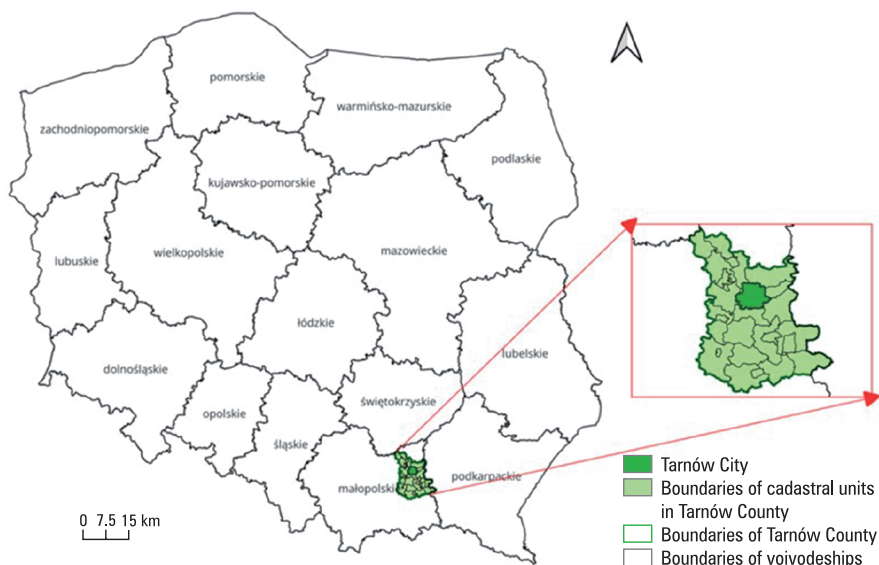
The aim of the study was to determine the effectiveness of the land consolidation process as a corrective tool used in response to the spatial effects of linear investment implementation, using the example of the Klikowo consolidation area in the city of Tarnów. The analysis focused on assessing the impact of consolidation on improving

the agrarian structure, communication accessibility of cadastral plots, and the quality of cadastral data.

The study was based on the comparative analysis method using cadastral data and land consolidation documentation regarding the studied area. Changes in the number and area of plots before and after the consolidation were analyzed, the improvement of their shape and layout was assessed, and the accessibility of plots to public roads was examined. GIS tools were used to visualize the spatial effects of the consolidation process. The analysis was supplemented by an assessment of the impact of land consolidation on the quality of cadastral data and the functioning of farmsteads, including a large agricultural enterprise operating in this area.

3. Description of the studied object

Tarnów is located in the north-eastern part of the Małopolska Province (voivodeship), covering an area of 72.4 km². The area covered by land consolidation procedure is located in the north-western part of Tarnów. This is the area of the former cadastral municipality of Klikowa, currently one of the city's districts. According to the land and building register, it includes cadastral districts no. 01, 02, 03, 04, 07, 08 and 09. To the west, it borders the cadastral district of Bobrowniki Wielkie (in Żabno municipality), and to the north-west, the cadastral district of Łęg Tarnowski (also in Żabno municipality). To the north, in the eastern part, it adjoins the lands of the village of Pawężów (in Lisia Góra municipality). To the east and south, Klikowa borders the remaining areas of the city of Tarnów. Figure 1 shows the location of the 'Klikowa' land consolidation object.



Source: Authors' own study

Fig. 1. Location of the city of Tarnów in the context of the entire country and the Małopolska Province

The consolidation process covered 1955 cadastral plots with a total area of 436.12 ha. The communication system in the Klikowa area was characterized by a hierarchical-network structure. Provincial road no. 973 (Busko-Zdrój – Tarnów) ran through the central part of the consolidation area, while municipal roads were located mainly along the southern, northern and partially also the western border of the analyzed area. Despite the existence of the basic skeleton of the road network, the number of public roads was insufficient, which forced many users of agricultural land to use private roads – often subject to joint ownership and burdened with easements. A total of 374 entries regarding road easements were recorded in the land and mortgage registers.

To the south of the A4 motorway, there were numerous cadastral plots in the form of narrow strips of pastures, which once served as roads. However, they were largely overgrown and impassable, which limited their communication functionality. The existing road network did not provide all plots with effective transport access, which in many cases generated organizational and economic difficulties in conducting agricultural activities.

One of the key tools to improve this state of affairs was the comprehensive reconstruction of the spatial structure of farmsteads, carried out as part of the land consolidation process. At this point, we should note that access to plots located in the immediate vicinity of the motorway is sometimes taken into account already at the stage of designing a linear investment – through the implementation of collector and local roads, which are an integral element of the infrastructure. In this context, land consolidation plays a complementary role, enabling better connection of the newly created communication infrastructure with the existing agrarian structure, and thus increasing the spatial coherence of the entire farming system.

Despite the location of the analyzed area within the administrative boundaries of the city of Tarnów, part of the Klikowa district has retained a distinctively agricultural character. There are both family farms and operating agricultural enterprises, for which spatial conditions were of significant economic importance. For that reason, the land consolidation which had been carried out in that area was not only of an *ad hoc* nature, related to the organisation of space after the construction of the motorway, but also of a long-term nature – allowing for ordering of the legal status of the land, increasing the functionality of agriculturally used areas, and preparing them for further spatial and investment development of the city.

4. Analysis of the results of land consolidation

The land consolidation area was located in the former Galicja region, which was historically part of the lands under the Austrian partition. Traces of the occupier's influence and documentation prepared at that time are still visible today. Frequent discrepancies between the areas of cadastral plots, the effects of entries in the land and building cadastral database and cadastral maps versus the actual use of the land constituted a significant problem in the implementation of land consolidation process.

An additional difficulty was the examination of the legal status of the properties, which required the analysis of not only land and mortgage registers, but also old registers such as LWH (mortgage register number) and AWZ (land ownership deeds). Numerous technical reports and synchronization of cadastral plots required a significant amount of work so that the newly designed land layout would be acceptable to the respective participants in land consolidation.

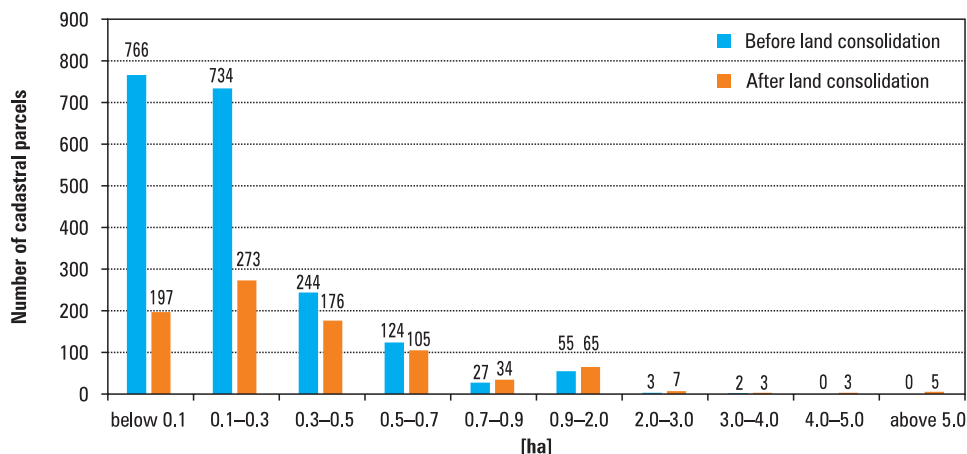
In the land consolidation aspect, there was significant land fragmentation, mainly caused by family divisions, which negatively affected the agrarian structure. Most cadastral plots had a size of less than 0.1 ha. The table below (Table 1) and the following graph (Fig. 2) compare the number and size of cadastral plots before and after land consolidation, covering 10 size ranges. The land consolidation process significantly reduced the number of the smallest cadastral plots, especially those below 0.1 ha and those in the range of 0.1–0.3 ha. The greatest difference concerns plots below 0.1 ha – their number dropped from 766 to 197, and the total area shrank from 32.6971 ha to 9.4022 ha, which means a reduction of 569 cadastral plots. This change significantly improved the spatial structure of the land.

Table 1. Fragmentation of cadastral plots before and after land consolidation

No.	Size (area) of plots according to range [ha]	Status before land consolidation		Status after land consolidation		Difference in the number of plots
		Number of plots	Size (area) of plots [ha]	Number of plots	Size (area) of plots [ha]	
1	below 0.1 ha	766	32.6971	197	9.4022	-569
2	0.1–0.3 ha	734	142.2622	273	56.2613	-461
3	0.3–0.5 ha	244	93.0758	176	68.0016	-68
4	0.5–0.7 ha	124	71.5136	105	31.5498	-19
5	0.7–0.9 ha	27	22.0623	34	27.1067	7
6	0.9–2.0 ha	55	61.4167	65	77.036	10
7	2.0–3.0 ha	3	7.4115	7	33.7972	4
8	3.0–4.0 ha	2	6.9971	3	10.1919	1
9	4.0–5.0 ha	0	0.0000	3	17.4655	3
10	above 5.0 ha	0	0.0000	5	98.4666	5
Total		1955	437.4351	868	437.5076	-1087

The next analysis concerned the elongation of cadastral plots. The key indicator in this respect is the ratio of the length to the width of the plot, which affects the number of returns during cultivation. The optimal ratio, according to the literature, is 1:5 [Woch 2001]. Land consolidation contributed to the reduction of the number of plots

with an excessively elongated shape, especially in the ranges of 1:10–1:9 and 1:9–1:7, which improved their functionality and facilitated agricultural use with the application of modern agricultural machines.



Source: Authors' own study

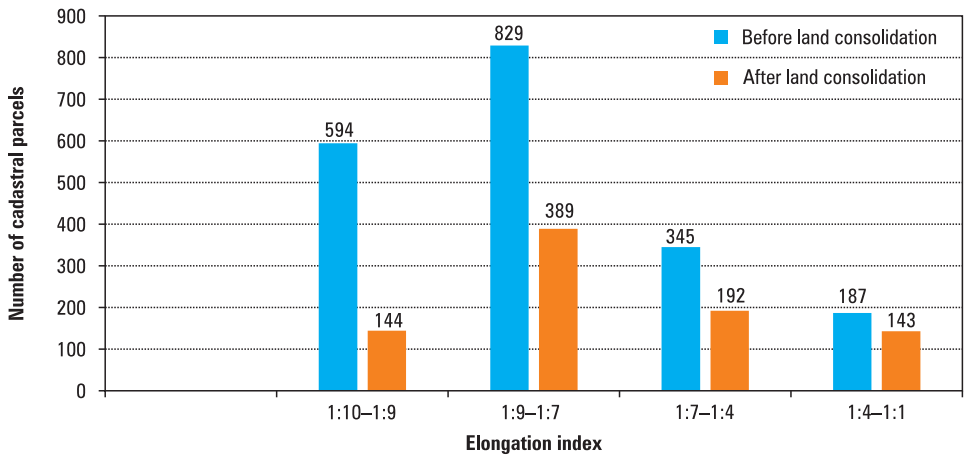
Fig. 2. Changes in the number and size of plots before and after land consolidation, according to size range

We should note that fields that are excessively short and wide (e.g. 1:2), with a small area, require frequent machine returns, which increases the loss of time and fuel. On the other hand, fields that are excessively long and narrow (e.g. 1:15) can make cultivation difficult; they may lead to erosion and problems with access to the plots.

Table 2. Comparison of the number of plots according to the range of plot elongation before and after land consolidation

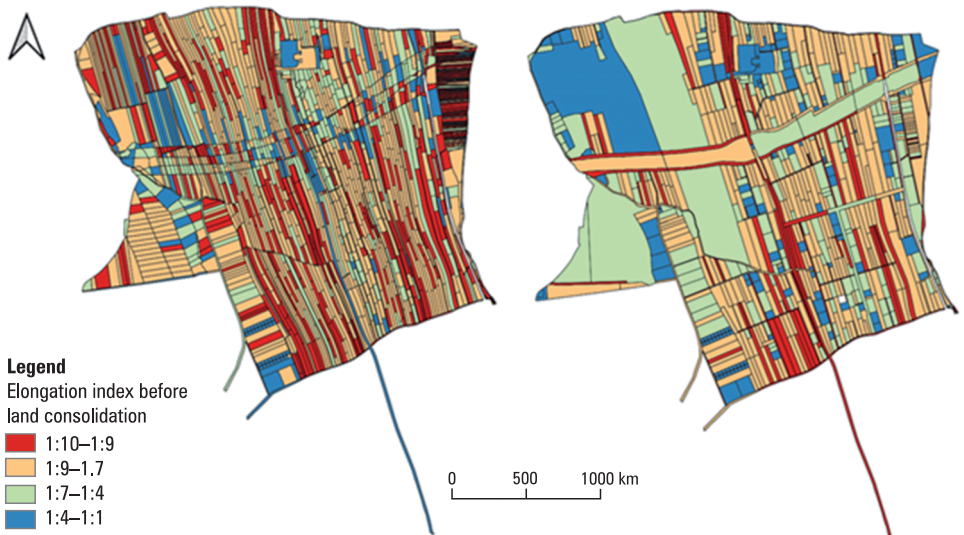
No.	Plot elongation ratio according to range	Status before land consolidation		Status after land consolidation		Difference
		Number of cadastral plots	Percentage share in the total number of plots	Number of cadastral plots	Percentage share in the total number of plots	
1	1:10–1:9	594	30.38	144	16.59	–450
2	1:9–1:7	829	42.40	389	44.82	–440
3	1:7–1:4	345	17.65	192	22.12	–153
4	1:4–1:1	187	9.57	143	16.47	–44
Total		1955	100	868	100.00	–1087

In order to clearly illustrate how the elongation of the plots changed before and after land consolidation, these differences were presented in a graph format (Fig. 3). The plots with the least favorable elongation parameters, i.e. those with the least proportional shape, are marked in red. In contrast, the plots with the most balanced proportions, which have the most functional shape, are marked in green and blue.



Source: Authors' own study

Fig. 3. Comparison of the number of cadastral plots according to the range of plot elongation



Source: Authors' own study

Fig. 4. Analysis of cadastral plot elongation parameters. To the left: before land consolidation, to the right: after land consolidation

The area subjected to land consolidation was also characterized by an unfavorable land layout. Land layout is the location of land belonging to an agricultural holding in relation to the habitat where residential and farm buildings are located [Act 1982, Jadczyzyn and Woch 2017]. Land layout has a tremendous impact on conducting agricultural activities, because improper land layout affects, among others, the loss of income of agricultural holdings. Small size of agricultural holdings, a large number of cadastral plots in a farm, small area of a cadastral plot, large distance between the land and the habitats, are the main reasons for the decrease (even by 30%) in agricultural income obtained in agricultural holdings [Woch 2007, Dudzińska 2012].

The results regarding changes in the number of cadastral plots in farmsteads after land consolidation are presented below. The analysis included several selected farmsteads, focusing on those that best illustrate the effects of land consolidation procedures. The selection was made based on the analysis of land consolidation results.

Eight examples of land consolidation participants were presented, including seven farmsteads and one enterprise operating in the area covered by land consolidation (Table 3).

Table 3. Comparison of the number of plots within farmsteads

No.	The number of cadastral plots		Difference
	Status before land consolidation	Status after land consolidation	
1	4	1	-3
2	6	2	-4
3	8	1	-7
4	6	1	-5
5	5	1	-4
6	5	1	-4
7	6	1	-5
8	204	7	-197

In six of the analysed farmsteads, the number of plots was reduced to one per farm. This means that the entire equivalent due was allocated in one cadastral plot (parcel). In the case of the seventh farmstead, the equivalent was allocated in two cadastral plots. The largest change occurred in the lands belonging to a large private enterprise operating in the studied area. Before land consolidation, the total area of its plots was 76.3745 ha, while after consolidation it increased to 76.5411 ha, which is a difference of 0.1666 ha. Before the reorganisation, these lands were significantly dispersed, covering as many as 204 cadastral plots. As a result of consolidation, the number of plots was reduced to only seven. The change in the location of the lands is presented in Figure 5.



Source: Authors' own study

Fig. 5. Analysis of the number of land plots (parcels) belonging to a private enterprise



Source: Authors' own study

Fig. 6. Land consolidation results for plots belonging to a private enterprise

It should be noted that the consolidation of land in the studied area of Tarnów not only improved the spatial structure of farms, but also significantly improved the opera-

tion of the private enterprise. Thanks to the reorganization of the areas, the company gained better conditions for conducting business, which may translate into its greater efficiency and growth.

Another analysis performed as part of the assessment of the conducted land consolidation procedure concerns the access of cadastral plots to public roads. The results of the analysis are presented in Table 4.

Table 4. Summary of the accessibility of cadastral plots to public roads before and after consolidation

Type of plots	Status before the consolidation of plots		Status after the consolidation of plots	
	Number of plots	Percentage share [%]	Number of plots	Percentage share [%]
Plots with access to a public road	625	31.97	737	84.91
Plots without access to a public road	869	44.45	23	2.65
The total number of roads	461	23.58	108	12.44
Total	1955	100.00	868	100.00

Table 4 shows a significant increase in the share of plots with direct access to public roads – from 31.97% before the consolidation to 84.91% after its completion. This proves the positive impact of the land consolidation process on the accessibility of land by road. At the same time, the number of plots designated for roads decreased more than fourfold – from 461 to 108. This does not mean a deterioration of the road system, but its rationalization and optimization.

As part of land consolidation, a detailed analysis of land assets belonging to the State Treasury – managed by the General Directorate for National Roads and Motorways – was carried out. These plots, previously fragmented and located in the strip around the motorway, were consolidated into larger complexes and moved to the eastern part of the consolidation area, including floodplains. Thanks to this solution, it was possible to more effectively develop the space and better adapt the communication system to local terrain conditions and the needs of land users.

An important element of the project was also the expansion and modernization of the road system, which was crucial for improving the accessibility of plots and ensuring efficient transport service for the entire area. As part of the consolidation works, the following were designed:

- 13,400 km of new roads to be built – enabling better connections between plots and increasing the accessibility of farmland and investment areas,
- 4,400 km of roads to be rebuilt – the modernization of which was aimed at improving the quality of the surface, increasing the load-bearing capacity, and adapting technical parameters to the applicable standards.

The implementation of these activities contributed to the increase in the functionality of the entire area covered by the consolidation, to improving transport conditions, and to increasing the efficiency of land management. The new spatial organization and modernized road infrastructure not only facilitated farming operations, but also created favorable conditions for future investments and local development. The new road system is presented in Figure 7.



Source: Authors' own study

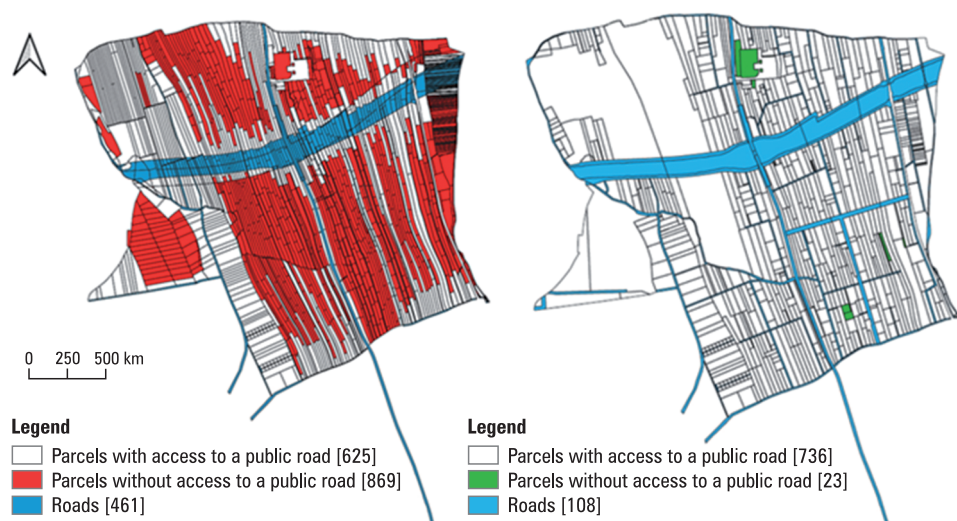
Fig. 7. Newly designed road network

An issue inextricably linked to the previous analysis is the question of access to public roads, which plays a key role in the effective use of land. In the context of agriculture, the lack of access to a public road may hinder the transport of farming products and access to agrotechnical services, which negatively affects the efficiency of management.

Before the land consolidation process, the total number of plots in the analyzed area was 1955, of which 461 plots were areas designated for roads, and that corresponded to 23.58% of the total number of plots. The spatial structure of the land was highly inefficient, as evidenced by the fact that only 31.97% of the plots had direct access to a public road, while as many as 44.45% (869 plots) were deprived of such access.

As a result of the implementation of the consolidation process, the total number of plots was significantly reduced, down to 868 in total. Of these, 108 are currently roads, which corresponds to 12.44% of the total number. The key result of the consolidation is a significant improvement in communication accessibility – plots with direct access to a public road constitute 84.91% (737 plots), which represents more than a two-fold increase compared to the state before the consolidation. At the same time, the number of plots without access to a public road decreased to 23 (2.65% of the total number), which represents more than an eight-fold decrease compared to the previous spatial layout. It should also be added that plots without direct access to public roads have access provided on the basis of a land easement or through another plot belonging to the same owner.

The analysis shows that the consolidation process contributed to a significant improvement in the efficiency of spatial development. The share of plots designated for roads decreased from 23.58% to 12.44%, which indicates the optimization of the communication system and a more efficient use of land. Additionally, a significant reduction in the number of plots without access to road infrastructure has a positive impact on the potential land use, both in terms of farming operations and investment activities. Figure 8 shows the change in the access of cadastral plots to public roads.



Source: Authors' own study

Fig. 8. Analysis of cadastral plot elongation parameters. To the left: before land consolidation, to the right: after land consolidation

As a result of the consolidation works that were carried out, the quality of data collected in the land and building register database has significantly improved [Doroż 2019, Taszakowski et al. 2021]. Thanks to conducting the soil classification of land and

the update of land uses, this database has become more consistent, precise and reliable. Currently, it contains updated and factually correct information on land uses, soil quality classes, and buildings.

With respect to cadastral plots, the cadastral database meets all accuracy standards specified in Polish law. Each boundary point has been given the ISD attribute (information on meeting accuracy standards), marked as 'meets the standard,' which confirms that its location has been determined in relation to the points of the horizontal geodetic or measurement network with an accuracy of no less than 0.10 m.

Significantly, as a result of the work conducted, each cadastral plot has an area determined with a precision of up to 0.0001 ha. At the same time, all discrepancies between the descriptive and the graphic parts of the land and building cadastral record have been eliminated. Currently, the area of cadastral plots is fully consistent in the cadastral database and in land and mortgage registers, as well as in the actual location in the field, whereas the conducted field measurements meet the highest accuracy standards.

An additional positive effect of the land consolidation is the assurance of full clarity and stability of the boundaries – each boundary point has been verified and permanently marked in the field in accordance with the applicable regulations, which eliminates doubts and potential future border disputes.

5. Conclusions

The land consolidation process in the studied area of Tarnów is an example of effective spatial intervention aimed at minimizing the negative effects of agricultural land fragmentation caused by linear investments, in particular the construction of motorways. Land fragmentation, resulting from the dynamic development of transport infrastructure, led to numerous problems in the management of agricultural space. In this context, conducting the consolidation operation was aimed at augmenting the spatial structure, improving land availability, and modernizing the road infrastructure.

As a result of the consolidation process, 1955 plots were spatially reorganized with a total area of 436.12 ha, which allowed for a significant reduction in land fragmentation. Particular attention was paid to eliminating the smallest cadastral plots, the number of which in the area range below 0.10 ha dropped from 766 to 197, and that represents a reduction of 569 plots. Similar changes also concerned larger area ranges, which significantly improved the functionality and efficiency of land use. In addition, the analysis carried out in this study showed a positive impact of consolidation on the shape of the plots, in particular in terms of their elongation, which translated into the optimization of agrotechnical processes and a reduction in costs related to cultivation.

Another important element of the conducted consolidation procedure was the improvement of communication accessibility. Before the process began, only 31.97% of the plots had direct access to a public road, while as many as 44.45% (869 plots) were cut off from the road infrastructure. After the completion of consolidation procedures, the situation improved dramatically – 84.91% of the plots obtained direct access to a public road, and the number of plots without such access dropped to only 23 (2.65%).

The number of plots designated for road infrastructure was also significantly reduced, which indicates the effective optimization of the communication system.

An additional positive effect of the consolidation process was the modernization and construction of road infrastructure. As part of the project, 13.4 km of new roads were planned, which allowed for better communication within the farms and the integration of agricultural areas. In addition, 4.4 km of existing roads were rebuilt, adapting them to modern utility standards and increasing their functionality. Such actions improved transport conditions, streamlined access to agricultural land, and enabled better management of economic space.

The consolidation procedures that were carried out also had a significant impact on improving the quality of cadastral data. As a result of the work carried out to update and verify information in the land and building cadastral database, a high level of consistency was achieved between descriptive and graphical data, eliminating previous discrepancies. Each cadastral plot (parcel) currently has an area settled with a precision of up to 0.0001 ha, and the boundary points meet the accuracy standards provided for in Polish geodetic law, with a specified position accuracy of no less than 0.10 m. This ensured the consistency of records in cadastral databases, land and mortgage registers, and the actual state in the field, which translates into greater legal certainty and the elimination of potential border conflicts.

To conclude, the land consolidation carried out in Tarnów brought numerous benefits both for agriculture and the development of the private sector. The optimization of the land structure, the improvement of communication accessibility, and the increase of the functionality of the plots all contributed to increasing the efficiency of management and the upgrading the utility value of the land. Moreover, the modern approach to spatial planning and taking into account the infrastructure and environmental aspects allowed for the implementation of activities in accordance with the principles of sustainable development. This example clearly demonstrates that well-planned and correctly conducted land consolidation process can be an effective instrument for the optimization of agricultural space and the improvement of management conditions in areas affected by land fragmentation resulting from the development of linear infrastructure.

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