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GIS TOOLS IN THE CONSERVATION AND SUSTAINABLE DEVELOPMENT NATIONAL PARKS, FORESTS AND RURAL AREAS

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Abstract

The problem of optimising the location of crops/plots in protected areas, national parks, farmland or forests involves trying to reconcile their proper functioning with nature conservation, the preservation of unique ecosystems or sustainable development. Such areas are crucial for the preservation of biodiversity and wildlife. This paper examines and discusses the impact of land consolidation in rural areas using GIS (Geographic Information System) tools. It performs a series of network analyses to determine the real distances (following the road network) and linear distances (rectilinear distances) between habitats and farmland. A tool was also developed to automate this process. The results obtained were visualised using map compositions, tables and graphs. The implemented project had a significant beneficial effect on the change in the land structure in the analysed village. The number of registered plots decreased by 40% (from 1,189 to 711) due to the consolidation process.

***Keywords**: GIS; Ecology; Ecological indicator; Preservation; Sustainability: Geography Computer; Optimalization, Rural studies*

Introduction

In any field of work, one of the most important factors is time and the ability to use it to get the best results and profits [1]. It is a particularly important aspect in the department of rapid movement and transport in both rural, urban and non-urbanised areas. For rural areas, an action has been carried out for many years to improve the shape and distribution of land cultivated by farmers, which is called land consolidation [2]. Unfortunately, this measure is very complicated and time-consuming, but very effective [3]. Land consolidation is the alteration of fragmented properties (of varying shape and area, located at a considerable distance from each other) or properties of incorrect configuration, which belong to different owners and are located in a given area, in order to create better conditions for agriculture [4]. In the case of cities, its design is already optimised at the planning stage to make the best use of the land, taking into account sustainability in terms of population needs, tourism, ecology, transport economics etc [5, 6]. Such measures are also being introduced in ecological sites, national parks, forests (Fig. 1) or protected reserves [7, 8].

Each of the above processes has a number of benefits: they reduce transport time and cost, optimise accessibility or use of individual properties. Additional advantages are: reduction of the number of plots of land (admistrative aspect); elimination of inaccessible (e.g. dead-end or no-

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entry) or unusable (e.g. uncultivated land) sites; reduction of the time it takes to reach a site (e.g. cultivation in protected areas); better access of sites to public roads or drainage areas [9, 10]. All of that should lead to main goal of land conslidation - effective and economical use of rural space [11].

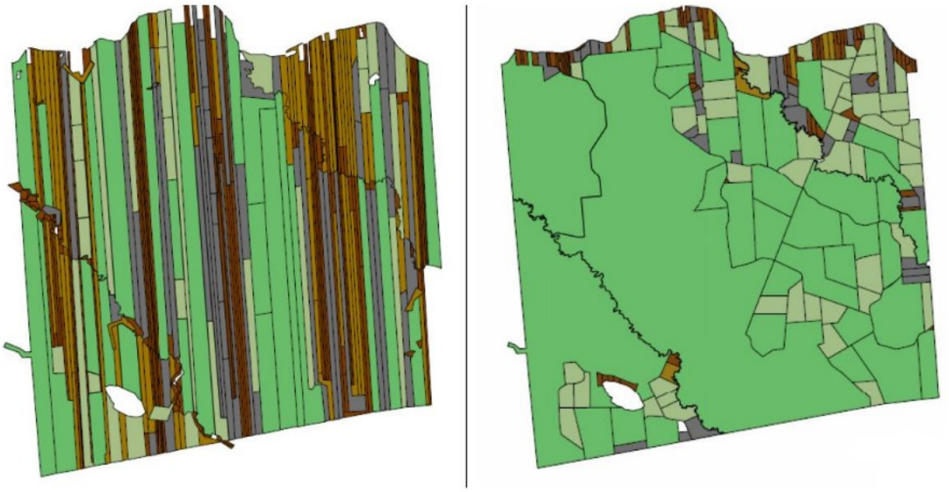

Fig. 1. Pahkakoski forest land consolidation project before and after land consolidation (Map ©National Land Survey of Finland, permission 051/MML/15) [10]

During land consolidation, the legal status of the property is also sorted out [12]. In addition, a properly conducted land consolidation process should demonstrate a positive or neutral impact on the environment. This ecological aspect is also taken into account when the environmental study or environmental impact assessment of the land consolidation project is drawn up at the outset [13]. Often tourist plots in national parks are located far from the main entrances. This may require a long and time-consuming trek or the use of additional means of transport, such as bicycles or parking buses. In the case of protected areas, improper management can lead to the degradation of natural habitats that are home to many plant and animal species. Changes to the landscape and simplification of the environment can affect the disappearance of rare species.

In the case of agricultural land, the following factors can be distinguished that influence the distribution and shape of the land [14, 15]:

– size of the land;
– number of parcels belonging to one owner;
– size of each parcel;
– shape of each parcel;
– spatial distribution of parcels;
– size distribution of parcels.

Unfortunately, there is no one-size-fits-all way to determine a favourable land distribution, as no measurement or indicator will take into account all of the above parameters. Many authors attempting to address this problem have taken into account the average number of plots per owner, the average size of the farm and the average size of the plot (fragmentation of parcels) in their research and analysis. A. Simmons [16] took into account the number of plots on the farm and the size of each plot. F. Dovrin [17] made calculations based on the distance a farmer would have to travel to reach each of his plots, including the return routeą. J. Januszewski [18] Like Simmons, he related the number of plots and their size per owner. However, he did not take into account the size of the holding, the distance of the plot and its shape. M.U. Igbozurike [19] unlike previous methods, he based his coefficient on the average size of the plots and the distance travelled by the farmer to visit all the plots. G.J. Schmook [20] determined the ratio between the area of the polygon that surrounds all the parcels of a farm and the area of that farm. The values of this ratio are always greater than 1 (high values indicate intensive land fragmentation). This method has the advantage that it takes into account both the size of the farm and the distance. Unfortunately, however, the number of plots per owner is ignored. Schmook also suggested another quotient presented as the ratio of the average distance of the plots to their average size.

Each method has greater or lesser limitations. The coefficients proposed above ignore non-spatial parameters such as the type of ownership, the lack of access of a land parcel or a property parcel with a dwelling house to a road. Therefore, new methods and formulas for calculating land distribution are emerging, increasingly sophisticated and accurate and based on large data sets. D. Demetriou *et al.* [14, 21] proposed a very complex algorithm to type highly fragmented areas. Nevertheless, distance should be considered as a key element for an accurate assessment of land distribution. The method of determining distance can have a impact on its value [22-24].

Parcel fragmentation, like dispersal, is an important factor in land distribution and therefore forms the basis for analysing the effects of land consolidation. This paper presents a comparison of the state before and after land consolidation, using a GIS (Geographic Information System). There are many elements and parameters that can be collated, compared with each other [25]. Especially as the availability of digital data increases [26]. The focus was mainly on linear and network analyses, comparing distances from the owner's place of residence to the parcels on the farm, and on changes related to the area for the owners concerned.

Methods

As a representative example, the village of Męcina Wielka was selected. It is located in the Lesser Poland Voivodeship, in the south of Poland, and consists of more than 95% forest and agricultural land. (Fig. 2). The entire administrative precinct of the village was subject to the land consolidation process, the total area of land that was subjected to this process amounted to 938 ha, including: 390ha of agricultural land (41.6%) and 510ha of forest land (54.4%). In total, it consisted of 1,189 land parcels belonging to 190 farms (owners). After land consolidation, the number of plots was 711.

This type of site was chosen because of its relatively regular shape, the large dispersion in size and shape of the plots and the very high proportion of land without human infrastructure, i.e. agricultural fields and forests, but containing access roads. As a result of the procedure, the number of plots was reduced by almost 40%, the co-ownership of plots was abolished and the distribution of plots in relation to the place of residence of the owners was significantly improved, and the area structure of the farms was improved.

For the analysis, vector data containing parcel and land use boundaries for the state before and after land consolidation and numerical data containing a list of parcels and owners were used. A selection of farms with at least two plots of land before and after land consolidation was made and it was verified whether there was a residential building on one of the plots. Final, taking into account the above assumptions, 73 owners containing 304 plots before land consolidation and 73 owners and 255 plots after land consolidation were accepted for the analysis (Fig. 3).

On the basis of these data, the:

i) polygon layers of land parcels before and after land consolidation containing information on parcel number, owner number, area of the parcel and information on whether and what building is on the parcel;

ii) a linear layer containing the location of roads before and after land consolidation (Fig. 4);
iii) a point layer of the centroids of the land parcels.

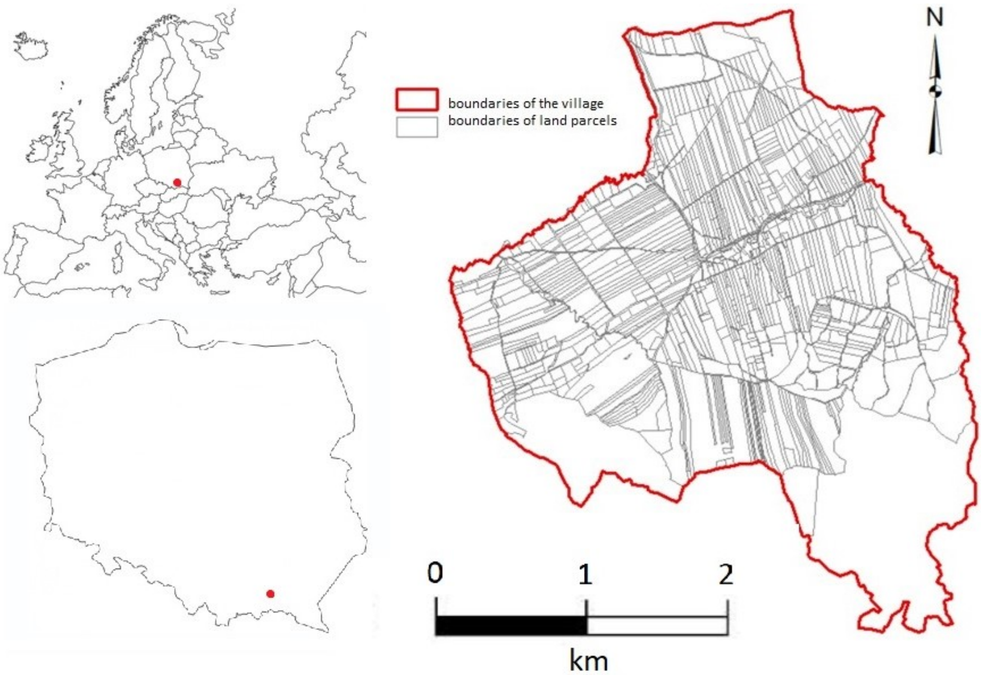

Fig. 2. Presentation of parcels included in the land consolidation process

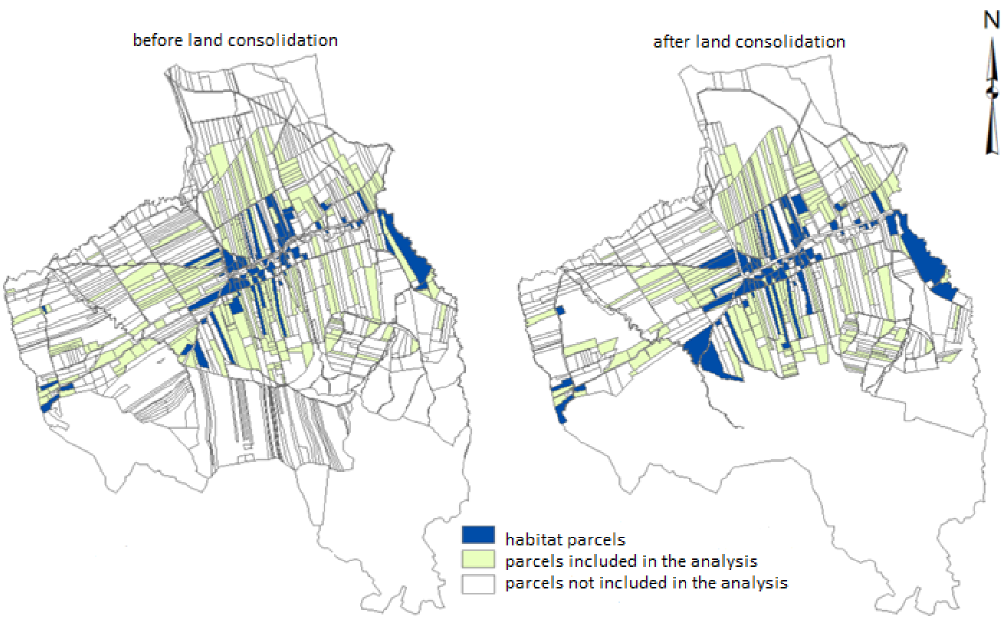

Fig. 3. Location of parcels included in the analysis

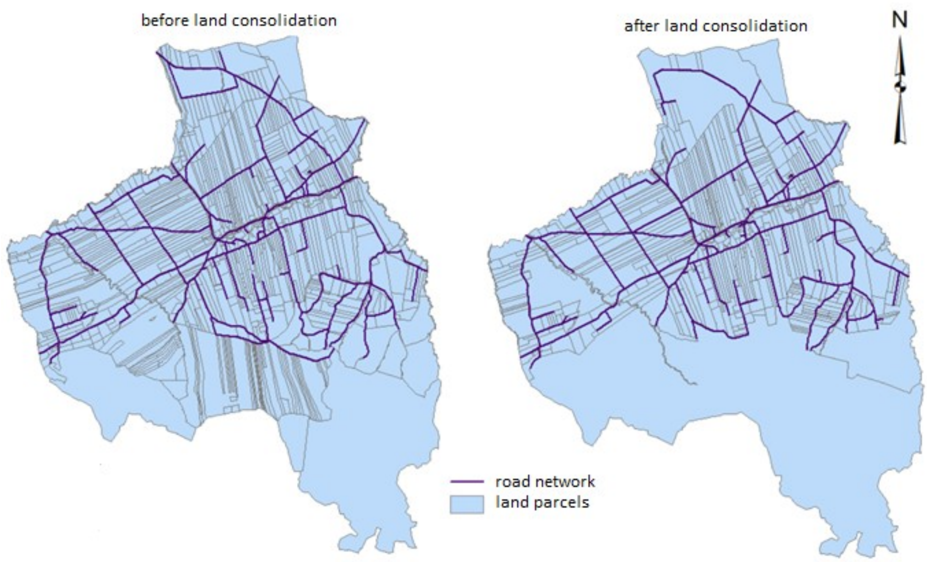

Fig. 4. Presentation of vectorised roads before and after land consolidation

On the basis of the prepared data, the distribution of agricultural land was calculated using network analysis functions by two methods (Fig. 5):

i) determination of the shortest distance from the geometric centre of the parcel of the holder's residence to the remaining land of the holding in a straight line;
ii) determination of the average distance along the road networks between the parcel and the remaining land of the holding, using network analyses.

Fig. 5. Map composite showing linear and network analyses before and after land consolidation

To automate the land distribution calculations, a model was created using the Model Builder tool (Fig. 6). In order to carry out the analyses with the model, two input layers are required: the centroids of the parcels of land and the network data set created for the topologically correct road layer. From the centroids of all plots of land, those which are the owner's residence plots and the owner's other land plots are selected. The selected centroids and the road network are the input data for the network analysis. Here, the user specifies the type of analysis, i.e. whether the distribution calculation is to take place along a straight line or along a road network (actual road). The model is marked in blue for the input data, green for the output data and yellow for the analyses performed on the data. The letter "P" denotes the data that the user enters.

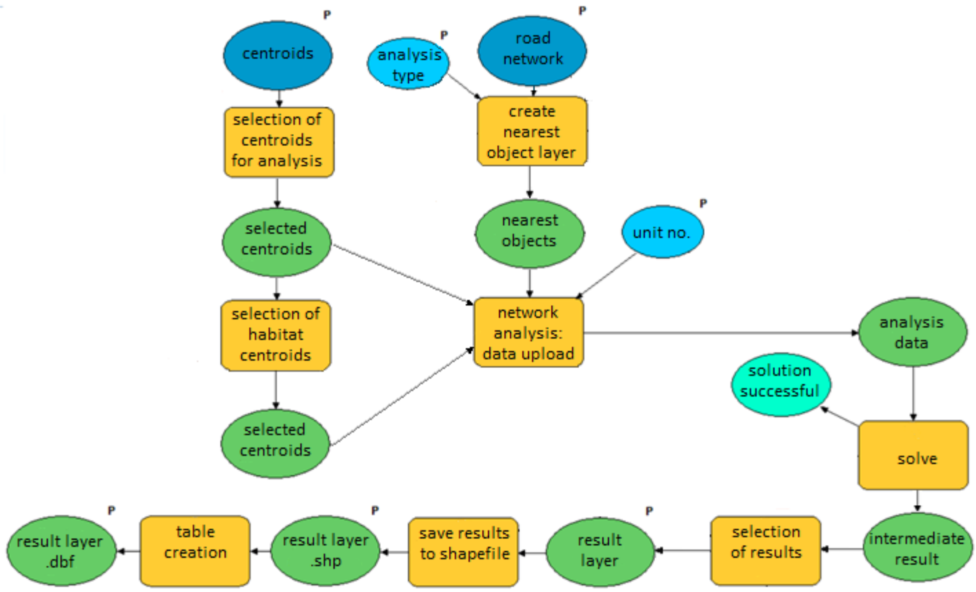

Fig. 6. Automated land distribution analysis created in Model Builder

The model was prepared in such a way as to be universal for both types of network analysis methods and to give the possibility of using it for other sites. Consequently, the distribution analyses were performed using a single model. The model allows the results to be saved at the designated location in shapefile format and to a table in *.dbf format. In addition, for the state before and after land consolidation, basic statistics were calculated for the area and number of owner plots. The area of the parcels in area ranges is also presented. Land distribution was calculated using the method proposed by G.J. Schmook [20]:

$$S = \frac{\sum_{j=1}^{k} \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} a_i}}{k} \tag{1}$$

where: S - Schmook’s index, n - number of plots of holding j, k - number of holdings, d - the actual distance from habitat to parcel of the holding, a - area of the plot.

This indicator is the quotient of the average distance from the owner's residence plot to the plots on the farm and the average plot area on the farm. The distance in this case was calculated along the road network (actual distance). The closer the value of the indicator is to zero, the more favourable the distribution for the unit.

Results

Based on the attribute tables of the parcel layers, an analysis of the area and abundance of parcels was carried out. Basic statistics were calculated. By reviewing the maximum and minimum values, very large discrepancies can be observed in the area of holdings from 0.1 up to 9ha (Fig. 7).

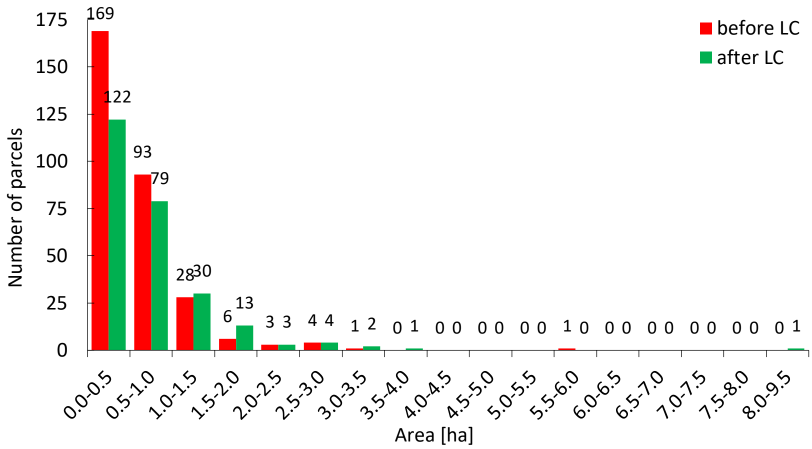

Fig. 7. Histogram of plot area distribution before and after land consolidation process

Table 1 it can be seen that the average area of the farm increased from 2.3630 to 2.4342ha. This is also true for the average area of plots in the individual units, where an increase was recorded from 0.5870 to 0.7355ha.

Table 1. Summary of owners' unit areas and parcel counts before and after the land consolidation process

Parameter	Before land consolidation			After land consolidation		
	Mean area [ha]	Mean number of parcels of one owne	Mean area of parcel of one oewner [ha]	Mean area [ha]	Mean number of parcels of one owne	Mean area of parcel of one oewner [ha]
Mean	2.3630	4	0.5870	2.4342	3	0.7355
Maximum	8.7851	10	2.1963	9.2095	7	3.0698
Minimum	0.0899	2	0.0450	0.1089	2	0.0363
Standard deviation	1.6485	2	0.41921	1.6638	2	0.5295

Table 2 shows the change in the area of holdings before and after the land consolidation process, using absolute values for the differences. The area of more than half of the owners (60.27%) changed slightly to 0.1ha. For six units, there was a significant increase or decrease in the area of the holding (above 0.5ha). This is mainly due to the removal of co-ownership for other owners. Large deviations affect the average values obtained and compared during the analyses.

The largest increase in area was recorded for unit No. 278 (0.7948ha), due to the additional equivalent from the abolition of co-ownership. The largest decrease in area occurred for holding no. 192 (-0.4078ha).

Table 2. Differences in owners' areas before and after land consolidation.

Area difference ranges	0-0.1 [ha]	0.1 - 0.2 [ha]	0.2-0.3 [ha]	0.3 - 0.4 [ha]	0.4 - 0.5 [ha]	powyżej 0.5 [ha]
Number of owners	44	14	4	3	2	6
Share [%]	60.27	19.18	5.48	4.11	2.74	8.22

During the land consolidation process carried out, the number of plots in the whole area decreased from 1189 to 711. As a result of the criteria assumed and described earlier, 73 units before land consolidation and 73 units after land consolidation were selected for the distribution analysis. For those owners selected for analysis, the number of plots before and after land consolidation is 304 and 255 respectively. The average number of plots per farm decreased from 4 to 3 (Table1). The overall area structure in the analysed village has improved. The land division is more organised and the plots themselves have more regular shapes (Fig. 8)

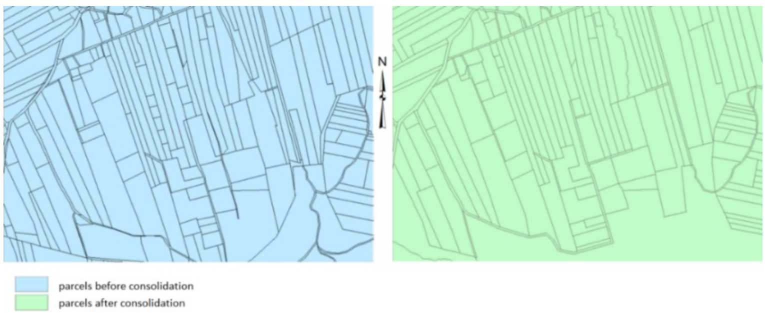

Fig. 8. Presentation of the area structure before and after the land consolidation process

A visual analysis of the whole area reveals that the land consolidation process has had the greatest impact on sorting out the stucture of parcels containing roads and forests, the number of parcels for these units has decreased by approximately tenfold (Fig. 9.)

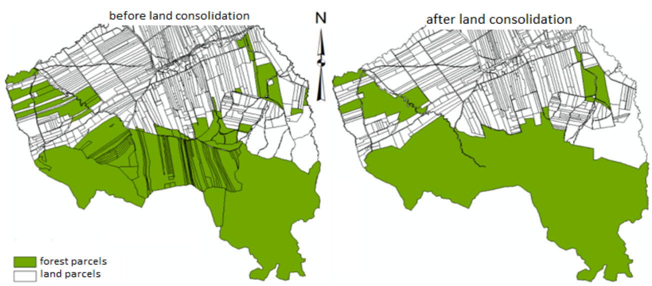

Fig. 9. Presentation of the impact of the land consolidation process on the structuring of forest parcels

Analysing results showed in Table 3, it can be observed that the average actual distance from the owner's residence plot to his other plots, contrary to the general assumptions of the land consolidation process, has increased by 152.22m. The average rectilinear distance has also increased, but its value is relatively low at 28.37m. However, considering the spread of the maximum and minimum values for the state before and after land consolidation, it can be concluded that these changes, as in the case of the analyses of the owners' areas, are not significant. The maximum reduction in average actual distance was 1802.74 and 664.21m for straight-line distances. The largest increases in linear distances and following the road network (actual) were 1220.93 and 2154.54m respectively.

Table 3. Differences in average distances of owners to parcels before and after land consolidation.

Parameter	Average distance to road		Change in average distance to road [m]	Average distance to road		Change in average distance to road [m]
	Before land consolidation [m]	After land consolidation [m]		Before land consolidation [m]	After land consolidation [m]	
Mean	562.87	715.09	152.22	366.42	394.79	28.37
Maximum	2,231.89	2,398.67	-1,802.74	2,140.65	1,476.45	-664.21
Minimum	0.23	0.48	2,154.54	24.32	14.96	1,220.93
Standard deviation	251.22	331.44	261.78	168.15	174.58	126.70

Table 4 and Figure 10 shows ranges of differences between the actual and linear distances are shown. The mean differences are 196.45m for the condition before land consolidation and 320.30m for the condition after land consolidation, respectively. This means that in general the distances measured along the road network (actual distances) are longer than the rectilinear distances. Only in the case of 15 register units (both before and after consolidation) the opposite situation occurred, i.e. rectilinear distances were longer than actual distances. However, these were small differences not exceeding 50m. Cases where the actual distance is smaller than the linear distance ooccurs for example, when the owner's plots are located on opposite sides of the road.

Table 4. Summary of network analyses - actual and linear distances

Ranges of actual and linear distance differences [m]	Before land consolidation		After land consolidation	
	Number of owners	Share [%]	Number of owners	Share [%]
-50 - 0	15	20.55	15	20.55
0 - 200	35	47.95	22	30.14
200 - 400	14	19.18	15	20.55
400 - 600	6	8.22	7	9.59
600 - 1000	1	1.37	9	12.33
Above 1000	2	2.74	5	6.85

Then the distances between the centroids are a few to several metres, while the distances measured along the road network are or are close to zero. The other cases show that the methods of measuring the linear distances between the plots of the owner's residence and the other plots are a simplified method of the actual distance measurements (following the road network). This is due to the different approach to the analyses performed. In the case of the network analyses, the actual distance between the plots routed along the road network is taken into account, while the values from the linear analyses are the result of determining the rectilinear distances between the centroids of the two plots.

Table 5 presents how the distances in the analysed owners have changed due to the land consolidation process. The largest number of holdings is in the range (-100) - 100m and is 33 for actual distances and 42 for linear distances respectively. Significant increases in actual distance (above 100m) occurred for almost 40% of the owners included in the analyses, for linear distances it is 26%.

Table 5. Distance interval analysis

Ranges of distance differences before and after land consolidation		Real distances		Linear distance	
		Number of owners	Share [%]	Number of owners	Share [%]
Less than -1000 m	Increasing the distance	4	5.48	1	1.37
(-1000) - (-500) m		9	12.33	1	1.37
(-500) - (-250) m		7	9.59	5	6.85
(-250) - (-100) m		9	12.33	12	16.44
(-100) - 0 m		18	24.66	12	16.44
0 - 100 m	Decreasing the distance	15	20.55	30	41.10
100 - 250 m		4	5.48	8	10.96
250 - 500 m		2	2.74	3	4.11
500 - 1000 m		4	5.48	1	1.37
More than 1000 m		1	1.37	0	0.00

A significant improvement (more than 100m) was recorded for 15% of holdings, analysing distances along the road network, and for 16% considering distances between plot centroids. Analysing the results obtained, it can be concluded that for a large proportion of holdings the location of plots in relation to the owner's residence plot has deteriorated (Fig. 10).

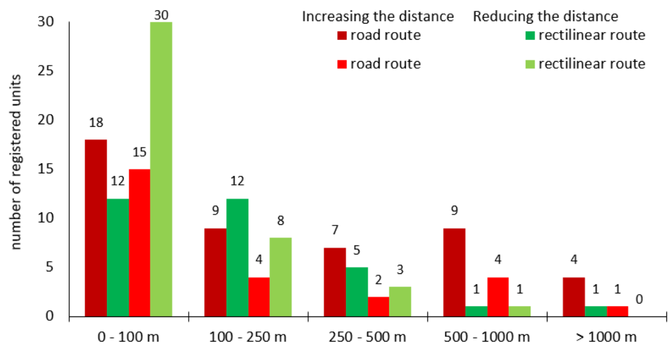

Fig. 10. Presentation of distance difference intervals before and after the land consolidation

In situations where, after land consolidation and exchange, the distances between the land in question and the owner's residence plots are greater compared to the state before land consolidation, it is possible to clarify in cases:

i) to increase the number of plots of land for the purpose of their later use and the access of the owner's residence plot to the road (Fig. 11)
ii) conducting land consolidation of roads (Fig. 12)
iii) improving the area structure of the farm after consolidation at the expense of extending the access distance to the land parcel (Fig.13.)

The value of the land distribution index according to Schmook [20] was calculated for each of 73 land registry units. The closer the value of the index is to zero, the more favourable the distribution is for the unit in question. In general, an improvement in the mean index value occurred - from 0.16 to 0.14, where 35 improved index value, 36 decreased and 2 did not change.

Fig. 11. Sample land distribution before and after land consolidation

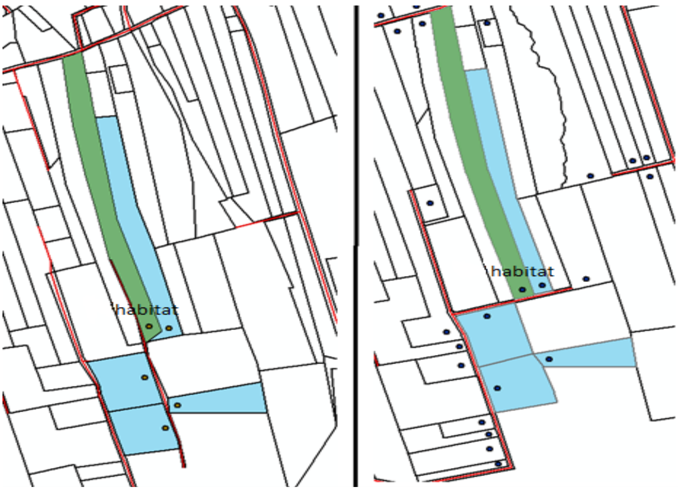

Fig. 12. Sample land distribution before and after land consolidation

Fig. 13. Sample land distribution before and after land consolidation

Discussion

The developed and implemented consolidation project significantly changed the land structure in Męcina Wielka. The number of plots decreased by 40% from 1,189 before consolidation to 711 after this process. By verifying the geometry of the plots, one can observe a significant improvement in their shapes. The road network was also modified to provide each plot with access to a public road.

The GIS tools used made it possible to analyse the effects of the land consolidation process. The analyses carried out indicated that the average distance between the owner's residence plots and the other land in the owners' data increased by 152.22m when distances along the road network were taken into account and by 28.37m when linear distances were taken into account. Unfortunately, it is difficult to consider these results as significant and conclude that there has been a significant increase in distance, due to the very large standard deviations for the mean distances of the owner's residence plots to the plots of the respective farm. Network analyses showed a significant increase in mean actual distance for almost 40% of the farms. This contradicts the premise of the land consolidation process, which is to reduce distances. However, when comparing wider land consolidation properties for farms where distances from the owner's residence plot have lengthened, other positive aspects have emerged. The overall area structure of the village has improved. Plots have a more regular shape and access to a public road. The fragmentation of plots, the largest for owners, which was not taken into account in the analyses (for example, due to the absence of the owner's residence plot in the land consolidation area) has been largely eliminated. The average number of plots, for farms considered for analysis, decreased from 4.18 to 3.49. When analysing the change in area, it can be seen that for more than half of the farms (60.27%) the change in area was very small (at the level of 0.0-0.1ha).

Conclusion

This work aimed to present the results of land consolidation using GIS tools to optimise the location of crops in rural areas, tree nurseries in forests or protected areas in national parks. Therefore, a number of steps were carried out, from data verification, through data preparation and processing, to performing network analyses - following the road network and along straight lines, calculating statistics and indicators. GIS software made it possible to visualise each of the data processing steps carried out and to present the results of the calculations. Using selection and symbolisation tools and through the creation of map compositions, it was possible to present the data in such a way that they were readable and reflected the problem under analysis in the best possible way. On this basis, the Fig. s attached in this thesis were created. The software also allows the creation of graphs, which are often the best method to illustrate certain relationships or differences.

The network analyses carried out made it possible to determine the linear distances between the centroids of the plots and the actual distances routed through the prepared road networks. The analyses were carried out between the owner's residence plots and the other plots owned by the landlord in question before and after the land consolidation process. Calculating these distances manually would have been very time-consuming. The work also made use of the Model Builder tool, in which a model was created that was responsible for automating the course of the analyses and calculations. The creation of the model parameters made it possible to prepare a versatile tool for performing network analyses for both the pre- and post-land consolidation states. Once built, the model can be subjected to numerous edits, depending on the user's needs and preferences. In this way, it is possible to implement one tool for analogous work performed in the future on other land consolidation sites.

From the obtained results, it can be concluded that for the analysed owners there is a slight improvement in the distribution and fragmentation of the land. This is mainly due to the analysed data sample. Selected farms that had their plots of owner residence in the land consolidation area were surveyed. Which was a necessary condition for calculating the distribution. Among other things, this condition eliminated forest plots and plots occupied by roads. The number of these plots in the land consolidation process was reduced by about ten times. This example clearly shows that the effects of land consolidation should be presented in the widest possible aspect.

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References

[1] M. Balawejder, K. Matkowska, E. Rymarczyk, *Effects of land consolidation in Southern Poland*, **Acta Scientiarum Polonorum Administratio Locorum**, 20, 2021, pp. 269-282, DOI: 10.31648/ASPAL.6573.

[2] A.S. Sánchez, K.P. Oliveira-Esquerre, I.B. dos Reis Nogueira, P. de Jong, A.A. Filho, *Smart Village Technology*, **Modeling and Optimization in Science and Technologies**, 17, 2020, DOI: 10.1007/978-3-030-37794-6.

[3] P. Kotlarz, *Analysis of the Influence of the Quality of Cadastral Data on the Process of Surveying Works in Poland*, **Geographic Information Systems Conference and Exhibition (Gis Odyssey 2017)**, 2017, pp. 196-202.

[4] I. Basista, M. Balawejder, *Assessment of selected land consolidation in south-eastern Poland*, **Land Use Policy**, 99, 2020, pp. 105033, DOI: 10.1016/J.LANDUSEPOL.2020.105033.

[5] R. Korneć, *Assessment of road transport ecological security impact in Poland*, **Scientific Journal of the Military University of Land Forces**, 203, 2022, pp. 113-125, DOI: 10.5604/01.3001.0015.8030.

[6] A.D. Ziegler, R.J. Wasson, Y. Sundriyal, P. Srivastava, G. Sasges, S.J. Ramchunder, C.E. Ong, S.K. Nepal, B.G. McAdoo, J. Gillen, D. Bishwokarma, A. Bhardwaj, M. Apollo, *A call for reducing tourism risk to environmental hazards in the Himalaya*, **Environmental Hazardd - Human and Policy Dimension, 22**, 2021, pp. 1–28. DOI: 10.1080/17477891.2021.1984196.

[7] H. Wang, Y. Zeng, *Policy Optimization for Hainan Tropical Rainforest National Park Based on Quantitative Comparison of Regional Policies of Free Trade Port Areas*, **Frontiers in Environmental Science**, 10, 2022, DOI: 10.3389/fenvs.2022.891432.

[8] L. Mu, L. Xing, Y. Jing, Q. Hu, *Spatial Optimization of Park Green Spaces by an Improved Two-Step Optimization Model from the Perspective of Maximizing Accessibility Equity*, **Land**, 12, 2023, pp. 948, DOI: 10.3390/land12050948.

[9] I. Basista, *The Use of GIS Tools in the Land Consolidation and Exchange Process : Examples*, **Infrastruktura i Ekologia Terenów Wiejskich (Infrastructure and Ecology of Rural Area**, IV(1), 2015, pp. 1047–1055. DOI: 10.14597/infraeco.2015.4.1.083.

[10] M. Louwsma, C. Lemmen, M. Hartvigsen, J. Hiironen, J. Du Plessis, M. Chen, P.M. Laarakker, *Land Consolidation and Land Readjustment for Sustainable Development – the Issues to be Addressed,* **Proceedings of FIG working week 2017 : Surveying the world of tomorrow: from digitalisation to augmented reality, 29 May - 2 June 2017, Helsinki, Finland,** Copenhagen, 2017, pp. 1–19.

[11] M. Balawejder, A. Warchoł, K. Konttinen, *Energy Efficiency in Agricultural Production—Experience from Land Consolidation in Poland and Finland*, **Energies**, 16, 2023, pp. 7598. DOI: 10.3390/en16227598.

[12] M. Zegar, A. Pęska-Siwik, K. Maciuk, *The problem of the modernisation of land and building register in Poland as exemplified by the village of Rejowiec*, **Budownictwo i Architektura**, 22, 2023, pp. 005-020, DOI: 10.35784/bud-arch.3219.

[13] I. Sówka, M. Skrętowicz, J. Zwoździak, J. Kunecka, *Application of a gis technique to odour emission inventory*, **Ecological Chemistry and Engineering S**, 18, 2011, pp. 445-453.

[14] D. Demetriou, J. Stillwell, L. See, *A new methodology for measuring land fragmentation*, **Computers, Environment and Urban Systems**, 39, 2013, pp. 71-80, DOI: 10.1016/j.compenvurbsys.2013.02.001.

[15] M. Dudzińska, K. Kocur-Bera, *Assessment of land fragmentation for the purpose of land consolidation works as exemplified by the Pasym commune*, **Geomatics, Landmanagement and Landscape**, 2, 2015, pp. 31-44, DOI: 10.15576/GLL/2014.2.31.

[16] A. Simmons, *An index of farm structure, with a Nottinghamshire example*, **East Midlands Geographer**, 3, 1964, pp. 255-261.

[17] F. Dovring, *Land and labour in Europe in the twentieth century*, **The Hague: Nijhoff**, 1965.

[18] J. Januszewski, *Index of land consolidation as a criterion of the degree of concentration*, **Geographia Polonica**, 14, 1968, pp. 291-296.

[19] M.U. Igbozurike, *Land tenure, social relations and the analysis of spatial discontinuity*, **Area**, 6, 1974, pp. 132-135.

[20] G.J. Schmook, *The spontaneous evolution from farming on scattered strips to farming in severalty in Flanders between the sixteenth and twentieth centuries: A quantitative approach to the study of farm fragmentation,* **Fields, Farms and Settlement in Europe,** Belfast, Ulster Folk and Transport Museum, 1976, pp. 107–117.

[21] D. Demetriou, **The Development of an Integrated Planning and Decision Support System** (IPDSS) for Land Consolidation, Springer International Publishing, Cham, 2014. DOI: 10.1007/978-3-319-02347-2.

[22] J. Janus, *A new approach to calculating distances to parcels: A way to increase the accuracy of farm efficiency analyses and the assessment of land consolidation projects*, **Computers and Electronics in Agriculture**, 175, 2020, pp. 105512, DOI: 10.1016/j.compag.2020.105512.

[23] J. Janus, *Measuring land fragmentation considering the shape of transportation network: A method to increase the accuracy of modeling the spatial structure of agriculture with case study in Poland*, **Computers and Electronics in Agriculture**, 148, 2018, pp. 259-271. https://doi.org/10.1016/j.compag.2018.03.016.

[24] P. Kontek, I. Basista, K. Maciuk, *GIS analyses of land consolidation in case of the highly fragmentated of parcels*, **Folia Forestalia Polonica**, 65, 2023, pp. 136-152, DOI: 10.2478/ffp-2023-0014.

[25] I. Basista, *The Tool for Assessing the Effectiveness of Land Consolidation*, **Geoinformatica Polonica**, 22, 2023, pp. 97-104, DOI: 10.4467/21995923GP.23.008.18607.

[26] M. Apollo, M. Jakubiak, S. Nistor, P. Lewinska, A. Krawczyk, Ł. Borowski, M. Specht, K. Krzykowska-Piotrowska, Ł. Marchel, A. Pęska-Siwik, M. Kardoš, K. Maciuk, *Geodata In Science - A Review Of Selected Scientific Fields*, **Acta Scientiarum Polonorum Formatio Circumiectus**, 22, 2023, pp. 17-40, DOI: 10.15576/ASP.FC/2023.22.2.02.

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