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THE METHODOLOGY OF STRAIGHTENING THE LAND PLOT BOUNDARY IN THE COURSE OF LAND CONSOLIDATION

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Abstract. The issue of land plot boundary straightening in the course of land consolidation has been examined in the study. Over the course of buying out and swapping, adjacent land plots are being incorporated into one land tenure. However, the land plots are inconvenient for cultivation due to broken boundaries. Measures on the boundary straightening comply with the demands of landowners at voluntary land consolidation, when they are interested in the least possible alteration of the boundaries of the existing land plots. The study aims at the substantiation of the methodology for the straightening of land plot boundary with the help of the peer exchange of their parts. Preconditions for the formation of broken boundaries in the course of land consolidation have been scrutinized. Algorithms for land plot boundary straightening with the help of the exchange of the parts of peer land plots have been suggested. The calculation of typical cases of broken boundary straightening has been suggested. The boundary straightening methodology has been tested in a land mass in Kyiv Region, Ukraine. The results of the research can be used in the course of voluntary land consolidation, at the developing of preliminary land reallotment plan for agricultural and built-up land.

Keywords: land reallotment, agricultural land, land exchange, land plot boundary, land consolidation, equal value.

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1. Introduction

The goal of land consolidation is the formation of land plots with the optimal area, configuration, and placement (Vitikainen, 2014; Hartvigsen, 2015). In case the consolidation is implemented by means of buying out of land plots, the issues of strip holding and the irrational configuration of land plots, i.e. broken boundary arise. Land consolidation may not be considered successful in case there are such drawbacks of land tenure (Palmer et al., 2004; Pašakarnis & Maliene, 2010). Strip holding is usually eliminated with the help of land exchange (Leń, 2017). The automation of land consolidation and land exchange using GIS (Basista, 2020; Janus & Ertunc, 2022) and other latest technologies is an advantage (Cienciala et al., 2022).

The incorporation of adjacent land plots in a land tenure is the result of land plots exchange (Leń, 2017). However, such consolidated land plots are often irrationally outlined (Malashevskyi & Malashevska, 2021b). Due to such configuration, agricultural productivity (Aslan, 2021) and land plot value is decreased (Demetriou, 2016; Ertunc, 2022). Scientific researches on the evaluation of land plot configuration (Foski, 2019; Geisse & Hudecova, 2019), including that in the course of land consolidation are widespread (Demetriou et al., 2012). In Ukraine, legislation on land plot exchange within a land mass facilitates the formation of broken boundaries (Verkhovna Rada of Ukraine, 2001). The land plot boundary straightening methodology is absent at the current stage; there are individual boundary adjustment initiatives only, and exclusively based on the exchange of peer land plot parts. Broken boundary is the reason for the trespassing of land plot boundary at agricultural activities (Borowiec & Marmol, 2022), which complicates taxation and land use control (Lai et al., 2018; O'Brien & Prendergast, 2014).

Generally, the issues of irrational configuration and placement are effectively resolved in the course of land readjustment (Ayranci, 2007; Harasimowicz et al., 2017). The improvement of the form of a land plot by replacing it with a peer one of a rectangular form has been suggested (Kwinta & Gniadek, 2017). Optimization and heuristic methods are used to carry out the process (Cao & Ye, 2013; Ligmann-Zielinska et al., 2008; Song & Chen, 2018). In practical terms, land readjustment is complicated due to the need for agreement with landowners and legislative regulation.

Measures on the boundary straightening comply with the demands of landowners at voluntary land consolidation, when they are interested in the least possible alteration of the boundaries of the existing land plots (Vitikainen, 2014). The advantages of land tenure optimization retaining the boundaries (Malashevskyi & Malashevska, 2022b) have been substantiated, for example, Thomas (2006) points out the high cost of demarcation in the course of land consolidation. The simplified and more cost- and time-efficient procedures of spatial optimization are crucial for the success of land consolidation (Vitikainen, 2014). It is worth mentioning that it is recommended to support and develop the voluntary land consolidation initiatives in the Eastern European countries (De Vries, 2022).

The goal of the study is the substantiation of boundary straightening methodology with the help of the peer exchange of their parts.

2. Materials and methods

2.1. The consolidated land tenure broken boundary

Broken boundaries can be predefined by the existing territory organization: due to bordering on natural objects like ravines, gullies, or water body protective zones, or artificial objects like wood lines, roads, reclamation canals, etc. (Malashevskyi & Malashevska, 2022a). The boundary can be broken due to design errors at the stage of land plot allocation, for example, in the course of distribution. It can be present in the historically formed land tenure. Developed land plots can have broken boundaries due to the existing buildings and structures, especially when the design failed to meet the required distances from boundaries to existing buildings and structures (Malashevskyi et al., 2021).

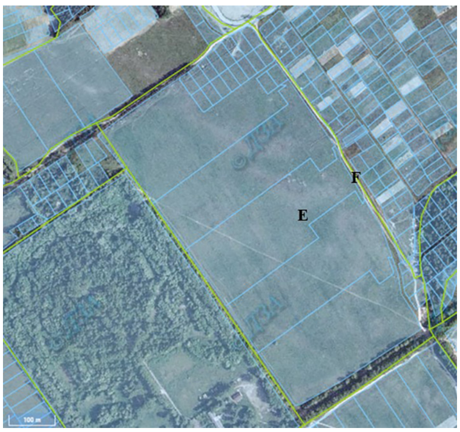

Figure 1. Land tenure boundary drawbacks after land consolidation. Public Cadastral Map of Ukraine

The consolidated land tenures, formed as the result of voluntary swapping and buying-out, often have a complicated outline and broken boundaries (Figure 1). With the establishment of agricultural land market in Ukraine, land consolidation through buying out is becoming more and more widespread. Land reallotment aiming at land consolidation, which could resolve the issue of irrational configuration, is not provided by law. The land composition facilitates the formation of broken boundaries and cutting-in: land plots are small and the land mass consists of a great number of land plots (Malashevskyi & Malashevska, 2021a).

The need for adjusting the boundaries is predefined by the impaired cultivation due to broken boundaries or complicated configuration (Leń, 2017). Obviously, broken boundaries cannot be adjusted in all cases. First of all, it is the case when the outline follows the shape of the existing natural and artificial objects. Straightening the boundaries is advisable, however, it can be limited by economic, environmental, and legal restrictions, as well as the technical possibility for the exchange.

Table 1 represents the stages of voluntary land consolidation projects, at which boundary straightening measures are implemented based on regulatory practices in Europe (Veršinskas et al., 2020).

Table 1. Boundary straightening in the course of voluntary land consolidation projects

Phases of the re-allotment planning process (according to Veršinskas et al., 2020)	Boundary straightening measures
Feasability Study	Determining, if boundary straightening is technically possible.
Public meeting to launch the re-allotment planning	Communication with landowners on: 1. The improvement of the configuration of neighbouring land plots after exchange or buying out. 2. The prospects of the exchange of peer parts of land plots for boundary straightening. It can facilitate the involvement of landowners into voluntary land consolidation.
Land Valuation	Defining the criteria, by which land productivity and soil fertility is evaluated for the exchange of peer parts of land plots. The implementation of relative value method according to FAO recommendations (Veršinskas et al., 2020).
Building up draft Land Consolidation Plan through Facilitated negotiations between participants	1. The exchange and buying out of land plots is carried out considering the fact the configuration of newly developed land plots can be improved by boundary straightening. 2. Boundary straightening after exchange and buying out.
Draft Land Consolidation Plan based on written consent from participants	The values and substantiation of areas for parts of land plots to be exchanged for boundary straightening are presented in the explanatory note

End of Table 1

Phases of the re-allotment planning process (according to Veršinskas et al., 2020)	Boundary straightening measures
Land Consolidation Plan is adopted and submitted for registration	The measures follow the general course of the adoption of Land Consolidation Plan

2.2. The exchange of peer parts of land plots

In practical terms, boundary straightening is the improvement of land plot configuration in order to gain the optimal configuration for agricultural activities with the least possible alteration of layout, i.e. the alteration of certain boundaries only.

The practical experience of boundary straightening witnesses: the exchange of peer parts of land plots is the most widespread. As a rule, the key precondition for boundary improvement is the unchanged area of land plots, i.e. the exchange of peer parts of land plots.

Generally, the boundary adjustment is carried out as follows:

- Determining the area of the part of land plot which forms the broken boundary or cuts in;
- Defining the design method for the peer part of land plot. Demands on land plot configuration are taken into account, i.e. the optimal configuration after land consolidation is designed; requirements on parallel and perpendicular sides, the direction of slopes, etc., should be met;
- Determining the final position of the boundary and landmark coordinates after straightening;
- Result evaluation.

The development of new boundaries is essentially the redevelopment of parts of land plots which make the broken outline. There are two methods: in the form of trapezoid/rectangle, and in the form of triangle.

Let us scrutinize the typical boundary straightening options by the exchange of peer parts of land plots with the example of the land mass (Figure 1).

In the first case (Figure 2) it is reasonable to develop the outline of the land plot close to a trapezoid by means

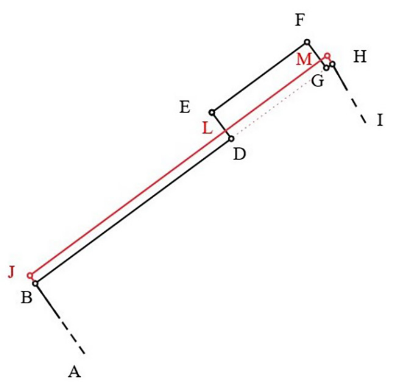

Figure 2. Boundary straightening after consolidation. Trapezoid design

of boundary *BDEFGH* adjustment. The new boundary is developed as a straight line segment parallel to side *BD*.

To fulfill this task without alteration of the area of land plots divided by the broken line *BDEFGH*, the exchange of the parts of land plots with the area *S* is carried out so, that:

$$S_{BJLD} + S_{GMKH} = S_{LEFM}. \quad (1)$$

The area of cutting-in *DEFG* is determined; and the part of the land plot *BJKH* of peer area is developed. The formula (1) can be presented as follows:

$$S_{BJKH} - S_{DLMG} = S_{DEFG} - S_{DLMG}, \quad (2)$$

i.e.:

$$S_{BJKH} = S_{DEFG}. \quad (3)$$

The area *S* of quadrangle *DEFG* should be determined, for example, by the coordinates of vertexes:

$$S_{BCDE} = \frac{1}{2}\begin{vmatrix} x_D - x_F & y_D - y_F \\ x_E - x_G & y_E - y_G \end{vmatrix}. \quad (4)$$

The new boundary *JK* (Figure 2) is developed parallel to *BH* so, that the area of trapezoid *BJKH* is equal to the area *S* of quadrangle *DEFG*. Then, with the determined area, trapezoid base *BH*, and initial direction angles, the second base of trapezoid *BJKH* is calculated:

$$JK = \sqrt{BH^2 - 2S(ctg\beta_B + ctg\beta_H)}, \quad (5)$$

where β_B and β_H – are base angles of the trapezoid *BJKH*. They are equal to the difference of the respective direction angles, which can be determined with geographic inverse by coordinates of respective points:

$$\beta_B = \alpha_{AB} - \alpha_{BH}; \quad (6)$$

$$\beta_H = \alpha_{HI} - \alpha_{BH}, \quad (7)$$

where: α_{AB} – is the direction angle of line *AB*, α_{HI} – is the direction angle of line HI, α_{BH} – is the direction angle of line *BH*.

At the next stage, the sides of trapezoid *BJKH* are determined:

$$BJ = \frac{2S}{(BD + JK)\sin\beta_B}; \quad (8)$$

$$KH = \frac{2S}{(BD + JK)\sin\beta_H}. \quad (9)$$

Then, the coordinates of the point *J*, which is placed on the right line *AB*:

$$X_J = X_B + JB\cos\alpha_{AB}; \quad (10)$$

$$Y_J = Y_B + JB\sin\alpha_{AB}. \quad (11)$$

The coordinates of point *K*:

$$X_K = X_H + KH\cos\alpha_{IH}; \quad (12)$$

$$Y_K = Y_H + KH\sin\alpha_{IH}. \quad (13)$$

Let us scrutinize the case, when it is reasonable to straighten the boundary by developing the part of the land plot in the form of a triangle (Figure 3).

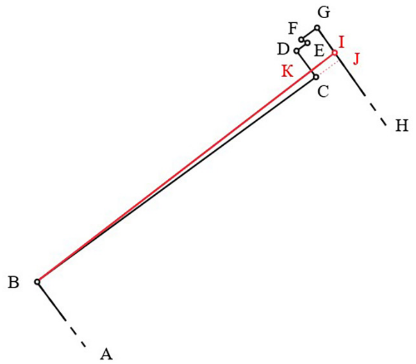

Figure 3. Boundary straightening after consolidation. Triangle design

To adjust the boundary *BCDEFG*, a new boundary *BI* is developed so, that the area of polygon *KDEFGI* is equal to the area of triangle *BKC*:

$$X_J = X_G + R\left(X_H - X_G\right); \quad (14)$$

$$Y_J = Y_G + R\left(Y_H - Y_G\right); \quad (15)$$

$$R = \frac{\left(X_B - X_C\right)\left(Y_G - Y_C\right) - \left(Y_B - Y_C\right)\left(X_G - X_C\right)}{\left(X_B - X_C\right)\left(Y_H - Y_G\right) - \left(Y_B - Y_C\right)\left(X_H - X_G\right)}. \quad (16)$$

After that, the area *SCDEFGJ* of the cut-in part of the land plot is determined, for example, by the coordinates of points *C*, *D*, *E*, *F*, *G*, *J* by formula:

$$2S = \sum_{i=1}^{n} x_i y_{i+1} - \sum_{i=1}^{n} x_i y_{i-1} \quad (17)$$

or

$$2S = \sum_{i=1}^{n} y_i x_{i-1} - \sum_{i=1}^{n} y_i x_{i+1}. \quad (18)$$

The gist of the task is to determine the position of point *I* of the project (adjusted) boundary. Point *I* is placed on the side *GH* (GJ) provided the area of triangle *BIJ* is equal to the area *SCDEFGJ*. Let us calculate the length of side *JI*:

$$JI = \frac{2S_{CDEFGJ}}{BJ \times \sin\beta_J}, \quad (19)$$

where β_J – is the angle between sides *JI* and *JB* of triangle *BIJ*. The angle is determined as the difference of the respective direction angles for direction *JD* (or *JI*) and *JB*:

$$\beta_J = \alpha_{JG} - \alpha_{JB}. \quad (20)$$

The coordinates of point *I* can be determined:

$$X_I = X_J + JI\cos\alpha_{JG}; \quad (21)$$

$$Y_I = Y_J + JI\sin\alpha_{JG}. \quad (22)$$

This is the way the exchange of parts of land plots of peer area is carried out. However, in the course of agricultural land consolidation, soil quality should be considered. In case the soil quality substantially differs across the land mass, the issue of the exchange of land plot parts of equal value arises.

2.3. The exchange of land plot parts of equal value

Peer exchange in the course of boundary straightening has some peculiarities. The main task is the evaluation of the parts of land plot, which form the brokenness, and defining the features which will allow for their comparison. The market valuation is not reasonable in most cases. Most factors influencing the market value of land plot like placement, outline, existing buildings and structures, etc., do not characterise the value of land plot parts which form the brokenness. Respectively, it is not reasonable to determine the value of these parts based on the area unit value of the whole land plot.

In practical terms, it is reasonable to consider soil quality at the exchange for boundary straightening. In Ukraine, soil quality is characterized by bonitet, which is the assessment of soil quality by a 100-point grading scale.

The determination of discounted value and calculation of peer exchange by the formula is suggested (Bugaienko, 2018):

$$\sum_{k=1}^{n} S_k B_k = \sum_{j=1}^{m} S_j B_j, \quad (23)$$

where: *S* – is the area occupied by the soil, *B* – is the ball-bonitet of the soil.

This approach is equal to agricultural land exchange based on normative monetary valuation in Ukraine.

The normative monetary value of an agricultural land plot is determined by the formula (Cabinet of Ministers of Ukraine, 2021):

$$v_i = S_i N K_{Li} \frac{B_i}{B_{Mi}}, \quad (24)$$

where *V* – the value of the land plot by normative monetary valuation; S_i – the area of the land plot, m^2; *N* – capitalized rental income from a unit of area (calculated by methodology (Cabinet of Ministers of Ukraine, 2021), is equal to 27,520 UAH per ha ($75.26 /1000 m2)); K_{Li} – the coefficient of the placement of the territorial community within the natural and agricultural region; B_i - the ball-bonitet of the soil suitability group of a certain natural and agricultural area; B_{Mi} – the mean ball-bonitet of the soil of respective cultivated land of a certain natural and agricultural area.

Obviously, for the exchange of land plots within one land mass, formula (24) is reduced to formula (23).

It is suggested to determine the area of peer land plots by the following algorithm:

1. Determining the area of the part of land plot which includes the broken boundary S_o;
2. The calculation of discounted value of the part of land plot which forms the broken boundary.
   The area S_{ok}, occupied by k-th soil within the part of the land plot which forms the brokenness is determined, and, with the help of ball-bonitet B_{ok}, the discounted value $\sum S_{ok} B_{ok}$ is determined;
3. Determining the area of the peer part of land plot by successive iterations. As far as the distribution of the soil is not uniform, it is suggested to determine the area of the peer part of land plot S by i successive iterations (Bugaienko, 2018).

It is suggested to iterate by the general formula:

$$S^{i+1} = S^i \frac{\sum_{k=1}^{n} S_{ok} B_{ok}}{\sum_{j=1}^{m} S_j^i B_j^i}, \qquad (25)$$

where: S_{ok} – is the area occupied by k-th soil within the part of the land plot, which makes the brokenness; B_{ok} – ball-bonitet of k-th soil within the part of the land plot, which makes the brokenness; S_j^i – is the area occupied by j-th soil within the peer part of the land plot at i-th iteration; B_j^i – ball-bonitet of j-th soil within the part of the land plot, which makes the brokenness; S^i – is the area of the peer part of the land plot at i-th iteration; n – is the number of soil suitability groups within the part of the land plot which makes the brokenness; m – is the number of soil suitability groups within the peer part of land plot.

The iteration process is convergent, if:

$$\sum_{k=1}^{n} S_{ok} B_{ok} < S^0 \ B^0, \qquad (26)$$

where: S_{ok} – is the area occupied by k-th soil within the part of the land plot, which makes the brokenness; B_{ok} – ball-bonitet of k-th soil within the part of the land plot, which makes the brokenness; n – is the number of soil suitability groups within the part of the land plot which makes the brokenness; S^0 – is the area of the land plot, within which the peer part of the land plot S_j is allocated; B^0 – is the average ball-bonitet of the land plot, within which the peer part of the land plot S_j is allocated.

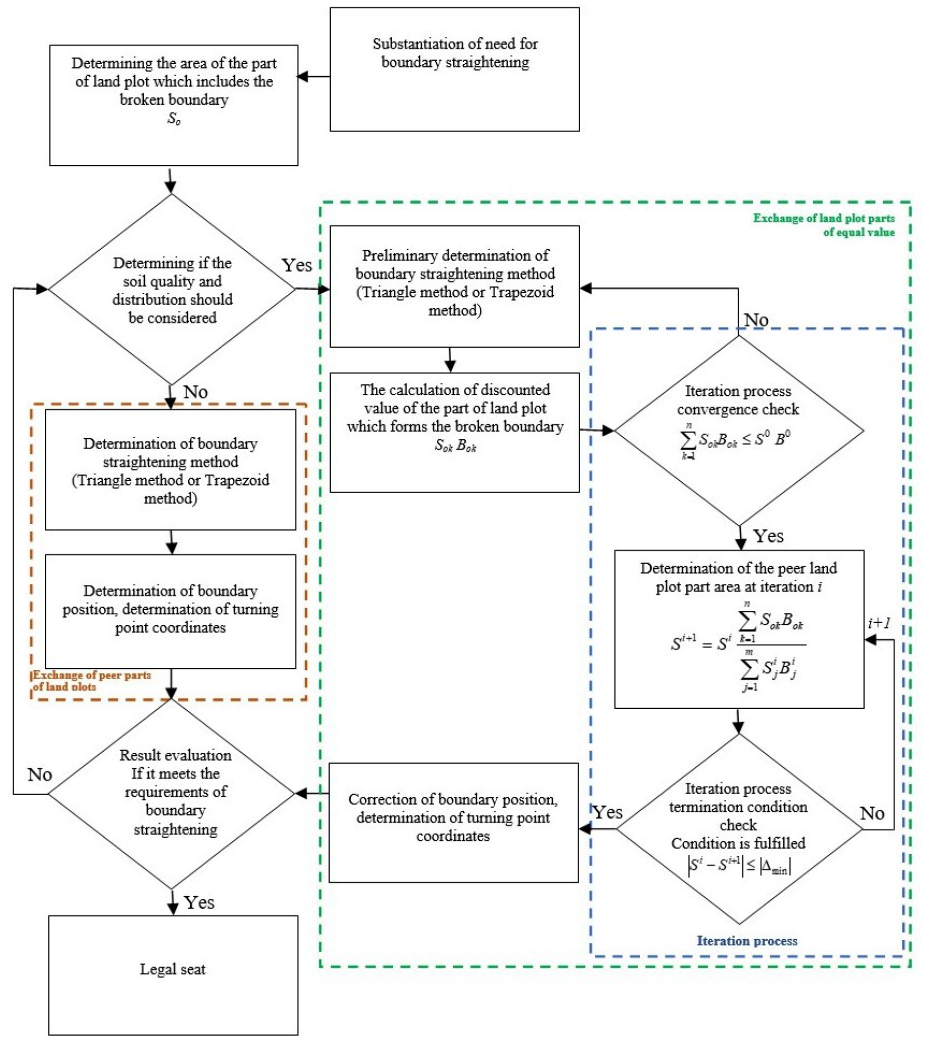

Figure 4. Flowchart of general stages of boundary straightening according to the methodology

The iteration process is over, if:

$$\left|S^i - S^{i+1}\right| \le \left|\Delta_{\min}\right|, \quad (27)$$

where Δ_{lim} – is the limit value of the deviation of area determination.

When the iteration process is over, a new boundary is developed in accordance with paragraph 1.2 for peer exchange (formulas (4)–(22)).

The general boundary straightening methodology is presented in Figure 4.

Let us eliminate the broken boundary of the land plot in the Figure 2, taking into consideration the soil quality (Figure 5).

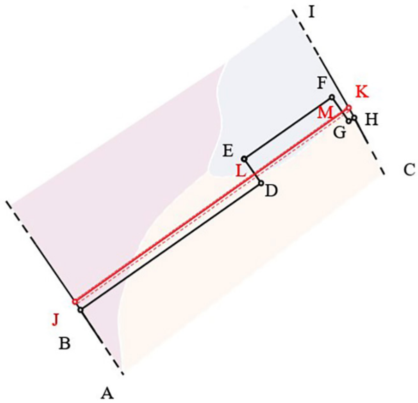

Figure 5. Boundary straightening considering soil quality

The parts of the land plot are exchanged so, that their discounted value is:

$$S_{BJLD} \times B^{av}{}_{BJLD} + S_{GMKH} \times B^{av}{}_{GMKH} = S_{LEFM} \times B^{av}{}_{LEFM}, \quad (28)$$

where B^{av} – is the mean ball-bonitet of the respective part of the land plot.

Similar to the exchange of peer parts of land plots (Formula (1)–(3)), the following equation is used at the developing:

$$S_{BJKH} \times B^{av}{}_{BJKH} = S_{DEFG} \times B^{av}{}_{DEFG}. \quad (29)$$

In this case, the brokenness area *SDMLG* is 6000 m^2. Two soil types occur within this part of the land plot (B_1 = 30, B_2 = 20). Discounted value is 165093,0.

Table 2. The area of the peer part of land plot

Iteration	Area *S*, m^2	Area, occupied by the soil with ball-bonitet, m^2		
		B = 30	B = 20	B = 25
0	6000.0	653.4	4720.2	626.4
1	7639.3	1096.4	5517.8	1025.2
2	7468.2	1046.2	5434.5	987.5
3	7483.1	1050.2	5441.8	991.2
4	7481.9	1053.9	5441.2	986.9
5	7481.1	1053.6	5440.8	986.7

The calculation of the area of the peer part of land plot by successive iterations (formula (25), (27)) is presented in Table 2.

As the result of iteration, the area of the peer part of the land plot is 7481.1 m^2. The part of the land plot is developed in the form of a trapezoid from the side *BI* (Figure 4). Calculation performed by formulas (5)–(13).

3. Results

Within the project land mass, boundaries have been adjusted and land plot configuration has been improved using the presented methodology (Figure 6).

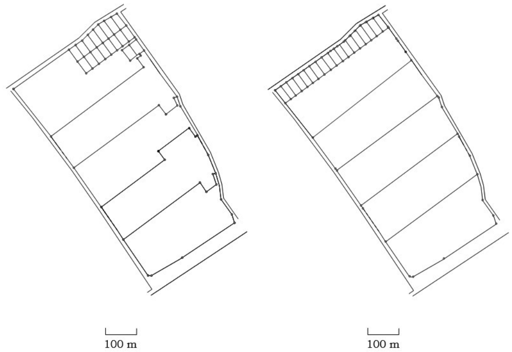

Figure 6. Consolidated land mass boundary straightening

The parts of land plots were designed in the form of trapezoid for land plots I, II, and III; in the form of trapezoid and triangle for the land plot IV; and the configuration of land plot V was improved by boundary straightening using the method of triangle and the readjustment of land plots VI to XVIII. The latter are situated at the rand of land mass, thus allowing to develop the land plot V close to rectangular form. Soil quality was considered at the development.

The results of the project are presented in Table 3.

Table 3. The area of land plots within the project land mass

Land plot	Area before project implementation, m^2	Area after project implementation, m^2
I	61 500	61 500
II	60 000	61 481
III	60 750	59 269
IV	59 250	59 250
V	61 514	61 014
VI	1500	1563
VII	1500	1563
VIII	1499	1561
IX	1499	1561
X	1499	1561
XI	1499	1561
XII	1499	1561

End of Table 3

Land plot	Area before project implementation, m^2	Area after project implementation, m^2
XIII	1499	1541
XIV	1499	1520
XV	1500	1500
XVI	1499	1499
XVII	1499	1499
XVIII	1499	1499
XIX	1499	1499
XX	1499	1499
XXI	1499	1499
XXII	1499	1499
XXIII	1500	1500
Total land mass	322 504	322 504

4. Discussion

The research findings have proven the land plot boundary adjustment by the exchange of peer parts of land plots can be the final stage of land consolidation, which is based on land plots exchange with keeping the placement of the initial land plots, i.e. it is the development of voluntary group and individual land consolidation according to FAO (FAO, 2003). In some cases, boundary straightening can be carried out in the course of simplified land consolidation at land plot exchange (FAO, 2003).

The method has been presented in this study for the first time, and it is an alternative to land readjustment, i.e., the alteration of placement, area, and configuration of land plots (Ayranci, 2007). It has the following advantages. In the course of boundary straightening, the significant improvement of land plot configuration can be achieved. It is cheaper, easier to implement, and can be a good option for individual initiatives by landowners as compared to land readjustment. Boundary straightening is effective in case the placement of land plot is crucial, for example, for land plots not subject to exchange (Yimer, 2014), and when boundaries should be kept as much as possible, i.e., in the complicated cases, when issues arise at the certain stages of land consolidation: registration, buying out, etc. The presented method is appropriate in cases the reallotment, for example, in the course of simplified land consolidation (FAO, 2003), is impossible due to unwillingness of some landowners within the project territory to participate, and their obligatory involvement is either not predefined by legislation or leads to the delayed project implementation.

The exchange of peer parts of land plots instead of those of equal area is predefined by the method, i.e., the soil quality is considered at boundary straightening. The benefits of boundary straightening are balanced with such approach, it facilitates the promotion of individual land consolidation, since it corresponds with the "at least as well off" principle (Veršinskas et al., 2020).

The method is especially topical for countries the voluntary land consolidation is recommended (Veršinskas et al., 2021; FAO, 2017). Land plot boundary straightening is the most effective in combination with land readjustment. The presented method can be used in land consolidation projects as a tool facilitating the project implementation with regard to regional peculiarities. The iterational determination of the peer land plot can be based on soil profitability indices instead of soil bonitet provided for Ukraine. Any other indices representing soil quality and fruitfulness (Astier et al., 2002; Cazorla et al., 2024) can be used in the formula (25).

5. Conclusions

In case land consolidation is carried out by buying out and swapping, the issue of broken boundaries arises. Usually, it is resolved by the exchange of peer parts of land plots. However, the cases the soil quality of land plots significantly differs are widespread. We suggest considering the soil quality in the course of the exchange of land plot parts aiming at boundary straightening. It is suggested to determine the discounted value in order to consider the soil quality. In Ukraine, ball-bonited is used as the soil quality indicator. The algorithm for the calculation of peer land plots has been presented. It is suggested to determine the peer parts of land plots by a series of successive iterations.

The methodology has been implemented at the consolidated land plot boundary straightening within the project land mass in Kyiv Region, Ukraine.

References

Aslan, Ş. T. A. (2021). Evaluation of land consolidation projects with parcel shape and dispersion. *Land Use Policy, 105*, Article 105401. https://doi.org/10.1016/j.landusepol.2021.105401

Astier, M., Maass, M., & Etchevers, J. (2002). Derivación de indicadores de calidad de suelos en el contexto de la agricultura. Sustentable derivation of soil quality indicators in the context of sustainable agriculture. *Agrocencia*, *36*, 605–620.

Ayranci, Y. (2007). Re allocation aspects in land consolidation: A new model and its application. *Journal of Agronomy*, *6*, 270–277. https://doi.org/10.3923/ja.2007.270.277

Basista, I. (2020). Application of GIS tools to describe the location of new registered parcels. *Geomatics and Environmental Engineering*, *14*(1), 5–13. https://doi.org/10.7494/geom.2020.14.1.5

Borowiec, N., & Marmol, U. (2022). Using LiDAR system as a data source for agricultural land boundaries. *Remote Sensing*, *14*(4), Article 1048.https://doi.org/10.3390/rs14041048

Bugaienko, O. (2018). the land reallocation model in the course of agricultural land consolidation in Ukraine. *Geodesy and Cartography*, *44*(3), 106–112. https://doi.org/10.3846/gac.2018.2049

Cabinet of Ministers of Ukraine. (2021). On approval of the methodology of normative monetary valuation of land plots. *Official Gazette of Ukraine*, *88*, 441. https://zakon.rada.gov.ua/laws/card/1147-2021-п

Cao, K., & Ye, X. (2013). Coarse-grained parallel genetic algorithm applied to a vector based land use allocation optimization problem: The case study of Tongzhou Newtown, Beijing, China.

Stochastic Environmental Research and Risk Assessment, *27*(5), 1133–1142. https://doi.org/10.1007/s00477-012-0649-y

Cazorla, X., Quisimalin, A., Ortega, M., Quintuña, P., & Cornejo, J. (2024). Soil evaluation through quality indicators. *ESPOCH Congresses: The Ecuadorian Journal of S.T.E.A.M.* https://doi.org/10.18502/espoch.v4i1.15801

Cienciala, A., Sobura, Sz., & Sobolewska-Mikulska, K. (2022). Optimising land consolidation by implementing UAV technology. *Sustainability*, *14*(8), Article 4412. https://doi.org/10.3390/su14084412

De Vries, W. (2022). Social aspects in land consolidation processes. *Land*, *11*(3), Article 452. https://doi.org/10.3390/land11030452

Demetriou, D. (2016). The assessment of land valuation in land consolidation schemes: The need for a new land valuation framework. *Land Use Policy*, *58*, 487–498. https://doi.org/10.1016/j.landusepol.2016.03.008

Demetriou, D., See, L., & Stillwell, J. (2012). A parcel shape index for use in land consolidation planning. *Transactions in GIS*, *17*(6), 861–882. https://doi.org/10.1111/j.1467-9671.2012.01371.x

Ertunc, E. (2022). A new approach with AHP for land grading in land consolidation projects. *Arabian Journal of Geosciences, 5*. https://doi.org/10.1007/s12517-022-09645-8

FAO. (2003). *The design of land consolidation pilot projects in Central and Eastern Europe*. FAO Land Tenure Studies no. 6. Rome. http://www.fao.org/docrep/006/Y4954E/y4954e00.htm

FAO. (2017). *FAO advises on land consolidation legislation in Ukraine*. http://www.fao.org/europe/news/detail-news/en/c/1068717

Foski, M. (2019). Using the parcel shape index to determine arable land division types. *Acta Geographica Slovenica*, *59*(1), 83–101. https://doi.org/10.3986/AGS.4574

Geisse, R., & Hudecova, L. (2019). Quantification of changes in the shape and dimensions of parcels in land consolidation. *Slovak Journal of Civil Engineering*, *27*, 39–44. https://doi.org/10.2478/sjce-2019-0006

Harasimowicz, S., Janus, J., Bacior, S., & Gniadek, J. (2017). Shape and size of parcels and transport costs as a mixed integer programming problem in optimization of land consolidation. *Computers and Electronics in Agriculture*, *140*, 113–122. https://doi.org/10.1016/j.compag.2017.05.035

Hartvigsen, M. (2015). *Experiences with land consolidation and land banking in Central and Eastern Europe after 1989*. http://www.fao.org/3/a-i4352e.pdf

Janus, J., & Ertunc, E. (2022). Towards a full automation of land consolidation projects: Fast land partitioning algorithm using the land value map. *Land Use Policy*, *120*, Article 106282. https://doi.org/10.1016/j.landusepol.2022.106282

Kwinta, A., & Gniadek, Ja. (2017). The description of parcel geometry and its application in terms of land consolidation planning. *Computers and Electronics in Agriculture*,*136*, 117–124. https://doi.org/10.1016/j.compag.2017.03.006

Lai, L., Davies, S., Wing, C. K., Ching, K., Chua, M. H., Leung, H., & Lorne, F. (2018). The determination of the "true" property boundary in planned development: A Coasian analysis. *The Annals of Regional Science*, *61*, 579–599. https://doi.org/10.1007/s00168-018-0871-8

Leń, P. (2017). Methodology of prioritization of land consolidation and land exchange interventions. *IOP Conference Series: Earth and Environmental Science*, *95*, 1–8. https://doi.org/10.1088/1755-1315/95/3/032010

Ligmann-Zielinska, A., Church, R., & Jankowski, P. (2008). Spatial optimization as a generative technique for sustainable multiobjective land-use allocation. *International Journal of Geographical Information Science*, *22*(6), 601–622. https://doi.org/10.1080/13658810701587495

Malashevskyi, M., & Malashevska, O. (2021a). The aims and trends of the sustainable land tenure formation in Ukraine: The spatial aspect. *Geodesy and Cartography*, *47*(3), 131–138. https://doi.org/10.3846/gac.2021.12791

Malashevskyi, M., & Malashevska, O. (2021b). The swapping approach in the course of land consolidation: Case study of Ukraine. *Geodesy and Cartography*, *47*(4), 200–211. https://doi.org/10.3846/gac.2021.13214

Malashevskyi, M., & Malashevska, O. (2022a). Land consolidation considering natural afforestation. *Geomatics and Environmental Engineering*, *16*(2), 5–19. https://doi.org/10.7494/geom.2022.16.2.5

Malashevskyi, M., & Malashevska, O. (2022b). Theory of combinations for land plot exchange modelling in the course of land consolidation. *Geodesy and Cartography*, *48*(1), 11–19. https://doi.org/10.3846/gac.2022.12883

Malashevskyi, M., Kovalchuk, I., & Malashevska, O. (2021). Reallotment over the course of the development of a rural settlement in Ukraine. *Geomatics and Environmental Engineering*, *14*(3), 115–127. https://doi.org/10.7494/geom.2021.15.3.115

O'Brien, D., & Prendergast, W. P. (2014). Proposed guidebook on established case law for land surveyors on property boundaries. *Survey Review*, *46*, 58–65. https://doi.org/10.1179/1752270613Y.0000000047

Palmer, D., Munro-Faure, P., & Rembold, F. (2004). Land consolidation and rural development in Central and Eastern Europe. *Fachbeiträge*, *129*(2), 132–135.

Pašakarnis, G., & Maliene, V. (2010). Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy*, *27*(2), 545–549. https://doi.org/10.1016/j.landusepol.2009.07.008

Song, M., & Chen, D. (2018). A comparison of three heuristic optimization algorithms for solving the multi-objective land allocation (MOLA) problem. *Annals of GIS*, *24*(4), 1–13. https://doi.org/10.1080/19475683.2018.1424736

Thomas, J. (2006). Attempt on systematization of land consolidation approaches in Europe. *Fachbeitrag*, *3*, 156–161.

Verkhovna Rada of Ukraine. (2001). *The land code of Ukraine.* Uriadovyi Kurier Ukrainian Government Publishing Body. https://zakon.rada.gov.ua/laws/show/2768-14

Veršinskas, T., Vidar, M., Hartvigsen, M., Mitic Arsova, K., van Holst, F., & Gorgan, M. (2021). *Land consolidation*. Legal Brief, 1. Rome, FAO.

Veršinskas, T., Vidar, M., Hartvigsen, M., Mitic Arsova, K., van Holst, F., & Gorgan, M. (2020). *Legal guide on land consolidation: Based on regulatory practices in Europe*. FAO Legal Guide No. 3. Rome, FAO.

Vitikainen, A. (2014). An overview of land consolidation in Europe. *Nordic Journal of Surveying and Real Estate Research*, *1*(1), 25–44. https://journal.fi/njs/article/view/41504

Yimer, F. A. (2014). *Fit-for-purpose land consolidation: An innovative tool for re-allotment in rural Ethiopia* [MSc Thesis]. University of Twente Faculty of Geo-Information and Earth Observation, Enschede, The Netherlands.