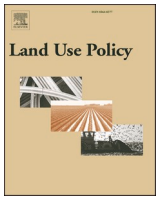
Land Use Policy 105 (2021) 105401



Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol





Evaluation of land consolidation projects with parcel shape and dispersion

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ARTICLE INFO

Keywords:
Minimum bounding geometry
Fragmentation
Shape metric
Distribution of parcels

ABSTRACT

Similar to many of the world's countries, Turkey has spent a large amount of money, time and effort on land consolidation (LC) work each year to provide the infrastructure required by agricultural lands, to minimize the problem of land fragmentation, to ensure the protection of agricultural lands, to increase agricultural production, to provide socioeconomic development in rural areas and to protect the rural landscape. However, not enough attention is given to the assessment of LC success. In this study, an approach is presented to assess the success of LC environmentally as measured by the number of parcels and parcel shape, which are important parameters related to LC project success. The E_iCEN, E_iLAP, and MBG_DoP indices were used to determine the dispersion of parcels owned by landowners. Minimum bounding geometry (i.e., the PAMPA, PPMBD and MBLW indices) was used for the analysis of parcel shape before and after LC. The indices proposed by this study are easily calculated parameters and can be important indicators in determining the success of a project after its termination.

1. Introduction

Land fragmentation, known as partitioning, pulverization, parceling and scattering (Bentley, 1987), is basically concerned with farms which are poorly organized in location and space (King and Burton, 1982). Land fragmentation is besides getting smaller and smaller over time, leads to physical dispersion of parcels (Niroula and Thapa, 2005). It also has negative effects on agricultural production (Lerman, 2005; Jha et al., 2005; Janus et al., 2016). Land fragmentation is a generalized phenomenon worldwide; for instance, it has occurred in South Asia (Niroula and Thapa, 2005), China (Nguyen et al., 1996; Wan and Cheng, 2001; Shuhao, 2005), India (Ram et al., 1999; Sengupta, 2006), Israel (Falah, 1992), Jordan (Jabarin and Epplin, 1994), Syria (Abdelali-Martini et al., 2003), Rwanda (Ntihinyurwa et al.2019), Spain (Colombo and Perujo-Villanueva, 2019), Cyprus (Demetriou et al. 2013; Demetriou, 2014), France (Latruffe and Piet, 2014), USA (Soltow, 1983; Verry, 2001; Brabec and Smith, 2002; Kjelland et al., 2007), and Turkey (Akkaya Aslan et al., 2007; Yaslioglu et al., 2009). Land fragmentation depends on many factors such as holding size, number of parcels each holding, size and shape of parcels and dispersion of parcels (King and Burton, 1982). Although there are reasons for land fragmentation may vary among countries and regions, there is general agreement on four main influencing factors: population growth, inheritance, land markets, and historical/cultural perspectives (King and Burton, 1982; Bentley, 1987; Niroula and Thapa, 2005).

LC has been a very important part of rural reform and productive rural development throughout the world for over a century to address land fragmentation problems, particularly in countries where agricultural land is highly fragmented and has been implemented in many countries around the world (Crecente et al., 2002; Derlich, 2002; Van Dijk, 2003, 2007; Thomas, 2004, 2006; Sklenicka, 2006; Yaslioglu et al., 2008, 2009; Arici and Akkaya Aslan, 2014; Degirmenci et al., 2017, Luo and Timothy, 2017).

As LC projects is complicated and costly projects, researchers have tried to better understand the associated concepts and improve the methodologies involved with their use to ensure their success (Colombo and Perujo-Villanueva, 2019). One of the most important steps in LC is evaluation. Several studies have been conducted to evaluate the efficacy of LC. (Crecente et al., 2002; Sklenicka, 2006; Yu et al., 2010; Cay and Uyan, 2013; Zhang and Zhao, 2013). Land consolidation project outputs are evaluated by many different methods (Miranda et al., 2006; Sklenicka, 2006). One way to assess the success of LC outcomes is to determine the change in land fragmentation before and after LC. There are commonly used indicators in assessing the effects of LC and the dynamics of land fragmentation (Crecente et al., 2002; Manjunatha et al., 2013; Rahman and Rahman, 2009; Janus and Markuszewska, 2017). The number of land parcels can be analyzed in relation to the total reparceling area, a specific farm, or the different size categories of the parcels in a given area. In addition, there are indicators of the Simpson index and Januszewski index, which are frequently used in land

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https://doi.org/10.1016/j.landusepol.2021.105401
Received 3 December 2019; Received in revised form 23 February 2021; Accepted 7 March 2021
Available online 13 March 2021
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consolidation to analyze changes in parcel size (Blarel et al., 1992; Januszewski, 1968).

In this study, approaches to determine the changes on parcel dispersion and shape, which are the most fundamental parameters in the success of LC projects, are presented. The dispersion of landowner's parcels was examined by two separate methods. The first was the distance to the village center (E_iCEN) and the second is the dispersion of landowner's parcels within themselves. Two different methods have been used to determine the dispersion of the landowner's parcels. The first method is based on the distance of the parcels to the largest parcel of the landowner (E_iLAP). The second method is the minimum boundary geometry method that is calculated to include all parcels owned by the landowner's. Minimum bounding geometry was used to analyze the parcel shape. In this analysis, the Rectangle by Area tool, which converts the current plot shape to the closest rectangle, is used. Using the rectangular area obtained, PAMPA, PPMBD and MBLW values were calculated for before and after LC. All the calculated indices were evaluated statistically with the indices commonly used in LC studies, and the results obtained are presented in the results and discussion Section.

2. Materials and methods

2.1. Description of study area

Data from the Tepealagöz LC project, which was completed in Cankırı – Kızılırmak, Turkey, were chosen as the material for this study. The project area was 168.86 ha, and there were 279 landowners. In the study area, there were 285 parcels before LC, and this number decreased to 105 after LC. There were a total of 279 enterprises in the project area, and shareholding was common. A total of 162 parcels were single shares, and the share rate in some parcels went up to 22. In this study, after LC, the shares were merged. The average parcel size, which was 0.59 ha before LC, increased to 1.61 ha after LC (Table 1). The cadastral maps for before and after LC are given in Fig. 1.

Data containing information about holdings and maps were obtained from the state-run private company that developed the project. The land fragmentation level was measured for a number of holdings based on the available data needed for the calculation methods. The holdings that were evaluated were chosen randomly. The features of the selected holdings are given in Table 2.

2.2. Analysis of parcel dispersion

In this study, two different methods were used to determine the spatial dispersion of the parcels. In the first method, standard distance, which is a basic measure of spatial distribution, was used (Ebdon, 1985; Wong and Lee, 2005). In this study, parcel distribution was determined in two ways. The first is the distance of the holding parcels to the village center, and the second is the distance of the holding parcels to the largest parcel. Thus, in both cases, the dispersion of the parcels can be calculated as follows:

$$DoP = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{hmx})^2 + \sum_{i=1}^{n}(y_i - y_{hmx})^2}{n}} \quad (1)$$

Table 1
Information about the project area before and after LC.

Project Information	Before LC	After LC
Number of parcels	285	105
Number of landholdings	279	279
Average parcel area (ha)	0.59	1.61
Average landholding area (ha)	0.60	0.60
Total project area (ha)	168.86	168.86

where x_{hmx} and y_{hmx} comprise the coordinates of the owner's village center or the coordinates of the centroid of the largest parcel; x_i and y_i comprise the coordinates of the centroid of parcel i; n is the number of parcels belonging to an owner.

The dispersion of parcels can have any positive value. There no concrete data in this index, so it is difficult for experts to define a value function according to their judgment. Therefore, a more general standardization method is proposed below.

$$E_i = 1 - \left(\frac{(S_i - minS) * 0.5}{meanS - minS}\right)\left(if S_i \le meanS\right) \quad (2)$$

$$E_i = 1 - \left(\left(\frac{(S_i - meanS) * 0.5}{maxS - meanS}\right) + 0.5\right)\left(if S_i > meanS\right) \quad (3)$$

where E_i is the standardized value of score S_i and minS, maxS, and meanS are the corresponding statistical values for all the scores in the sample. E_i was calculated as E_iCEN for the distance of the holding parcels to the village center and E_iLAP for the distance to the largest parcel of the holding parcels.

For the second method, the minimum bounding geometry was used to determine the dispersion of the parcels belonging to the landowner (MBG_DoP). The minimum bounding geometry is the smallest axis-aligned rectangle that encloses its D-dimensional data. The minimum bounding geometry offers three advantages: (i) are computed simply and with linear cost; (ii) are very compact to store, needing only two spatial points; and (iii) are very computationally economical to compare to each other using the overlap/intersection functions. The minimum bounding geometry calculation was made according to 5 different tools (Fig. 2): Convex_hull, Rectangle by Area, Rectangle by Width, Circle and Envelope.

The Convex_hull method, which minimized the area value, was used to determine the dispersion of the parcels. The data obtained by these methods were analyzed by adapting the novel shape metrics to the parcel data by Zhang and Atkinson (2016), which provided a measure of the fragmentation of landscape areas (Table 3). The MBG_DoP value was calculated according to PAMPA (the area ratio between a parcel and the MB box).

2.3. Analysis of parcel shape

The minimum bounding geometry is an important indicator that can be used in the analysis of parcel shape in LC projects. Minimum bounding geometry was also used in the analysis of parcel shape in this study. It is desirable that the parcel shapes are close to a rectangular shape. The most commonly used tools for analyzing patch fragmentation are Envelope, Rectangle by Area, and Rectangle by Width. In this study, the Rectangle by Area tool was used in the analysis of the parcel shape because it turned the parcel shape into the shape nearest a rectangle. PAMPA, PPMBD and MBLW values were calculated for the parcels before and after LC (Table 3). The data in this study were analyzed according to the most widely used indices for analyzing the shape and distribution of parcels in LC projects (Table 4). All results were evaluated statistically.

3. Results

The dispersion of the parcels of landowners was examined by two separate methods. The first was the distance to the village center. Farm centers are located in villages. Therefore, the distance from the farmers' lands to the village center was calculated according to the situation before and after LC. As shown in Table 5, the mean dispersion of parcels decreased from 3104 m before LC to 2921 m after LC. Here, the E_iCEN value is between 0 and 1. As the value approaches 1, the parcels of the landowner approach the village center. When the mean E_iCEN values obtained after LC were observed, some of the enterprises moved to a

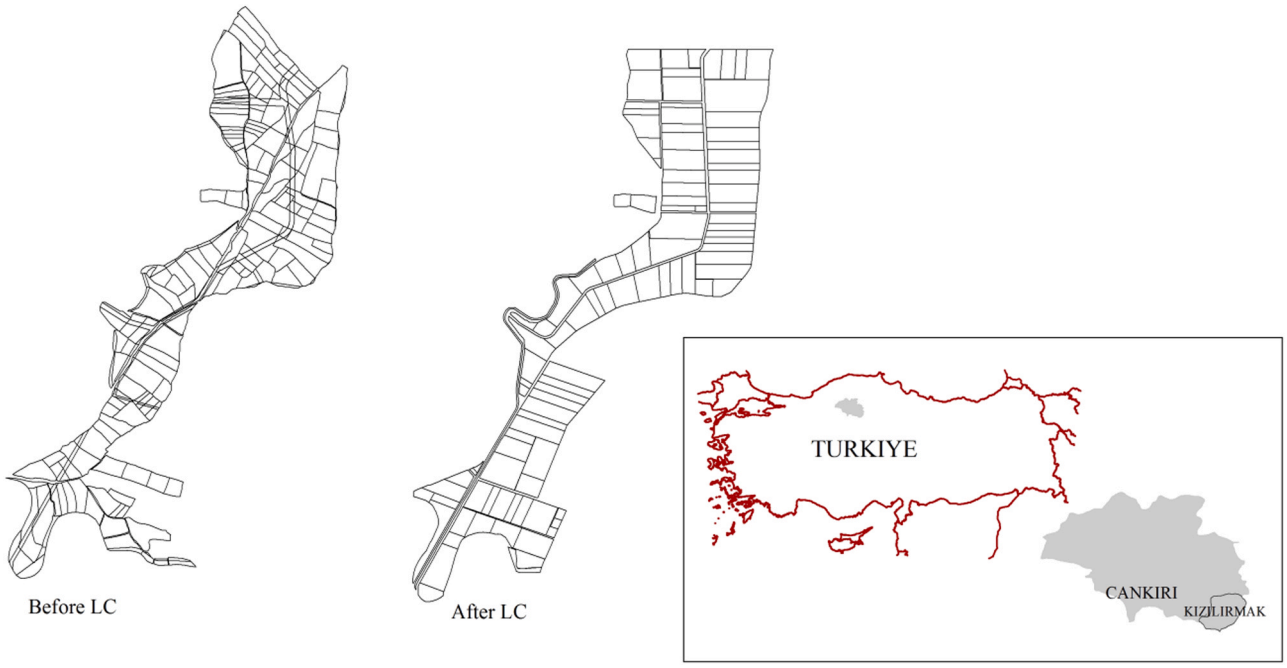


Fig. 1. Cadastral maps before and after LC.

Table 2
Main features of the selected holdings evaluated.

Ownership ID	Parcel area (ha)	Number of parcel	
		Before LC	After LC
2	1.11	6	1
6	4.86	10	3
18	5.41	2	1
21	2.05	2	1
40	1.81	11	1
105	7.71	8	1
116	1.91	2	2
128	2.80	6	1
228	3.54	5	1

position closer to the village center, while some of them maintained their current position. The mean E_iCEN increased from 0.40 to 0.44 after LC.

The second method for determining the dispersion of parcels owned by the landowners is based on the location of their parcels. The dispersion of parcel value is based on the distance of the parcels to the largest parcel of the landowner (E_iLAP). Minimum bounding geometry was used to determine the dispersion of the parcels belonging to the landowner (MBG_DoP). The Convex_hull tool, which minimizes the area value, was used to determine the dispersion of the parcels (Fig. 3). The MBG_DoP value was calculated according to the area ratio between a parcel and the MB boxes.

The E_iLAP and MBG_DoP values calculated here also showed the rate at which the parcels were combined. In LC, parcels were mostly collected around the largest parcel owned by the landowner. Here, the E_iLAP and MBG_DoP values are between 0 and 1. When the value approaches 1, it shows that the parcels of the landowner are gathered together. The average E_iLAP and MBG_DoP values obtained after LC indicated that the landowners' parcels were close to 1 or 1. As shown in Table 6, the E_iLAP value before LC varied between 0.25 and 0.75, and the MBG_DoP value ranged between 0.07 and 0.91. While the number of parcels decreased after LC, some E_iLAP and MBG_DoP values became 1, whereas other values approached 1, indicating that the parcel locations were clustered together. The E_iLAP and MBG_DoP values before and after LC were compared with the Simpson and Januszewski indices (Table 6).

The descriptive statistics of the indices for the dispersion of ownership are given in Table 7.

The correlation matrix is given in Table 8. A positive correlation was found between the E_iLAP and MBG_DoP indices and the indices of Simpson and Januszewski. This is a positive result for the E_iLAP and MBG_DoP values as a fragmentation index.

Minimum bounding geometry was also used in the analysis of parcel shape in this study. In terms of agricultural land management, it is desirable that parcels are close to rectangular. For this purpose, the existing parcels were converted to the rectangle closest to the current parcel shape with the Rectangle by Area tool in the minimum bounding geometry analysis toolbox. Before and after LC, PAMPA, PPMBD and MBLW values were calculated with the area and perimeter values of the newly formed rectangle from the existing parcel. When the PAMPA and PPMBD values approach 1, the shape of the parcel approaches a rectangular shape. When the MBLW value approaches 1, the shape of the

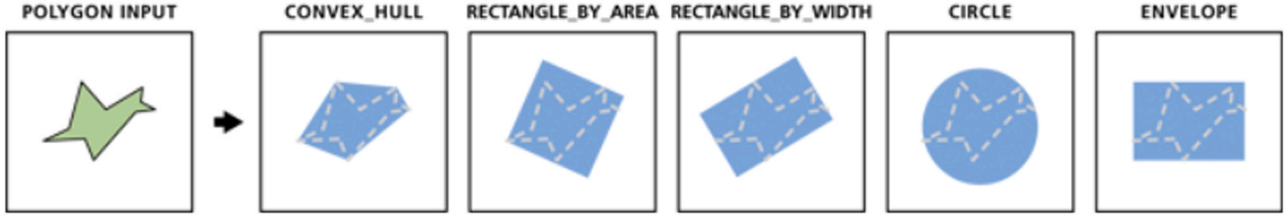


Fig. 2. Minimum bounding geometry types.

Table 3
Detailed description of the shape metrics.

Indices	Formula	Description
MBLW = Patch length-to-width ratio	L/W	Description of vector parcel elongatedness. The larger the value, the more elongated the shape. It is not desirable for LC projects to have a value greater than 10
PAMBA = Area ratio between parcel and MB box	PA/MBA	Description of vector parcel compactness. Ranges between 0 and 1, higher values indicating the more regular shape and lower values the more the more compact the shape.
PPMBP = Perimeter ratio between parcel and MB box	PP/MBP	Description of vector patch roughness. If the value is equal to 1, parcel shape is equal to MB shape, smaller than 1 is the rougher the parcel edge.

Table 4
Indices used to analyze the shape and distribution of parcels in LC.

Index	Formula	Resource	Parameters needed
Simmons	$Simmons = \frac{\sum_{i=1}^{n} A_i^2}{A}$	Simmons (1964)	A_i: Area of i th parcel
Januszewski	$\text{Januszewski} = \frac{\sqrt{A}}{\sum_{i=1}^{n}\sqrt{A_i}}$	Januszewski (1968)	A: Total size of the holding
Fractal Dimension	$FD = \frac{2\ln p_i}{\ln A_i}$	Krummel et al. (1987)	n: number of parcels belong the holding
Shape Index	$SI = \frac{p_i}{\sqrt[2]{\pi A_i}}$	McGarical and Marks (1995)	p_i: Perimeter of i th parcel
Areal Form Factor	$AFF = \frac{A_i}{p_i^2}$	Witney (1988) and Gonzalez et al. (2004, 2007)	

Table 5
Dispersion of parcels by village center.

Ownership ID	Before LC		After LC	
	The mean dispersion of parcel	E_iCEN	The mean dispersion of parcel	E_iCEN
2	3615	0.17	3625	0.15
6	2893	0.51	2628	0.6
18	3900	0.04	3755	0.1
21	3000	0.45	1825	0.84
40	2442	0.64	1974	0.79
105	2916	0.50	3794	0.08
116	2958	0.50	2821	0.55
128	3538	0.21	3988	0
228	2671	0.57	1876	0.82
Mean	3104	0.40	2921	0.44

parcel is close to a square. The MBLW value is also the width/length ratio of the parcel. The PAMPA, PPMBD and MBLW values obtained before and after LC were compared with the SI, FD and AFF indices, which are commonly used in the analysis of parcel shape (Table 9).

The correlation matrix of all parcel shape indices, given in Table 10, is significant at the 0.01 and 0.05 levels. PAMPA and AFF correlated negatively with the SI and FD indices. As a result, the correlation of the PAMPA, PPMBD and MBLW indices with the SI, FD and AFF is a positive result for the usability of these indices in parcel shape analysis. Since the PAMPA indices shows correlation with SI, FD, and AFF indices of 0.01 significance, it may be the most suitable indices for use in shape analysis among the proposed indices.

4. Discussion

In this study, some indicators were used to determine dispersion of parcels and for the analysis of parcel shape before and after LC. Dispersion of parcels also refers to the fragmentation of land. The fragmentation of land ownership is a major obstacle to the effective management and sustainability of agricultural farms. This fragmentation is often caused by small farms where their costs are very important, sometimes by damaging them and leaving their land. One of the most common ways of reducing land fragmentation is LC. LC is a complex, costly and long process and its results need to be carefully evaluated. Various researchers have stated that there is no standard, comprehensive measurement method for evaluating LC projects (Gasiorowski and Bielecka, 2014). Land fragmentation is effected by various parameters including holding size, number of parcels, size of parcels, shape of parcels, spatial distribution of the parcels, size distribution of parcels and internal fragmentation (Platonova et al., 2011; Demetriou et al., 2011; Aasmäe and Maasikamäe, 2014; Kirmikil et al., 2017).

The E_iCEN, EiLAP and MBG_DoP indices were used to determine the dispersion of parcels owned by landowners. While E_iCEN analyzes the distance of these parcels to the village center, the E_iLAP and MBG_DoP indices analyze the distance of the parcels to each other. When calculating E_iCEN and E_iLAP indices, parcel gravity centers are taken into account. The parcel center of gravity can come out of the parcel boundary in the parcels where the parcel shape is so untypical. To avoid this, the "inside" command was used when calculating the parcel gravity centers. Thus, the center of gravity of each parcel is calculated to remain within the parcel. E_iLAP and MBG_DoP indices serve the same purpose. Both indices take a value between 0 and 1. The closer to the 1 obtained, the closer the parcels to each other, the closer to the 0, the further away from each other.

The E_iLAP and MBG_DoP index values were found to be statistically significant compared to the Simpson and Januszewski indices that are used by many researchers.

The Simpson and Januszewski indices were found to be positively correlated with and very similar to those of previous studies (Degirmenci et al., 2017; Demetriou et al., 2013). The Simpson and Januszewski indices calculate the landowner's total parcel areas. Since E_iLAP takes into account the distance between parcel centers, it uses point values. Since MBG_DoP takes into account all parcels and the areal values between them, it uses area-based values. In this context, MBG_DoP appears as a stronger index in determining the parcel dispersion.

The savings from the reduction of parcel distribution become even more important in the largest areas. LC does not solve the problem of small landowner size, but by regulating ownership, reducing the number of parcels owned by farmers, makes it easier to operate and reduces the number of neighboring farmers possible in the future (Colombo and Perujo-Villanueva, 2019).

In this study minimum bounding geometry was used for the analysis of parcel shape before and after LC. PAMPA, PPMBD and MBLW parameters calculated before and after LC were compared with the SI, FD and AFF indices and found to be statistically significant.

SI, FD and AFF indices analyze the parcel shape over the existing area-perimeter relationship of the parcel, while the proposed indices analyze the parcel's resemblance to the nearest rectangle. PAMPA uses area value, PPMBD uses perimeter value and MBLW uses width-length ratio. The PAMPA index is the ratio between the existing parcel area and the rectangular area closest to the parcel, and it stands out statistically more than other indices in analyzing the similarity of the parcel shape to the ideal shape. However, the fact that the parcel shape always approaches the quadrilateral cannot be considered as ideal. In this context, the width-length ratio (MBLW) of the parcel is an important criterion. By evaluating these two indices together, parcels can be evaluated quickly with both shape and width-length ratio harmony.

Parcel shape and edge length are among the most important criteria

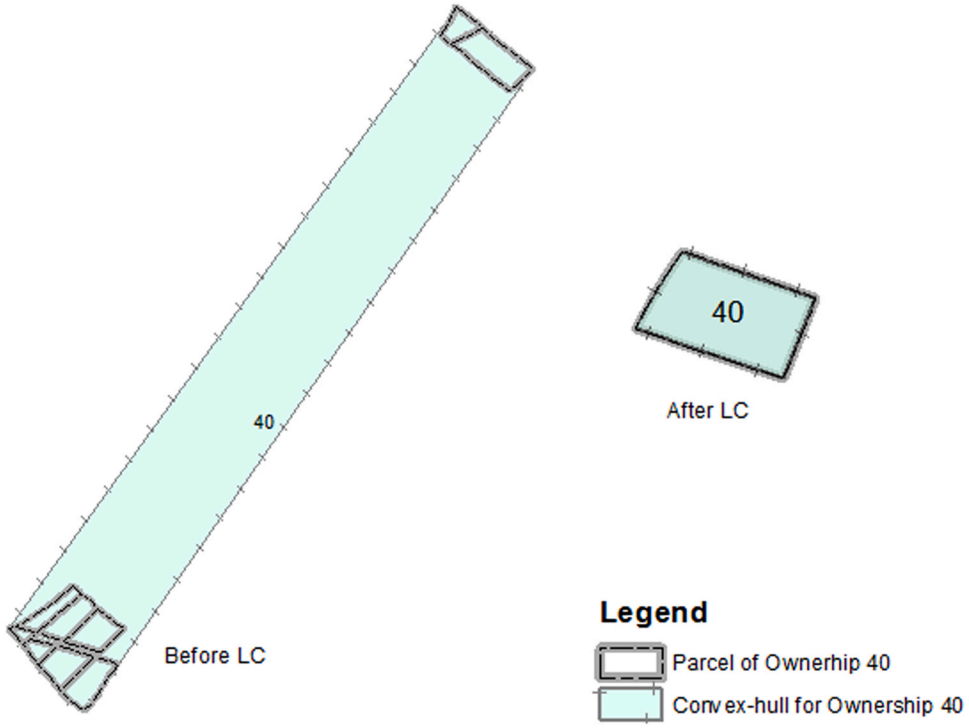


Fig. 3. Minimum bounding geometry analysis for the calculation of the dispersion of the parcels.

Table 6
Dispersion of the largest parcel of the landowners.

Ownership ID	Before LC				After LC			
	E_iLAP	MBG_DoP	Simmons	Januszewski	E_iLAP	MBG_DoP	Simmons	Januszewski
2	0.45	0.57	0.28	0.44	1	1.00	1	1
6	0.55	0.05	0.17	0.35	0.83	0.08	0.37	0.59
18	0.75	0.91	0.69	0.74	1	1.00	1	1
21	0.75	0.05	0.58	0.72	1	1.00	1	1
40	0.25	0.13	0.13	0.32	1	1.00	1	1
105	0.48	0.14	0.34	0.44	1	1.00	1	1
116	0.75	0.05	0.61	0.73	0.75	0.06	0.61	0.73
128	0.54	0.07	0.20	0.42	1	1.00	1	1
228	0.60	0.17	0.40	0.51	1	1.00	1	1
Mean	0.57	0.24	0.38	0.52	0.95	0.79	0.89	0.92

Table 7
Descriptive statistics of the dispersion of ownership indices.

	Minimum	Maximum	Mean	Std. deviation	Variation coeff (%)
E_iLAP	0.25	1.00	0.76	0.24	31.24
MBG_DoP	0.05	1.00	0.51	0.44	86.27
Simmons	0.13	1.00	0.63	0.34	53.41
Januszewski	0.32	1.00	0.72	0.26	36.10

Table 8
Pearson correlation coefficient matrix for the indices of dispersion of ownership.

Indicators	E_iLAP	MBG_DoP	Simmons	Januszewski
E_iLAP	1			
MBG_DoP	0.729**	1		
Simmons	0.935**	0.850**	1	
Januszewski	0.956**	0.814**	0.994**	1

** Correlation is significant at the 0.01 level (2-tailed).

in determining the most efficient use of agricultural land. It has a direct impact on time and labor productivity. Parcel shape is important for the use of agricultural machinery because it is difficult to work with machines in some parcel shapes (Kirmikil and Arici, 2013; Janus and Markuszewska, 2019). The main purpose of land consolidation is to reduce the number of parcels and to create well-shaped parcels. Planning the parcels owned by a landowner as close to each other as possible is important for agricultural management. However, parcels formed after land consolidation not only grow better in terms of agriculture, and the actual effects take much longer than the assumed 30 years for dynamic economic indices (Janus and Markuszewska, 2019). Changes in the number and shape of parcels, thus occurring in the land fragmentation parameters, reduce the total production costs of a particular agricultural segment (Tan et al., 2008). To ensure a comprehensive assessment of the benefits of land consolidation projects, it is necessary to develop methods for evaluating non- economic effects of the projects and expressing them in monetary terms (Wojewodzic et al., 2021). After the land consolidation, parcel scatter and parcel shape analysis is important in terms of controlling the project and evaluating its success. These evaluations should be made with indices that can be calculated quickly and easily interpreted. The indexes suggested in this study can

Table 9
Indicators in parcel shape analysis.

Ownership ID	Before LC						After LC					
	SI	FD	AFF	PAMBA	PPMBD	MBLW	SI	FD	AFF	PAMBA	PPMBD	MBLW
2	1.30	1.42	0.048	0.66	0.86	2.16	1.65	1.38	0.029	0.97	0.98	6.54
6	1.47	1.41	0.039	0.65	0.90	2.90	1.43	1.33	0.040	0.91	0.96	4.18
18	1.23	1.30	0.053	0.65	0.84	1.78	1.14	1.27	0.060	0.93	0.97	1.17
21	1.30	1.33	0.047	0.58	0.85	1.63	1.19	1.30	0.056	0.95	0.97	2.02
40	1.29	1.42	0.049	0.76	0.90	2.46	1.17	1.29	0.058	0.93	0.96	1.84
105	1.44	1.43	0.045	0.69	0.90	3.07	1.38	1.32	0.042	0.98	0.99	3.80
116	1.42	1.36	0.044	0.74	0.90	3.38	1.20	1.30	0.056	0.87	0.91	2.21
128	1.41	1.38	0.045	0.71	0.89	3.21	1.36	1.31	0.043	0.97	0.98	3.57
228	1.46	1.40	0.039	0.67	0.88	3.06	1.13	1.27	0.045	0.91	0.95	1.29

Table 10
Pearson correlation coefficient matrix of the parcel shape indices.

Indicators	SI	FD	AFF	PAMBA	PPMBD	MBLW
SI	1					
FD	0.51**	1				
AFF	−0.73**	−0.63**	1			
PAMPA	−0.45**	−0.67**	0.47**	1		
PPMBD	0.27**	0.006	−0.25**	0.54**	1	
MBLW	0.16**	−0.12*	−0.16**	0.44**	0.46**	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

be calculated quickly in the GIS environment; It can be interpreted easily and clearly.

5. Conclusion

Land consolidation is a complex and demanding process that requires expensive, long time and labor. In land consolidation, each project area has different characteristics and can have its own unique conditions and desires. Therefore, it is very difficult to achieve the same standards in all projects. However, the main purpose of land consolidation projects is to minimize land fragmentation as much as possible. For this reason, it is necessary to analyze the change in land fragmentation after each project and analyze the project in this direction.

As a result, these indicators were used to determine the land fragmentation before and after land consolidation and the analysis of shape the change in the parcels. These indicators can be used for comparisons in terms of dispersion and shape of parcels before and after land consolidation. In land consolidation projects, it is important to analyze the project achievements in this direction as it would be beneficial for the farmers to reduce the number of parcels belonging to the farmers.

Recently, as in many disciplines the use of geographic information systems in LC projects has become widespread. Since the indices proposed by this study are easily calculated parameters. They can be important indicators in determining the success of a project after its completion. As a result, the proposed methods can be applied relatively easily using GIS and can be used in many areas other than land consolidation.

CRediT authorship contribution statement

Şerife Tülin Akkaya Aslan: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft preparation, Writing - review & editing.

References

Aasmäe, K., Maasikamäe, S., 2014. Internal fragmentation of agricultural parcels. Res. Rural Dev. 2, 278–282.

Abdelali-Martini, M., Goldey, P., Jones, G.E., Bailey, E., 2003. Towards a feminization of agricultural labour in northwest Syria. J. Peasant Stud. 30 (2), 71–94.

Akkaya Aslan, S.T., Gundogdu, K.S., Yaslioglu, E., Kirmikil, M., Arici, I., 2007. Personal, physical and socioeconomic factors affecting farmers' adoption of land consolidation. Span. J. Agric. Res. 5 (2), 204–213.

Arici, I. and Akkaya Aslan, S.T., 2014, Arazi Toplulaştırması Planlama ve Projelemesi. Dora pp. 237, ISBN: 978–605-4798–49-0 (in Turkish).

Bentley, W., 1987. Economic and ecological approaches to land fragmentation: in defence of a much-maligned phenomenon. Annu. Rev. Anthropol. 16 (3), 46–57.

Blarel, B., Hazell, P., Place, F., Guiggin, J., 1992. The economics of farm fragmentation—evidence from Ghana and Rwanda. World Bank Econ. Rev. 6 (2), 233–254.

Brabec, E., Smith, C., 2002. Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States. Landsc. Urban Plan. 58 (2–4), 255–268.

Cay, T., Uyan, M., 2013. Evaluation of reallocation criteria in land consolidation studies using the Analytic Hierarchy Process (AHP). Land Use Policy 30, 541–548.

Colombo, S., Perujo-Villanueva, M., 2019. A practical method for the ex-ante evaluation of land consolidation initiatives: fully connected parcels with the same value. Land Use Policy 81, 463–471.

Crecente, R., Alvarez, C., Fra, U., 2002. Economic, social and environmental impact of land consolidation in Galicia. Land Use Policy 19 (2), 135–147.

Degirmenci, H., Arslan, F., Tonçer, R., Yoğun, E., 2017. Evaluation of land fragmentation parcel shapes before land consolidation project: a case study of Tırhan Village in Niğde Misli Plain. J. Agric. Fac. Gaziosmanpasa Univ. 34 (3), 182–189.

Demetriou, D., 2014. The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation. Springer International Publishing Switzerland, Zug, p. 340.

Demetriou, D., Stillwell, J., and See, L., 2011, The development and evaluation of a new model for measuring land fragmentation. University of Leeds, School of Geography, Working Paper 11/05.

Demetriou, D., Stillwell, J., See, L., 2013. A new methodology for measuring land fragmentation. Comput., Environ. Urban Syst. 39, 71–80.

Derlich, F., 2002, Land consolidation: a key for sustainable development French experience. In: Proceedings of the XXII International FIG Congress, 19–26 April, 2002, Washington, D.C., USA.

Ebdon, D., 1985. Statistics in Geography. Blackwell Publishing, Oxford.

Falah, G., 1992. Land fragmentation and spatial control in the Nazareth metropolitan-area. Prof. Geogr. 44 (1), 30–44.

Gasiorowski, J. and Bielecka, E., 2014, Land Fragmentation Analysis Using Morphometric Parameters. In Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE (Vol. 9, p. 1).

Gonzalez, X.P., Alvarez, C.J., Crecente, R., 2004. Evaluation of land distributions with joint regard to plot size and shape. Agric. Syst. 82, 31–43.

Gonzalez, X.P., Marey, M.F., Alvarez, C.J., 2007. Evaluation of productive rural land patterns with joint regard to the size, shape and dispersion of plots. Agric. Syst. 92, 52–62.

Jabarin, A.S., Epplin, F.M., 1994. Impacts of land fragmentation on the cost of producing wheat in the rain-fed region of northern Jordan. Agric. Econ. 11 (2–3), 191–196.

Janus, J., Markuszewska, I., 2019. Forty years later: Assessment of the long-lasting effectiveness of land consolidation projects. Land Use Policy 83, 22–31. https://doi.org/10.1016/j.landusepol.2019.01.024.

Janus, J., Mika, M., Leń, P., Siejka, M., Taszakowski, J., 2016. A new approach to calculate the land fragmentation indicators taking into account the adjacent plots. Surv. Rev. 50 (358), 1–7.

Janus, J., Markuszewska, I., 2017. Land consolidation – a great need to improve effectiveness. A case study from Poland. Land Use Policy 65, 143–153.

Januszewski, J., 1968. Index of land consolidation as a criterion of the degree of concentration. Geogr. Pol. 14, 291–296.

Jha, R. , Nagarajan, H.K. and Prasanna, S., 2005, Land Fragmentation and its Implications for Productivity: Evidence from Southern India. ASARC Working Paper 2005/01, Australia South Asia Research Centre, RSPAS. Division of Economics, Australian National University.

King, R., Burton, S., 1982. Land fragmentation: notes on a fundamental rural spatial problem. Prog. Hum. Geogr. 6 (4), 475–494.

Kirmikil, M., Akkaya Aslan, S.T., Gundogdu, K.S., Arici, I., 2017. The hidden fragmentation after land consolidation in Turkey. Fresenius Environ. Bull. 26, 5882–5890.

Kirmikil, M., Arici, I., 2013. The role of land consolidation in the development of rural areas in irrigation areas. J. Food, Agric. Environ. 11 (2), 1150–1155.

Kjelland, M., Kreuter, U., Clendenin, G., Wilkins, R., Ben, X., Afanador, G., 2007. Factors related to spatial patterns of rural land fragmentation in Texas. Environ. Manag. 40 (2), 231–244.
Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V., Coleman, P.R., 1987. Landscape pattern in a disturbed environment. Oikos 48, 321–324.
Latruffe, L., Piet, L., 2014. Does land fragmentation affect farm performance? A case study from Brittany, France. Agric. Syst. 129, 68–80.
Lerman, Z., 2005, Farm fragmentation and productivity: Evidence from Georgia. Discussion Paper No. 8.05. Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, 10p.
Luo, W., Timothy, D.J., 2017. An assessment of farmers' satisfaction with land consolidation performance in China. Land Use Policy 61, 501–510.
Manjunatha, A.V., Anik, A.R., Speelman, S., Nuppenau, E.A., 2013. Impact of land fragmentation, farm size, land ownership and crop diversity on profit and efficiency of irrigated farms in India. Land Use Policy 31, 397–405.
McGarical, K. and Marks, B.J., 1995, FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Washington. D.C., U.S. Department of Agriculture, Forest Service, General Technical Report No PNW-GTR-351.
Miranda, D., Crecente, R., Alvarez, M.F., 2006. Land consolidation in inland rural Galicia, N.W. Spain, since 1950: An example of the formulation and the use of questions, criteria and indicators for the evaluation of rural development policies. Land Use Policy 23 (11), 511–520.
Niroula, G.S., Thapa, G.B., 2005. Impacts and causes of land fragmentation and lessons learned from land consolidation in Asia. Land Use Policy 22 (4), 358–372.
Nguyen, T., Cheng, E.J., Findlay, C., 1996. Land fragmentation and farm productivity in China in the 1990s. China Econ. Rev. 7 (2), 169–180.
Ntihinyurwa, P.D., Vries, W.T., Chigbu, U.E., Dukwiyimpuhwe, P.A., 2019. The positive impacts of farm land fragmentation in Rwanda. Land Use Policy 81, 565-58.
Platonova, D., Setkovska, L., Jankava, A.I., 2011. Assessment principles of land fragmentation. Balt. Surv. 11, 117–124.
Ram, K.A., Tsunekawa, A., Sahad, D.K., Miyazaki, T., 1999. Subdivision and fragmentation of land holdings and their implication in desertification in the Thar Desert, India. J. Arid Environ. 41 (4), 463–477.
Rahman, S., Rahman, M., 2009. Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. Land Use Policy 26 (1), 95–103.
Sengupta, N., 2006. Fragmented landholding, productivity, and resilience management. Environ. Dev. Econ. 11 (4), 507–532.
Simmons, A.J., 1964. An index of farm structure, with a Nottingahmsire example. East Midl. Geogr. 3, 255–261.
Shuhao, T., 2005, Land fragmentation and rice production: a case study of small farms in Jiangxi Province. P.R. China, PhD thesis, Wageningen University.
Sklenicka, P., 2006. Applying evaluation criteria for the land consolidation effect to three contrasting study areas in the Czech Republic. Land Use Policy 23 (4), 502–510.
Soltow, L., 1983. Land fragmentation as an index of history in the Virginia military district of Ohio. Explor. Econ. Hist. 20 (3), 263–273.
Tan, S., Heerink, N., Kruseman, G., Qu, F., 2008. Do fragmented landholdings have higher production costs? Evidence from rice farmers in Northeastern Jiangxi province, P.R. China. China Econ. Rev. 19, 347–358.
Thomas, J., 2004, Modern land consolidation: recent trends on land consolidation in Germany. In: Proceedings of Symposium on Modern Land Consolidation, 10–11 September 2004, Volvic (Clermont-Ferrand), France.
Thomas, J., 2006. Property rights, and fragmentation and the emerging structure of agriculture in Central and Eastern European countries. J. Agric. Dev. Econ. 3 (2), 225–275.
Van Dijk, T., 2003. Scenarios of Central European land fragmentation. Land Use Policy 20, 149–158.
Van Dijk, T., 2007. Complications for traditional land consolidation in Central Europe. Geoforum 38, 505–511.
Verry, E.S., 2001, Land Fragmentation and Impacts to streams and fish in the central and upper midwest. In: Proceedings, Society of American Foresters, 2000 national convention (pp. 38–44), November 16–20, Washington, DC.
Wan, G.H., Cheng, E.J., 2001. Effects of land fragmentation and returns to scale in the Chinese farming sector. Appl. Econ. 33 (2), 183–194.
Witney, B., 1988. Choosing and Using Farm Machines. Edinburgh, Scotland, Land Technology Ltd, p. 412.
Wojewodzic, T., Janus, J., Dacko, M., Pijanowski, J., 2021, Measuring the effectiveness of land consolidation: An economic approach T based on selected case studies from Poland. Volume 100, ⟨10.1016/j.landusepol.2020.104888⟩.
Wong, D., Lee, J., 2005. Statistical Analysis of Geographic Information: With ArcView and ArcGIS. Wiley, New Jersey.
Yaslioglu, E., Arici, I., Kuşçu, H., Gundogdu, K.S., Akkaya Aslan, S.T., Kirmikil, M., 2008. Adoption factors of irrigation systems whose projects are synchronized with land consolidation. Kuwait J. Sci. Eng. 35 (2A), 1–10.
Yaslioglu, E., Akkaya Aslan, S.T., Kirmikil, M., Gundogdu, K.S., Arici, I., 2009. Changes in farm management and agricultural activities and their effect on farmers' satisfaction from land consolidation: the case of Bursa-Karacabey, Turkey. Eur. Plan. Stud. 17 (2), 327–340.
Yu, G., Feng, J., Che, Y., Lin, X., Hu, L., Yang, S., 2010. The identification and assessment of ecological risks for land consolidation based on the anticipation of ecosystem stabilization: a case study in Hubei Province, China. Land Use Policy 27, 293–303.
Zhang, C., Atkinson, P.M., 2016. Novel shape indices for vector landscape pattern analysis. Int. J. Geogr. Inf. Sci. 30 (12), 2442–2461.
Zhang, Z.F., Zhao, W., 2013. A parametric approach to assess the sustainability of land consolidation: a case study in Shandong Province, north China. Agroecol. Sustain. Food Syst. 37 (4), 444–464.