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A New Approach to Measure Parcel Shapes for Land Consolidation

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ABSTRACT
Land consolidation (LC) is of significant importance and is an application that decreases land fragmentation level and deformed parcels, which reduce agricultural production, increasing fuel consumption and labor cost in the agriculture sector. The present research focuses on parcel shapes and investigates a new index measuring complexity of parcels. The most commonly used indices (fractal dimension, shape index, form factor, areal form factor, area perimeter ratios, and the number of points) are compared with the new shape index. The new shape index is calculated with the parcel's area and minimum bounding geometry of the parcel using geographic information systems. The new approach was applied to the cadastral data consisting of different types of parcel shapes before LC in a village in Mersin, Turkey. The new shape index showed a good performance in terms of measuring shape complexity and is easily applicable. The presented method may be used to assess LC projects or to determine priority areas for LC.

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Arazi Toplulaştırma Projelerinde Parsel Şekillerinin Değerlendirilmesi: Yeni Şekil İndeksi Yaklaşımı

ÖZET
Tarım sektöründe, arazi toplulaştırma çalışmaları, arazi parçalılık seviyesinin azaltılması ve şekilleri bozulmuş parsellerin yeniden düzenlenmesi açısından büyük öneme sahiptir. Parsel şekillerinin düzensiz olması ve arazi parçalılığı yakıt tüketimini ve işgücü ihtiyacını arttırmaktadır. Bu çalışma parsel şekillerinin düzensizliğini ölçmek amacıyla yeni bir şekil indeksi üzerine odaklanmıştır. Parsel şekillerinin düzensizliğini ölçmek amacıyla yaygın olarak kullanılan göstergelerden şekil indeksi, şekil faktörü, alansal şekil faktörü, alan-çevre oranları ve parseli oluşturan nokta sayısı indekleri, yeni şekil indeksi ile karşılaştırılmıştır. Yeni şekil indeksi, coğrafi bilgi sistemi kullanılarak hesaplanan parsel alanı ve parseli çevreleyen en küçük dikdörtgenin alanı ile hesaplanmaktadır. Araştırmada Mersin İli'nde bulunan bir köyün arazi toplulaştırma öncesi kadastro verileri kullanılmıştır. Kolay uygulanma ve hesaplama yöntemi olan yeni şekil indeksi, parsel şekillerinin düzensizliğini ölçme açısından diğer şekil indekslerine göre daha iyi performans göstermiştir. Sonuçta, yeni şekil indeksi, arazi toplulaştırma projelerinin değerlendirmesinin yanında öncelikli proje alanlarını belirlemek amacıyla da kullanılabilir.

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INTRODUCTION
The land structure of farms is one of the essential factors to increase agricultural production. Adequate holding size, non-fragmented holding, and suitable parcel shape are important for a wide range of agricultural production processes. Land administration issues, readjustment, and land consolidation have received considerable critical attention to achieve sustainable farming lands. There are an increasing number of studies that recognizes

the importance of agricultural land management in European countries such as Spain (Ónega-López et al., 2010), France (Latruffe and Piet, 2014), Estonia (Jürgenson, 2016; 2017; Looga et al. 2018), Poland (Kapidura et al., 2014; Leń, 2018; Leń and Noga, 2018; Wójcik-Leń et al., 2018) mostly Central and Eastern Europe (Van Holst et al., 2018) and in the other countries (Chen et al., 2018; Sadegh et al., 2018; Djanibekov and Finger, 2018; Asiama et al., 2017).

In the history of the development of agricultural lands, fragmented and deformed parcel shapes are thought of as a critical factor in the circumstances decreasing profitability of enterprises (Gonzales et al., 2004; Ayrancı, 2004; Aslan et al., 2007; Hristov, 2009; Vijulie et al., 2012; Kirmikil and Arıcı, 2013; Colombo et al., 2017). Land fragmentation negatively impacting a range of agriculture processes such as plantation, maintenance, fertilization, irrigation, and harvest. Deformed parcel shapes have also led to a decline in agricultural production (Janus et al., 2016). Land consolidation is a significant solution to these problems within the field of land readjustment. Historically, the term "land consolidation" has been used to describe an application that provides sustainable land structure and develops road and irrigation services in rural areas (Değirmenci et al., 2017; 2018). A considerable amount of literature has been published on the effects of land consolidation. Existing researchers recognize the critical role played by land consolidation. Recently investigators examined the effects of land consolidation on climate change (Stańczuk-Gałwiaczek et. al., 2018), fuel consumption, labor and machinery (Sharifzadeh et al., 2018; Değirmenci et al., 2017; Küsek, 2014), designing of irrigation schemes (Akkaya et al., 2017), parcel size (Boztoprak, 2015) and transportation (Harasimowicz et al., 2017; Platonova et al., 2011; Platonova, 2014).

The main challenge faced by researchers is measuring the success level of land consolidation. Measuring parcel shape complexity is one of the most frequently stated problems with land fragmentation. Several attempts were made to create shape indices measuring the complexity of parcel shape. Mostly used shape indices by researchers are fractal dimension (Krummel et al., 1987), shape index (McGarigal et al., 1995), form factor (Lewis et al., 1997), areal form factor (Gonzales et al., 2004; 2007), areal perimeter ratios (Libecap and Lueck, 2009; Jiao et al., 2012), number of points (Gasiorovski and Bielecka, 2014). The calculation of these indices is based on area and perimeter. So far, very little attention has been paid to the other features of shape features such as length of sides, acute angles, reflex angles, convexity, and compactness. The study of Demetriou et al. (2013) presents a new shape index to measure shape complexity. They improved that some indices (fractal dimension, shape index, and areal form factor) but do not accurately measure shape complexity when specific parcels are investigated.

On the other hand, Bayram and Değirmenci (2018) stated that the fractal dimension, shape index, and form factor could be used to make a quick evaluation for a vast number of parcels. However, these indices don't give accurate results for a specific parcel. And more studies were conducted with shape indices calculated by perimeter and area (Huang et al., 2015; Feng and Liu 2015; Popov, 2017; Yu et al., 2018). Kwinta and Gniadek (2017) proposed another methodology with an equivalent rectangle to determine parcel shape. The experimental data are somewhat controversial, and there is no general agreement about which shape index should be used in agriculture. For this reason, the main aim of the study is to explore a new shape index measuring parcel shape complexity with simple parameters.

MATERIAL and METHODS

Cadastral data before the land consolidation project of Halitağa village located in Mersin was taken as a material (Figure 1-2). In the study, the cadastral data sustained 193 parcels covering 16.49 ha of the village. The mean parcel size was 4.4 ha. The reason for choosing cadastral data before land consolidation was to find different shapes of parcels to evaluate. The village had ordinary parcel shapes, which are common in Turkey.

Methods

Fractal dimension (FD), shape index (SI), form factor (FORM), areal form factor (AFF), area-perimeter ratio 1-2-3 (APR1, APR2, APR3), number of points (NoP), and new shape index (NSI) created are used to evaluate parcels belongs farmers in Halitağa village in Mersin/Turkey. Indices used are given in Table 1 below with formulas calculating via three parameters;

- A_i: area of i parcel,
- A_{min}: area of minimum bounding geometry of i parcel (smallest rectangle covers the parcel),

P_i: the perimeter of i parcel.

The area of minimum bounding geometry is calculated by the tool (Data Management Tool/ Features/ Minimum Bounding Geometry) of ArcMap 10.6 version of ArcGIS. The number of points calculated with the help of ArcMap 10.6. The attribute table of shapefile is opened, new field added and as a calculator code "NoP==!shape!.pointcount-1" is written on the field of calculator Python tool. The new parcel shape index is calculated with minimum bounding geometry areas is divided into a parcel area. If a parcel is a rectangle, minimum bounding geometry with rectangle should cover it, and the areas should be the same. When the difference is getting larger between two areas, the parcel's shape complexity is getting an increase. This idea demonstrates NSI as an agricultural parcel shape index.

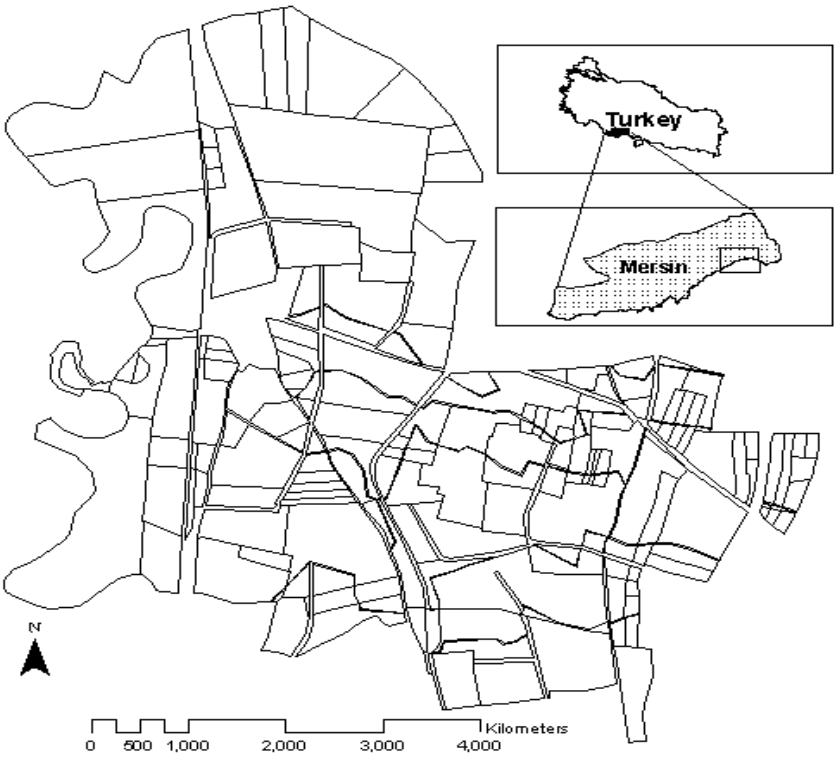


Figure 1. Location of Halitağa Village
Şekil 1. Halitağa Köyü lokasyon haritası

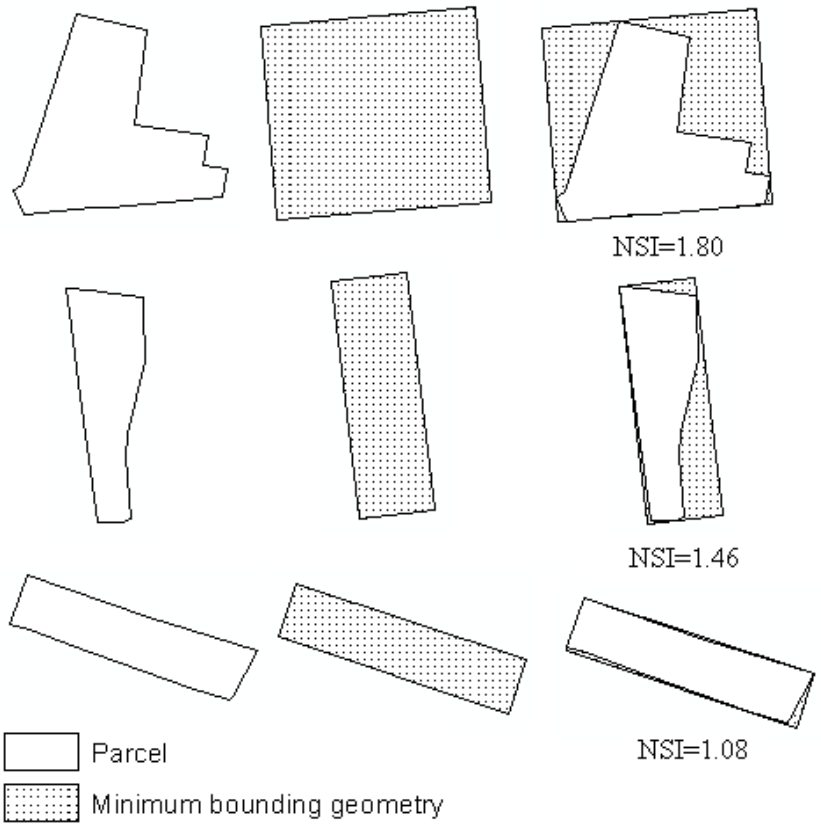


Figure 2. New shape index approach
Şekil 2. Yeni şekil indeksi yaklaşımı

Table 1. Parcel shape indices and formulas
Çizelge 1. Parsel şekil göstergeleri ve formülleri

Indices *Göstergeler*	Code *Kısaltma*	Formula *Formül*	Range *Aralık*	Optimum value *Optimum değer*	Utilization *Kaynaklar*
Fractal dimension	FD	$FD = \frac{2ln(P_i)}{ln(A_i)}$	[1,2]	1	(Krummel et al., 1987)Demetriou et al., 2013)
Shape index	SI	$SI = \frac{P_i}{2\sqrt{\pi A_i}}$	[п/2,+∞)	1	(McGarigal et al., 1995)
Form factor	FORM	$FORM = \frac{4\pi A_i}{P^2}$	(0,1)	1	(Russ, 2002; Lewis et al., 1997)
Areal form factor	AFF	$AFF = \frac{A_i}{P_i^2}$	(0,+∞)	1	(Gonzales et al., 2004;2007)
Area-perimeter ratio 1	APR1	$APR1 = \frac{P_i}{4\sqrt{A_i}}$	($\sqrt{\pi}$/2,+∞)	1	(Jiao and Liu, 2012)
Area-perimeter ratio 2	APR2	$APR2 = \frac{A_i}{P_i}$	(0,+∞)	1	(Demetriou et al., 2013)
Area-perimeter ratio 1	APR3	$APR3 = \frac{P_i}{\sqrt{A_i}}$	(0,+∞)	1	(Libecap and Lueck, 2009)
Number of points	NoP	-	[3,+∞)	4	(Gasiorowski and Bielecka, 2014)
New shape index	NSI	$NSI = \frac{A_{min}}{A_i}$	[1,+∞)	1	(Arslan et al., 2018)

RESULT and DISCUSSION

Table 2 presents the summary statistics for shape indices. What stands out in the table is the variation coefficient of the indices. Variation coefficient (VC) helps compares the standard deviation between different indices in percentages. VC of APR1, APR2, and NoP favourably changed when compared to the other indices. The values FD calculated for parcels are the values closest to each other. The purpose of the summary statistics given below is to show the range of shape indices values.

Table 2. Summary statistics for parcel shape indices
Çizelge 2. Parsel şekil indeksleri temel istatistikleri

Indices *Göstergeler*	FD	SI	FORM	AFF	APR1	APR2	APR3	NoP	NSI
Max	1.83	2.81	0.82	0.07	0.97	144.27	9.98	45	4.17
Min	1.23	1.10	0.13	0.01	0.98	1.52	3.91	3	1.02
Mean	1.33	1.41	0.56	0.04	1.65	36.50	4.99	9.48	1.46
*Var coef (%)	5.59	21.28	29.11	29.11	59.70	69.61	21.28	71.59	28.38

*Variation coefficient, FD: Fractal dimension, SI: shape index, FORM: form factor, AFF: areal form factor, APR-1-2-3: area perimeter ratio 1-2-3, NoP: number of points, NSI: new shape index

Correlation analysis illustrates the relation between shape indices, and results were given in Table 3. The correlations between NSI and the other indices are significant at the p=0.05 level except for APR2. A comparison of the findings with the study of Bayram and Değirmenci (2018) confirms the correlation between FD, SI, and FORM. Interestingly, the correlation was observed between methods, although calculation methods of NSI differ from the other indices, and it was one of the most striking observations to continue to this study.

Table 4 shows shapes which are chosen randomly to illustrate the change of indices' values of shapes. An optimum value of all shape indices is one, while NoP is expected to be 4. Values of fractal dimension, shape index, form factor, areal form factor, area perimeter ratios, and the number of parcels gave inconsistent results regarding optimum values and shape view. For example, FD was calculated as 1.41 for parcel no 240 while 1.33 for parcel no 217, which was supposed to have better shape according to value. On the other hand, the other indices show similar performance, which is not accurate except NSI. Rectangle parcels that are suitable for agriculture have values of NSI close to 1.

Table 3. Correlation among parcel shape indices including NSI
Çizelge 3. Parcel şekil indeksleri ve NSI arasındaki korelasyon

Correlation Analysis *Korelasyon*		SI	FORM	AFF	APR1	APR2	APR3	NoP	NSI
FD	cc	0.662	-0.610	-0.610	0.662	-0.673	0.662	-0.243	0.215
	p	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.003***
SI	cc		-0.932	-0.932	1.000	-0.238	1.000	0.287	0.513
	p		0.000***	0.000***	0.000***	0.001***	0.000***	0.000***	0.000***
FORM	cc			1.000	-0.932	0.209	-0.932	-0.318	-0.501
	p			0.000***	0.000***	0.004***	0.000***	0.000***	0.000***
AFF	cc				-0.932	0.209	-0.932	-0.318	-0.501
	p				0.000***	0.004***	0.000***	0.000***	0.000***
APR1	cc					-0.238	1.000	0.287	0.513
	p					0.001***	0.000***	0.000***	0.000***
APR2	cc						-0.238	0.556	-0.0258
	p						0.001***	0.000***	0.722
APR3	cc							0.287	0.513
	p							0.000***	0.000***
NoP	cc								0.400
	p								0.000***

Significance level at *** p<0.01, **p<0.05, *p<0.10 value, cc: correlation coefficient, p: p value, FD: Fractal dimension, SI: shape index, FORM: form factor, AFF: areal form factor, APR-1-2-3: area perimeter ratio 1-2-3, NoP: number of points, NSI: new shape index

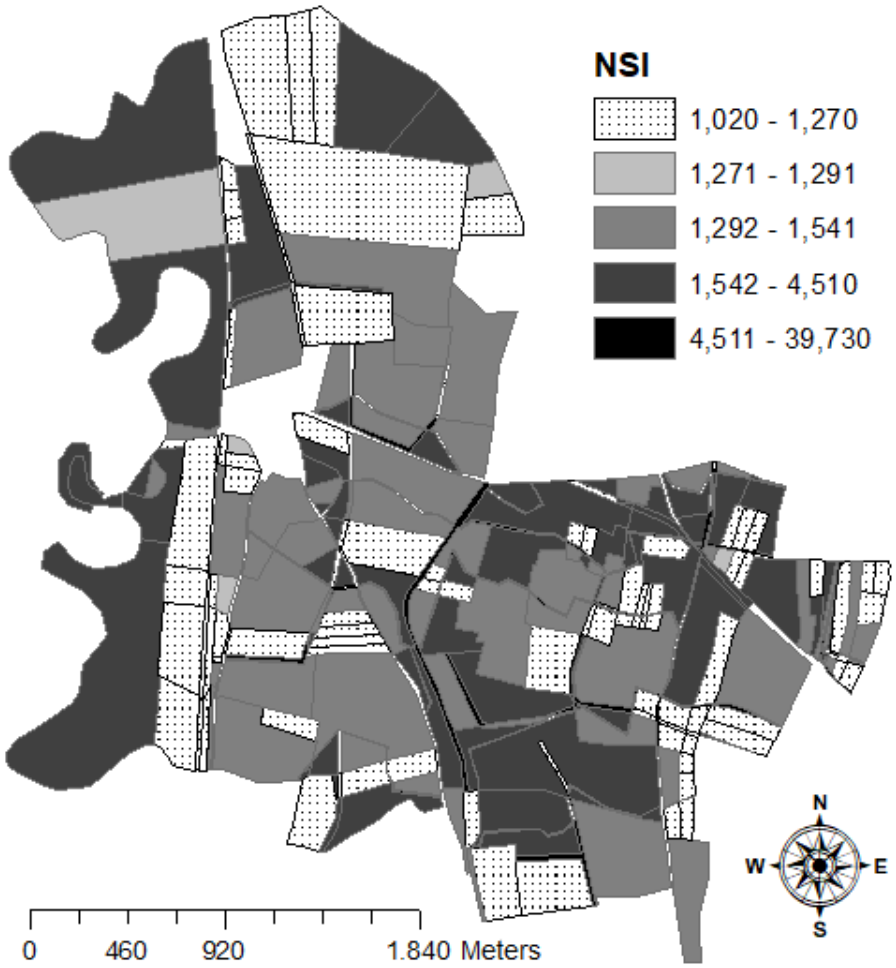
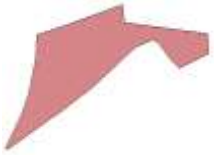


Figure 3. Spatial NSI (new shape index) classification (geometrical interval) of Halitağa village' parcels
Şekil 3. Halitağa Köyü'nün yeni şekil indeksi sınıflandırma haritası

Table 4. Some chosen parcels with values of indices
Çizelge 4. Seçilen parsellerin şekil indeks değerleri

Parcel no *Parsel numarası*	Parcel shape *Parsel şekilleri*	Value of shape indices* *Parsel şekil gösterge değerleri*		Parcel no *Parsel numarası*	Parcel shape *Parsel şekilleri*	Value of shape indices *Parsel şekil gösterge değerleri*	
240		FD: 1.41 SI: 3.15 FORM: 0.40 AFF: 0.03 APR1: 1.40	APR2: 11.63 APR3: 5.59 NoP: 4 NSI: 1.02	188		FD: 1.30 SI: 2.45 FORM: 0.67 AFF: 0.05 APR1: 1.05	APR2: 29.20 APR3: 4.33 NoP: 5 NSI: 1.29
210		FD: 1.42 SI: 2.55 FORM: 0.61 AFF: 0.05 APR1: 1.13	APR2: 8.05 APR3: 4.53 NoP: 6 NSI: 1.05	52		FD: 1.30 SI: 2.53 FORM: 0.62 AFF: 0.05 APR1: 1.12	APR2: 32.79 APR3: 4.49 NoP: 12 NSI: 1.39
63		FD: 1.38 SI: 3.59 FORM: 0.31 AFF: 0.02 APR1: 1.59	APR2: 19.28 APR3: 6.35 NoP: 4 NSI: 1.07	57		FD: 1.26 SI: 2.35 FORM: 0.73 AFF: 0.06 APR1: 1.04	APR2: 63.46 APR3: 4.16 NoP: 15 NSI: 1.46
124		FD: 1.42 SI: 2.38 FORM: 0.70 AFF: 0.06 APR1: 1.06	APR2: 7.37 APR3: 4.22 NoP: 5 NSI: 1.09	172		FD: 1.29 SI: 3.00 FORM: 0.45 AFF: 0.04 APR1: 1.33	APR2: 61.93 APR3: 5.31 NoP: 16 NSI: 1.81
138		FD: 1.30 SI: 2.46 FORM: 0.66 AFF: 0.05 APR1: 1.09	APR2: 32.50 APR3: 4.36 NoP: 7 NSI: 1.11	217		FD: 1.33 SI: 3.45 FORM: 0.34 AFF: 0.03 APR1: 1.53	APR2: 40.16 APR3: 6.12 NoP: 21 NSI: 2.15
125		FD: 1.33 SI: 2.71 FORM: 0.54 AFF: 0.04 APR1: 1.20	APR2: 23.27 APR3: 4.81 NoP: 5 NSI: 1.20	201		FD: 1.42 SI: 4.89 FORM: 0.17 AFF: 0.01 APR1: 2.17	APR2: 18.72 APR3: 8.67 NoP: 37 NSI: 2.60

*FD: Fractal dimension, SI: shape index, FORM: form factor, AFF: areal form factor, APR-1-2-3: area perimeter ratio 1-2-3, NoP: number of points, NSI: new shape index

It was tried to present the performance of the new shape index with specific examples above. Figure 3 shows the spatial distribution of all parcels classified by NSI values. Black-colored parcels with NSI values more than 2 are unshaped and are not convenient for farming. It is also apparent white-colored parcels have complexity less than shades of grey colored parcels.

Figure 4 presents that some cases that NSI may not show good performance to measure shape complexity. Some shapes with the value of NSI close to 1 may be very narrow, long rectangular plots. It is possible to solve this situation by classifying by aspect ratio. Parcels' aspect ratio is recommended to be between 1: 3 and 1: 8 in Turkey, and it may change in every

country. Some type of parcel shapes may not be measured properly with NSI. For instance, L-shaped parcels that may be defined as deformed according to NSI values even they are suitable for agricultural production. Some type of parcels that NSI is not adequate to measure their shape complexity are given in the figure.

There is limited literature on measuring shape index in rural areas. The latest and most extensive study about shape index was conducted by Demetriou et al. (2013). They suggested a shape index calculated by several parameters (length of sides, acute angles, reflex angles, boundary points, compactness, regularity). The shape index was suggested to use in land consolidation. Kwinta and Gniadek (2017) carried out another study on parcel geometry. They recommend a new methodology to measure parcel shape complexity with an equivalent rectangle of a parcel. However, the study mostly focused on land fragmentation. The current study with NSI gives simple and easy applicable methodology using just two parameters (area of the parcel and minimum bounding parcel geometry).

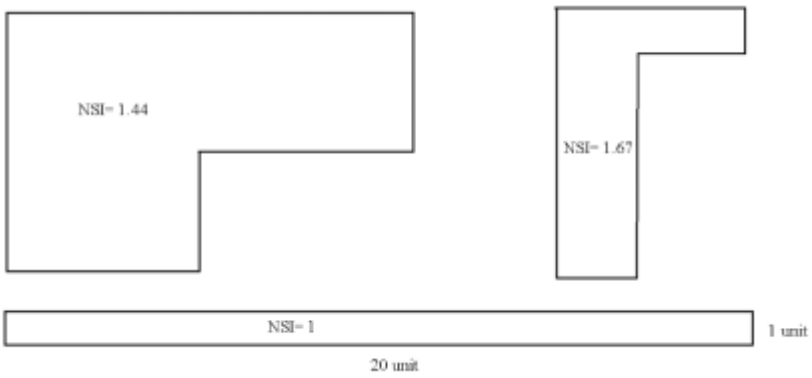


Figure 4. Some parcel shapes where it is not convenient to use the NSI
Şekil 4. Yeni şekil indeksi kullanımının elverişli olmadığı parsel şekilleri

CONCLUSION

Objective of this investigation was to present a new parcel shape index to measure shape complexity. The study revealed a significant correlation between shape indices commonly used among researchers. The findings reported here shed new light on measuring a parcel's deformation level in a rural area. Existing shape indexes are controversial and can be inadequate to meet the needs due to calculation methodology or parameter requirements. The current study suggests that a new shape index can measure parcel shape complexity in the assessment of land consolidation projects or rural areas. It can also be used to determine priority areas for land consolidation. The index sustained a low performance in measuring some rare circumstances, such as L-shaped and narrow parcels. However, such situations may not occur frequently, and could be fixed easily with aspect ratio. In upcoming studies, the new shape index should be tested in other countries to determine its universal use in rural areas.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

Contribution of the Authors as Summary

Authors declares the contribution of the authors is equal.

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