ACTA GEOGRAPHICA SLOVENICA

GEOGRAFSKI ZBORNIK

2019
59
1

ACTA GEOGRAPHICA SLOVENICA
GEOGRAFSKI ZBORNIK
59-1 • 2019

Contents

Special issue – Green creative environments

ISSN 1581-6613
9 771581 661010

ACTA GEOGRAPHICA SLOVENICA

59-1
2019

ISSN: 1581-6613
COBISS: 124775936
UDC/UDK: 91

Issued by/izdajatelj: Geografski inštitut Antona Melika ZRC SAZU
Published by/založnik: Založba ZRC
Co-published by/sozaložnik: Slovenska akademija znanosti in umetnosti

Address/Naslov: Geografski inštitut Antona Melika ZRC SAZU, Gosposka ulica 13, SI – 1000 Ljubljana, Slovenija

The papers are available on-line/prispevki so dostopni na medmrežju: http://ags.zrc-sazu.si (ISSN: 1581–8314)

Ordering/naročanje: Založba ZRC, Novi trg 2, p. p. 306, SI – 1001 Ljubljana, Slovenija; zalozba@zrc-sazu.si

Annual subscription/letna naročnina: 20 € for individuals/za posameznike, 28 € for institutions/za ustanove.
Single issue/cena posamezne številke: 12,50 € for individuals/za posameznike, 16 € for institutions/za ustanove.

Cartography/kartografija: Geografski inštitut Antona Melika ZRC SAZU
Translations/prevodi: DEKS, d. o. o.
DTP/prelom: SYNCOMP, d. o. o.
Printed by/tiskarna: Tiskarna Present, d. o. o.
Print run/naklada: 350 copies/izvodov

The journal is subsidized by the Slovenian Research Agency and is issued in the framework of the Geography of Slovenia core research programme (P6-0101)/revija izhaja s podporo Javne agencije za raziskovalno dejavnost Republike Slovenije in nastaja v okviru raziskovalnega programa Geografija Slovenije (P6-0101).

The journal is indexed also in/revija je vključena tudi v: SCIE – Science Citation Index Expanded, Scopus, JCR – Journal Citation Report/Science Edition, ERIH PLUS, GEOBASE Journals, Current geographical publications, EBSCOhost, Geoscience e-Journals, Georef, FRANCIS, SJR (SCImago Journal & Country Rank), OCLC WorldCat, Google scholar, and CrossRef.

Oblikovanje/Design by: Matjaž Vipotnik.

Front cover photography: Stone bridge over the Rak River on the outskirts of the Rakov Škocjan polje, which is otherwise known for its beautiful natural bridges (photograph: Matej Lipar).
Fotografija na naslovnici: Kamniti most čez reko Rak na obrobju kraškega polja Rakov Škocjan, ki je sicer bolj znano po čudovitih naravnih mostovih (fotografija: Matej Lipar).

Acta geographica Slovenica, 59-1, 2019, 83–101

USING THE PARCEL SHAPE INDEX TO DETERMINE ARABLE LAND DIVISION TYPES

Mojca Foški

The shapes or individual parcels are often well distinguished in the landscape.

DOI: https://doi.org/10.3986/AGS.4574
UDC: 528.44(497.4Gorenje pri Divači)
COBISS: 1.01

Using the parcel shape index to determine arable land division types

ABSTRACT: This paper presents a new index for determining the shape of land parcels. Parcel shapes are usually represented descriptively (i.e. ribbon-shaped, rectangular, irregularly shaped), which is useless for automated distinguishing between parcel shapes or for determining and distinguishing between the patterns formed by parcels. Thus, we developed a Parcel Shape Index (IOP) to describe parcel shape characteristics, and then tested it in the test area of Gorenje pri Divači to analyse selected fields – as irregular blocks, enclosures, continuous strips, and furlongs. We found that IOP allows for a differentiation of parcels according to their shape as well as parcel patterns formed due to the individual types of dividing arable land.

KEY WORDS: agricultural land, parcels, Parcel Shape Index, parcel shape, descriptive statistics, hierarchical clustering, Slovenia

Uporaba indeksa oblike parcel (IOP) za določanje tipa poljske razdelitve

POVZETEK: V prispevku predstavljamo nov indeks za določanje oblike parcel. Obliko parcel najpogosteje podajamo opisno (trakasta, pravokotna, nepravilnih oblik), kar je neuporabno za avtomatizirano razločevanje parcel po obliki in ugotavljanje ali razločevanje vzorcev, ki jih tvorijo parcele. Za opis oblikovnih značilnosti parcel smo izdelali indeks oblike parcele (IOP), ga preverili na testnem območju Gorenja pri Divači ter z njim analizirali izbrana polja v grudah, celkih, sklenjenih progah in delcih. Ugotovili smo, da IOP omogoča razlikovanje parcel po obliki, kakor tudi razlikovanje parcelnih vzorcev, ki jih tvorijo parcele v posameznem tipu poljske razdelitve.

KLJUČNE BESEDE: kmetijska zemljišča, parcele, indeks oblike parcel, oblika parcel, opisna statistika, hierarhična analiza, Slovenija

Mojca Foški
University of Ljubljana, Faculty of Civil and Geodetic Engineering
mfoski@fgg.uni-lj.si

The paper was submitted for publication on March 15th, 2016.
Uredništvo je prejelo prispevek 15. marca 2016.

1 Introduction

The shape describes the geometric form of two- or three-dimensional spatial objects (MacEachren 1985), while according to The Standard Slovene Dictionary (Slovar slovenskega knjižnega jezika 2000) it is the appearance of a phenomenon in space. The shape is one of the most important characteristics of a spatial element and is usually represented descriptively, i.e. the lake is elongated, the parcel is rectangular, the city is irregularly shaped. People perceive standard shapes (round, rectangular, triangular) similarly; however, it is difficult to represent irregular shapes in such a way that people perceive them similarly, i.e. in a unified manner. It is even more difficult to compare irregularly-shaped spatial phenomena with each other and observe their changing over time.

The process of defining shape was particularly of relevance to geographical study in the 1960s (Boyce and Clark 1964). Already in 1822, Ritter compared the area of a geographical phenomenon to that of the smallest circumscribing circle (Frolov 1975). The usefulness of knowing and determining shapes in geography was described in detail by Wentz (2000); for economic geography purposes Simons (1974) determined the shape of cities. In ecology (Eason 1992; Gutzwiller and Anderson 1992; Comber, Birnie and Hodgson 2003) topics such as the impact of territory shape in habitats on the distribution of plant and animal species are addressed; in landscape planning the impact of the shape of landscape structures on landscape appearance (hereinafter: landscape) is investigated (Krummel et al. 1987; Milne 1991; Rutledge 2003; McGarigal and Marks 1995; McGarigal 2013, 2015). The distinguishing between various shapes of spatial phenomena is relevant in remote sensing (Zhang et al. 2006). The shape of a phenomenon is significant in computer sciences (Sagiv, Reps and Wilhelm 2003) both in terms of visualisation or interpretation, i.e. computer geometry. The detection and distinguishing between shapes attracted the interest of psychology (Landau, Smith and Jones 1988).

Land parcels are an important spatial phenomenon. They reflect the diversity of natural conditions and human adaptation to the landscape (Kladnik 1999). In agricultural, forest, and built-up areas, parcels are distinguished by shape. Based on the parcel shape and the parcel pattern we can draw conclusions about natural geographic features of space, such as relief shapes, gradient, and altitude (Fialkowski and Bitner 2008). Accordingly, Ilešič (1950) considered parcel shape to be the key factor for field pattern classification. A field is a continuous area of arable land in a settlement (Slovar slovenskega knjižnega jezika 2000).

The shape of field parcels is the consequence of settlement, land cultivation methods (plough, ploughshare), and the agricultural regime (Ilešič 1950; Blaznik 1970). The changing of parcel shapes at the contact of agricultural and built-up spaces points to the pressures of urban growth (Irwin and Bockstael 2004). The shape of parcels is important for agriculture as it influences the economic viability of machining operations (Coelho, Pinto and Silva 2001; Touriño et al. 2003; Gonzalez, Alvarez and Crecente 2004; Gonzales, Marey and Alvarez 2007; Aslan, Gundogdu and Arici 2007; Amiama, Bueno and Alvarez 2008; Libecap and Lueck 2009; Zondonadi et al. 2013). Bielecka and Gasiorowski (2014) drew conclusions about land fragmentation in relation to parcel shapes. Oksanen (2013) studied land parcel shapes in Finland in relation to the automation of agricultural processes, and Demetriou, Stellwell and See (2012), Demetriou, See and Stellwell (2013), and Demetriou (2013, 2014) studied parcel shapes when developing an application for land consolidation planning in Cyprus.

In studying the parcel shape it is essential that the shape is changed into a numerical value – index of shape (Wentz 2000). This way we can compare and observe the changing of parcel shapes and parcel patterns formed by the parcels.

Shape indices fall into two classes: indices with one variable (single-parameter indices), which give a value for only one property, and indices with several variables (multiple parameter indices), which describe the characteristics of a shape with the use of more complex mathematical functions. Shape is usually too complex to be described using a single parameter (Ehler, Cowen and Mackey 1996; Wentz 2000), or rather several independent single-parameter indices are needed to describe a complex shape (Oksanen 2013; Demetriou 2014), and these indices should meet certain criteria (Lee and Sallee 1970; Wentz 1997; Wentz 2000; Demetriou, See and Stillwell 2013):

- different numerical values must be ascribed to different shapes,
- similar shapes must have similar values,
- indices must be useful both with concave and convex phenomena,
- indices must identify holes in polygons,

- indices must be independent of the size of phenomena,
- indices must be independent of movements, rotations, and scale,
- the input data must be prepared simply,
- indices must be easy to understand and the results easy to interpret,
- indices must have a value range (as a rule, the value increases from 0 to 1) and it must be determined which shape has the value of 1, and
- the values obtained must reflect human perception of a spatial phenomenon.

In terms of the shape feature that we want to describe, we distinguish between indices describing the perimeter, plane characteristics, and geometry (Zhang and Lu 2004; Chaudhuri 2013).

The basic hypothesis is that using a numerical value – the shape index – we describe the shape of a spatial phenomenon, such as a parcel. Accordingly, we developed a Parcel Shape Index (IOP). The study was narrowed down to those parcels that are in fields. Ilešič (1950) proposed a system of dividing arable land based, in fact, on parcel shape; he divided Slovenian fields into basic types (irregular blocks, furlongs, continuous strips, and enclosures) and transitional types (transitional shapes between irregular blocks and furlongs, division into irregular or block furlongs, combination of continuous strips and regular furlongs). Accordingly, parcels in areas with blocks and enclosures have distinctly irregular shapes, while parcels in areas with furlongs are generally rectangular, with a side ratio up to 1 : 10, while continuous strips are distinctly belt-like or rectangular with a side ratio even up to 1 : 100. The index's adequacy was checked against the basic arable land types, while their applicability was checked in the classification of various types of arable and division.

2 Methods

The method consists of four steps:
- IOP determination,
- testing of IOP on a sample case of the field at Gorenje pri Divači (hereinafter: Gorenje),
- determination of IOP for parcels of basic types of arable land division and statistical processing of IOP values, and
- hierarchical clustering of fields.

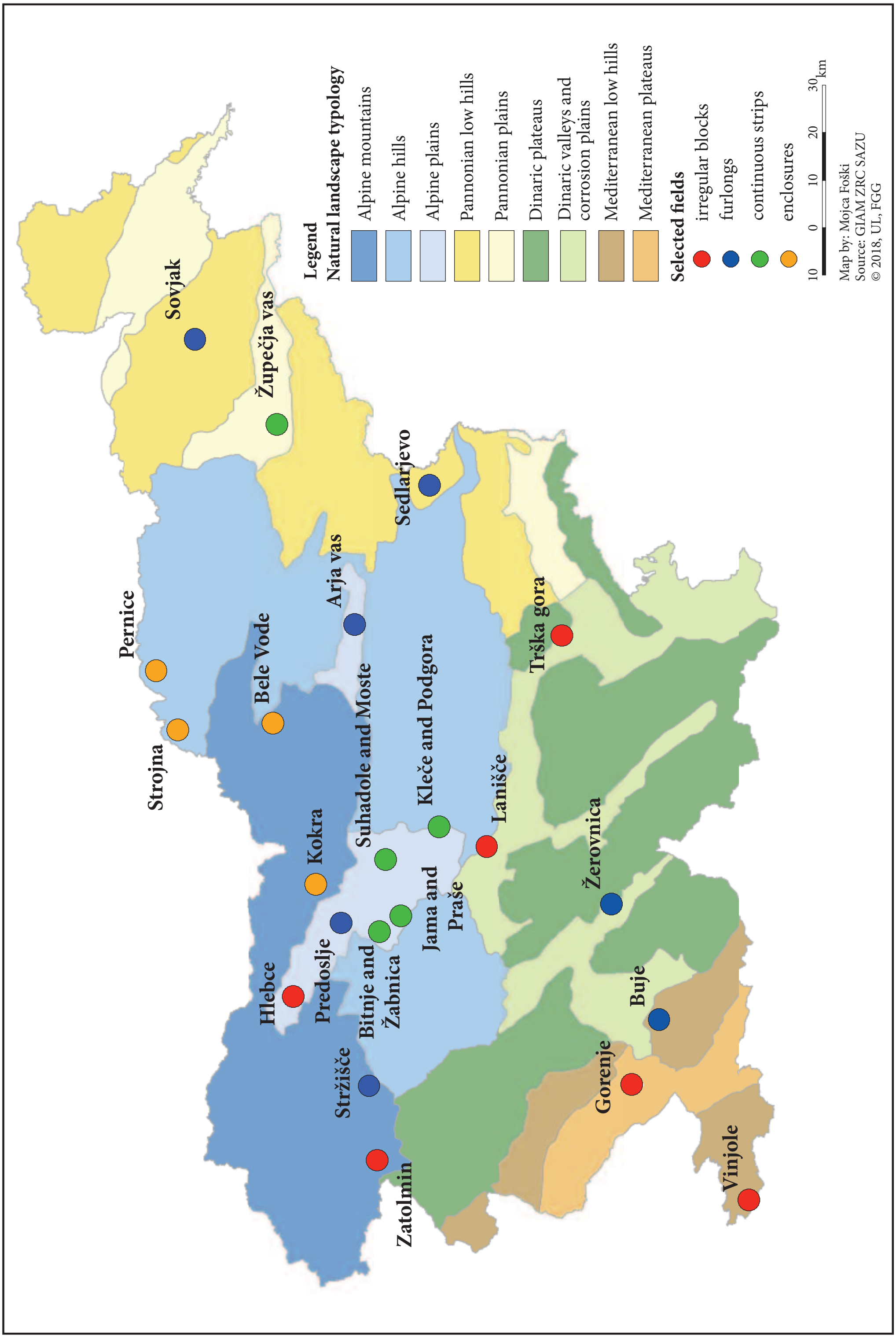
IOP determination was based on the literature and characteristics of arable land parcel shapes in Slovenia, using several single-parameter indices: indices for perimeter, plane, and parcel geometry description. The indices were standardised using a value function (Beinat 1997; Malczewski 1999, 2011; Sharifi, Herwijnen and Toorn 2004). A rectangular parcel with a 1 : 2 side ratio was selected as the reference parcel shape. This side ratio is the first whole side ratio value that distinguishes a rectangle from a square.

We selected 22 test fields among fields as irregular blocks, furlongs, continuous strips, and enclosures (Table 2). The areas of these fields were determined using Ilešič's original classification (1950) (e.g. Arja vas, Predoslje, Kokra, Bitnje and Žabnica, Zatolmin) and/or the data from the Franciscan Cadastre (Internet 1), digital orthophotos, and land cadastre data acquired through the Surveying and Mapping Authority of the Republic of Slovenia in 2015, whereby various landscape types were considered (Perko, Hrvatin and Ciglič 2015; Figure 1). The field divisions were based on geographical dividing lines (to the stream, road, forest, and village) or the cadastral municipality boundary. The fields were named after the closest settlement (e.g. Arja vas) or a geographical area (e.g. Trška gora).

The data from the land cadastre depiction, based on which the IOP was calculated, were organised by excluding all parcels designated as built-up or related land or body of water according to the Register of Existing Agricultural and Forest Land Use (Internet 2). In cases of agricultural buildings (e.g. a granary or a hayrack) with land under the building (parcel), this land was aggregated with the neighbouring parcel.

IOP was calculated for 13,725 land parcels in all test fields. Indicators of descriptive statistics were calculated for all test fields (Table 2): number of parcels in a field (N), minimum value (MIN), maximum value (MAX), average value (AVG), median (Me), mode (Mo), standard deviation (σ), asymmetry coefficient (y_1), and coefficient of kurtosis (y_2). The obtained IOP values were shown on histograms (10 classes, class width 0.1). Statistical values were demonstrated using a box-and-whiskers plot (Figure 8).

Figure 1: Distribution of test fields by various landscape types of Slovenia. ➤


Legend
Natural landscape typology
Alpine mountains
Alpine hills
Alpine plains
Pannonian low hills
Pannonian plains
Dinaric plateaus
Dinaric valleys and corrosion plains
Mediterranean low hills
Mediterranean plateaus
Selected fields
irregular blocks
furlongs
continuous strips
enclosures
10 0 10 20 30 km
Map by: Mojca Foški
Source: GIAM ZRC SAZU
© 2018, UL, FGG
Sovjak
Župečja vas
Sedlarjevo
Arja vas
Pernice
Bele Vode
Strojna
Trška gora
Suhadole and Moste
Kleče and Podgora
Kokra
Lanišče
Žerovnica
Jama and Praše
Hlebce
Predoslje
Bitnje and Žabnica
Buje
Stržišče
Gorenje
Zatolmin
Vinjole

In the last step, we classified the fields into groups using Ward's hierarchical clustering method (Breskvar Žaucer and Košmelj 2006; Bastič 2006; Figure 9). Indicators of descriptive statistics were used for the cluster analysis, and Euclidian distance was used as cluster criterion.

Statistical data processing and depiction using histograms and box-and-whiskers plots demonstrated whether IOP reflected the parcel shapes concerned and whether the parcel shape was, in fact, characteristic for the various types of arable land division according to Ilešič.

The analysis was based on the data from the land cadastre depiction by the Surveying and Mapping Authority of the Republic in Slovenia, acquired in 2015, in *ArcGis 10.3*; *Microsoft Excel* 2010 and *IBM SPSS* 23 software were used for calculations and statistical processing.

2.1 IOP determination and its verification on the sample case of Gorenje

2.1.1 Indices for describing plane characteristics: compactness index /I_{kom}

In this group we typically use indices describing the ratio between area (A) and perimeter (P) (Santiago and Bribiesca 2009; Li, Goodchild and Church 2013), which are often referred to as compactness indices.

Besides the initially produced factor P/A proposed by Ritter (Frolov 1975) other indices are also used, e.g. indices of ratios $4A/P^2$ (Miller 1953), A/P^2 (Gonzalez, Alvarez and Crecente 2004), $P/2\sqrt{\pi A}$ (Aslan, Gundogdu and Arici 2007) and $\sqrt{A}/0.282 \cdot P$ (Chan and So 2006). The most frequently used compactness index was developed by Osserman (1978) and is also used here; it is described by the equation

$$I'_{kom} = \frac{4\pi A}{P^2}$$

The equation's advantage is that π shifts the value area of the initial indices in the range of 0 to 1. The value of 1 describes the most compact phenomenon – the circle. Wentz (2000) found that this index is not the most appropriate for very diversified phenomena, but it is insensitive to scale, displacement, and rotation variations, independent of the size of the phenomenon, and applicable to both raster and vector data (Sonka, Hlavac and Boyle 1993; Santiago and Bribiesca 2009; Oksanen 2013; Bielecka and Gasiorowski 2014).

Indices from this group also have some shortcomings. In particular, they do not reflect the characteristics of a shape, but rather compactness according to a comparable geometric shape, i.e. a circle in our case (MacEachren 1985; Angel, Parent and Civco 2010). They cannot be used to measure features such as the presence of holes, expansion, or fragmentation. Parcel shapes should not be described using only these indices as they only take into account the area and perimeter characteristics (Demetriou, See and Stillwell 2013).

I'_{kom} was standardised to determine parcel compactness, because the parcels were, of course, not round. In determining the value function sixth degree polynomial was used (Demetriou 2014), while the function was determined so that for the parcels with a side ratio (of 1 : 2) whose I'_{kom} equals 0.70, the value $I_{kom} = 0.99$ was assumed, while for the parcels with I'_{kom} less than 0.33 (side ratio 1 : 8) the value of $I_{kom} = 0$ was assumed (Figures 2 and 3). Other values were determined using the value function (Figure 2):

$$I_{kom} = V(I'_{kom}) = -372.614(I'_{kom})_i^6 + 1319.19(I'_{kom})_i^5 - 1820.87(I'_{kom})_i^4 + 1$$

$$1227.22(I'_{kom})_i^3 - 414.436(I'_{kom})_i^2 + 66.207(I'_{kom})_i - 3.908$$

The value function is determined so that all parcels with a side ratio up to 1 : 4 get a higher compactness index, which allows for differentiation from longer parcels (with side ratio over 1 : 8) (Figure 3). The compactness index was calculated for the test case of Gorenje and graphically shown (Figure 5 A) in 10 equal classes with a degree of 0.1.

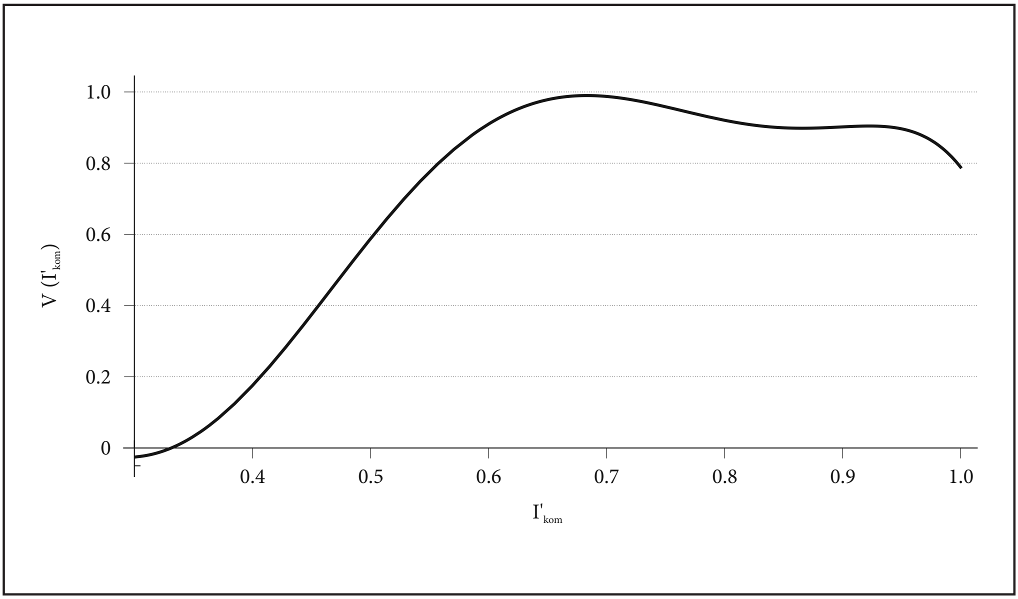


Figure 2: Value function for determining I_{kom}

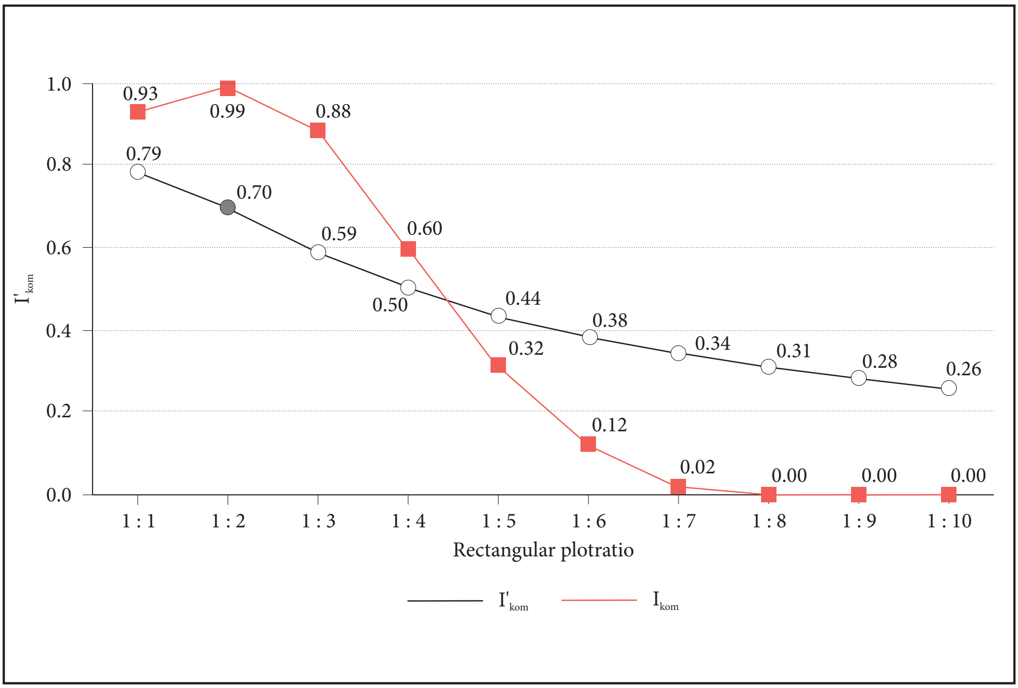


Figure 3: Ratio between index I'_{kom} and its standardised value I_{kom}. I_{kom} has the maximum value for parcels with a side ratio of 1 : 2; while it equals 0 with parcels with a side ratio above 1 : 8.

2.1.2 Indices of the special characteristics of the geometry of the phenomenon: Perforation Index/I_{luk}

Some characteristics of phenomena cannot be described using the compactness index, so we used Wentz's perforation index (2000), by subtracting it from 1:

$$I_{luk} = 1 - \frac{B_i}{A_i}$$

where B_i is the total area of all holes in object i and A_i is the total area of object i.

The parcels without holes were ascribed the maximum value of 1, while the value of 0 could not be reached. In the Gorenje test area (Figure 5 B) we only showed parcels with an I_{luk} other than 1, and due to reasons of clarity the parcels with the perforation index of 1 were not coloured.

2.1.3 Indices for perimeter description

Index of Edge Roughness/I_{naz}

These indices describe the roughness of the edge of a geographical object. On the basis of the ratio between an object and its corresponding convex hull, they are most frequently used to describe the perimeter characteristics. The amplitude index $((P - P_k) / P)$ considers the ratio between the perimeter of an object (P) and the perimeter of the convex hull (P_k), while the convexity index $((A_k - A) / A_k)$ considers the ratio between the area of object A and the area of the convex hull (A_k) (Brinkhoff et al. 1998). Chan in So (2006) used the comparable surface area ratio, Iivarinen et al. (1997), Angel, Parent and Civco (2010), and Zondonali et al. (2013) used the ratio between the perimeter of object P and its convex polygon P_k, which was also used here; the edge roughness index was written as:

$$I_{naz} = \frac{P}{P_k}$$

The index has the value of 1 if the parcel is convex. With the value nearing 0, diameter roughness increases. The value of 1 is ascribed to all convex parcels, while the value of 0 is unattainable. The calculation of I_{naz} in the test field of Gorenje is shown in ten equal classes with a rate of 0.1 (Figure 5 C), red shades indicating jagged-edged parcels, while the darkness of the blue indicates smoother edges.

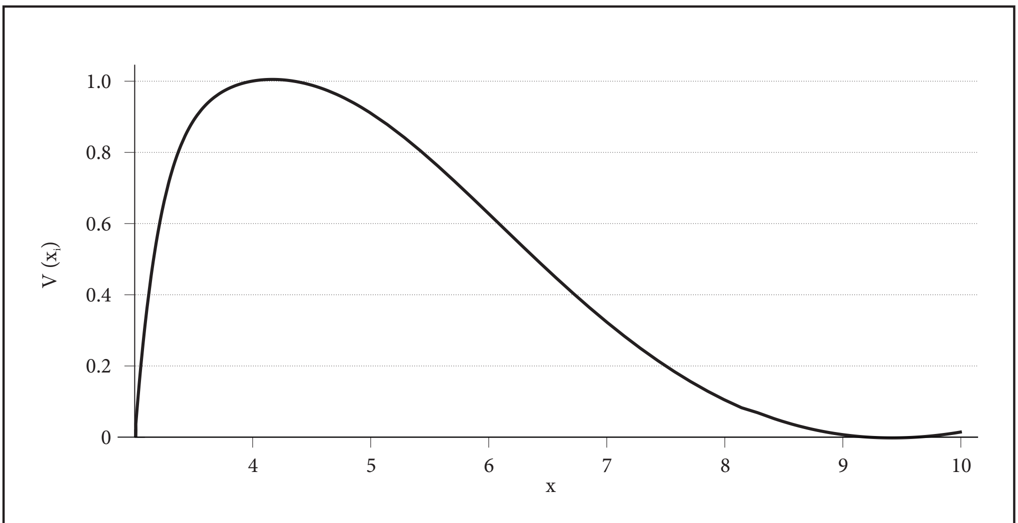
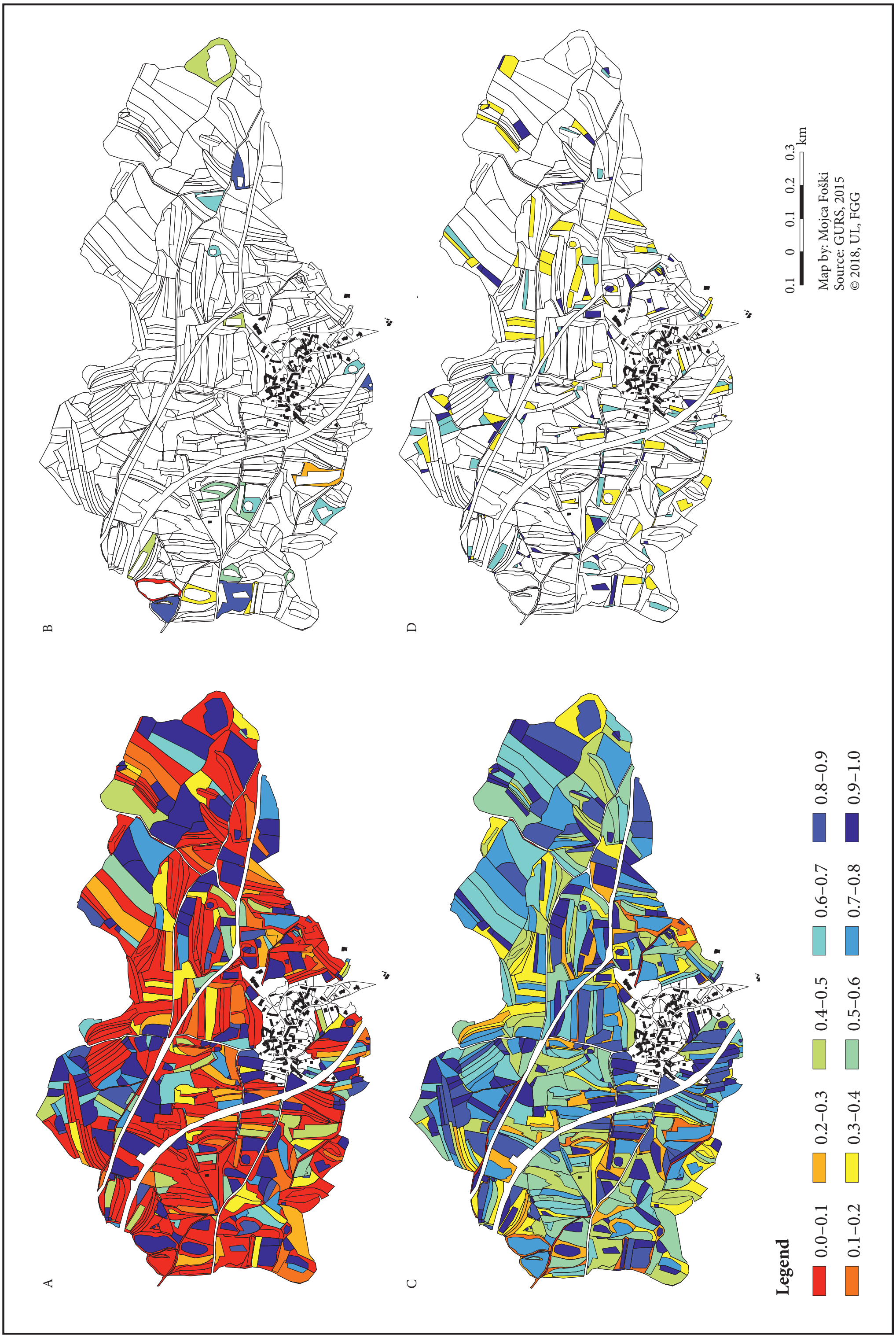


Figure 4: Value function for standardising the number of vertices (I_{ogl}).

Figure 5: Compactness Index (A), Perforation Index (B), Index of Vertices (C), and Edge Roughness Index (D) for Gorenje. ➤


A
B
C
D
Legend
0.0–0.1
0.1–0.2
0.2–0.3
0.3–0.4
0.4–0.5
0.5–0.6
0.6–0.7
0.7–0.8
0.8–0.9
0.9–1.0
0.1 0 0.1 0.2 0.3 km
Map by: Mojca Foški
Source: GURS, 2015
© 2018, UL, FGG

Index of Vertices (I_{ogl})
Indices of the number of perimeter vertices are frequently used to describe the characteristics of a parcel perimeter (Brinkhoff et al. 1998; Demetriou, Stellwell and See 2012). The reference parcel has four vertices; by increasing the number of vertices, the deviation from a rectangle increases. Parcels with three vertices also considerably deviate from a rectangle. The standardisation of the number of vertices in a value range from 0 to 1 was made using a value function after Demetriou (2014) (Figure 4), where x_i is the number of vertices:

$$I_{ogl}=V(x_i)=14.45-\frac{407.76}{x_i}+\frac{4280.97}{x_i^2}-\frac{20959.323}{x_i^3}+\frac{49141.25}{x_i^4}-\frac{45677.80}{x_i^5}$$

All parcels with more than 10 vertices were ascribed the value of 0. The index of vertices was calculated for Gorenje. We showed the parcels with I_{ogl} other than 0 (Figure 5 D).

2.2 Parcel Shape Index (IOP)

The parcel shape index can be written using the equation:

$$IOP=\frac{\sum_{j=1}^{n} I_j w_j}{n}$$

where I_j is one of the aforementioned indices and W_j is the index weight. If the indices are equally weighted (with a value of 1), then for each parcel i IOP is calculated as the arithmetic mean of four single-parameter indices:

$$IOP=\frac{I_{kom}+I_{naz}+I_{luk}+I_{ogl}}{4}$$

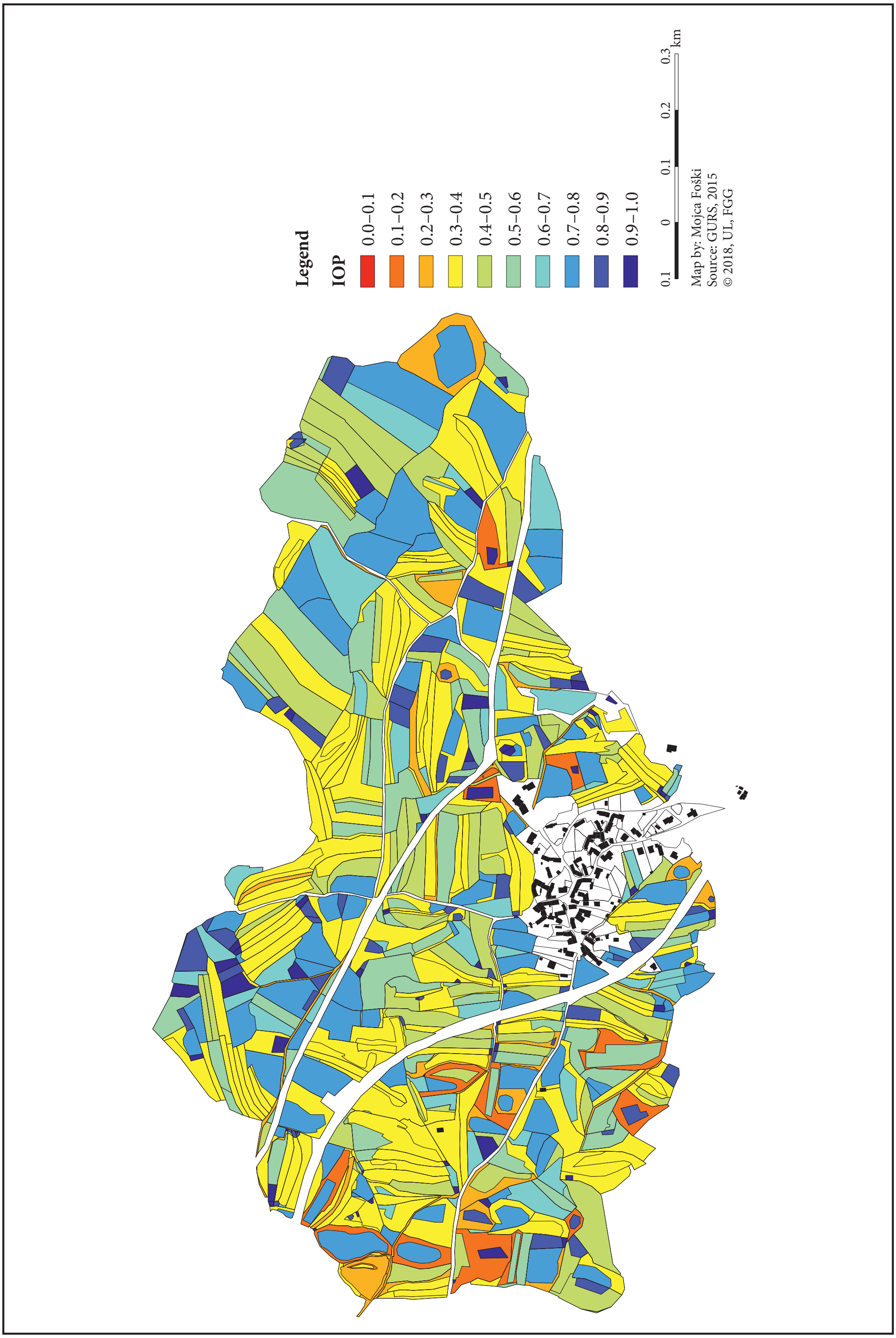
The Pearson correlation coefficient between the indices of compactness, roughness, perforation, and vertices for the 722 parcels in Gorenje is low (Table 1), indicating the indices' mutual independence, which satisfies one of the basic criteria for combining single-parameter indices.

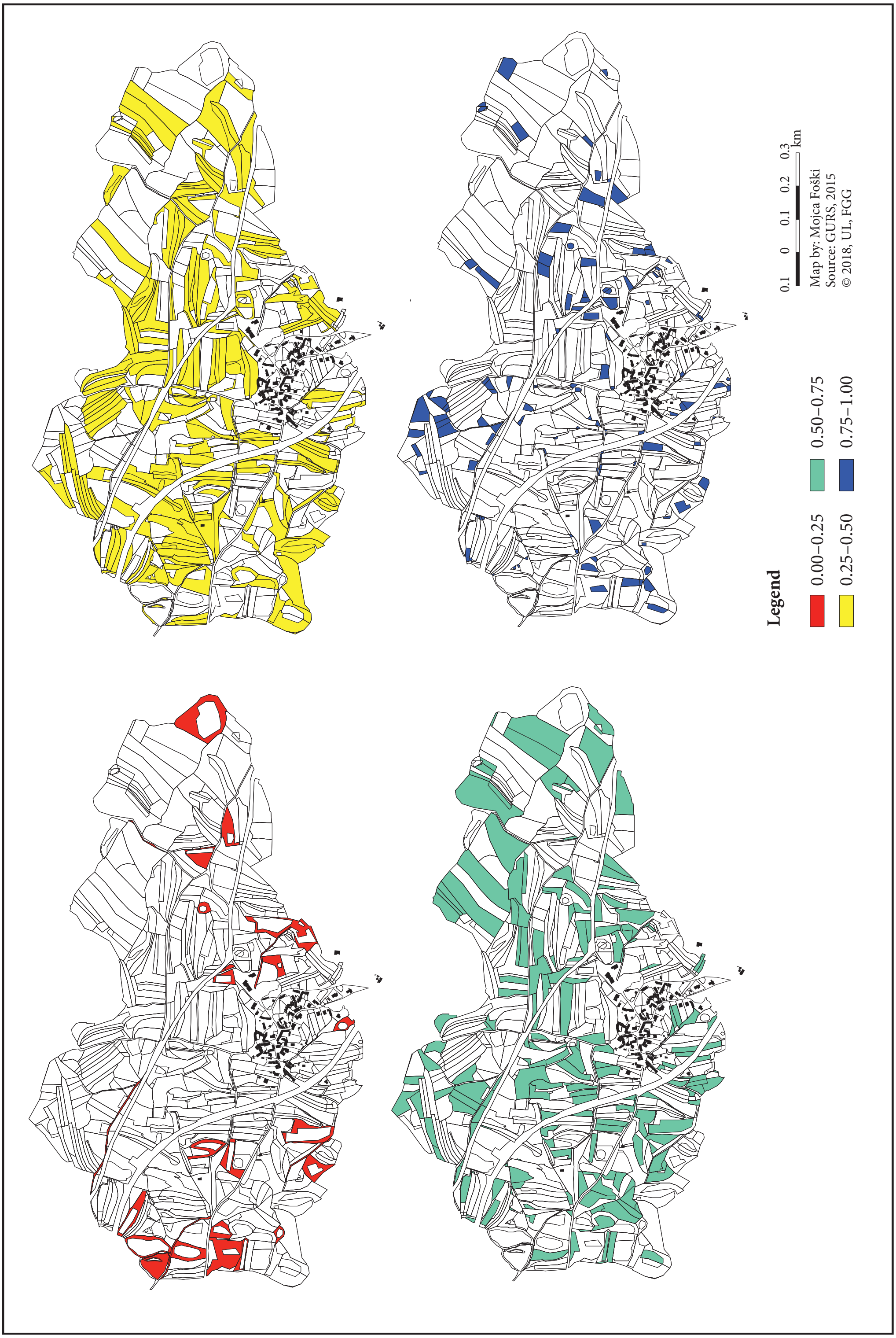
Table 1: The Pearson correlation coefficient between the indices for Gorenje.

Correlation coefficient	I_{kom}	I_{naz}	I_{ogl}	I_{luk}
I_{kom}		0.24	–0.19	0.045
I_{naz}			–0.30	0.20
I_{ogl}				–0.25
I_{luk}				

IOP is in the range of 0 to 1. Given the value functions in the standardisation procedure, the value of 1 is ascribed to the parcels with a side ratio of 1 : 2, without holes, with four vertices, and with a completely smooth edge. The depiction of IOP in the four value classes (Figure 6 below) shows that the parcels with distinctly irregular shapes (jaggedness, holes) are in the lowest class, while rectangular parcels with a low side ratio are in the highest class. The parcels within a class are visually similar (Figure 6); IOP is applicable both in convex and concave parcels, independent of parcel size, insensitive to scale and rotation variations, and easy to calculate, and thus meets all the criteria for determining indices.

Figure 6: IOP in 10 classes with a rate of 0.1 (page 93) and in four classes with a rate of 0.25 (page 94) for Gorenje. ➤ p. 93–94


Legend
IOP
0.0–0.1
0.1–0.2
0.2–0.3
0.3–0.4
0.4–0.5
0.5–0.6
0.6–0.7
0.7–0.8
0.8–0.9
0.9–1.0
0.1 0 0.1 0.2 0.3 km
Map by: Mojca Foški
Source: GURS, 2015
© 2018, UL, FGG


Legend
0.00–0.25
0.25–0.50
0.50–0.75
0.75–1.00
0.1 0 0.1 0.2 0.3 km
Map by: Mojca Foški
Source: GURS, 2015
© 2018, UL, FGG

3 IOP results in the selected test cases

IOP was calculated for 22 selected fields (Table 2, Figure 1) in irregular blocks, furlongs, continuous strips, and enclosures. For each test field we calculated the indicators of descriptive statistics for IOP, while the distribution of IOP values was shown on histograms (Table 2) and box-and-whiskers plots (Figure 7). The statistical values were compared and it was determined whether IOP reflected the actual characteristics of a parcel shape and if the parcel shape was, in fact, characteristic for the various types of arable land division according to Ilešič. Using the hierarchical clustering method, the fields were clustered into groups, and the results were depicted using a dendrogram (Figure 8).

We used descriptive statistics, histograms (Table 2), a comparison of box-and-whiskers plots (Figure 7), and depiction of hierarchical clustering (Figure 8) to try to establish similarities between parcel shapes and the patterns formed by the parcels. The IOP distribution in fields as furlongs and fields as irregular blocks is very similar (with the exceptions of Vinjole and Trška gora), where two modes are observed (0.35 and 0.75). This was also confirmed by the classification into the same group using the hierarchical clustering method.

The parcel shapes in areas of continuous strips also show great similarity. The mode class is 0.3-0.4 or 0.4-0.5. The narrowest is the second quartile (maximum densification of parcels), while the asymmetry coefficient (y_2) is positive in all test fields (asymmetry to the right). The fields are classified as continuous strips, except for Kleče and Podgora. The fields of Buje and Žerovnica also belong to this group, even though Ilešič classified them as furlongs (belt-like furlongs), while their parcel shape was distinctly belt-like, which is characteristic for parcels in continuous strips.

The analysed fields as furlongs can be classified into two groups (Figure 8). The first group is Arja vas, Predoslje, Kleče, and Podgora, and the second group is Trška gora, Stržišče, Sovjak, Sedlarjevo, and Vinjole. The groups are combined in the next aggregation. Ilešič classified Vinjole and Trška gora as winegrowing blocks, while in terms of parcel shape (rectangular with a small side ratio) the fields are comparable to furlongs.

Table 2: Descriptive statistics and IOP histograms for all fields considered.

		IOP									
		N	*AVG*	*MIN*	*MAX*	*Me*	*Mo*	*σ*	γ_1	γ_2	*histogram*
IRREGULAR BLOCKS	Gorenje	722	0.60	0.09	0.98	0.49	0.36	0.22	0.38	-1.16	
	Zatolmin	517	0.56	0.12	0.98	0.58	0.35; 0.74	0.24	-0.02	-1.29	
	Vinjole	422	0.69	0.13	0.98	0.76	0.75	0.19	-0.86	-0.05	
	Lanišče	272	0.54	0.20	0.97	0.52	0.36	0.19	0.31	-1.11	
	Trška gora	388	0.66	0.24	0.98	0.72	0.75	0.19	-0.43	-1.00	
	Hlebce	622	0.56	0.12	0.98	0.58	0.35	0.24	-0.02	-1.29	
FURLONGS	Žerovnica	1247	0.47	0.18	0.98	0.42	0.37	0.13	1.25	2.17	
	Buje	332	0.52	0.14	0.98	0.42	0.38	0.23	0.72	-0.91	
	Predoslje	389	0.65	0.24	0.98	0.66	0.75	0.19	-0.05	-1.11	
	Arja vas	761	0.61	0.21	0.98	0.58	0.42	0.21	0.31	-1.27	
	Stržišče	282	0.66	0.19	0.98	0.73	0.75	0.22	-0.44	-1.03	
	Sovjak	1009	0.70	0.18	0.98	0.77	0.71	0.20	-0.53	-0.79	
	Sedlarjevo	206	0.67	0.24	0.98	0.72	0.75	0.19	-0.47	-0.76	
CONTINUOUS STRIPS	Jama and Praše	338	0.51	0.21	0.98	0.44	0.37	0.19	0.86	-0.20	
	Kleče and Podgora	368	0.60	0.31	0.98	0.53	0.41	0.22	0.51	-1.24	
	Suhadole and Moste	705	0.52	0.22	0.98	0.41	0.37	0.21	1.08	-0.30	
	Bitnje and Žabnica	2861	0.52	0.11	0.98	0.46	0.44	0.19	0.59	-0.44	
	Župečja vas	624	0.51	0.19	0.98	0.44	0.38	0.18	0.99	0.09	
ENCLOSURES	Pernice	222	0.55	0.10	0.98	0.55	0.35; 074	0.22	0.00	-1.24	
	Bele vode	1010	0.55	0.07	0.98	0.52	0.35; 0.75	0.23	0.16	-1.28	
	Kokra	212	0.59	0.10	0.97	0.59	0.35; 0.75	0.23	0,12	-1.24	
	Strojna	216	0.52	0.06	0.98	0.49	0.32; 0.75	0.24	0.24	-1.26	

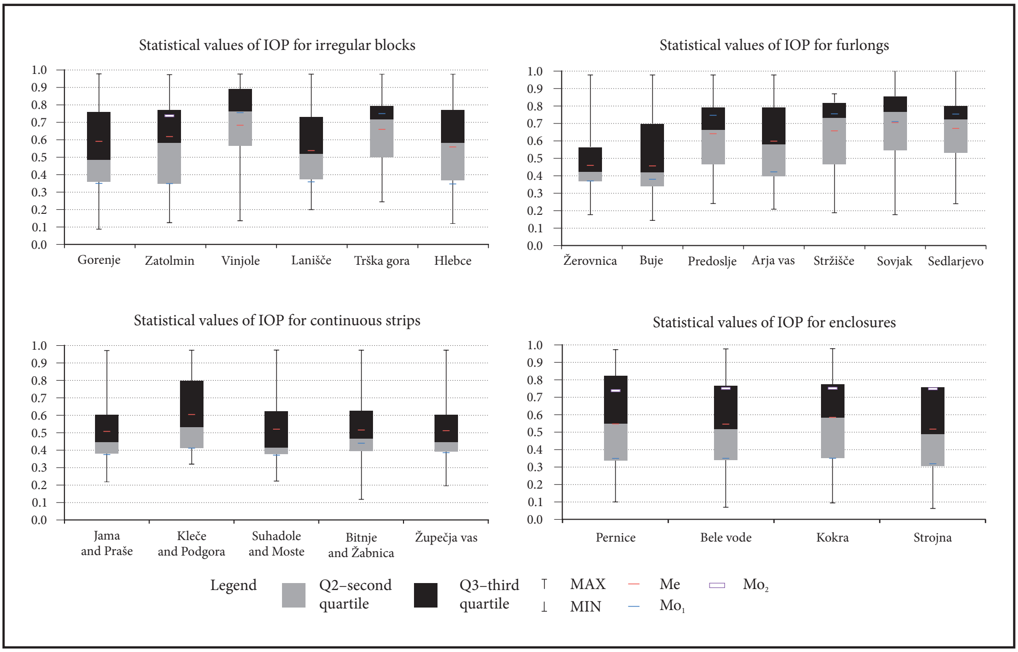


Figure 7: Box-and-whiskers plots for IOPs for all selected test fields shown on the same graph for fields as irregular blocks, furlongs, continuous strips, and enclosures.

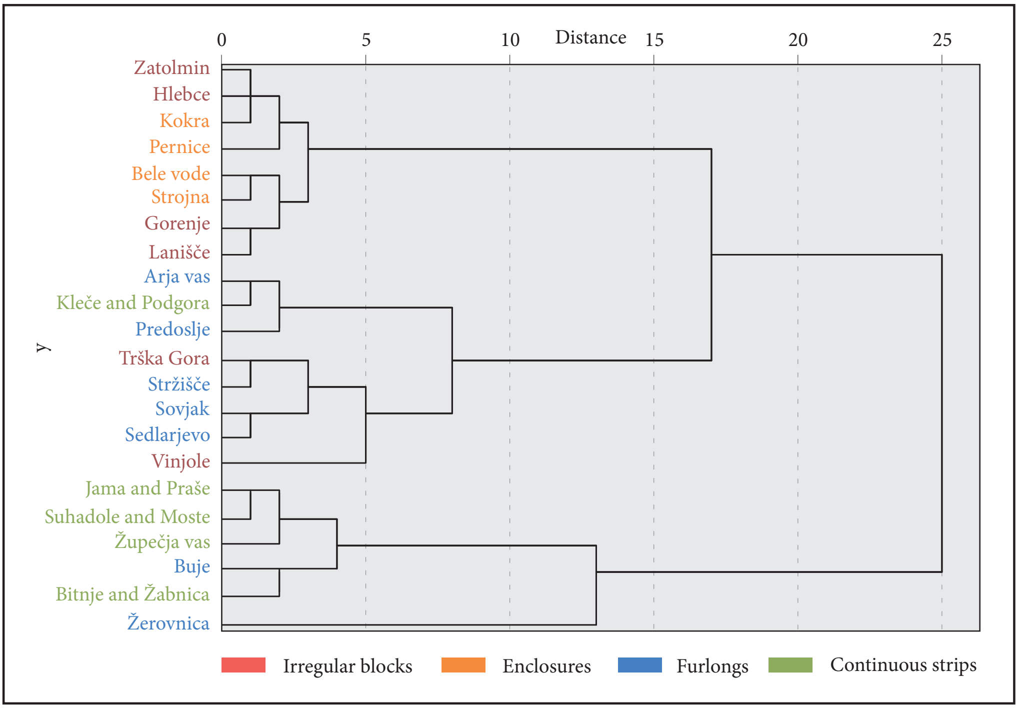


Figure 8: Dendrogram of the hierarchical clustering of fields into groups using Ward's method.

4 Discussion

IOP is the arithmetic mean of four mutually independent single-parameter indices that also consider the holes in parcels, which was not found with other authors (Tourino et al. 2003; Aslan, Gundogdu and Arici 2007; Amiama, Bueno and Alvarez 2008; Zondonadi et al. 2013; Demetriou 2014; Bielecka and Gasiorowski 2014). In Slovenia, parcels with holes are the consequence of natural geographic features and specifics of the Franciscan Cadastre, where for each type of land use a separate parcel was determined, even though neighbouring parcels belonged to the same proprietor (Ferlan 2005). In cases where a field was in the middle of a meadow or a at the bottom of a sink hole there are holes in parcels preserved to the present day. In Slovenia, holes are present mostly in irregular blocks and enclosures, and exceptionally also in areas of continuous strips (Bitnje), so we feel that this feature should be taken into account in IOP. A hole in a parcel decreases IOP, while the proportion of parcels with lower IOP increases in the pattern, which is characteristic for irregular blocks and enclosures.

Some authors determined parcel shape only by using the compactness index (Bielecka and Gasiorowski 2014; Oksanen 2013; Zondonadi et al. 2013), which has several shortcomings (Demetriou, See, and Stillwell 2013). The values were standardised to a reference parcel shape only by Demetriou (2014). This standardisation to a reference parcel shape is necessary, even though the determination of a reference parcel varies depending on the study purpose. Using this standardisation we delineated the rectangles with a more favourable side ratio (up to 1 : 8) from distinctly elongated rectangles (belts).

The IOP calculation for the Gorenje test area demonstrated (Figure 6) that parcels in the individual classes are visually similar. But then over a larger sample (all 22 fields, 13,725 parcels) it became evident that the IOP value for long and narrow parcels in the area of continuous strips was similar to the values of irregular parcels in the areas of irregular blocks, i.e. between 0.30 and 0.45 (Figure 10). Future work should include an index to improve the determination of the characteristics of very long and narrow parcels (e.g. ratio between the shortest and the longest diagonal of a parcel).

Despite this deficiency, the statistical data analysis of various types of arable land division (Figure 7) and hierarchical clustering (Figure 8) demonstrated that IOP allows for distinguishing between fields as continuous strips from other types of fields mostly because these two types of parcel shapes usually do not occur together. In Slovenia, continuous strips are more frequent in plains, in particular in Sorško polje (Ilešič 1950), and are a reflection of systematic settlement (Blaznik 1970), while irregular blocks are characteristic of a more diverse terrain and are classified as the oldest type of arable field division (Blaznik 1970).

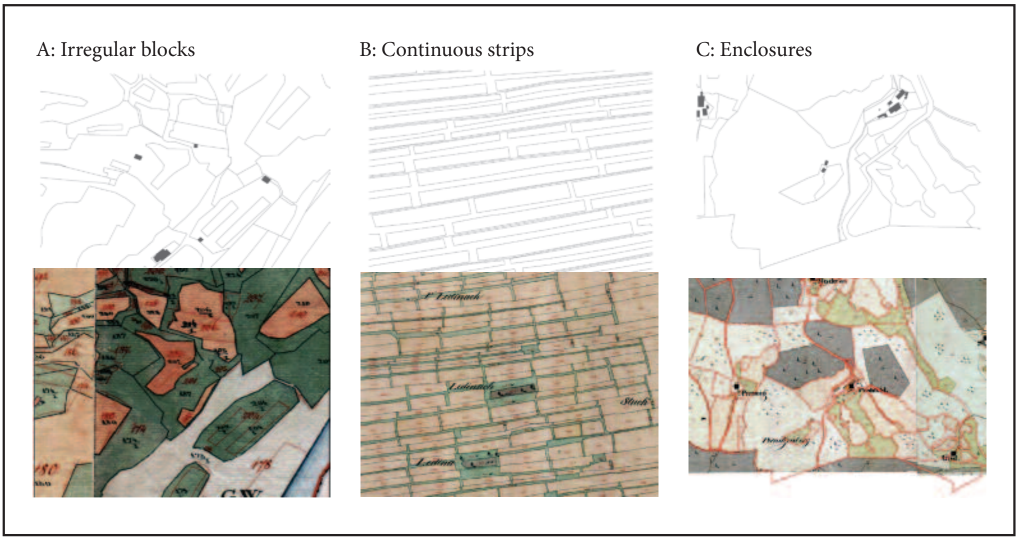


Figure 9: Sections from the land cadastre depiction (Geodetska uprava RS 2015; above) and sections from the Franciscan Cadastre (Arhiv RS; below) with cases of holes in irregular blocks (Zatolmin, A), continuous strips (Bitnje, B), and enclosures (Pernice, C).

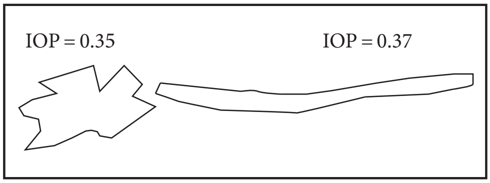


Figure 10: The case of similar IOP values for two parcels different in shape.

This arable land division analysis is mostly based on the study results by Ilešič from 1950. His study remains the only study for the area of the entire Slovenia and to date has not been systematically revised. This is why there are deviations between Ilešič's definition of the individual arable land types and the results indicated by the IOP analysis in parcels from 2015.

IOP allows for the classification of fields and even the exclusion and aggregation of fields that stand out according to their parcel shape characteristics. The fields with a proportion of IOP above 0.7 (Vinjole, Sedlarjevo, Sovjak, Stržišče and Trška gora), which were classified either as irregular blocks or furlongs according to Ilešič, should be classified into a new group.

We noticed deviations in the classification of fields based on parcel shapes with furlongs and continuous strips. Ilešič classified the fields of Kleče and Podgora as continuous strips, while according to IOP they were classified as furlongs due to the shorter strips. Buje and Žerovnica were classified as furlongs because of short strips.

Based on the statistical differences between fields we can identify some new groups and propose improvements upon Ilešič's field classification. This is the case with winegrowing areas, which are either considered irregular blocks or furlongs. This way we confirmed the working hypothesis about the possibility of producing a numerical index for describing parcel shapes to be used to determine and classify fields.

The use of the Parcel Shape Index has a wide ranging applicability. Parcel shape is important in agriculture in terms of the rational use of individual parcels (Zondonadi et al. 2013), while in Slovenia parcel shape should be included in identifying protected farmsteads and used in the analysis of GERK (Graphical Unit of Agricultural Land) and RABA (Register of Existing Agricultural and Forest Land Use) data kept by the ministry responsible for agriculture.

The parcel shape is, of course, not the only criterion for determining arable land division types, so it would be advisable to determine indices for other field characteristics, such as land distribution (Simmons 1964; Januszewski 1968; Igbozurike 1974; Gosar 1978; Razpotnik Visković 2012) and land use diversity (McGarigal in Marks 1995; McGarigal 2013, 2015).

5 Conclusions

The paper shows that IOP values and statistical indicators vary among fields as irregular blocks, enclosures, continuous strips, and furlongs. Ilešič's classification of fields in the selected test fields was mostly confirmed. Out of 22 fields 17 were classified in line with Ilešič's system. But because Ilešič also included other indicators in the determination of arable land division types, such as land fragmentation, the number of indices considered should be increased. Using the hierarchical clustering method and based on IOP fields can be classified into classes, which allows for confirmation and improvement upon the existing typification. Even though it is very difficult to describe all the visual characteristics of a spatial object using shape indices (Williams and Wentz 2008), doing so nonetheless limits an individual's subjectivity. Furthermore the transformation of a shape's characteristics to numerical values allows for easier processing and comparison of data. IOP could help us to observe the changing of parcel shapes (e.g. in a field). This would be particularly applicable where agricultural and built-up land meet, where the transformation of the shape of a parcel into (as a rule) a square indicates the purpose of transforming agricultural land into built-up land.

6 References

Amiama, C., Bueno, J., Alvarez, C. J. 2008: Influence of the physical parameters of fields and the crop yield on the effective field capacity of a self-propelled forage harvester. Biosystems Engineering 100-2. DOI: https://doi.org/10.1016/j.biosystemseng.2008.03.004

Angel, S., Parent, J., Civco, D. L. 2010: Ten compactness properties of circles: measuring shape in geography. Canadian Geographer-Geographe Canadien 54-4. DOI: https://doi.org/10.1111/j.1541-0064.2009.00304.x

Aslan, T., Gundogdu, K., Arici, I. 2007: Some metric indices for the assessment of land consolidation projects. Pakistan Journal of Biological Sciences 10-9.

Bastič, M. 2006: Metode raziskovanja. Maribor.

Beinat, E. 1997: Value functions for environmental management. Dordrecht.

Bielecka, E., Gasiorowski, J. 2014: Land fragmentation analysis using morphometric parameters. The 9th International Conferenc Environmental Engineering. DOI: https://doi.org/10.3846/enviro.2014.205

Blaznik, P. 1970: Gospodarska in družbena zgodovina Slovencev. Poljska razdelitev. Ljubljana.

Boyce, R., Clark, W. 1964: The concept of shape in geography. Geographical Review 54-4.

Breskvar Žaucer L., Košmelj K. 2006: Metode za razvrščanje enot v skupine; osnove in primer. Acta agriculturae Slovenica 87-2.

Brinkhoff, T., Kriegel, H. P., Schneider, R., Braun, A. 1998: Measuring the complexity of polygonal objects. Munich.

Chan, A. H. S., So, D. K. T. 2006: Measurement and quantification of visual lobe shape characteristics. International Journal of Industrial Ergonomics 36-6. DOI: https://doi.org/10.1016/j.ergon.2005.10.005

Chaudhuri, D. 2013: Global contour and region based shape analysis and similarity measures. Defence Science Journal 63-1. DOI: https://doi.org/10.14429/dsj.63.3767

Coelho, C., Pinto, P. A., Silva, M. 2001: A systems approach for the estimation of the effects of land consolidation projects (LCPs): A module and its application. Agricultural Systems 68-3. DOI: https://doi.org/10.1016/S0308-521X(00)00061-5

Comber, A. J., Birnie, R. V., Hodgson, M 2003: A retrospective analysis of land cover change using polygon shape index. Global Ecology and Biogeography 12-3.

Demetriou, D. 2013: LACONISS: A Land Consolidation Integrated Support System for planning and decision making. Zfv-Journal of Geodesy, Geoinformation and Land Management 138-2.

Demetriou, D. 2014: The development of an integrated planning and decision support system (IPDSS) for land consolidation. London. DOI: https://doi.org/10.1007/978-3-319-02347-2.

Demetriou, D., See, L., Stillwell, J. 2013: A parcel shape index for use in land consolidation planning. Transactions in GIS 17-6. DOI: https://doi.org/10.1111/j.1467-9671.2012.01371.x.

Demetriou, D., Stillwell, J., See, L. 2012: Land consolidation in Cyprus: Why is an integrated planning and decision support system required? Land Use Policy 29-1. DOI: https://doi.org/10.1016/j.landusepol.2011.05.012

Eason, P. 1992: Optimization of territory shape in heterogeneous habitats – a field-study of the red-capped cardinal (Paroaria-Gularis). Journal of Animal Ecology 61-2. DOI: https://doi.org /10.2307/5332

Ehler, G. B., Cowen, D. J., Mackey, H. E. jr. 1996: Development of a shape fitting tool for site evaluation. 7th International symposium on spatial data handling. DOI: https://doi.org / 10.2307/490799

Ferlan, M. 2005: Geodetske evidence. Ljubljana.

Fialkovski, M., Bitner, A. 2008: Universal rules for fragmentation of land by humans. Landscape Ecology 23-9. DOI: https://doi.org/10.1007/s10980-008-9268-x

Frolov, Y. S. 1975: Measuring shape of geographical phenomen – history of issues. Soviet Geography Review and Translation 16-10.

Gonzalez, X. P., Alvarez, C. J., Crecente, R. 2004: Evaluation of land distributions with joint regard to plot size and shape. Agricultural Systems 82-1. DOI: https://doi.org/10.1016/j.agsy.2003.10.009

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. Agricultural Systems 92-1-3. DOI: https://doi.org/10.1016/j.agsy.2006.02.008

Gosar, L. 1978: Prispevek k preučevanju razdrobljenosti posesti. Geografski vestnik 50.

Gutzwiller, K. J., Anderson, S. H. 1992: Interception of moving organisms: influences of patch shape, size and orientation on community structure. Landscape Ecology 6-4. DOI: https://doi.org/10.1007/BF00129707

Igbozurike, M. U. 1974: Land tenure relations, social relations and the analysis of special discontinuity. Area 6-2.

Iivarinen, J., Peura, M., Särelä, J., Visa, A. 1997: Comparison of combined shape descriptors for irregular objects. British Machine Vision Conference Essex. Internet: http://www.bmva.org/bmvc/1997/papers/062/bmvc97.htm (10. 8. 2015).

Ilešič, S. 1950: Sistemi poljske razdelitve na Slovenskem. Ljubljana.

Internet 1: http://arsq.gov.si (20. 2. 2015).

Internet 2: http://rkg.gov.si/ GERK (20. 2. 2015).

Irwin, E. G., Bockstael, N. E. 2004: Land Use externalities, open space preservation, and urban sprawl. Regional Science and Urban Economics 34-6. DOI: https://doi.org/10.1016/j.regsciurbeco.2004.03.002

Januszewski, J. 1968: Index of Land Consolidation as a criterion of the degree of concentration. Geographica Polonica 14.

Kladnik, D. 1999: Leksikon geografije podeželja. Ljubljana.

Krummel, J. R, Gardner, R. H., Sugihara, G., O'Neill, R. V. O., Coleman, P. R. 1987: Landscape patterns in a disturbed environment. Oikos 48.

Landau, B., Smith, L. B., Jones, S. S. 1988: The importance of shape in early lexical learning. Cognitive Development 3-3. DOI: https://doi.org/10.1016/0885-2014(88)90014-7

Lee, D., Sallee, T. 1970: A method of measuring shape. Geographical Review 60-4.

Li, W., Goodchild, M. F., Church, R. 2013: An efficient measure of compactness for two-dimensional shapes and its application in regionalization problems. International Journal of Geographical Information Science 27-6. DOI: https://doi.org/10.1080/13658816.2012.752093

Libecap, G., Lueck, D. 2009: The demarcation of land and the role of coordinating institutions. The National Bureau of Economic Research. Working Papers Series 14942.

MacEachren, A. 1985: Compactness of geographic shape: comparison and evaluation of measures. Geografiska Annaler B, Human Geography 67-1.

Malczewski, J. 1999: GIS and multi-criteria decision analysis. New York.

Malczewski, J. 2011: Local weighted linear combination. Transactions in GIS 15-4. DOI: https://doi.org/10.1111/j.1467-9671.2011.01275.x

McGarigal, K. 2013: Landscape pattern metrics. Encyclopedia of environmetrics. Chichester. DOI: https://doi.org/10.1016/0169-2046(91)90034-J

McGarigal, K. 2015: Fragstats help. University of Massachusetts. Internet http://www.umass.edu/landeco/research/fragstats/documents/fragstats.help.4.2.pdf (10. 9. 2015).

McGarigal, K., Marks, B. J. 1995: Fragstats: Spatial pattern analysis program for quantifying landscape structure. Washington.

Miller, V. C. 1953: A quantitative geomorphic study of the drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical Report 3. Columbia University Department of Geology. New York.

Milne, B. T. 1991: The utility of fractal geometry in landscape design. Landscape and Urban Planning 21, 1-2. DOI: https://doi.org/10.1016/0169-2046(91)90034-J

Oksanen, T. 2013: Shape-describing indices for agricultural field plots and their relationship to operational efficiency. Computer and Electronics in Agriculture 98. DOI: https://doi.org/10.1016/j.compag.2013.08.014

Osserman, R. 1978. The isoperimetric inequality. Bulletin of the American Mathematical Society 84-6. Internet: http://www.ams.org/journals/bull/1978-84-06/S0002-9904-1978-14553-4/S0002-9904-1978-14553-4.pdf (10. 5. 2015).

Perko, D., Hrvatin, M., Ciglič, R. 2015: Metodologija naravne pokrajinske tipizacije Slovenije. Acta geographica Slovenica 55-2. DOI: https://doi.org/10.3986/AGS.1938

Razpotnik Visković, N. 2012: Vloga mešanih kmetij v gospodarski, okoljski in prostorski preobrazbi obmestij. Doktorska disertacija. Univerza v Ljubljani, Interdisciplinarni podiplomski študij prostorskega in urbanističnega planiranja. Ljubljana.

Rutledge, D. 2003: Landscape indices as measures of the effects of fragmentation: Can pattern reflect process? Wellington.

Sagiv, M., Reps, T., Wilhelm, R. 2003: Parametric shape analysis via 3-valued logic. ACM Transactions on Programming Languages and Systems 24-3. DOI: https://doi.org/10.1145/514188.514190

Santiago, R. S., Bribiesca, E. 2009: State of the art of compactness and circularity measures. International Mathematical Forum 4-27.

Sharifi, A., Herwijnen, M., Toorn, W. 2004: Spatial decision support systems. Lecture Notes. ITC, International Institute for Geo-Information Science and Earth Observation. Enschede.

Simmons, A. J. 1964: An Index of Farm Structure, with a Nottinghamshire example. Nottingham.

Simons, P. L. 1974: Measuring shape distortions of retail market areas. Geographical Analysis 6-4. DOI: https://doi.org/10.1111/j.1538-4632.1974.tb00518.x

Slovar slovenskega knjižnega jezika 2000: Internet: http://bos.zrc-sazu.si/sskj.html (15. 11. 2015).

Sonka, M., Hlavac, V., Boyle, R., 1993: Image processing, analysis, and machine vision. Boston. DOI: https://doi.org/10.1007/978-1-4899-3216-7

Touriño, J., Parapar, J., Doallo, R., Boullon, M., Rivera, F., Bruguera, J., Gonzalez, X. Crecente, R., Alvarez, C. 2003: A GIS-embedded system to support land consolidation plans in Galicia. International Journal of Geographical Information Science 17-4. DOI: https://doi.org/10.1080/13658810310000072636

Wentz, E. 1997: Shape analysis in GIS. Internet: http://www.mapcontext.com/autocarto/proceedings/auto-carto-13/pdf/shape-analysis-hi-gis.pdf (15. 4. 2015).

Wentz, E. 2000: A shape definition for geographic applications based on edge, elongation, and perforation. Geographical Analysis 32-2 DOI: https://doi.org/10.1111/j.1538-4632.2000.tb00419.x

Williams, E. A., Wentz, E. 2008: Pattern analysis based on type, orientation, size, and shape. Geographical Analysis 40-2. DOI: https://doi.org/10.1111/j.1538-4632.2008.00715.x

Zhang, D., Lu, G. 2004: Review of shape representation and description techniques. Pattern Recognition 37-1. DOI: https://doi.org/10.1016/j.patcog.2003.07.008

Zhang, S. Q., Zhang, J., Li, F., Cropp, R. 2006: Vector analysis theory on landscape pattern (vatlp). Ecological Modelling 193, 3-4. DOI: https://doi.org/10.1016/j.ecolmodel.2005.08.022

Zondonadi, R. S., Luck, J. D., Stombaugh, T. S., Shearer, S. A. 2013: Evaluating field shape descriptors for estimating off-target application area in agricultural fields. Computers and electronics in agriculture 96. DOI: https://doi.org/10.1016/j.compag.2013.05.011