

# LANDSCAPE SHAPE INDEX, AS A POTENTIAL INDICATOR OF URBAN DEVELOPMENT IN HUNGARY

PÉTER GYENIZSE<sup>1</sup>, ZITA BOGNÁR<sup>1</sup>, SZABOLCS CZIGÁNY<sup>1</sup>,  
TIBOR ELEKES<sup>2</sup>

<sup>1</sup> University of Pécs, Institute of Geography of the Faculty of Sciences, 7624 Pécs, Ifjúság útja 6., Hungary

<sup>2</sup> University of Miskolc, Institute of Geography of the Faculty of Earth Science and Engineering, 3515 Miskolc-Egyetemváros, Hungary  
E-mail: gyenizse@gamma.ttk.pte.hu

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## Abstract

The study of settlement shape, morphology and structure is a classic topic of urban geography. Since the 1960s multiple shape indices have been developed. Urban patterns were then compared with geometric forms or, alternatively their temporal changes were tracked and analysed. In the current study we adapted the landscape shape index (LSI) to analyse the historical shape development of eight Hungarian cities. The LSI is capable to demonstrate the functional and mutual relationship between the developed area and their immediate physical and natural environment. Over the past 230 years the land area of the studied cities has increased manifold for several reasons: on average, an areal increase of 10.4 to 24.5 was observed for the eight settlements, while their perimeter increased by 8.8 to 30.3 times. Simultaneously with their size growth, the studied cities are characterized by an increasingly fragmented and dissected ground plans. Consequently, due to the longer border between the developed areas and the adjacent natural zones, urban areas have become increasingly sensitive to environmental effects over the past century, while mutual ecological and environmental interactions has also considerably increased between the adjoining zones. In general, cities of hilly and low-mountain areas had the highest LSIs, whereas cities located on relatively flat grounds had comparatively low LSIs. We also investigated the rank correlation of the historical change of LSI of the studied settlements. Cities of high positive correlations (> 0.9) were classified into two major categories. Miskolc, Pécs, Szeged and Kecskemét belonged to the group of higher LSIs, whereas Székesfehérvár and Nyíregyháza fell into the class of medium LSIs and the third category included Debrecen and Győr; cities of low (< 0.9) LSIs. Based on the temporal trends of the LSIs, our results provide applicable information for decision makers in order to monitor, manage and track their investments, city management policies and infrastructural development strategies.

**Keywords:** ground plan shape, urban development, urban-environment interaction, shape index

## 1. Introduction

A sound and widespread applied classification policy and nomenclature have been developed over the past century by European scientists, and primarily with the leadership of German urban geographers (e.g.: Gradmann, 1913; Harald – Cay 1972; Schlüter, 1899, 1903; Wolf, 1968, 1972). Besides the international interest, many

Hungarian research papers have also been published on the temporal evolution of settlement structure studies. Factors of the natural environment (relief, hydrography, soil properties, etc.) has influenced unequivocally the development settlement shapes in many cases, as it has been supported by mapping and field surveys (e.g. Prinz, 1922; Mendöl, 1963; Marosi – Szilárd, 1974; Lovász, 1977; Gyenizse – Lovász, 1996).

Based on settlement ground plan shape pattern, many settlement types are distinguished, including cluster (nucleated), circular, disperse, single-street, spool-shaped and chess-table-shaped municipalities. Detailed maps provided ample information on large-scale settlement pattern and settlement shape studies. Ground plan shapes of settlements are influenced by physical geographical properties, including, among many others, topography, hydrography and soil properties. The magnitude of these impacts can be evaluated by field studies and spatial pattern analyses (e.g. Mendöl, 1963; Marosi – Szilárd, 1974; Lovász, 1977; Gyenizse – Lovász, 1996). While there is a large number of comprehensive studies on ground plan shapes (e.g.: Bátky, 1918; Csapó, 2005; Elekes, 2008; Gyenizse et al., 2011; Lenner, 2012), very few papers focus on the quantification of the magnitude of ecological impacts, shape-influencing environmental factors and the functional interrelationship between settlements and their environment (Harald – Cay, 1972; Perényi, 1975; Lovász, 1977; Elekes, 2008; Gennaio et al., 2009). However, no studies have yet been conducted on the temporal and historical changes of the indices indicating the impact of environment on urban ground plan shapes. To quantify, statistically analyse and spatially interpret available data, GIS softwares are indispensable tools nowadays (Nagyváradi – Pirkhoffer, 2008; Szabó, 2001; Szabó et al., 2015).

For the characterization of urban ground plan shapes, several types of shape indices have been developed since the early 1960s. One of the first shape indices was developed by Boyce and Clark (1964), who provided the first empirically-based quantitative classification of ground plan shapes. With this method they calculated their shape indices of multiple North-American cities.

According to Medda and her co-authors the method of Boyce – Clark was also applied by others e.g. Lo 1980; Griffith et al. 1986, however calculations were burdened with multiple problems, like the value of shape

indices changed as a function of the size and orientation of the form, and also depended on the number of applied radii (Medda et al. 1998). Upgraded shape index values usually range between 0 and 1, thus they are capable for the comparison of settlement ground in a numerical way.

Batty – Longley (1994) developed a model with the application of allometry and fractal geometry. Their method was based on the theory that cities grow by the multiplication of their basic units. Consequently the largest settlement of the system is a larger version of the smaller ones. According to Jakobi – Ónodi (2012) the temporal examination of fractal dimension is a suitable method to investigate the development density and continuity of urban areas. The authors used this method mainly to examine the central (downtown) structure of the cities.

Urban sprawl has been a widespread phenomenon over the last decades, which has been tracked and observed by GIS and remote sensing tools, like satellite imagery (e.g. Aljoufie et al. 2013; Ferreira et al. 2010; Gennaio et al. 2009). By examining South-American cities, Inostroza and his co-authors (2013) separated three developmental categories (fill-in, axial and isolated) on the basis of size, spatial pattern, development rate and building density.

Landscape shape index (hereafter LSI) has been widely used in landscape ecology worldwide and was introduced to indicate the divergence of the shape of a landscape patch from the circle which is considered ideal (Patton, 1975; Lóczy, 2002; Szabó – Csorba, 2009; Szabó, 2012). Plant associations of circular shape (shortest perimeter compared to its area patches), within a certain size category, are considered as the most stable and resistant against the outer negative effects in ecological sense.

$$D = \frac{P}{2 \cdot \sqrt{A} \cdot \pi} \quad (1)$$

, where D is the LSI, P is the perimeter and A is the area.

Herzog et al. (2001) investigated how

landscape changed over a certain period in Saxony, Germany, an area heavily affected by mining and agriculture. Their goal was to track how useful geometry-based landscape metrics are in the monitoring of landscape changes. According to the Spearman's rank correlation they found limited relationship between the size of landscape patches and shape indices.

According to Wrabka et al. (2003) there are many indicators which are used to evaluate the changes of ecosystem processes induced by land use. These indicators relate to e.g. landscape diversity, landscape structure, naturalness of landscapes and land-use intensity.

Csorba (2006) defined some indicators for landscape ecological evaluations and for characterising landscape structure. He examined the density and also the shapes of the landscape patches on the basis of the CORINE classification.

Mezősi – Fejes (2004) separated different scale levels: patch, class of patches and landscape. Those indices, which could be applied to measure the fragmentation of the landscape, linked to the two smaller levels. However the indices, related to for example spatial heterogeneity, could be only used on landscape level. According to Mezősi – Fejes (2004) the regular, less complex patches are of human origin, and the stretched and rounded forms developed in a natural way.

LSI is suitable for the shape characterization of settlements, and suitable tool to determine the development status and direction of large urban areas. Nevertheless, it does not show the growth or decline of urban areas in an absolute sense, still, it is a relative indicator that quantitatively indicates selected attributes of the relevant built-up areas in terms of the mutual relation between the urban area and its immediate environment.

We interpreted the built-up area in a wider sense, as we also considered those areas where human activity profoundly transformed the urban environment, like backyards, houses and other dwellings, public squares and streets, indicating

highly fragmented and dissected areas. Furthermore, for the studied settlements, paved and developed districts are randomly distributed within the broader administrative borders, i.e. districts of primarily recreational purposes in the outskirts also belong to the city in an administrative sense.

In our opinion the shape index of the built-up area and the change of this index give indirect information on the following urban relations:

- Relation with the 'natural environment'. The relationship between the settlement and its environment is bidirectional. Settlements, where LSI is high due to its intense fragmentation, have a longer borderline with the adjacent and surrounding forests, lakes, and agricultural areas. However, the increased length of borderline intensifies the human effect on the environment, generating larger environmental pollution. Similarly, certain city districts are increasingly prone to undesired environmental impacts and natural disasters, although the spatial extent of the impact is more isolated in the case of highly fragmented settlements (e.g. in case of intense snowing only little, isolated parts become inaccessible, while protection against floods is less challenging due to the scattered and partially isolated settlement structure).
- Relation with the 'social environment' for defensive purposes; it has been irrelevant since the early 1800s.
- Management and maintenance costs of the settlement. A well-operating linear infrastructure is indispensable for the appropriate operation and transportation structure of cities. Relatively shorter streets and public utilities, or shorter bus routes, are necessary in a compact settlement. However the construction and maintenance of these infrastructural facilities in a highly fragmented settlement mean relatively high maintenance cost.
- 'Settlement-psychology'. In the previ-

ous points we reviewed viewpoints where compact settlement-structure was more beneficial than high shape indices. From psychological aspects, sparsely populated, low building-density settlements, typical for instance in Northern Europe and the sparsely populated parts of the North America, are shown to be mentally advantageous for the residents (Perényi, 1975, 1987).

Data collection is relatively easy in the case of the methodologies elaborated by Boyce and Clark (1964) and Medda and her co-authors (1998), and the fractal dimensional analytical methods. However the authors did not emphasize the temporal changes sufficiently, and did not use their methods to soundly analyse the interaction between urban sprawl and the natural environment. Studies on remote sensing based urban sprawl also ease environmental studies, but, for obvious reasons, data availability is limited in time.

To overcome both data collection challenges and temporal shortage (short observation time period) issues, in the current study we have adapted and introduced a landscape shape index (LSI) that is novel in urban geography. A former and significantly different version of the LSI has already been used in landscape ecology. In the current study the LSI has been adapted to urban geography and has been implemented to monitor the interactions between developed areas and their natural environment on the time scale of centuries.

## **2. Methodology**

Over the course of the present research project we processed and analysed maps and orthophotos of eight Hungarian cities with populations exceeding 100 000 residents (Miskolc, Pécs, Székesfehérvár, Debrecen, Nyíregyháza, Kecskemét, Szeged and Győr). Multiple maps were analysed for the determination of the temporal changes of LSI: the oldest analysed map dates from the

end of 18th century (1783 to 1784) and the latest were orthophotos taken in 2005. From the first military survey we only digitized the contiguous developed areas, while scattered and isolated farms and small group of dwellings, located at a distance of more than 150 meters from the main body of the settlements, were ignored in the analyses. Only two exemptions were included in our study, namely for the cities of Szeged and Győr, where city districts are located across the local rivers.

We digitised the contiguous built-up areas of the cities with Cartalinx software. Since the lowest resolution of the employed maps was 1:25 000, to obtain equal resolution for each city at each time step, the resolution of high-resolution maps (e.g.: 1:10 000) was generalized to 1:25 000. The digitized contours of the maps were then used to calculate perimeters, area and LSIs of the given settlements (Fig.1. and Tables 1-3.). Quantitative map data were then statistically compared with physical geographical and hydrologic conditions, in order to derive conclusions on the development of the interrelationship between urban areas and their immediate environment (visual map interpretation).

Obviously LSI values have continuously changed over the studied period, however the direction of changes were different for the eight studied cities. Data were analysed with the Spearman ranking correlation statistical method (Table 4.). If high correlation was found between the LSIs of two given cities, then they likely had similar development trend and environmental relations and vulnerability over the studied period. If the correlation coefficient exceeded 0.8, then the correlation is considered high between the two studied cities (Bugya, 2003). Table 4 shows the relevant shape index changes for the studied cities, however similarities are also illustrated in Fig. 2.

## **3. Results**

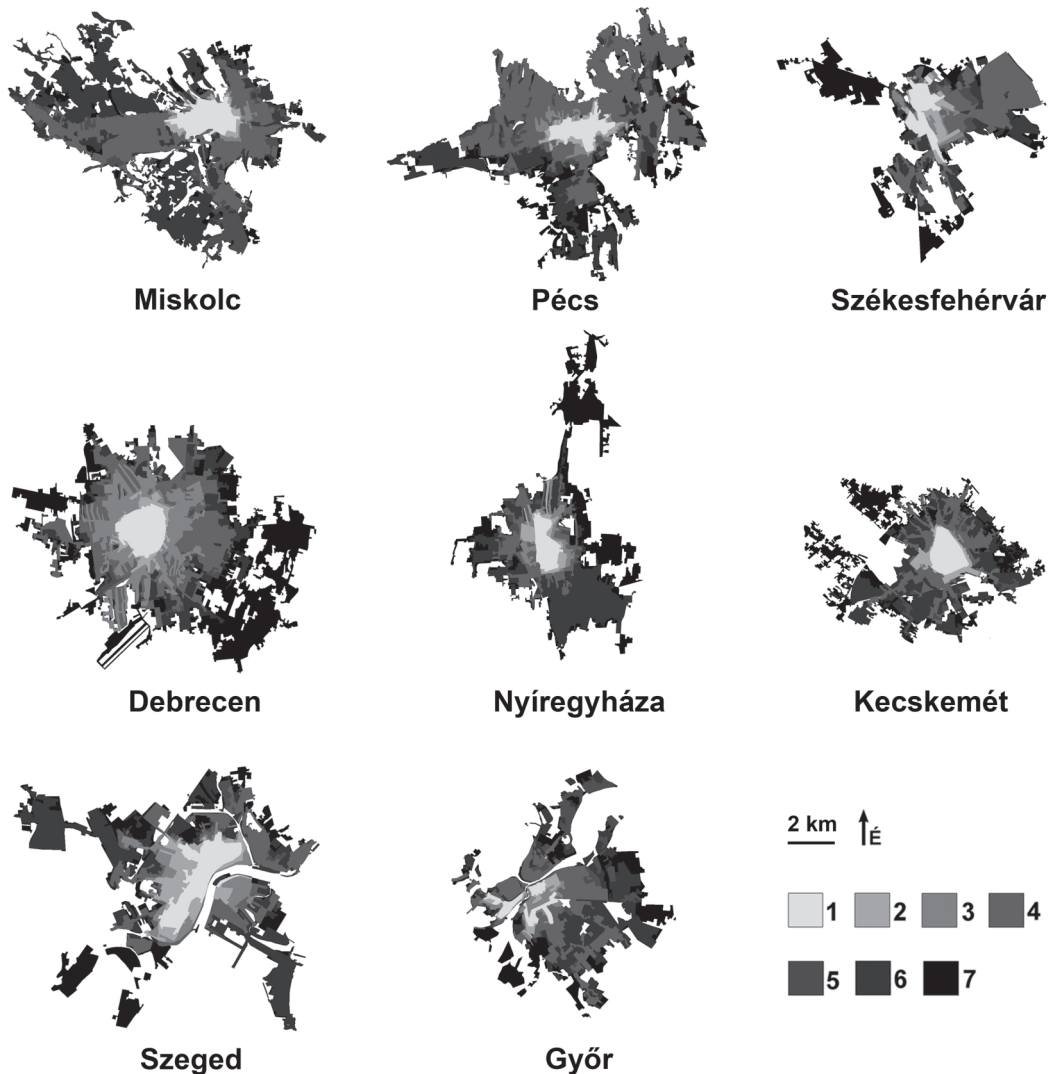


Fig.1. The growth of the built-up areas of the eight studied provincial cities from the 18th to the 21st century (1 = 1783-1784; 2 = 1840-1864; 3 = 1880-1884; 4 = 1950-1952; 5 = 1964-1967; 6 = 1980-1999; 7 = 2005)

**Temporal analysis of the areal parameters for the eight studied cities**

At the end of the 18<sup>th</sup> century the area of the studied cities ranged between 1.4 to 4.6 km<sup>2</sup>, while only the perimeter of Szeged exceeded 20 km. LSIs in the majority of the studied cities were close to 1 indicating circular ground plans. The LSI of the cities of the Great Hungarian Plain (GHP), including Kecskemét (surrounded by wooded city

walls), Debrecen and Nyíregyháza were below 2. The ancient cores of these three cities were situated in areas devoid of floods and inland waters. During the establishment of the settlements, microrelief significantly impacted the growth of the built-up areas, however its impact gradually decreased with time. The site-selection of Nyíregyháza was markedly influenced by the location of wetlands, marshes and lakes that considerably increased the defensibility of



the city. Debrecen was established at the meeting point of the Hajdúság loess ridge, the sandy Nyírség and clayey, salt-rich soils of the Hortobágy. Kecskemét is situated in the Kiskunság where land is dissected by spacious flats and loessy-sandy ridges.

The LSI of Pécs and Miskolc ranged between 2.0 and 2.3 at the end of the 18th century. As the first military survey illustrates, the centre of Miskolc is situated in the eastern foreground of the Bükk Mountains, at the meeting point of transport routes. The marshy areas of the Szinva Stream and the Sajó River predetermined the site selection. In this period the ground plan of the city stretched in east-west direction in accordance with the direction of the valley. The downtown area of Pécs was established on the southern slopes of the Mecsek Hills. The town, which was squeezed between the swampy Pécs Basin and the steep slopes of the Mecsek Hills, also stretched in east-west direction. The ground plan of Pécs had already outgrown the town wall by the late second half of the 18th century. Győr possessed the highest shape index of 3.9 at that time, which is likely explained by two main reasons. Firstly, certain districts of the city are separated by the Rába River; secondly the area between the former moat and the subsequently built residential area was undeveloped at this time. Szeged, which was established on the sandbanks of the Tisza River and had a stretched ground plan, was less fragmented and its shape index was 2.8 in this period. At the end of the 18th century Székesfehérvár (2.6) belonged to the group of settlements of high shape indices. Its city centre was built on islands in the marshes of Sárvíz and which providing protection for the local residents. But as a result of the considerable construction works in the 18<sup>th</sup> century the town expanded to the south on higher grounds devoid of inland water and floods.

The low LSIs at the end of the 1700s indicate that the cities had much less impact on their environment than exerted today. A century after the end of the Ottoman regime

the shape of the studied cities was generally compact, circular-shaped for defensive reasons. In this period the natural factors still influenced the shape of the ground plan of settlements significantly, but this effect decreased significantly over the technical development of the next centuries.

The area and the perimeter of most cities increased 1.5 to 2-fold by the second half of the 19th century compared to their former extent. Debrecen is an exception in this respect, as its area increased by 4.5-fold and its perimeter by 11-fold. It resulted in a significant growth of the LSI (6.8), and, as a result, Debrecen and Nyíregyháza experienced the largest growth of the LSI over the 19th century. New town parts were built right beyond the city walls (e.g. the 'kertek' in Debrecen, and the 'Ó and Új-szöllő' in Nyíregyháza), but farther away from the towns farms also appeared. Consequently the length of the perimeter significantly increased, leading to an increased LSI. A similar process was observed in Pécs, a city with higher-than-average LSI, where the southern slopes of the Mecsek Hills were increasingly built-up due to the large number of newly established properties and vineyards, resulting in a fragmented ground plan.

Large environment-transforming processes began in the studied cities in the 1860s and 1870s, including river regulation works and wetland drainage. Fine examples for projects of these types include the restoration works in downtown Szeged following the 1879 catastrophic flood, and the diversion of the Rába River in Győr. Additionally, population growth triggered the development of new residential districts in all studied cities.

Based on their mid-20<sup>th</sup> century area-perimeter ratio, the studied settlements are classified into two main groups. Miskolc, Pécs, Debrecen and Szeged were relatively large in size, as their area exceeded 20 km<sup>2</sup>, while their perimeter reached 100 km. The cities of Székesfehérvár, Nyíregyháza, Kecskemét and Győr remained relatively small in size at that

Table 1. The changes of the extent of developed areas of the studied cities (km<sup>2</sup>)

Period of observation	Miskolc	Pécs	Székesfehérvár	Debrecen	Nyíregyháza	Kecskemét	Szeged	Győr
1783-1784	3.4	2.5	2.7	3.1	1.9	2.1	4.6	1.4
1840-1864	4.2	3.2	4.0	4.3	3.1	3.2	8.4	2.0
1880-1884	4.9	4.4	5.1	13.9	4.2	3.2	11.8	3.0
1950-1952	21.6	29.5	16.9	26.3	8.9	9.3	20.4	11.8
1964-1967	26.0	30.0	17.9	27.7	9.3	10.3	21.3	14.7
1980-1999	52.2	41.9	23.6	34.8	21.9	20.7	36.9	24.9
2005	56.2	51.1	34.9	55.7	34.1	28.9	47.9	34.2

Table 2. The perimeter of the developed areas of the studied cities over the period of interest (km)

Period of observation	Miskolc	Pécs	Székesfehérvár	Debrecen	Nyíregyháza	Kecskemét	Szeged	Győr
1783-1784	13.3	12.9	15.4	8.2	7.6	5.9	21.1	16.3
1840-1864	17.4	18.6	23.9	18.7	16.0	12.2	30.7	20.7
1880-1884	22.6	25.5	24.3	90.4	25.6	14.6	36.5	19.8
1950-1952	124.4	157.8	75.2	112.5	62.2	74.2	111.3	84.5
1964-1967	137.1	149.5	72.1	105.2	59.3	82.6	113.3	107.1
1980-1999	304.6	230.7	78.9	132.4	83.0	134.2	176.9	115.8
2005	285.9	211.9	136.0	221.5	127.1	178.1	189.7	110.0

Table 2. The perimeter of the developed areas of the studied cities over the period of interest (km)

Period of observation	Miskolc	Pécs	Székesfehérvár	Debrecen	Nyíregyháza	Kecskemét	Szeged	Győr
1783-1784	2.0	2.3	2.6	1.3	1.6	1.1	2.8	3.9
1840-1864	2.4	2.9	3.4	2.6	2.5	1.9	3.0	4.1
1880-1884	2.9	3.4	3.0	6.8	3.6	2.3	3.0	3.2
1950-1952	7.6	8.2	5.2	6.2	5.9	6.9	6.9	6.9
1964-1967	7.6	7.7	4.8	5.6	5.5	7.3	6.9	7.9
1980-1999	11.9	10.1	4.6	6.3	5.0	8.3	8.2	6.5
2005	10.8	8.4	6.5	8.4	6.1	9.3	7.7	5.3

time. Pécs had the highest shape index (8.2) in the 1950s, where, due to the intensification of coal mining, increased population began to develop both the fragmented surfaces of the Mecsek Mountain and the hilly areas south to the Pécs Basin. Similar processes were observed in Miskolc, where urban sprawl was enhanced by the development of the local heavy industry. Significant expansion was observed to the west in the Szinva Valley and the adjacent foothill areas. The high shape indices of Győr and Szeged were caused by the administratively adjoined districts, formerly individual suburban settlements across the Tisza Rivers and the Rábca (e.g. Újszeged, Révfülé, Győrsziget), respectively.

In the ground plan of Kecskemét there were 'extensions', i.e. distant outskirts districts that administratively belonged to the city characterized with scattered dwellings and buildings in of a farmland area. These 'extensions' caused a higher than average LSI value in Kecskemét. In the examined period Nyíregyháza and Székesfehérvár formed the most compact settlements. An additional LSI increase of 1.5 to 2.5-fold has been observed in all studied cities since the 1950s. During the socialist era forced industrialization went on in most Hungarian cities, which attracted a large number of work force into the cities of intense industrial activities, resulting in the development of block house residential

districts along the outer perimeter and the axial main transportation routes of the settlements. Miskolc and Pécs continued to have the highest LSI among the studied cities at this time. The LSI of Miskolc was close to 12 at this time, a value about twice as much as the LSI of Nyíregyháza, Győr and Székesfehérvár.

However, this newly built areas are prone to catastrophic natural events, especially to hydrologic disasters like floods (e.g. the flood of Szinva Stream in 2010), heavy erosion and the accumulation and deposition of mud or mixed debris. Many cities in the GHP are affected by high groundwater levels and inland waters. Floods especially threaten the industrial and residential districts of Győr and Szeged built on former floodplains (e.g. the flood wave in Szeged in 2006 exceeded the height of the dams).

#### Comparison of temporal changes of LSI since the late 1700s with rank correlation

We also compared the shape indices of the studied cities with rank correlation (Table 4.). The correlation was positive for all studied cities, with a value ranging between +0.54 and +1.0. Correlation coefficients higher than +0.8 in the rank correlation matrix were used for the generation of a correlation network (Fig. 2.). However, the correlation network showed no, or very little similarities for the analysed cities in terms of urban impact on the natural environment. Very high correlations (above +0.9) were found for Miskolc, Pécs, Szeged and Kecskemét.

Temporal changes of the LSI, nonetheless, were very different in the studied cities in the GHP indicating relatively abrupt changes over the entire studied period. Similarly to Pécs and Miskolc, two abrupt LSI changes were observed in Szeged and Kecskemét over the mid-20th century. LSIs were lower for Székesfehérvár and Nyíregyháza in the 1950s, indicating a relative decrease, as their LSIs were above the average in the 19th century. For 2000, two distinct categories can be identified based on the LSI rank correlation values: the first group of cities consisted of cities with high rank correlation, and the cities with lower rank correlation values belonged to a second, smaller group. LSI rank correlation of Kecskemét bears the most similarities with the majority of the other studied cities (Fig. 2.), showing high LSI correlation with five other cities. Consequently the two categories could be linked loosely via Kecskemét. Interestingly, the change of the LSI rank correlation of Debrecen shows similarity solely with Nyíregyháza, and the correlation values of Győr does not reach 0.8 with any cities. Therefore, despite the difference in environmental interaction between the urban areas and their environment, cities of the same categories are exposed to bidirectional impacts of similar magnitude when mutual environmental controls between the cities and their natural environment are considered.

Table 4. Cross-correlation matrix of the LSIs of the analysed cities

	Miskolc	Pécs	Székesfehérvár	Nyíregyháza	Debrecen	Kecskemét	Szeged	Győr
Miskolc	-							
Pécs	0.96	-						
Székesfehérvár	0.71	0.75	-					
Nyíregyháza	0.75	0.79	0.96	-				
Debrecen	0.61	0.54	0.71	0.82	-			
Kecskemét	0.96	0.93	0.82	0.86	0.75	-		
Szeged	0.96	1.00	0.75	0.79	0.54	0.93	-	
Győr	0.54	0.57	0.75	0.79	0.50	0.57	0.57	-



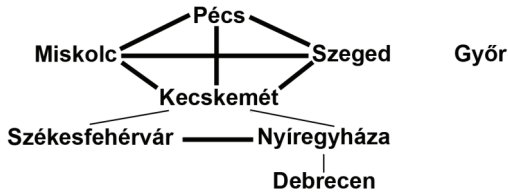


Fig. 2. Similarity network of the correlation among the changes of the shape index of cities (thin lines designate rank correlation ranging between +0.80 and +0.89; thick lines indicate rank correlation higher than +0.90)

#### 4. Discussion

Studies on the ground plan shape of settlements are integral parts of urban geography. This challenging research topic has been recently supported by various GIS methods that provide excellent opportunity for quantitative analyses. In the current study we have adapted the so-called ecological shape index into ground plan shape analysis of eight Hungarian cities. This LSI clearly demonstrates the mutual relations between the developed areas and their environment. We analysed the temporal changes of LSI at a historical time scale using the military and civil topographic maps, spanning for a time interval of 230 years. By vectorising the ground plan shape of the studied eight cities, perimeters of the settlements were calculated for seven periods of time using GIS programmes.

During the statistical analyses of the obtained numerical data we found a pronounced increase in land area since the end of the 18th century. At that time most of the studied cities covered areas of just a few square kilometres, with the exception of Szeged, where the city perimeter exceeded 20 km. The shape indices of the cities located in the GHP were close to the value 1 indicating circular outline. Miskolc and Pécs, cities located on foothill positions, had an LSI value between 2.0-2.3 in the late 1800s. The cities of Székesfehérvár, Szeged and Győr, heavily dissected and fragmented by water courses, had somewhat higher LSIs ranging between 2.6 and 3.9. Due to defensive purposes, a century after the fall of the Ottoman Empire,

the compact size and circular shape of the settlements were still clearly observable for many cities in Hungary. The low LSIs at that time indicated a lower degree of human influence on their environment compared with the conditions today.

In the second half of the 19<sup>th</sup> century the LSIs of the studied cities were low, indicating a moderately fragmented ground plan. Debrecen was an exception where all examined areal data increased excessively. The defensive function of the town walls ceased, thus new town parts were built along and beyond them, increasing the environment-transforming potential of all studied cities.

The area and the perimeter of the studied cities increased significantly once again until the 1950s, reaching a mean value higher than 5 for every studied settlements. In this period Pécs had the highest shape index (8.2), where, due to intense coal mining, the significantly increased population began to inhabit not only the fragmented surfaces of the Mecsek Hills but also in the hilly areas south to the Pécs Basin. Similar processes were observed in Miskolc, where heavy industry attracted a large number of employees into the city. The high LSIs of Győr and Szeged were caused by the administratively connected town parts across both the Rába and Rábca Rivers. The reason of the higher than average LSI value of Kecskemét roots in the administrative attachment of former residential districts from the outskirts to the main body of the city. The most compact settlements remained Nyíregyháza (5.2) and Székesfehérvár (5.9) in the observed period.

According to the 2005 orthophotos, similarly to the former periods of observation, Miskolc (11.9) and Pécs (10.1), predetermined by the dissected topography, have the highest LSIs. In contrast, Nyíregyháza, Győr and Székesfehérvár, located on relatively flat grounds, maintained their moderate fragmentation, with LSIs of 4.6 to 6.5.

Finally, we analysed the temporal changes of LSIs for all cities for the past 230 years.

Cities with high LSIs experienced similar or almost identical changes of ground plan shape and size in a given period of time. We also compared the LSIs of the studied cities with rank correlation. Cities of high correlation coefficients (higher than +0.9) were classified into two categories. Miskolc, Pécs, Szeged and Kecskemét belonged to the group of higher LSIs, while Székesfehérvár and Nyíregyháza fell into the category of relatively low LSI. Although the character of the actual environmental conflicts could be different for the studied cities, the environmental conflict potential in cities of high LSIs is higher in the group of low LSIs. Based on the temporal trend analyses of the LSIs and the rank correlation coefficients among the studied settlements, our results provide relevant information for decision makers in order to monitor, manage and track their investments, city management policies and infrastructural development strategies.

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