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ANALYSIS OF CHANGES TO THE LANDSCAPE IN TRANSITIONAL ZONES OF MEDIUM-SIZED CITIES OF CENTRAL EUROPE

Iwona Cieślak, Karol Szuniewicz, Szymon Czyża

Summary

The article presents results of an analysis of changes to the landscape in zones directly bordering with Central European cities of medium size. Authors have designated and analysed 57 zones as buffers contained within a radius of 30 km from the administrative city boundaries. Transformations of the landscape were determined on the basis of three indicators showing the fragmentation of the land use forms, distortions of area patches with different land uses, and an increase in the diversification of functions. The data adopted for the study originated from *CORINE Land Cover*, determined for two points of time i.e. the years 2006 and 2012. The obtained results indicate that the changes to the landscape, identified on the basis of the selected indicators, are strongly linked to the increase in the size of urban areas. The analysis also showed a clear differentiation between cities situated in Central European countries.

Keywords

land use • landscape transformations • GIS analysis • CORINE Land Cover • urbanisation

1. Introduction

Increasing urbanisation is a sign of the times, and a result of civilisation development. The phenomenon of urbanisation causes dramatic changes in the landscape [Mu et al. 2016]. The rate, intensity, and dynamics of these changes has become alarming, and has been more and more frequently a subject of research for various areas, and in relation to various aspects of life: economic, social, and environmental, among others [Heilig 1994, Henneberry 2000, Sassen 2011, Guy and Fang et al. 2015].

As a result of increasing urbanisation, the uses of space are diversified; the space gets functionally fragmented. Buildings get more varied, and more densely located [Antrop 2004]. These are the most visible effects of transformations, which create the "physiognomy" of space i.e. the landscape [McDonell and Pickett 1990]. Hence, the most frequent studies in the field of urbanisation include landscape studies.

There are many indicators providing an opportunity to follow the dynamics of landscape transformations [McGarigal and Marks 1995]. They are most often applied as characteristics of the spatial structure [Roo-Zielińska et al. 2007], making it possible to measure the composition, distribution, and spatial relationships between various forms of land cover [Walz 2011]. They are also practical tools for planning and monitoring the changes occurring in the environment, and for searching for sustainable solutions [Francis et al. 2016]. Since the spatial structure may affect various environmental, social, and economic phenomena, the ability to estimate changes to the landscape structure over time may be crucial for our understanding of the dynamics of these phenomena [Esbah et al. 2008].

Cartographic data are particularly useful for determining the indicators of landscape structure. Remote sensing and GIS technologies are indispensable and effective tools for determining the measures of the structure [Maktav et al. 2002, Liu et al. 2009]. Remote sensing data may be used for documenting land use at various scales, for the purposes of space management at a global, regional, and local level [Cieślak et al. 2016a]. The above-mentioned technologies offer much greater possibilities for obtaining more detailed inventories of environmental resources, and for analysing the acquired data in time and space [Turner et al. 2001]. Due to the development of GIS techniques in the processing of this data, the changes in question may be analysed from different perspectives and in relation to quality spatial data, enabling social or economic analyses [Verd and Porcel 2012]. The main purpose of the present article is to explore the possibilities of using existing GIS databases to study landscape changes.

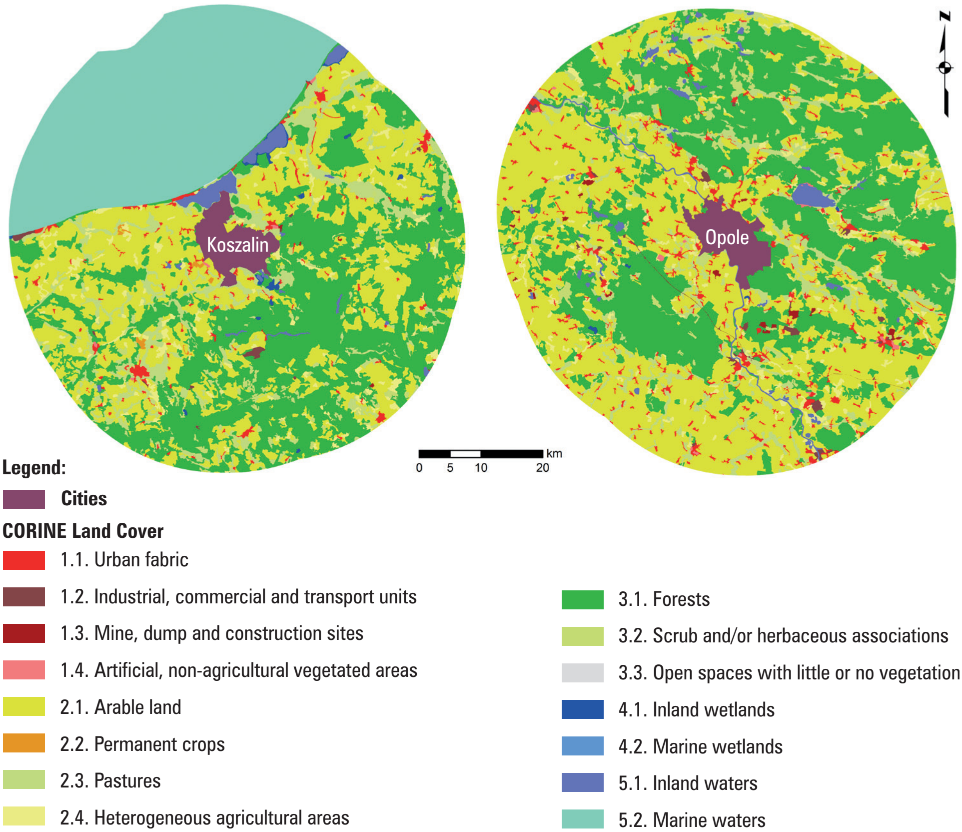
On the basis of the development of these technologies, many databases and software tools for monitoring changes to space and land use have been set up. In addition to spatial data available on the European Environment Agency (EEA) websites, it is worth paying attention to the *Urban Atlas*, which contains spatial data concerning the functional zones of urban areas. Interesting information on the use of space can also be found in a set of data related to the *CORINE Land Cover* (CLC) project concerning the use of land based on all forms of use found on the European continent [Feltynowski 2016].

2. Determination of the range in terms of the area and databases

In order to investigate the dynamics of changes occurring in the structure of the landscape of transitional zones, we have decided to use *CORINE Land Cover* CLC maps of land use for the years 2006 and 2012. This is a data set created as part of the CORINE Land Cover project. It was a continuation of the CLC1990 and CLC2000 projects completed by the European Environment Agency (EEA), and its key objective was to further document the changes in land cover, and to collect and update comparable data in Europe [Bielecka 2007, Kizos and Koulouri 2010].

At the European level, both CLC2012 and CLC2006 were coordinated by the EEA, and the Inspectorate for Environmental Protection was responsible for performance at the national level [Poławski and Gąsiorowski 2011].

The detailed elaboration of land use forms that were adopted for analysis concerns the 2nd level of CLC, and is provided in the key to Figure 1. The various forms were distinguished within the framework of five main groups of land cover considered at the 1st level of CLC [CLC-2006, 2007].



Source: Authors' own work based on CLC data

Fig. 1. Examples of transitional zones delineated around the cities of Kalisz and Opole

It was assumed that the cities selected on the basis of demographic criterion would be considered for the study. This was due to the conviction that the population size, as the main originator of human pressure, is the appropriate selection criterion [Szymańska and Matczak 2002]. The analyses took into account Central European cities with average population from 80 thousand to 200 thousand inhabitants. It was concluded that for these cities, the dynamics of development of transitional zones might be the most visible.

Transitional zones are defined as a space contained in a buffer delineated from the administrative boundaries of cities to the boundary line set out with a radius of 30 km from these boundaries. An example of the delineated zones is shown in Figure 1.

In this way, 57 areas were specified, from which areas characterised by high resistance to human pressure were excluded. For the purposes of this study, the above-mentioned areas were considered to be those where land uses are constant and undergo no major changes over the years [Cieślak et al. 2016b]. Marine waters were included among such areas. A list of cities considered in the study along with the determination of their surface area within administrative boundaries, the number of inhabitants, and the surface area of the delineated buffer are provided in Table 1.

3. Methodology of research

For the obtained 57 transitional zones, three indicators were determined, informative of on the scale of landscape transformation. The adopted indicators were developed as part of the research into landscape fragmentation [McGarigal and Marks 1995]. These studies have a strong environmental inclination, and are based on the theory of patches and corridors [Forman and Godron 1986]. In the significantly transformed, cultural landscapes, among which the landscapes of transitional zones analysed for the selected cities should undoubtedly be classified, patches should be identified as fragments of space with a uniform use.

Based on this theory, indicators of the density of land use forms, shape, and diversification were selected for the purposes of the study into changes to the structure of the landscape of transitional zones.

As regards the analysis of the forms of land use, the *Patch Density (PD)* indicator was applied.

$$PD = \frac{n_i}{A} \cdot (10000) \cdot 100 \tag{1}$$

where:

n_i – number of areas with a uniform use (patches) within the studied area,
A – surface area of the studied area.

PD indicator may take values above 0, with no specified upper limit. This indicator shows the level of fragmentation of the land use. With the intensification of transformation of natural landscapes, there is a tendency towards diversification of the forms of land use up to a certain threshold. The level of demand for products and services that require various ways of management of this space has been on the increase [McGarigal and Marks 1995]. With this growing demand, the diversification of land uses increases up to the moment when the majority of the area under transformation is urbanised. Then, a sort of stabilisation of land use occurs, while the development of urbanisation takes place through the intensification of space use, e.g. increasing the density of the buildings, increasing the height of the buildings, and the development of underground structures.

The next indicator refers to the diversification of the shapes of patches i.e. fragments of spaces with uniform land use. This is the *Mean Shape Index* (*MSI*).

$$MSI = \frac{\sum_{j=1}^{n}\left(\frac{p_{ij}}{2\sqrt{\pi \cdot a_{ij}}}\right)}{n_i} \quad (2)$$

where:

n – number of patches in the landscape of patch type (class) i,
p_{ij} – perimeter of patch ij,
$j = 1, \ldots, n$ patches,
p_{ij} – surface area of patch ij.

MSI equals the sum of the land use perimeter (m) divided by the square root of land use area for each of the corresponding land uses, adjusted by a constant to adjust for a circular standard (vector) or square standard (raster), divided by the number of land uses of the same type; in other words, *MSI* equals the average shape index of land uses of the corresponding land use type.

MSI takes values higher than 1. *MSI* is equal to 1 when all patches of the corresponding patch type are circular (vector) or square (raster); *MSI* increases without limit as the patch shapes become more irregular [Howard 2005].

The last indicator refers to the diversification of space use forms. It is the *Simpson's Diversity Index* (*SIDI*):

$$SIDI = 1 - \sum_{i=1}^{m} P_i^2 \quad (3)$$

where:

P_i – proportion of the landscape occupied by patch type (class) i.

The value of the index may oscillate starting from 0, and approach 1. *SIDI* equals 1 minus the sum of the proportional abundance of each land cover type squared, across all land cover types.

SIDI equal 0 when the surface only contains 1 land use (i.e. no diversity). *SIDI* approaches 1 as the number of different land use types increases (i.e. patch richness, PR), and the proportional distribution of surface area among them becomes more equitable [Herzog and Lausch 2001].

Landscape metrics may be applied directly as a feature of spatial structure, or it may be interpreted in terms of the function or cause and effect [Roo-Zielińska et al. 2007]. The directions of their dynamics may be studied as well. The latter possibility may indicate the levels of the development of regions in which the studied spaces are located, and in combination with other indicators e.g. an increase in the surface area of urbanised areas, it may indicate the nature of the changes occurring within the space.

For the purposes of the analysis of landscape changes occurring in the suburban space of medium-sized cities of Europe, the described landscape indicators were calculated for the two points in time (2006 and 2012). Such an interval was dictated by the access to the CLC database. At the same time, this appears to be a good interval for the observation of changes occurring within the space.

Based on calculation results, descriptive statistics of the studied indicators were determined. Their minimum and maximum values in the sets, arithmetic means, and standard deviations were determined. Moreover, calculations of increases in particular indicators in the years 2006–2012 were conducted as well.

For the purposes of the present analysis, percentage increases in indicators in the years under analysis were calculated, with the year 2006 adopted as the baseline. Similarly, an increase in the surface area of urbanised areas (*Ua*) within the studied zones was calculated in relation to the same time points, and based on the CLC data.

$$\Delta P_z = \left(\frac{x_z^{2012} - x_z^{2006}}{x_z^{2006}} \right) \cdot 100 \tag{4}$$

where:

- ΔP_z – percentage increase, where *z* is, respectively, *PD*, *MSI, SIDI,* or *Ua*,
- x^{2006} – value for the year 2006,
- x^{2012} – value for the year 2012.

Results of the calculations are provided in Table 1; in addition, the country of the cities' location is indicated.

The obtained results of increases of the *PD*, *MSI* and *SIDI* indicators were compared with the increment of the urbanised areas within the studied city buffers, while examining the correlation between increases in landscape indicators and the increase in the surface area of urbanised areas.

4. Results

Results of the performed analysis indicated an increase in the studied indicators during the period from 2006 to 2012.

Even though the *PD* indicator did not change its statistical metrics, significant changes to the distribution of its values is apparent. In the year 2006, the indicator ranged from 0.25 (for Bermerha – 17) to 0.81 (Daugavpils – 41), with an average of 0.51 and a standard deviation of 0.14. In the year 2012, these values ranged from 0.26 (Olsztyn – 45) to 0.81 (Daugavpils – 41), with an average of 0.51 and a standard deviation of 0.14. On the other hand, having analysed the chart in Table 1, one can notice that the *PD* indicator presented a negative increase only for 14 studies objects, and zero value for one object. In the remaining 42 cases, there an increase of that index was observed, up to as high as 57.5%.

According to descriptive statistics, the *MSI* indicator did not change significantly either. In 2006, it ranged from 1.76 (Wolfsburg – 8) to 2.21 (Liberec – 35), with a statistical mean of 1.97, and a standard deviation of 0.09. In 2012, these limits changed slightly from 1.84 (Legnica – 46) to 2.22 (Liberec – 35) with an average of 2.04, and a standard deviation of 0.08. On the other hand, similarly to other indicators, having analysed Table 1, one may notice that the indicator, over a period of six years, reached a negative increase for only seven cities, while for the remaining 50, the increase was positive, with the maximum growth of 12.71% obtained by Osnabrück – 16.

Having summarised descriptive statistics for the *SIDI* indicator, it was concluded that in 2006, it reached values from 0.54 (Osnabrück – 16) to 0.80 (Saarbrelcken – 29), with an arithmetic mean of 0.69, and a standard deviation of 0.07. These statistics did not change significantly; with the exception of the minimum value of the set in 2012 at a level of 0.55 for the same city, and a replacement of the leader's position by Daugavpils – 41, neither the average nor standard deviation changed. Negative increases of the index were recorded more often than in the other indices – for as many as 25 cities. On the other hand, a maximum positive increase was observed at a level of 7.15% in Gera – 19 (Table 1).

Table 1. Percentage increases in urbanised areas and studied indicators for 2012 in relation to 2006

No.	City	Country	City area [m^2]	Population [M]	Buffer zone surface area [m^2]	Δ*Ua*	Δ*PD*	Δ*MSI*	Δ*SIDI*
1	Ludwigshafen	Germany	78528068.39	164718	4065669653.10	9.03	9.93	5.60	0.49
2	Potsdam	Germany	188744256.40	167745	4787288811.72	8.83	19.62	7.35	3.21
3	Falrth	Germany	63783050.94	124171	3835895925.63	9.70	4.25	6.47	–4.71
4	Ingolstadt	Germany	134236507.00	132438	4381180463.00	16.66	20.75	7.13	–4.37
5	Erlangen	Germany	77530516.24	108336	3998284677.57	11.81	11.44	6.61	–4.25
6	Oldenburg	Germany	104389022.00	163830	4074002780.10	24.11	14.95	6.31	–7.01
7	Regensburg	Germany	81022565.23	145465	3989175479.55	6.00	17.40	8.85	–4.10
8	Wolfsburg	Germany	206005147.60	124045	4621756444.49	9.34	3.01	12.65	3.51
9	Cottbus	Germany	165315589.80	99687	4567561156.48	4.88	31.02	3.66	–3.16
10	Walrzburg	Germany	88470585.62	124873	4095609056.09	15.01	2.04	5.01	–0.27
11	Pforzheim	Germany	99195550.13	122247	4082403685.95	9.94	0.30	6.22	–4.12
12	Ulm	Germany	119890251.30	122636	4379086185.19	12.46	4.68	5.55	–8.02
13	Koblenz	Germany	106687223.30	112586	4171323038.33	23.30	14.04	5.14	–0.80
14	Darmstadt	Germany	123805940.70	155353	4327905421.30	10.59	–3.24	4.28	0.32
15	Kassel	Germany	107694505.30	197984	4177971420.05	22.98	5.23	2.76	0.28
16	Osnabrück	Germany	121256753.80	162403	4260421568.14	31.53	35.70	12.71	0.89
17	Bremerhaven	Germany	72324976.77	114025	4271780005.54	7.09	14.40	9.22	–3.76
18	Salzgitter	Germany	226109410.00	101079	4988238474.04	10.76	0.23	7.33	1.18
19	Gera	Germany	152964430.30	96011	4507012552.10	9.56	57.51	6.28	7.15

Table 1. cont.

No.	City	Country	City area [m²]	Population [M]	Buffer zone surface area [m²]	Δ*Ua*	Δ*PD*	Δ*MSI*	Δ*SIDI*
20	Jena	Germany	114963827.40	109527	4181926680.80	11.35	51.46	5.73	4.19
21	Offenbach	Germany	45686710.66	123734	3740209685.92	11.20	–1.35	3.74	0.92
22	Heilbronn	Germany	100954440.40	122567	4326179991.12	12.27	–3.73	4.31	–2.54
23	Paderborn	Germany	181557359.70	148126	4644983179.69	20.65	5.14	3.02	–1.39
24	Siegen	Germany	116212087.80	102355	4328405371.77	13.86	–1.40	1.18	–6.73
25	Trier	Germany	119153993.20	114914	4405016513.87	26.71	2.56	6.04	–3.53
26	Gasttingen	Germany	118003606.70	118914	4254059865.53	16.48	7.92	6.34	0.15
27	Heidelberg	Germany	110193721.60	156267	4208763790.29	7.81	–2.87	5.01	–0.84
28	Hildesheim	Germany	93150212.95	101667	4041066987.06	8.62	0.34	3.30	0.68
29	Saarbralcken	Germany	170345328.40	178151	4686548598.99	13.95	3.42	4.80	–2.26
30	Reutlingen	Germany	88014669.53	114610	4325540248.25	9.01	8.82	6.59	–3.04
31	Olomouc	Czech Republic	103242405.40	101154	4333166237.75	0.20	–1.17	0.24	1.12
32	České Budějovice	Czech Republic	55675268.11	93513	4011479147.18	2.72	–0.27	–0.41	1.34
33	Plzeň	Czech Republic	138047659.40	169858	4322083956.20	2.06	0.64	–0.86	0.87
34	Hradec Králové	Czech Republic	105673543.80	92891	4073973896.99	1.10	1.25	–0.43	0.99
35	Liberec	Czech Republic	106130983.10	103288	4116926305.13	–1.06	1.66	0.41	–0.90
36	Pardubice	Czech Republic	82658782.07	89638	4221671006.70	1.33	1.39	–0.43	1.50
37	Ústí nad Labem	Czech Republic	94127006.19	93248	4303362749.17	0.96	6.16	–0.51	–0.51
38	Panevezys	Lithuania	49517117.88	97589	3838898802.91	–0.48	0.88	0.29	0.10
39	Klaipeda	Lithuania	89071507.16	158891	4157225504.61	0.76	0.96	–0.11	2.59
40	Siauliai	Lithuania	80856552.66	106847	4082236509.82	0.23	0.12	0.41	0.09
41	Daugavpils	Latvia	72129384.08	85286	3755994022.16	0.53	–0.21	0.22	4.26
42	Presov	Slovakia	70389680.21	89959	4023508363.85	1.79	–0.35	0.23	–0.04

43	Kielce	Poland	109529108.10	198046	4156538803.68	2.71	0.00	0.05	–0.42
44	Elbląg	Poland	79706752.49	121642	4589851420.08	5.38	–0.82	0.32	–0.20
45	Olsztyn	Poland	88221113.85	173444	4002717651.66	8.33	0.10	0.93	0.81
46	Legnica	Poland	56266710.84	100886	3984902867.51	4.57	–2.01	0.15	–0.62
47	Koszalin	Poland	98280518.02	107970	3811642808.94	1.01	0.75	–0.03	0.88
48	Tarnów	Poland	72305976.51	110644	4189638890.44	0.81	0.85	0.12	0.33
49	Zielona Góra	Poland	278329502.90	138711	3864938771.68	8.16	1.21	0.23	0.37
50	Gorzów Wielkopolski	Poland	85741668.66	123762	5017483279.90	3.45	0.79	0.42	0.23
51	Bielsko-Biała	Poland	124274513.00	172591	4009172244.14	9.82	3.90	0.78	0.65
52	Płock	Poland	87923716.43	121731	4286329059.86	1.03	0.28	0.35	0.53
53	Toruń	Poland	115562929.40	202689	4053602715.02	26.99	0.24	0.34	0.38
54	Włocławek	Poland	84208629.88	113041	4318820881.45	37.99	–1.63	0.97	–0.39
55	Rzeszów	Poland	116326041.50	185895	4367125604.82	64.30	–0.39	0.63	0.40
56	Wałbrzych	Poland	84641534.00	115453	4325013835.83	6.22	0.21	0.46	0.03
57	Opole	Poland	96438755.29	118931	4027531362.60	1.08	–0.38	0.18	0.46

Source: Authors' own study

5. Summary and conclusions

Based on the presented analysis results, it can be concluded that the urbanisation of suburban zones leads to structural changes in the landscape, which are proportional to the range of that urbanisation. Increases in the *PD*, *MSI*, and *SIDI* indicators are strongly correlated with the increase in urbanised area *Ua* (Table 1). However, it should be emphasised that an increase in the values of these indicators in the dimension of urbanised zones, in contrast to environmentally valuable spaces, has a negative connotation, as it indicates the intensification of processes, which are adverse to the landscape.

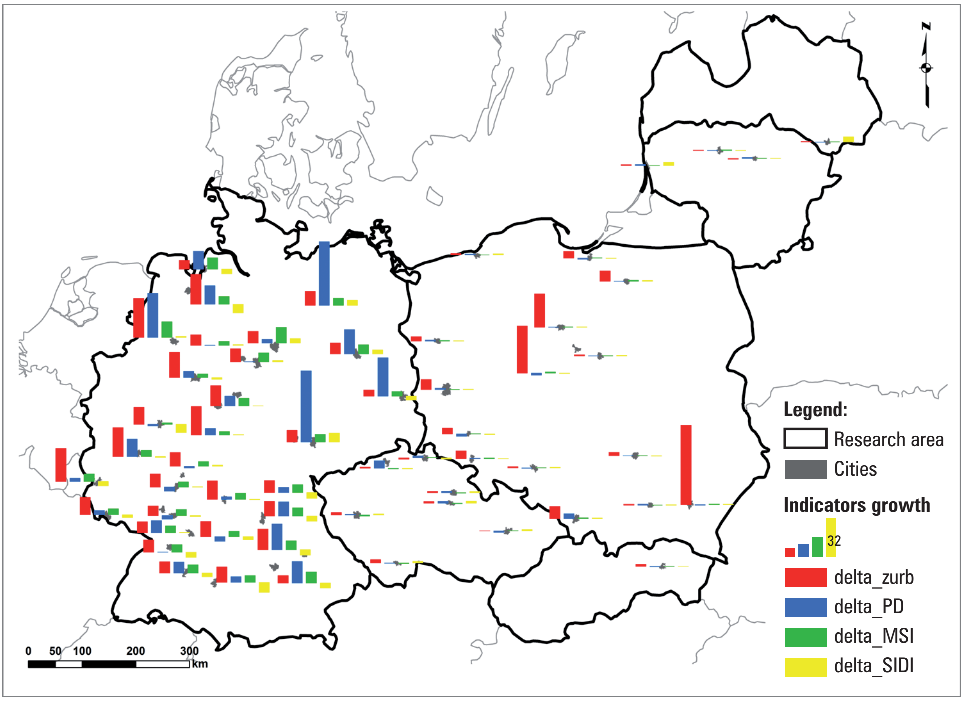
The increase in the *PD* indicators confirms the phenomenon of fragmentation of land use zones existing within the studies areas, which means that this space is becoming fragmented, and that – particularly for environmentally valuable spaces – implies their slow disappearance.

The increase in the *MSI* indicator represents chaotic development of land use zones, and aggressive emergence of other forms of land use. The planned and deliberate introduction of such development into the space is usually related to the smoothing of lines that separate different land uses. Where these lines are complicated, it usually means that the more aggressive forms have been penetrating into the space used for environmental or agricultural purposes.

Smaller increases for the analysed interval are observed for the *SIDI* indicator. This means that the number of land use forms is not increasing significantly. Considering the land use forms taken into account and complying with the CLC, their number is fairly stable and proportional to the surface area.

Attention is drawn to the clear division of cities based on the recorded increases in indicator values, and the location of cities. The first, rather significant conclusion is that half of the analysed cities, considered to be medium-sized, are located in Germany. This may indicate an increase in the density of the space of this category with cities of the western part of Europe, and a smaller effect of globalisation in the east-central part of Europe. Another conclusion arising after analysis of Figure 2 is that the indicator increases are closely linked with the location of cities within Europe. German cities are characterised by a significantly greater increase in the surface area of urbanised areas, greater increases in the *PD* and *MSI* indicators, and slightly negative increases in the *SIDI* indicator, which may indicate the accidental emergence of new forms of land use.

In a part of Central Europe represented by cities of Poland and Slovakian Presov, one may notice great increases in the surface area of urbanised areas, which do not yet translate into significant changes in the landscape indicators. The indicator increases are small.



Source: Authors' own study

Fig. 2. Spatial distribution of the increases in the *PD*, *MSI*, *SIDI*, and *Ua* indicators

Minimum changes to both the surface area of urbanised areas and the studied indicators can be observed in cities of Lithuania, Latvia, and the Czech Republic. On the one hand, a conclusion may be drawn that the landscape in transitional zones of these cities is stable, while on the other hand, the absence of an increase in the surface area of urbanised areas may indicate low development potential of these cities and their regions.

The performed analysis confirms the results of research into adverse changes in the landscape, caused by the phenomenon of urbanisation. The results also show differences in the development of various regions of Europe, and the still existing differences between the western part of Central Europe and the so-called Eastern Bloc countries.

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Dr inż. Iwona Cieślak
Uniwersytet Warmińsko-Mazurski w Olsztynie
Instytut Geoinformacji i Kartografii
ul. Prawochenskiego 15, 10-720 Olsztyn
e-mail: isidor@uwm.edu.pl
ORCID: http://orcid.org/0000-0003-4219-5718

Dr inż. Karol Szuniewicz
Uniwersytet Warmińsko-Mazurski w Olsztynie
Instytut Geoinformacji i Kartografii
ul. Prawochenskiego 15, 10-720 Olsztyn
email: karol.szuniewicz@uwm.edu.pl
ORCID: https://orcid.org/0000-0003-4048-2772

Dr inż. Szymon Czyża
Uniwersytet Warmińsko-Mazurski w Olsztynie
Instytut Geoinformacji i Kartografii
ul. Prawochenskiego 15, 10-720 Olsztyn
e-mail: szymon.czyza@uwm.edu.pl
ORCID: https://orcid.org/0000-0002-2957-1689