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Analysis of the Variation of the Areas Under Urbanization Pressure Using Entropy Index

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Abstract

Rural development is closely related to the transformation of land space in the immediate vicinity. The fast growth of Large Urban Zones (LUZ) entails rapid changes in land use not only within the city but also outside its territory, even covering whole regions. The impact of LUZ on social and economic communities living in areas close to the urban zones is noticed by many authors and it's especially manifested in forming and thus in land use. Based on these considerations, on the basis of free access spatial data and GIS technology, the authors tried to identify some relationships in the transformation of the structure of spatial capabilities in suburban areas. The study was based on Corine Land Cover (CLC) - surface data obtained by the visual interpretation of satellite images made at the request of the European Environment Agency (EEA), in order to monitor changes in coverage and land use in Europe. Collected in the previous campaign, and now updated every five years the data provide interesting and valuable source of information for analysing and modelling of spatial processes.
Based on the obtained data set, the authors using the entropy index, then an indicator of multifunctionality decided to capture the dynamics of change and indicate possible trends of development in the coming years. Definition of entropy follows directly from the Second law of Thermodynamics, and frequently researchers used this value to study the changes of states of various phenomena, including the dynamic development of the area under urbanization pressure. Based on the results obtained erected the argument that the high value of entropy, which is a measure of disorder, is associated with a greater diversity of the area, thus a confirmation of the high dynamics of changes in land use. The authors decided to analyze these issues based on comprehensive and standardized data sets, which is CLC.

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The purpose of the research was to develop a method to unify the perception of the structure of space, and consequently determine the rules and principles in its place. In the process indicate the space that was to become the subject of research based on the location of the cities that these areas interact. The methodology focuses on a comparison of Central European cities with similar populations, taking into account their choice of countries with diverse economic development.
The criterion relating to the number of inhabitants was introduced to the comparability of units and the areas they served. In order to indicate the variability of individual space conditions based on data from the years 2000 - 2012. The last phase assumed to build a forecast of transformations founded, another point in time.

1. Introduction

Urban areas and those in their immediate vicinity are subjected to the pressure of urbanisation, which causes continuous and dynamic changes in the ways they are used. Therefore, they pose an interesting object for analysis which, in terms of the suburbanisation phenomenon, aligns indisputably with the current trends in scientific research. Strong influence of urban centres on the functioning of suburban areas should be related not only to quantitative, qualitative and structural changes in how the space is shaped at a given moment, but also to the living standard of the residents, demonstrated in the growing environmental, social and economic cost of the processes taking place. This is acknowledged by a number of scientific publications, showing the unquestionably negative impact of urbanised areas on valuable natural land [1]. The development of suburban areas, which – due to historical reasons – used to have agricultural function, now involves the expansion of areas designated for non-agricultural purposes. In order to determine the nature and dynamics of the changes taking place in suburban areas, indicators are sought which allow a more precise description. An attempt to identify such processes is the introduction of the concept of multi-functionality of space, relating to the indeterminacy, ambiguity and uncertainty of those spatial systems [2]. Since, in addition to the internal features, the appearance of specific uses of space is also largely affected by random factors, reflected in various possibilities of use, a probabilistic approach should be applied in the presentation of the occurrence of individual states. This approach provides a basis to apply a measure of spatial disorder referred to as entropy, which allows taking into account the probabilities of occurrence of individual spatial conditions.

The concept of entropy was first introduced in 1867 by physicist Rudolf Clausius in conjunction with the formulated second law of thermodynamics. Through its importance relating to transformations, it is applied in many areas of science, allowing for more accurate descriptions of changes taking place in the systems under consideration. Accordingly, the idea of modelling of urban and rural areas using the entropy index emerged in the 1970s, following the Wilson’s publication (1970) [3]. The studies pointed out the usefulness and value of this tool in solving problems related to dynamic modelling of systems, location models, as well as the optimisation of systems and procedures.

The interest in analysing spatial conditions and comparing them in different points in time is reflected in many publications [4]. Furthermore, the versatility of the entropy index makes it possible to apply it as a measure of the degree of both organisation and chaos, homogeneity and diversity, usefulness or uselessness, order or lack of order in a variety of spatial structures relating to three aspects: location, process dynamics, as well as size and scalability [5].

2. Application of entropy measure and multifunctionality index

The application of the entropy measures and the multi-functionality index in analysis of spatial structure transformations in suburban areas requires the use of standardised data sets and GIS applications [6], which allow for the execution of the relevant spatial analyses. To this end, the data of Corine Land Cover, which are available free of charge and allow users to capture the changes in cover and space usage in Europe, was used. In order to define alternative functions occurring in the analysed areas, fifteen classes of land cover were applied, constituting the second level of data detailing for anthropogenic, agricultural and forested areas, wetlands and water areas. The data collected made it possible to determine the degree of spatial organisation at a given point in time. The next step involved generalisation in order to determine the overall cover area of individual land classes, which were then used to calculate the probability of specific land uses to occur at a given area, [7]. The above values were calculated with the following formula:

$$p_i = \frac{\mathrm{Pow}_{\mathrm{CLC}}}{\mathrm{Pow}_{\mathrm{CAL}}} \tag{1}$$

where pi: probability of occurrence of an i-th manner of land use; $\mathrm{Pow}_{\mathrm{CLC}}$: surface area of the i-th manner of land use, $\mathrm{Pow}_{\mathrm{CAL}}$: overall area of the area of study.

Afterwards, by referencing the individual probability values with the concept of entropy, defined by Shannon (.......) as the loss of information, it became possible to identify an average level of the spatial state indeterminacy using the following formula:

$$H = \quad c\sum_{i=1}^{n} p_i \log p_i \tag{2}$$

where *H*: mean entropy; *c*: constant, *pi*, probability of occurrence of and i-th manner of land use.

Based on the above formula, the entropy can take zero value, if the phenomenon studied is not random and involves only one possible manner of land use. However, for equally probable spatial conditions, entropy reaches its maximum value as determined with the formula:

$$H_{\mathrm{MAX}} = \quad c\log p_i \tag{3}$$

where H_{MAX}: maximum entropy; *c*: constant, *pi*: probability of occurrence of each manner of land use.

The last stage assumed determination of the multi-functionality degree as a measure of diversity of land uses in suburban areas, thus providing a complementary and universal factor. Because of its structure, it allows taking into account the above spatial parameters, enabling a comparison of a variety of spatial objects. The multi-functionality degree takes the values as in the following formula:

$$W = 0.01\frac{\mathrm{nH}}{P_{\mathrm{MAX}}H_{\mathrm{MAX}}} \tag{4}$$

where: W: is the measure of multi-functionality degree; n: number of maximum probability cases, P_{MAX} : maximum probability value of the manners of use; H_{MAX}: theoretical maximum value of the entropy of probabilities.

3. Results and Discussions

The study focused on the analysis of suburban areas of cities in Central Europe, with a similar population in the range of 100 to 200 thousand inhabitants. The assumptions made resulted in the choice of 63 cities with diverse territorial, social and economic potential, in Poland, Germany, the Czech Republic, Slovakia, Lithuania and Latvia. In the first place, while delimiting suburban areas, an assumption was made to study an area within 30 kilometres from the administrative borders of those cities. Such designated buffer zones allowed for the extraction of information on the land cover within them from the CLC database. The next stage of the research involved determination of the abovementioned multi-functionality indicators and, consequently the degree of multi-functionality itself. It should be noted that the performance of spatial analyses was possible thanks to the use of tools available within the GIS. For the research in question, the ArcGis platform created by ESRI was used. Processing of the results obtained involved visualisation with thematic maps applying Jenks Natural Breaks with division into five classes.

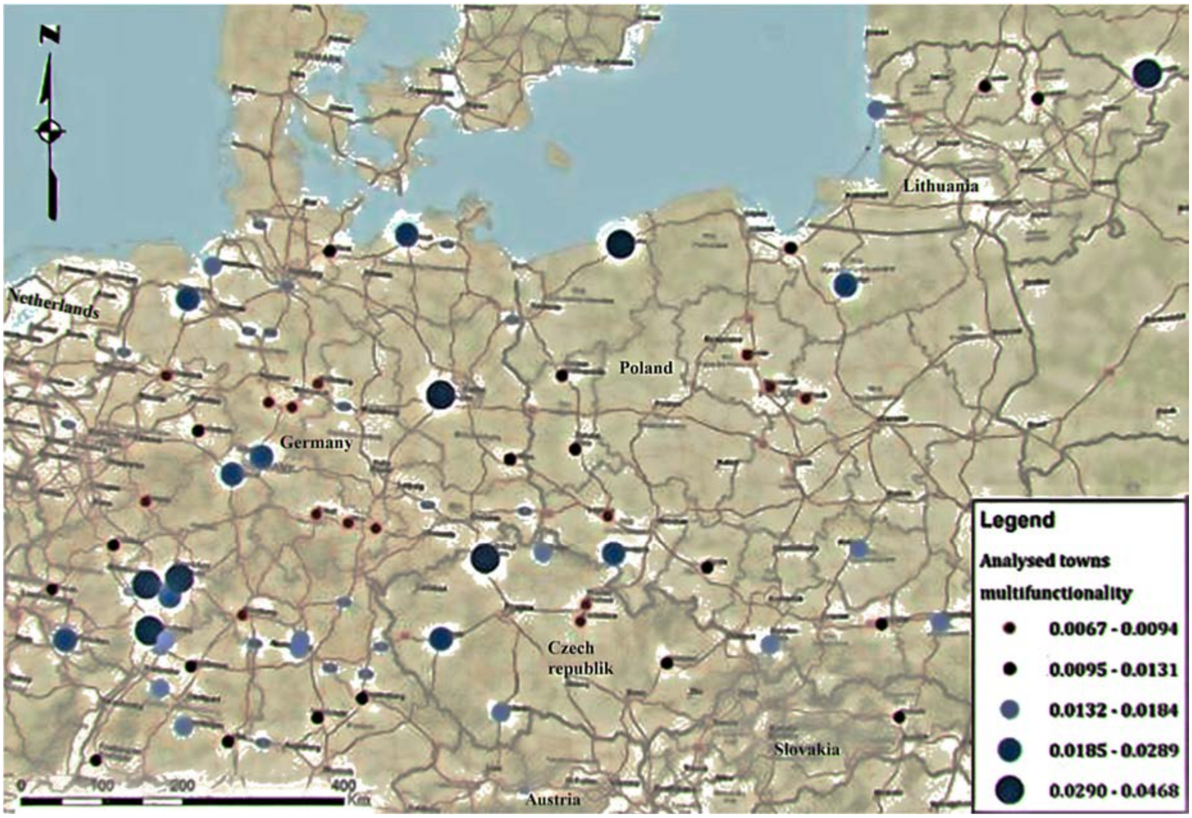

Fig. 1. Diversification of the multi-functionality degree map in the cities studied.

The spatial analysis performed, taking into account diversity degree of multi-functionality of individual suburban zones, showed the most numerous classes to include 19 areas for which the degree of multi-functionality falls in the range from 0.0095 to 0.0131. On the other hand, the smallest group, accounting for 7 zones, included the area for which the index values were the lowers, falling in the range from 0.0292 to 0.0468. The results obtained are more precisely presented in the table below and on the map.

4. Summary

The results obtained for the values of the degree of multi-functionality achieved point to the mono-functional character of the suburban areas analysed. This is acknowledged by the low index values in all analysed areas, the greatest being only 4.6%, as determined for the suburban area of the city of Potsdam. The reason for that is the clear domination of agricultural and forested areas in those zones. In order to increase the usefulness of said index as a tool for studying suburban areas, one should consider taking into account such elements as the effect of individual manners of use on the dynamics of the changes taking place, whether through exerted pressure or increased resistance to transformations.

Table 1. Summary of suburban areas taking into account the division into the multi-functionality index classes

Classes	City investigated	Multi-functionality index intervals
Class I	Osnabrück, Płock, Włocławek, Toruń, Erfurt, Walrzburg, Siegen, Hildesheim, Salzgitter, Legnica, Jena, Pardubice, Wolfsburg, Hradec Králové, Gera	<0.0067 - 0.0094)
Class II	Zielona Góra, Elbląg, Lalbeck, Gorzów Wielkopolski, Ingolstadt, Poniewież, Presov, Regensburg, Paderborn, Opole, Freiburg, Olomouc, Tarnów, Szawle, Koblenz, Cottbus, Ulm, Trier, Heilbronn	(0.0094 - 0.0131)
Class III	Erlangen, Rzeszów, Kłajpeda, Falrth, Pforzheim, Bremerhaven, České Budějovice, Kielce, Reutlingen, Liberec, Heidelberg, Bielsko-Biała	<0.0131 - 0.0184)
Class IV	Saarbralcken, Darmstadt, Gasttingen, Wałbrzych, Kassel, Plzeň, Olsztyn, Rostock	<0.0184 - 0.0289)
Class V	Oldenburg, Offenbach, Ústí nad Labem, Ludwigshafen, Koszalin, Daugavpils, Mainz, Potsdam	<0.0289 - 0.0468)

The set of values determined is characterised by low variability range, which might be proof of well-established structure of suburban areas of the cities that meet the assumptions made. For more accurate determination of the parameters of this structure, a more comprehensive analysis should be performed using detailed land coverage description provided at CLC level 3 [8]. Moreover, the measure developed allows for a more accurate analysis of the dynamics of the processes taking place, provided that its value is determined for individual points in time. The multi-functionality measure adopted is of universal nature and allows the comparative analyses of the development of individual settlement units. Note that some cities show a tendency to increase diversity in their suburban areas. This results in a higher than in other cases increase of the percentage of areas with anthropogenic nature, which diversify the suburban space to a greater extent.

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