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Short Communication

Land Use Structure as the Basis for Indicators Determining Spatial Development of the Environment

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Abstract

The transfer of urban spatial forms out of its center, as well as the uncontrolled expansion of large cities and urban sprawl have become a significant problem. These processes, especially when they occur in environmentally sensitive areas, may cause serious problems. The aim of this research was to propose – on the basis of land use structure – indicators that will quantitatively determine the characteristics of development of areas around large cities. Such indicators can be helpful in identifying issues and problems in spatial development of the environment.

Keywords: CORINE Land Cover, indicators, land use, spatial development, urban sprawl

Introduction

The system transformation in Poland after 1989 spurred the transfer of urban spatial forms and forms of life in the city out of its center, as well as the uncontrolled expansion of large cities and "spreading" of cities (urban sprawl) [1]. Even though the issues of suburbanization have already been discussed in numerous studies, the matter remains far from being fully explored. There are still many aspects left to investigate scientifically. What is more, research on metropolitan areas still poses countless questions and problems of a theoretical and empirical nature. The reviewed scientific literature indicates that the analysis of urbanization processes and of land use remains one of the most important areas of study on metropolitan areas in Poland [2, 3].

Scientific publications on this matter analyze various aspects of urban area development, with the focus being on social (demographic changes, migration), economic (investment plans, infrastructural and transport interconnection), environmental (degradation of the environment), planning (real-estate market, issued planning permissions), or spatial issues (changes regarding land use) [4-14]. Intensive and interesting research about evaluation of urban sprawl by using some landscape metrics has been carried out in recent years in China [15-18], but due to specificity and the scale of urbanization processes in this country, they may not relate to European conditions.

In former attempts to evaluate suburbanization in Poland the topical focus was mostly on social and demographic issues, with the most frequently analyzed indicators being: the population number, the average population density, or indicators concerning migration processes, the location of business entities, or of construction traffic [19]. Such an approach results not only from the complexity of the process, but also from the ways and methods of registering phenomena taking place in a suburban area – above all the topical range of studies and statistical indicators [20]. This is why the spatial aspect – in terms of land cover and land use – may constitute a significant approach in the analysis of suburbanization. By relating spatial connections and interdependence, data on land cover and land use may be perceived as an important factor of monitoring the changes that environmental management is subject to.

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Due to the fact that land use and land cover structure is the basis for defining indicators of urban sprawl in this research, it was reasonable to examine the current research on this field. Although lots of land use and land cover indicators have been developed and introduced for various applications in recent years [21-26], they don't directly concern assessing suburbanization and urban sprawl processes. However, some concepts related to them were used in this research.

Research Methodology

The zone that constituted the basis for evaluating land use in correlation to urban transformation was the Warsaw Metropolitan Area (Obszar Metropolitalny Warszawy), consisting of 72 communes (Fig. 1A). The researched surface area amounts to 6,205 km² which constitutes over 17% of the overall area of the Masovian Voivodeship. The investigated area boasts a population of 2,943,600, which represents 58% of the inhabitants of the Masovian Voivodeship [27, 28]. A database on land cover in Poland in 2006, created with the help of satellite photographs within the framework of the CORINE Land Cover program, served as the basis for drawing up a profile of land use in relation to suburbanization. Due to the adopted mapping detail the database presents land use forms for a minimum mapping unit of 25 ha with a minimum width of 100 m [29]. The ESRI ArcGIS software was used to perform spatial analyses and to make maps presented in the figures.

In the study it was assumed that land use on the study site would be divided into three categories. The first one was residential land on which the process of land development involves the densification of existing settlements or the extending and densifying of existing settlement grids. The second category covered areas on which the forms of land use could be changed – for instance from a rural area to developable land, which means it will be available for development. The third category consists of areas that were nondevelopable, be that due to their current use, environmental value, or legal status. Taking into account those conditions, the source data base was subjected to re-classification; as a result of the aggregation conducted for this study, a database was generated which consisted of three land use categories: residential land, nonresidential land, and nondevelopable land (Fig. 1B).

Publications and expert studies feature many indicators that can be used in research concerning urban transformation. Taking into account the research results and experience to date, the following indicators were adopted for the purpose of this study: residential density, continuity, concentration, and the degree to which different land uses coexist within the same area. [30-32]. The above-mentioned indicators have been calculated on the basis of a grid of basic spatial units of 1 km², into which the analyzed area has been divided. In addition, each base spatial unit has been allocated a weight reflecting the sum of the surface area of residential and non-residential land in the spatial unit (weight 1 for a base spatial unit with the sum of the area of those lands amounting to 1 km², 0.5 for 0.5 km², etc.)

Residential density is understood as the ratio of the average share of residential land to the sum of residential and nonresidential area in a commune. It seems that using those two classes of land use as a reference level to calculate residential density and not taking into account land that has been excluded from development renders this indicator more exact, as it means that the indicator considers only those lands in a commune for which there are no natural or legal barriers preventing the transformation into residential land. Residential density is calculated as follows:

$$G = \frac{\sum_{i=1}^{n} Z_i}{\sum_{i=1}^{n} S_i} = \frac{Z}{S}$$

...where:

G – is residential density (of a commune)

Z_i – is the area of residential land in basic spatial unit i

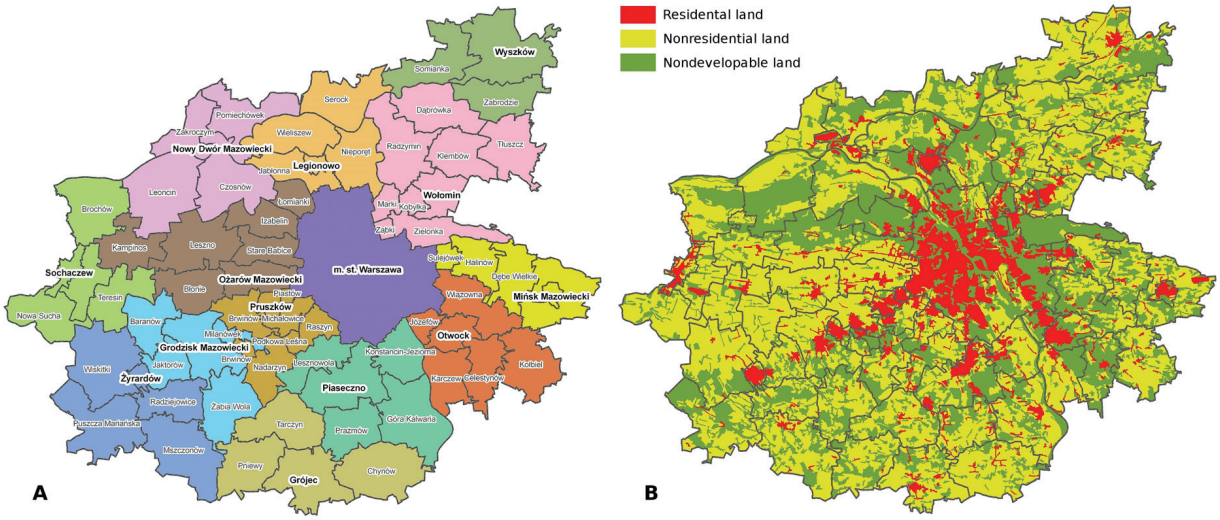

Fig. 1. Warsaw metropolitan area: A – administrative division, B – land use.

S_i – is the sum of the surface area of residential and non-residential land in spatial unit *i*
Z – is the surface area of residential land in the whole area (of the commune)
S – is the sum of the surface area of residential and non-residential land in the whole area (of the commune)
n – is the number of spatial units (in a commune)

One of the indicators important for the evaluation of land use is the continuity of development of land, that is the degree to which land has been developed – to a certain level of density – in an unbroken fashion. The continuity of development has been calculated as follows:

$$C = \frac{\sum_{i=1}^{n}((D_i \geq \frac{\sigma}{2}) \rightarrow w_i, (D_i < \frac{\sigma}{2}) \rightarrow 0)}{\sum_{i=1}^{n} w_i}$$

...where:
C – is the continuity
G_i – is the residential density for spatial unit *i*
w_i – is the weight of spatial unit *i*
n – is the number of spatial units (in a commune)
σ – standard deviation of the value of residential density for all basic spatial units for the entire Warsaw Metropolitan Area

Both density and continuity of development are not enough to yield a complete picture of the spatial distribution of buildings. Two areas may boast similar density and continuity indicators, but they may still be different in terms of the concentration of housing units. As a result, it became necessary to broaden the analysis of land use by introducing the indicator of concentration, which defines the degree to which housing units are disproportionately located or spread in a commune (but not including nondevelopable land) and which shows the level of concentration of development. The concentration indicator is calculated on the basis of the coefficient of variation as follows:

$$K = \frac{\sqrt{\frac{\sum_{i=1}^{n} w_i (G_i - G)^2}{\sum_{i=1}^{n} w_i}}}{\frac{\sum_{i=1}^{n} w_i G_i}{\sum_{i=1}^{n} w_i}}$$

...where:
K – is the concentration of development
G_i – is the density for spatial unit *i*
G – is the density for the whole area (of the commune)
w_i – is the weight of spatial unit *i*
n – is the number of spatial units (in a commune)

The last indicator considered in the study and reflecting land use in circumstances of suburbanization is the co-occurrence of land uses in a given area, which is the degree to which various forms of land use exist together on relatively small areas within the same commune. The coexisting land use indicator is calculated as follows:

$$W_{(a_1,..,a_m)} = m \frac{\sum_{i=1}^{n} \sqrt[m]{w_i \prod_{j=1}^{m} G_{a_j i}}}{\sum_{i=1}^{n} w_i}$$

...where:
W – is the co-efficient of co-occurrence of land use forms on the studied area
m – is the number of coexisting land cover forms taken into account in the study
G_{aji} – density of land cover form a_j within spatial unit *i*
w_i – is the weight of spatial unit *i*
n – is the number of spatial units (in a commune)

Unlike for the three former indicators, in the case of mixed uses the density of a land use form is calculated as the relation of the area on which this land use is applied in a particular spatial unit to the sum of areas on which all other land uses, taken into account in the study, prevail. This is formulated as follows:

$$G_a = \frac{S_a}{\sum_{j=1}^{m} S_j}$$

...where:
G_a – is density of land use *a*
S_a – is the surface area on which land use *a* is applied – within the given area
S_j – is the surface area on which land use *j* is applied – in the whole area
m – is the number of coexisting land uses taken into account in the study

The values of all four above-mentioned indicators are contained in a range of <0,1>. In order to ensure a clearer understanding of the matter, the indicators have been expressed as a percentage for all communes of the Warsaw metropolitan area.

Results and Discussion

The Warsaw Metropolitan Area is characterized by a diversified share of developed land in the overall region. Next to communes with a high ratio of development, as in Legionowo (87.8%), there are communes where residential land constitutes only a small share of land use – for example in the Leoncin Commune (0.2%) (Fig. 2A).

Areas standing out in terms of a high ratio of development can be found in Warsaw – the central part of the metropolitan area (47.6%), as well as in the southeast, the south, and the northeast of Warsaw, which is clearly correlated to the communication tract Grodzisk Mazowiecki – Warsaw – Wołomin. Low degrees of residential development are encountered in the eastern, northern, and northwestern parts of the studied area and in rural communes south of the analyzed area.

A characteristic feature of the Warsaw metropolitan area is the relatively large amount of nonresidential land contained within. These may constitute a type of natural reserve of developable land. Nonresidential land covers 51.7% of the total surface area of the metropolitan area. The biggest reserve of developable land is located in communes to the west and the north of Warsaw, as well as in communes lying to the southwest of Warsaw (Fig. 2B). A smaller share of nonresidential land in the total area of communes can be observed in the closest vicinity of Warsaw.

Important biological, climatic, soil-protection, and landscape functions, as well as subjecting many areas to legal protection, has substantially impacted the structure and spatial distribution of areas that ought to be excluded from development. This class of land use could be attributed to 36.6% of the whole analyzed area and it dominated in communes with large protected forests (Fig. 2C).

The expansion of residential, office, and commercial buildings on the metropolitan area is reflected in the density of residential land. In the case of the Warsaw Metropolitan Area this particular indicator is extremely differentiated in terms of space (Fig. 3A). Areas with a residential density indicator of over 40% cover the centre of the metropolitan area, as well as communes located in the direct vicinity of Poland's capital. Clearly delineated clusters of high-density built-up areas also exist in communes adjacent to the city of Warsaw from the east, as well as those located on communication routes. In 19 communes – mostly rural ones, and above all to the southwest, west, and north of the metropolitan area – the built-up area density ratio is relatively low (less than 5%).

The continuity of development is another manifestation of suburbanization processes. In the case of the Warsaw Metropolitan Area the degree of continuity of development clearly correlates to the degree of density of housing units. The high level of the residential density coincides here with a high degree of the continuity of developed lands within a commune. This has been confirmed by an analysis of information featured on statistical maps (Fig. 3B).

Developed areas are characterized by a varying degree of concentration and clustering in particular communes. An even distribution of developed land and a lack of a clear concentration of residential land can be found on high density built-up areas with a high level of continuity. At the same time one may notice a clear concentration of residential land in communes with low density and low continuity values (Fig. 3C).

The result of urban sprawl processes is a differentiated level of co-occurrence of various land uses on a given area. In the Warsaw Metropolitan Area one may detect both cases of a high degree of diversification of areas with differing land uses, as well as areas where this co-occurrence is limited, whereas the structure of land use is uncomplicated. High levels of this indicator – in all three combinations – can be observed in the vicinity of the metropolis, which indicates a far-reaching heterogeneity of land uses on those areas. However, on the outskirts of the metropolitan area the co-occurrence indications are small, with the exception of the co-occurrence of nonresidential and nondevelopable land (Fig. 3D).

Conclusions

The current structure of land use in the Warsaw Metropolitan Area has resulted from numerous processes, including the expansion of residential housing, office and commercial buildings, and the extension of technical and communication infrastructure. Those transformations have affected size and spatial distribution of developed land, undeveloped and nondevelopable land, and the diverse levels of density, continuity, and concentration of housing within particular communes.

The indicator analysis points out that suburbanization processes contribute to the establishment of two basic types of spatial distribution of land use. The first one includes communes with a high level of residential density and continuity which, at the same time, lack any obvious concentration or clustering patterns. They are located in the centre of the metropolitan area and consist of Warsaw and communes surrounding the capital, tracts located alongside communication stretches, and enclaves separated from the high-density zone connected with Warsaw (Legionowo, Ząbki, Piastów, Podkowa Leśna, Pruszków). These districts are character-

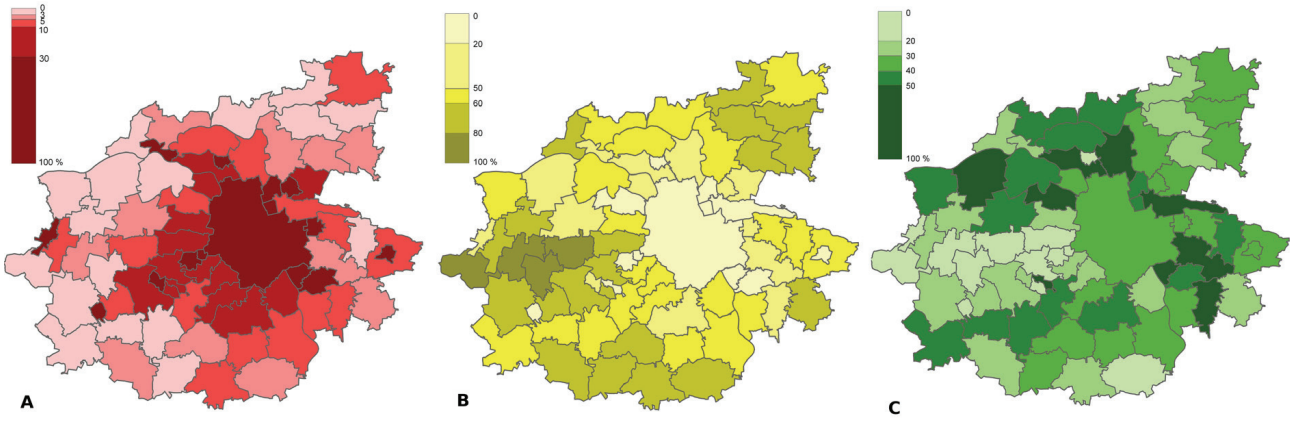

Fig. 2. Warsaw metropolitan area. Share of various land types in the overall area of a commune: A – residential, B – nonresidential, C – nondevelopable.

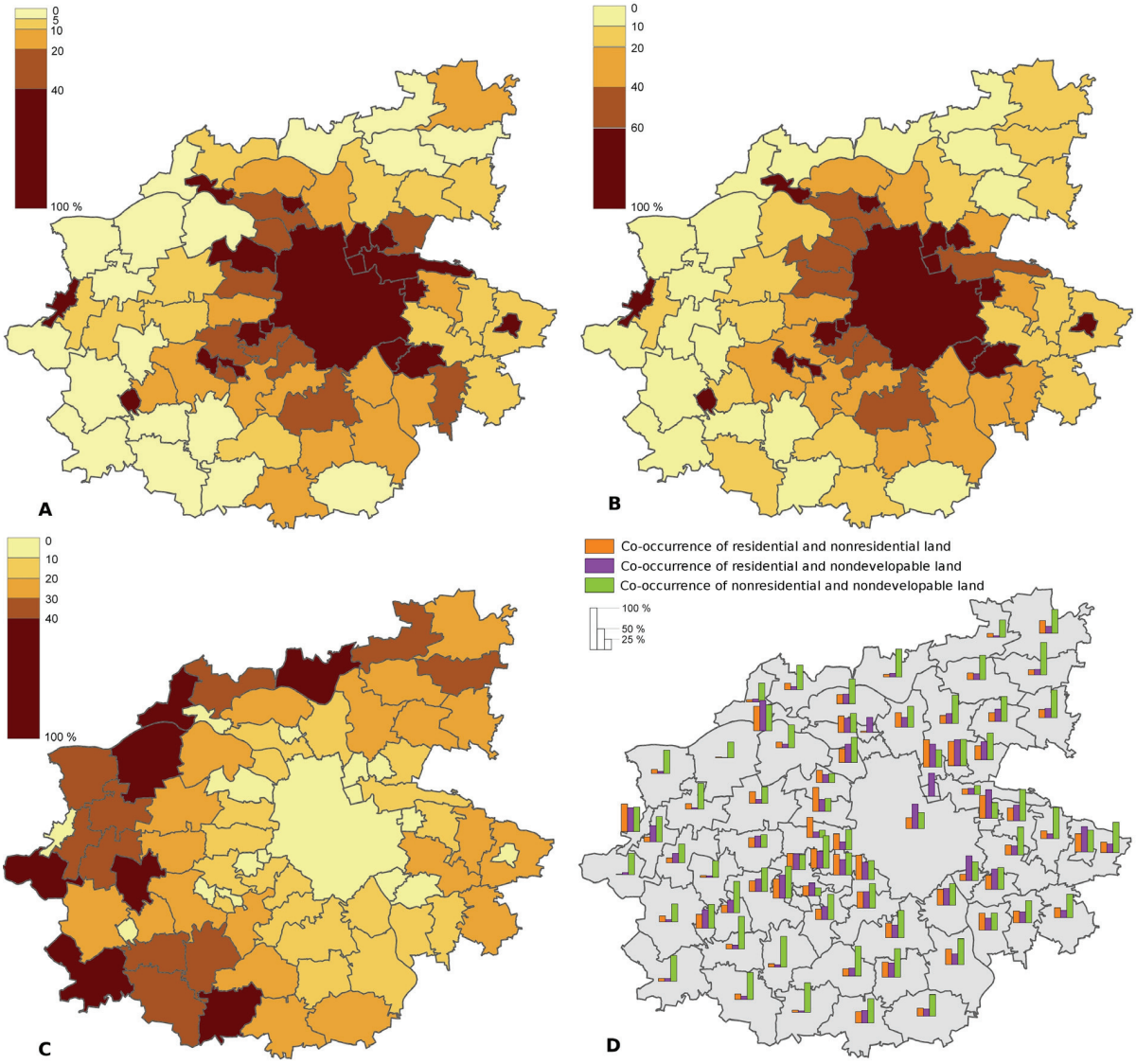

Fig. 3. Indicators characterizing suburbanization for the Warsaw metropolitan area O: A – residential density, B – continuity, C – concentration, D – co-occurrence of various forms of land use.

ized by a significant co-occurrence of residential land and nondevelopable land (mostly forests and water), which, in view of the insignificant share of non-residential land, translates into development pressure with regard to nondevelopable land. A completely different spatial distribution of land uses is found in communes located in the Northeast of the southern part of the Warsaw metropolitan area (as in the communes Dąbrówka, Somianka, and Chynów). These are typical rural communes that have a low share of residential area. Such a structure of land use is characterized by low levels of residential density and continuity. Another noticeable feature of such areas is a low level of co-occurrence of residential land with nonresidential land and nondevelopable land, which may indicate that those communes could become a potential area of residential development.

The implementation of a social and spatial planning policy and the management of metropolitan areas requires a broad and unbiased knowledge of the terrain. It would be worthwhile to make an attempt to build a hybrid model to analyze urban transformation and to work out a standard set of indicators that could combine the spatial aspect of land use with the social and economic dimension of land use. Moreover, the proposed indicators may constitute a solid basis for developing a complex suburbanization index to assess the urban sprawl process, which could be used for spatial management planning purposes.

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