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CHANGES AND CORRELATIONS IN LAND-USE STRUCTURE WITHIN THE ADMINISTRATIVE BOUNDARIES OF A TOWN – A CASE STUDY

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ABSTRACT

Urban areas continuously evolve. The main drivers of spatial change in towns and cities are urbanization processes. The aim of this study was to analyze changes in the process of urban development spanning a period of 30 years and to analyze the correlations between the distribution of various land-use types. The results were compared with the land use balance made in the 1970s. In the present study, the distribution of different land use categories in urban space was mapped with very high accuracy. The results of this study validate that areas with specific functions tend to coexist, whereas other areas exist separately in different parts of the town. Active urbanization processes were observed in the analyzed town. Developed and urbanized areas (mainly with residential functions) were significantly expanded in the analyzed period. The spatial and functional structure of the analyzed town and its development potential within the administrative boundaries are influenced by the geographic location, which significantly obstructs further expansion of developed areas. The proposed methodology can be used to improve land management in urban areas and can be implemented in other spatial units.

Key words: land use, urban change, Spearman's rho, Geographic Information System, succession of functions

INTRODUCTION

Urban areas continuously evolve. The spatial development of human settlements is determined by natural conditions which play the key role in the establishment of cities and towns, initiation of new activities and changes in urban structures. Urbanization processes are the main drivers of spatial change in contemporary cities and towns (Słodczyk 2001, Longley 2002, Araya and Cabral 2010, Amin et al. 2012, Onose et al. 2013, Feltynowski 2017, Senetra and Szarek-Iwaniuk 2019). The urban fabric is characterized by a succession of functions, where selected functions are rapidly replaced with other functions (Miszewska 2000). Effective urban planning requires a thorough understanding of the changes that take place in the rapidly evolving urban environment (Yang 2002, Sanchez 2004, Sancar et al. 2009). Developed areas in cities and towns have exerted irreversible changes in the natural environment. Developed areas are centers of social and economic activity, and they act as landmarks that give cities and towns their unique character. Undeveloped land is characterized by low levels of transformation of the natural environment, and it does not differ considerably from rural land outside the administrative boundaries

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of a city or town (Liszewski 1973). Various statistical and cartographic methods are used in studies of urban space. Geographic information system (GIS) tools support analyses of the rate of changes in space, but detailed rules for mapping spatial changes have not been proposed to date (Kałamucki and Buk 2010, Kuźma and Stachowicz 2016). While analyzing the city spatial structure, Matczak (1999) relied on a network of regular squares to analyze the land use structure and the co-occurrence of different land-use types in urban space.

Changes in land-use in urban areas are usually analyzed based on satellite data (e.g. Corine Land Cover), but the resolution of satellite images for small and medium-sized towns is generally low. These data sources are characterized by low accuracy and a high degree of generalization. The advantage of the research, based on space inventory presented by the authors, is a great precision of the distribution of selected land-use categories in city space.

The aim of this study was to describe changes in the process of urban development spanning a period of 30 years and to analyze the correlations between the distribution of different land-use types: residential areas, services, industrial and storage facilities, urban greens and recreational areas, other developed areas, water bodies, forests, agricultural land and other undeveloped land. The results were compared with the land use balance made in the 1970s (Grocholska 1973). In the present study, the distribution of different land use categories in urban space was mapped with very high accuracy. The results allow for tracking changes occurring in city space and evaluate the presence of particular land-use categories.

MATERIALS AND METHODS

Research area

The study was carried out in Ostróda, located in the Ostróda county, Region of Warmia and Mazury in Poland (Fig. 1). Ostróda has a population of 32,996, and it occupies an area of 14.15 km^2 (Central Statistical Office 2019). The town is situated in the Iława Lakeland whose geomorphological features were shaped during the last glacial period. There are five lakes, marshes and forests within the town's administrative boundaries. Ostróda has good access to public transport networks, which contributes to the development of the local economy, services and tourism. Its geographic location drives the development of built-up and urbanized areas. Numerous water bodies and marshes pose a barrier to spatial development (Fig. 2).

The sources of data and methods

The sources of data for the presented analysis were land-use maps developed in 1988 (Borejszo 1988) and 2017 based on detailed surveys and orthophotomaps. The maps are highly detailed and accurate.

The following categories of areas were used to classify land-use types in Ostróda:
- developed and urbanized areas: residential areas, roadways and transport networks, services, industrial and storage facilities, urban greens and recreational areas, other developed areas;
- undeveloped areas: water bodies, forests, agricultural land and other undeveloped land.

Due to the necessity to standardize the legends of both maps, for the research on land-use changes in 1988 and 2017, forests and agricultural land were included in the category: other undeveloped areas.

The analysis relied on cartographic and statistical methods, and data were processed in ArcGIS and Statistica software. Cartographic and statistical methods were deployed in the first stage of research (land-use structure and changes). The source materials (the map of 1988, survey results and orthophotomaps for generating a valid land-use map) were calibrated and subjected to vectorization to produce a set of shape files with different land-use categories. The process of generating base maps is laborious and time consuming, but it accurately renders the spatial structure of the examined area. A spatial database containing information on land use in 1988 and 2017 was developed. The resulting data were used in calculations to determine the main changes in land use in the analyzed period.

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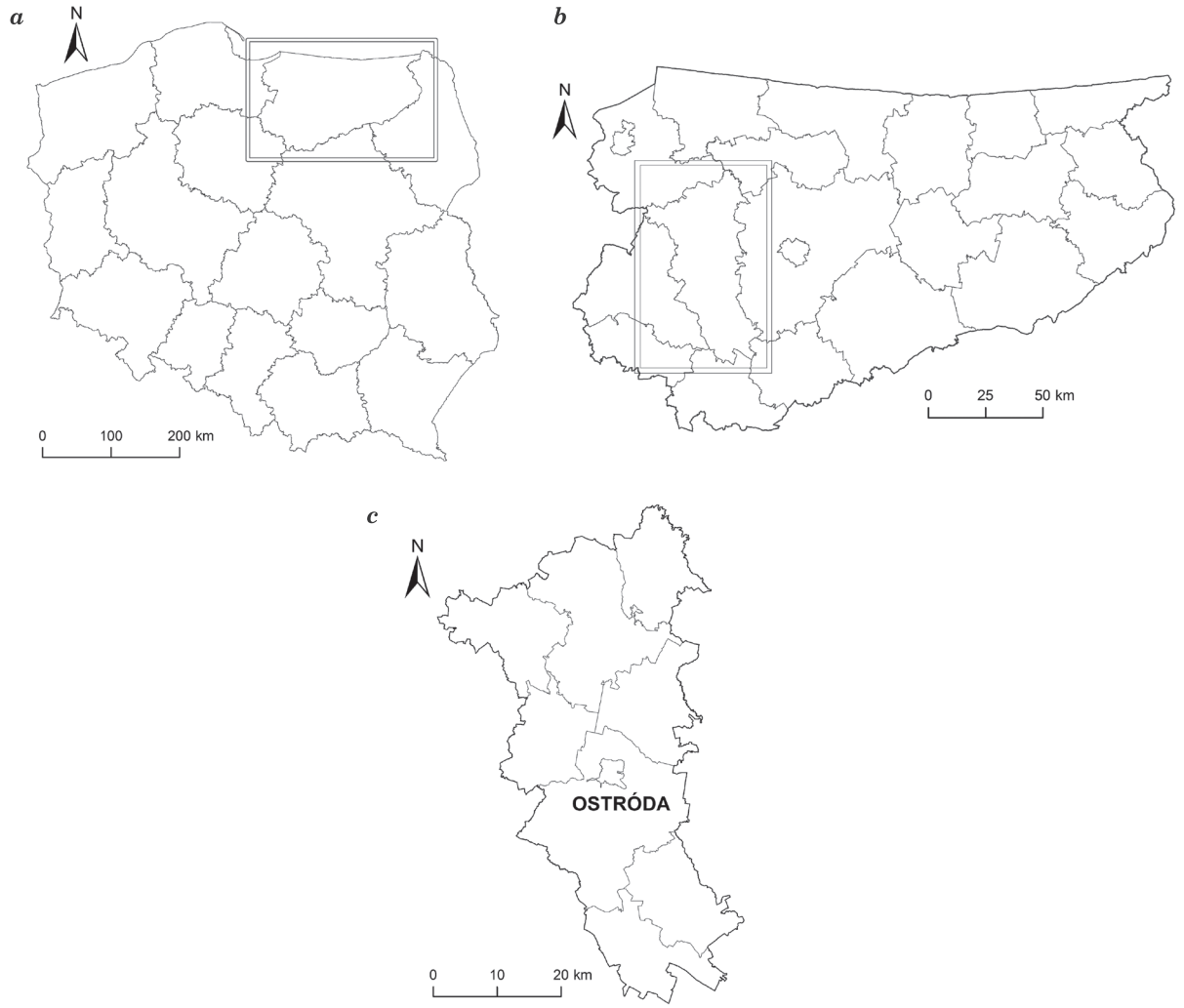

Fig. 1. Area of the study: *a* – location of the town of Ostróda in Poland; *b* – the region of Warmia and Mazury; *c* – Ostróda county
Source: own study

The co-occurrence of different land-use types was determined in the second stage of the study. The map of Ostróda was overlaid with a grid of polygons measuring 500 x 500 m each. The size of the polygons supported a detailed analysis of the study area. A total of 79 polygons were created, and each polygon was assigned a unique name (Fig. 3). The area occupied by every land-use type was calculated inside every polygon. The resulting data were exported and processed statistically, including the correlation analysis.

The co-occurrence of different land-use types was evaluated by Spearman's rank correlation analysis (Spearman`s rho). This non-parametric measure assesses the monotonic relationship between random variables. The values of Spearman's rank correlation coefficient range from -1 to 1, where a positive value denotes the presence of a positive correlation, and a negative value denotes a negative correlation. Spearman's rho represents the correlations between different land-use types. In this study, the results were regarded as statistically significant at $p \leq 0.05$.

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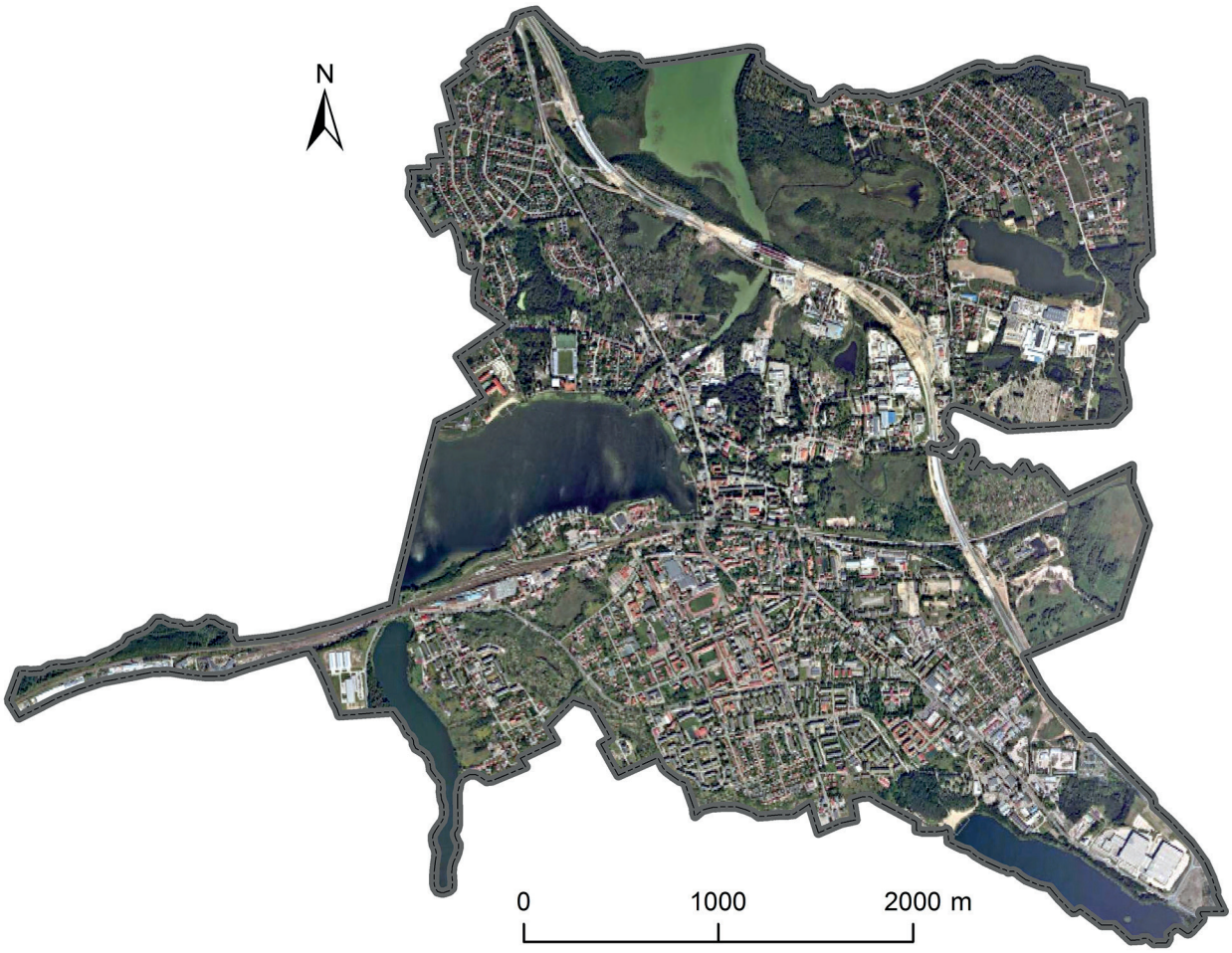

Fig. 2. Ortophotomap of Ostróda
Source: own study

Unlike Pearson's correlation coefficient, Spearman's rho can be used to evaluate non-linear relationships (Spearman 1904, Kendall 1948, Hauke and Kossowski 2011). Spearman's rank correlation analysis is deployed in geographic studies. Hauke and Kossowski (2011) compared the values of Pearson's product-moment correlation coefficient and Spearman's rank correlation coefficient as well as their statistical significance for different sets of data describing regional indices of socio-economic development. Spearman's rank correlation analysis was applied to test for a relationship between the mean land-use/land-cover change and the size of protected areas (Maiorano et al. 2008). The authors measured the changes in land-cover/land-use between 1990 and 2000 using two Corine land cover maps. The discussed measure was also used to investigate the relationships between land use and water quality (Tu 2011, Ding et al. 2015).

Changes in land-use were investigated over a period of 30 years, and the correlations between various categories of land in Ostróda were evaluated.

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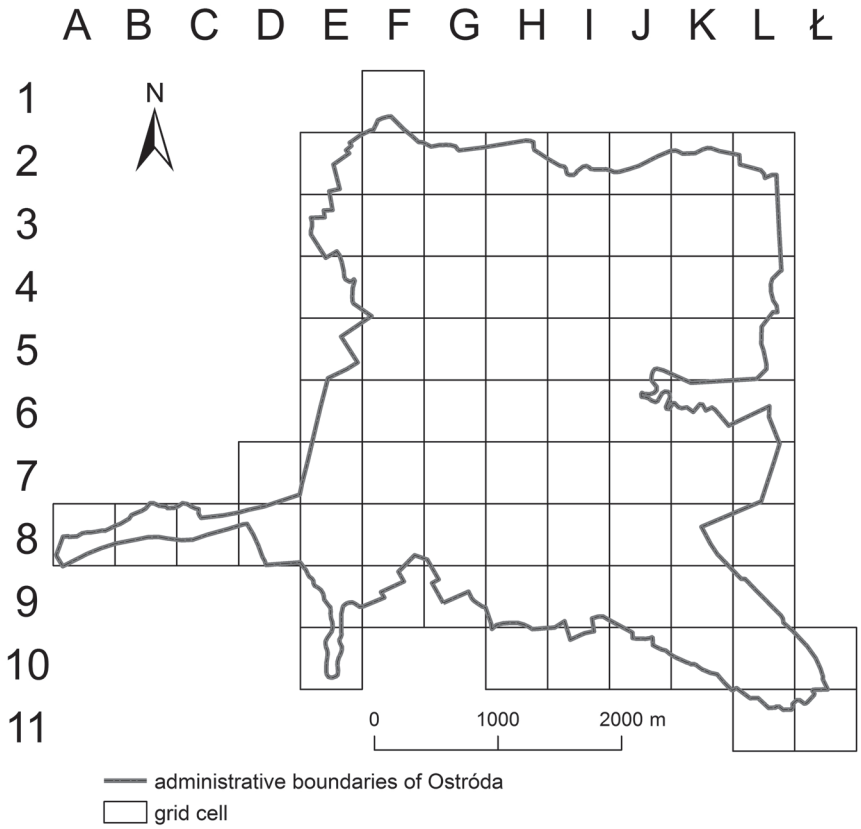

Fig. 3. The grid of polygons measuring 500 x 500 m overlaid on the research area
Source: own study

RESULTS AND DISCUSSION

Changes in land-use structure

Ostróda is a town with a favorable geographic location and good access to public transport networks, factors that drive its dynamic development. These factors have contributed to a steady increase in the proportion of developed and urbanized areas which covered 58.37% of the town's territory (8.26 km^2) in 2017. Urban growth is considerably affected by environmental factors, mainly the distribution of water bodies and terrain features. In some cases, environmental features pose a considerable barrier to growth, in particular in development projects covering large territories.

A comparison of land-use patterns revealed considerable changes between 1988 and 2017 (Fig. 4) . The area and proportion of undeveloped land decreased by 20% in the analyzed period which can be attributed mainly to urban expansion. Undeveloped land would have been depleted at a faster rate had it not been for the fact that the growth potential of Ostróda's urbanized zones is limited by the town's geographic location and the presence of lakes, marshes and protected areas.

Considerable changes were observed in the proportion of land occupied by services (whose area doubled) due to changes in the national economy after the political transformations of 1989. The area occupied by roadways and transport networks increased by approximately 30% as a result of technological progress and the growth of the automotive industry.

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The proportion of land occupied by industrial and storage facilities decreased in the analyzed period. Residential areas have the highest share of urban land use, and their share of total land increased from 34.4% in 1988 to 40% in 2017. In the analyzed period, the area of land occupied by residential functions increased by nearly 40% from 2.36 km^2 to 3.30 km^2. The share of residential areas in the total area of the town increased by 6.5% from 16.8% in 1988 to 23.3% in 2017. These changes induced a minor decrease in the area occupied by urban greens and recreational premises. In Ostróda, urban expansion is limited mainly by local physiographic conditions, and future residential projects are most likely to target developed and urbanized areas. The town also has a high share of undeveloped land (18.73%), mostly marshes, meadows and tree clusters (including Natura 2000 areas). However, most undeveloped land does not constitute a land reserve for future development projects. Ostróda abounds in lakes which occupy 14.2% (2.01 km^2) of its area. A high proportion of undeveloped lands, water bodies, services, urban greens and recreational areas as well as good access to public transport networks significantly contribute to Ostróda's tourism potential. An analysis of the share of uninvested areas in 2017 and its suitability for development also revealed that protected areas account for nearly 15% of Ostróda's territory (36% of undeveloped land).

The gained results were confronted with the land use balance in Ostróda from 1970 in order to broaden the time horizon (Grocholska 1970). One did not decide, however, on a direct comparison of the results in the charts or tables due to the fact that the author had considered different land-use categories. Moreover, in the group of developed and urbanized areas, one could distinguish only two categories: residential areas and roadways and transport networks. In this research, six categories were distinguished. What is more, the surface of the city was smaller by several km^2 in the time range between 1988 and 2017. In 1970, the city occupied 9.39 km^2, but in the research period, it was 14.15 km^2.

In the land-use structure in 1970, developed and urbanized areas were dominant. They covered 44.52% of the city space. The residential areas selected by Grocholska (1973) covered 37.17% of the city space and the roadways and transport networks covered 7.35%. Over a third of the city space (35.25%) was agriculturally used and 14.05% was covered with water bodies. In relation to 1970, the surface and the share of developed and urbanized areas increased in 2017. The agricultural area was marginal (0.21% of the city surface in 2017). The results show that the acreage of developed and urbanized areas, particularly residential areas, still grows and cover next larger areas previously used for agriculture or undeveloped

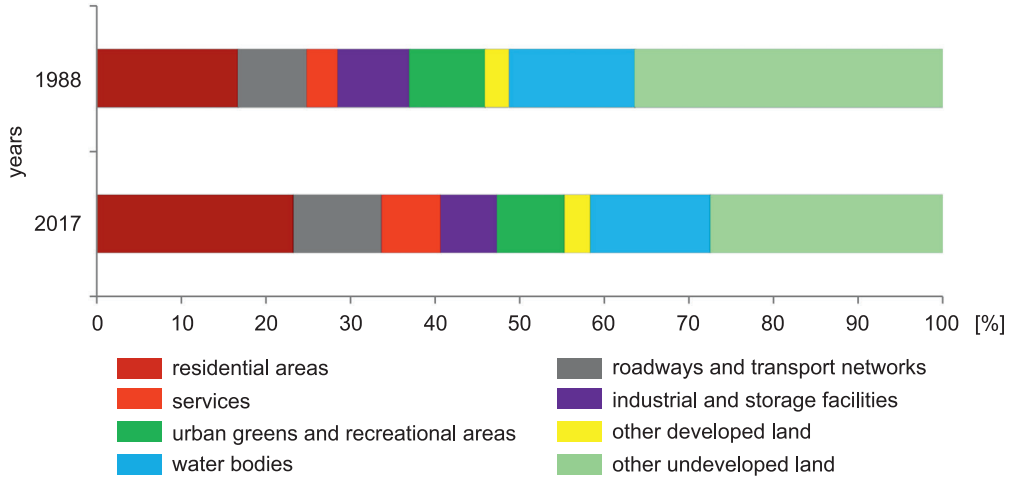

Fig. 4. Land-use structure in Ostróda in 1988 and 2017
Source: own study

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areas. These processes increase residential density in the existing residential areas, but they also lead to the development of residential functions on undeveloped land in the vicinity of the existing residential districts.

Co-occurrence of different land-use types

The co-occurrence of different land-use types in Ostróda in 2017 was measured by Spearman's rank correlation analysis (Table 1). Selected land-use types tended to coincide, whereas other land-use types existed in isolation; however, the observed correlations were not statistically significant.

The highest positive correlation was observed between residential areas and services (0.4614). This correlation is characteristic of urban space where residential buildings often host service outlets. Urban residents require access to commercial services, but also educational, health care and public administration facilities. A positive correlation was also noted between residential areas and transport networks (0.2074). The highest negative correlation was determined between residential areas vs. water bodies (-0.3138), other undeveloped land (-0.1807) and industrial and storage facilities (-0.1692). Transport networks were most strongly correlated with services (0.3870) and industrial and storage facilities (0.2974), and they were bound by a negative correlation with water bodies (-0.2416). Services were correlated mainly with residential areas and transport networks, and they were bound by a weaker correlation with urban greens and recreational areas (0.1468). Industrial areas tended to co-occur with transport networks (0.2974) as well as other undeveloped land (0.1724). Industrial facilities are usually zoned outside the urban core and residential areas, and they require good access to transport networks. Water bodies were weakly correlated with forests (0.0961) and were bound by negative correlations with most land-use types. The results of this study validate the co-occurrence of selected land-use types in urban areas which contribute to an improvement in the standard of living.

CONCLUSIONS

The land-use structure of an urban area is influenced by environmental factors as well as socioeconomic factors. The existing land-use types enable cities and towns to fulfill specific functions and create a supportive living and working environment for the local residents. The studied phenomenon can also be analyzed in a reverse direction – land management and the allocation of different activities to specific units of area lead to environmental transformations, mainly changes in water relations and the depletion

Table 1. Co-occurrence of different land-use types in Ostróda in 2017

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	**1.0000**	0.2074	0.4614	-0.1692	0.0536	-0.0346	-0.3138	-0.1400	0.1810	-0.1807
2		**1.0000**	0.3870	0.2974	0.0742	0.1802	-0.2416	-0.0771	-0.0410	0.0070
3			**1.0000**	-0.0054	0.1468	0.0911	-0.1554	-0.2735	-0.0656	-0.1352
4				**1.0000**	0.0198	0.0065	-0.0729	0.0103	-0.0633	0.1724
5					**1.0000**	0.0372	0.0026	-0.1331	-0.0615	-0.0027
6						**1.0000**	-0.0920	-0.1091	-0.0264	-0.0430
7							**1.0000**	0.0961	-0.0621	-0.1435
8								**1.0000**	-0.0633	0.1207
9									1.0000	-0.0911
10										1.0000

Key: *1* – residential areas; *2* – roadways and transport networks; *3* – services; *4* – industrial and storage facilities; *5* – urban greens and recreational areas; *6* – other developed land; *7* – water bodies; *8* – forests; *9* – agricultural land; *10* – other undeveloped land
Source: own elaboration

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of plant cover. This is an inevitable process because urbanization relies on vacant land reserves or minimally developed land. Sound urban planning solutions and local zoning plans prevent chaotic urban growth.

The changes in the land-use structure of Ostróda between 1988 and 2017 were driven by numerous factors, where the political transformations of 1989 and Poland's accession to the European Union played the key role. The spatial and functional changes associated with land-use allocation in the analyzed town revealed the greatest decrease in the proportion of vacant land as a result of progressing urbanization. The urban fabric of Ostróda was characterized by a succession of functions, where selected functions were replaced with other functions to cater to the town's burgeoning needs. The development of built-up and urbanized areas (mostly residential) is constrained mainly by natural barriers (water bodies, marshes, protected areas).

The results of this study and the existing planning documents suggest that only a small proportion of undeveloped land in Ostróda will be developed in the future. Most undeveloped land in the town does not constitute a land reserve for future development projects.

The obtained results constitute empirical confirmation of the observed phenomena, which confirms the validity of the adopted methodology. The proposed methodology can be used to improve land management in urban areas and can be implemented in other spatial units, including small and medium-sized towns, large cities, urban districts, and rural areas.

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