Forests as the Key Component of Green Belts Surrounding Urban Areas

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Abstract

The development of Polish cities leads to the urbanization of the surrounding rural areas. The National Urban Development Plan until 2030 has introduced the concept of obligatory green belts around metropolitan and regional hubs to prevent uncontrolled suburbanization. This study analyzes the distribution and spatial continuity of forests and the spatial relationships (spatial autocorrelations) between the forests situated in the rural suburbia of Olsztyn, north-eastern Poland. The aim of the analysis was to evaluate the spatial continuity of forests by grouping similar objects and identifying areas which could be included in green belts. The location quotient (LQ) and the Gini coefficient were taken into account in the analysis of the spatial distribution of forests. Local Moran's statistics were calculated and spatial clusters were identified to illustrate the diversity of the examined suburban space based on the similarity of the neighbouring objects (cadastral districts) and to determine the statistical significance of these relationships. The results of the study reveal spatial irregularities and disproportions in the distribution of forests in the suburban zone of Olsztyn as well as the presence of local instabilities and discontinuities. The municipalities surrounding Olsztyn are characterized by relatively high density of forests which build a green belt. The values of the location quotient in the analyzed cadastral districts and the values of the Gini coefficient point to moderately uniform spatial distribution of forests in Olsztyn suburban area. The low values of *LQ* in the districts situated along the eastern and southern boundaries of Olsztyn denote lower availability of forests and, consequently, lower quality of life. The applied methods are useful tools for evaluating, planning and optimizing the spatial distribution of forests around large urban centres.

Keywords: forest area, suburban zone, green belt, spatial concentration, spatial autocorrelations

Introduction

Progressive urbanization contributes to inconveniences in everyday life, including pollution (more traffic), higher transportation costs due to increased mobility, disappearance of green spaces, spatial chaos, difficult access to social infrastructure and lower standard of living. Most large European cities are deficient in green space, and the availability and quality of green areas are the key considerations in the choice of residential and recreational locations. Organised natural spaces, including forests, such as municipal forests, within urban areas and in their direct vicinity, improve the quality of life (Nielsen et al. 2017, Degórska 2012, Pluta 2010). Green spaces and forests in urban areas and the rural-urban fringe enable local residents to get in touch with nature, and they alleviate the negative consequences of urban life (Zhang et al. 2015). Urban green space is a key component of dense urban environments which considerably enhances the aesthetic value of large cities. The biological and health-promoting functions of urban green space have been described by Branas et al. (2011), Wolch et al. (2014) and Botchwey et al. (2014). These authors have emphasized the positive influence of urban greens on the health and well-being of city residents. According to Kemperman and Timmermans (2014), urban greens promote social interactions, and deeper and more meaningful interpersonal relations tend to flourish in areas that are abundant in greenery.

Green spaces also increase the prices of residential property in urban areas (Herath et al. 2015, Islam et al. 2012). The scarcity of land for the development of green infrastructure is one of the key problems in contemporary cities. Urban green spaces should be planned and developed with the involvement of local community members to promote social interactions and stabilize dysfunctional real estate markets (Schilling and Logan 2008). Obligatory green belts surrounding functional metropolitan and regional areas have been introduced by the National Spatial Strategy 2030 to counteract progressing urban sprawl and promote sustainable development (Resolution of the Council of Ministers No. 239 of 13 December 2011).

Green spaces in suburban areas are referred to as green belts. Green belts are composed mainly of forests (Konijnendij 2010) which are natural ecosystems with low levels of anthropogenic pressure. Green spaces with predominance of forests are one of the most important and most socially desirable components that influence the functional and spatial structure of urban areas and enhance the scenic appeal of cities. In addition to their high environmental value, urban green spaces improve the local landscape and add structure to urban systems. Green belts directly limit development and are regarded as one of the most restrictive local policy instruments which contain urban sprawl and contribute to the development of compact cities. The current approach to urban development promotes the construction of compact cities within administrative boundaries to minimize the uncontrolled growth of suburban areas and the degradation of rural green spaces. Green belts are important urban containment tools. Forests play a particularly significant role in this process, which is why they enjoy higher levels of legal protection than other green spaces. Forests restrict uncontrolled urbanization, but they are also under considerable pressure from investors, which is why their area has been decreasing gradually in many parts of the world. Despite their positive influence, forests can also contribute to leapfrog development (Siedentop et al. 2016, Gant et al. 2011, Whitehand and Morton 2003) in areas that are even further removed from the urban core.

The aim of this study was to analyze the distribution of forests in the municipalities surrounding the city of Olsztyn, a regional hub in northern Poland. The results were used to determine whether statistical indicators can be reliably used to plan and modify the spatial distribution of forests in functional urban areas. The spatial continuity of forests was evaluated in the municipalities situated in the Olsztyn suburban zone. The density and distribution of forests were analyzed in cadastral districts (villages) to determine the cohesiveness of areas that constitute the green belt of Olsztyn.

Green belts surrounding urban areas – concept and roles

Green belts surrounding urban areas are an effective tool in sustainable spatial development, but they are difficult to implement and manage. In line with the National Spatial Development Concept 2030 (MRR 2012), the green belt concept should be developed and implemented throughout Poland by 2033. Green belts are defined as open landscapes with cultural functions that should receive special protection on account of rapid urban sprawl rather than the need to preserve their existing values (Dylewski 2009). The National Spatial Development Concept 2030 emphasizes the importance of green belts in highly developed areas, in particular in functional urban areas. The strategy proposes to expand ecological corridors in large cities and to connect them with open spaces surrounding urban areas. Statutory protection should be granted to preserve the integrity and ecological status of areas with the highest natural value that remain under the direct influence of metropolitan areas (Resolution of the Council of Ministers No. 239 of 13 December 2011).

Urban planning principles were revolutionized after World War II when the need for sustainable development was recognized. Green belts are an important element of the sustainable development concept (Evans 2003). In functional urban areas, the ecological coherence of space can be improved through nature compensation. Great Britain is a good example of this strategy, where green belts have been created and maintained for more than 50 years. Green belts constitute a priority in urban planning (Chunyang et al. 2017, Zhang et al. 2016, Gant et al. 2011, Amati and Taylor 2010, Gunn 2007, Lloyd and Peel 2007). The significance of this concept has been recognized by many countries, and its applicability for urban planning and managing functional urban areas is studied in the ecological context. Green belts absorb carbon dioxide, store and purify water, improve the quality of public green spaces and recreational areas, and increase the quality of life (Amati 2008; Oleyar et al. 2008, Boentje and Blinnikov 2007; McPherson et al. 1997). Green belts effectively reduce traffic and industrial noise levels, and they should consist of plant species that absorb and are resistant to air pollutants (gaseous pollutants and dust). Green spaces in cities and the surrounding areas should be developed with the involvement of air-purifying plants (Karbalaei et al. 2015, Islam et al. 2012, Pathak et al. 2011). The loss of green belts surrounding large cities leads to profound and irreversible changes in the local landscape, lowers air quality and exerts a negative influence on local residents and social interactions. Privatization and investment processes contribute to the irreversible loss of green belts surrounding large urban cores (Manea et al. 2010, Boetje and Blinnikov 2007).

Community involvement plays an important role in the process of managing green belts and urban green spaces. The distribution and amelioration of green belts surrounding urban areas remain insufficiently investigated. Attempts have been made to determine the directions and the extent of measures aiming to reform the green belt around the London metropolitan area based on a survey of local residents (Amati 2007). Ineffective management of green belts surrounding urban areas has negative social implications, and it obstructs or contributes to the loss of recreational and sports facilities and playgrounds (Manea et al. 2010). The local authorities can promote social processes that contribute to the effective management of urban greens, including community recreation sites and tourist attractions (Murtini et al. 2017).

Surveyed area

Olsztyn is situated in north-eastern Poland, and it is the capital city of the Warmian-Masurian Voivodeship (Figure 1). Olsztyn is surrounded by six rural municipalities that are part of the Olsztyn Functional Urban Area. The population of Olsztyn is around 180,000, and the population of its functional urban area is estimated as 233,000.

Figure 1. Surveyed area - Region of Warmia and Mazury. Source: Own elaboration based on http://atlas.warmia.mazury.pl/lasy/

The population of the analyzed municipalities increased during the evaluated period (Table 1). In each municipality, population growth resulted mainly from residential construction and the inflow of new inhabitants who moved from Olsztyn to the suburbia.

Table 1. Relative population growth over the period of 1998-2015 within Olsztyn and the rural municipalities surrounding Olsztyn

Municipality	Increase in 1998-2015, persons	Relative increase in 1998-2015, %
Barczewo	1 780	20.88
Dywity	3 700	48.99
Gietrzwałd	1 244	23.57
Jonkowo	1 967	38.26
Purda	1 363	18.93
Stawiguda	3 165	65.80
Olsztyn	2 089	1.22

Source: Own elaboration based on Central Statistical Office data

A significant increase in forest area and a decrease in agricultural area were observed in the surveyed region between 1998 and 2015 (Figure 2, Table 2).

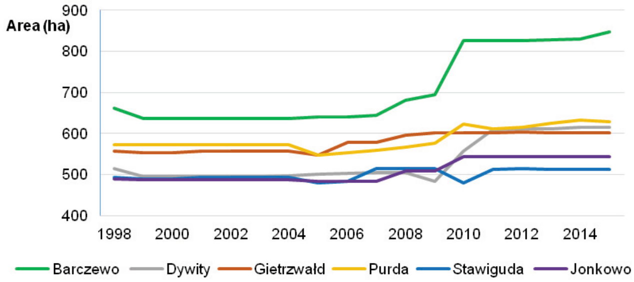

Figure 2. Increase in forest area in 1998-2015 in rural municipalities surrounding Olsztyn
Source: Own elaboration based on Statistical Office data

Table 2. Relative increase in forest area and agricultural area over the period of 1998-2015 within the rural municipalities surrounding Olsztyn

Municipality	Increase in 1998-2015, ha		Relative increase in 1998-2015, %	
	Forest	Agricultural land	Forests	Agricultural land
Barczewo	185.62	-128.00	28.02	-0.84
Dywity	100.60	-475.00	19.55	-4.89
Gietrzwałd	44.13	-366.00	7.92	-5.70
Jonkowo	54.19	-303.00	11.06	-3.58
Purda	57.07	-848.00	9.97	-8.00
Stawiguda	20.84	-278.00	4.23	-5.47

Source: Own elaboration based on Central Statistical Office data

According to the Regulation of the Minister of Regional Development and Construction of 29 March 2001 on the land and building register (ISAP 2016), forests constitute land defined as “forests” in the Forest Act of 28 September 1991 (ISAP 2018). Forests are defined as:

1) an uninterrupted stretch of land with a minimum area of 0.10 ha, covered with forest vegetation (forest nurseries), including trees, shrubs and undergrowth, or periodically covered with forest vegetation or devoid of forest vegetation: a) which is intended for forest production, constitutes a nature reserve or a part of a national park or a natural monument;

2) land intended for forest production or forest management, including buildings, structures, drainage systems, administrative boundaries, forest roads or tracks,

land occupied by power lines, forest nurseries, timber storage yards, forest parking lots and tourist facilities.

The observed decrease in agricultural area is also linked with the direct proximity of the urban core. Agricultural land in suburban areas is converted to residential, recreational, commercial and industrial uses.

Forests cover of the analyzed area is around 40%. Fertile, moist, loamy and nutrient-rich soils occupy the northern part of the examined region. Spruces, pines and oaks are the predominant tree species. Nutrient-deficient sandy soils predominate in the southern part of the analyzed area. These habitats consist mostly of fresh coniferous forests and fresh mixed coniferous forests which occupy around 50% of the area, as well as fresh mixed forests and fresh forests which occupy approximately 40% of the area. The most prevalent tree species are pines and larches which account for around 65% of all trees in the studied area. When combined with spruces, these three species accounts for more than 70% of the trees in the evaluated region. The proportions of the major tree species are presented in Figure 3.

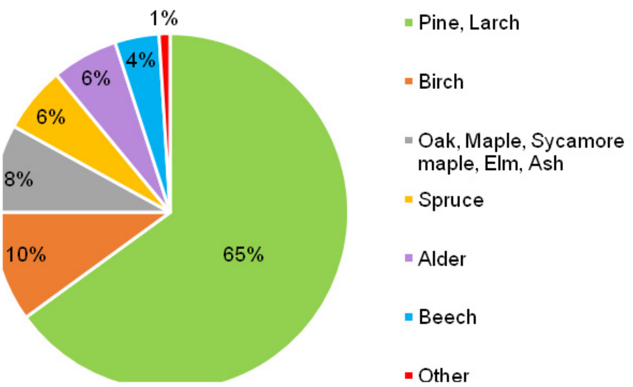

Figure 3. Species composition of tree stands in the evaluated area.
Source: Own elaboration based on the data provided by the Regional Directorate of State Forests in Olsztyn

Local habitat conditions and the species composition of tree stands are influenced by climate. The studied area has a continental climate with short summers and relatively long winters. The growing season lasts for around 190 days. Average humidity is 82% and average temperature is 7.5 °C (Forest Management Plan, Olsztyn Forest District 2015).

In the analyzed territory, forest area has increased steadily since 2005, which can be attributed to the forest management policy. The national forest management policy supports the afforestation of poor soils that are not suitable for agricultural production. Afforestation projects also contribute to rational land-use patterns and increase biological diversity (Kowalski 2014). In Poland, afforestation projects are implemented pursuant to the provisions of the National Program for Expanding Forest Cover (KPZL). The aim of the programme is to increase forest cover in Poland and to optimize the spatial and temporal distribution of forests. The afforestation needs of the municipalities situated in the Olsztyn suburban zone have been determined based on the provisions of the KPZL. The municipalities of Purda, Stawiguda and Jonkowo are characterized by the lowest values of the synthetic indicator of afforestation needs (2-10). Average values of the above indicator (10-15) were determined in the municipalities of Dywity and Gietrzwałd. The municipality of Barczewo, which witnessed the highest increase in forest cover (Figure 2), is characterized by the highest value of the analyzed indicator (15-21) (Lasy Państwowe 2016, 2017). In 1980, Barczewo, Dywity and Jonkowo had high afforestation needs, and the greatest demand for afforestation projects was noted in Jonkowo (Siuta and Żukowski 2017).

It should be noted that Olsztyn was characterized by high forest cover in both 1980 and 2016. The above can be attributed mainly to the fact that Olsztyn hosts the largest municipal forest in Europe with an area of more than 1,400 ha.

Materials and Methods

The spatial distribution of forests in the rural municipalities surrounding Olsztyn was analyzed in four stages as follows.

1. In the first stage, rural municipalities which are the parts of the Olsztyn Functional Urban Area were selected, and data relating to cadastral districts (villages) were statistically processed.

2. In the second stage, the distribution of forests was analyzed based on the values of the location quotient (LQ) (Suchecki, and Antczak 2010). Cadastral districts differ in area, which makes the results difficult to compare. This obstacle was eliminated by introducing a relative variable to calculations. To minimize the differences in the area of cadastral districts, a weight variable was introduced as the ratio of the area of a cadastral district to the area of a municipality. The distribution of the analyzed variable and the weight variable were determined by comparing their proportions. Forest density was calculated as the ratio of forest area in the analyzed district to the reference area. It was assumed that forest density would be identical in the reference area, which supported the identification of areas with a common resource. The location quotient was calculated according to formula 1 (Suchecki and Antczak. 2010):

$$LQ_k^i = \frac{u_k^i}{u_{kb}} \quad (1)$$

where $u_k^i = x_{ki} / x_{bi}$ is the proportion of forests in the k^{th} district in the total value of a given land-use category in a municipality, … is the proportion of the area occupied by *k* districts in the total area of a municipality (weight variable), x_{ki} is the value of aggregate variable *x,* the forest area in a district, x_{bi} is the forest area in a municipality, $\sum_i x_{ki}$ is the total area of different land-use types in the k^{th} district (area of a cadastral district), $\sum_k \sum_i x_{ki}$ is the total area of different land-use types in the municipality (area of a municipality).

3. In the third stage, the spatial distribution of forests was determined mathematically with the use of the Gini coefficient (*G*). The Gini coefficient is defined as the ratio of the area between the uniform distribution line and the Lorenz curve. *G* equalled to 0 corresponds to perfect equality (all elements of the surveyed population have an equal share of the resources, i.e. forest area is comparable in the surveyed districts). *G* equalled to 1 represents complete inequality (one element of the surveyed population accumulates all resources, i.e. all forests are clustered in a single district) (Preda et al. 2015). The higher the value of *G*, the greater the inequality. Values below 0.2 are generally indicative of low inequality. Values between 0.2 and 0.5 correspond to moderate inequality, whereas values higher than 0.5 denote significant inequality (Haidich, Ioannidis 2004). The Gini coefficient measures the distribution of the analyzed phenomenon relative to equal distribution in the total value of the analyzed variable (formula 2):

$$G = \left(\frac{2}{n^2\bar{x}}\right)\sum_{i=1}^{n}\left(\left(i - \frac{n+1}{2}\right)x_i\right) \tag{2}$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ n is the number of spatial units, x_i is the forest area in the i^{th} spatial unit.

4. In the fourth stage of the study, the values of local Moran's *I* statistic were calculated to identify differences in the suburban areas based on the similarities between the neighbouring districts and the statistical significance of those similarities. The local Moran's *I* is a local indicator of spatial association (LISA) statistic which determines the strength of correlations between the value of the analyzed variable in the surveyed spatial unit and the value of that variable in the neighboring units (subject to their proximity). This statistic represents the correlations between the global average for the entire evaluated space and the average values noted in the constituent units. It is used to detect clusters of spatial units with similar values of the analyzed variable (significantly above/below the cluster average) (Herbst and Wójcik 2013, Felcenloben 2011). Clusters group objects with similar distribution of the analyzed variable, and the local Moran's *I* denotes the significance of the spatial distribution of similar values in the vicinity of the examined object. The above supports an evaluation of the evaluated object similarity to the neighbouring units and the significance of that correlation (Janc 2006, Anselin 1995). Spatial units can have different values (Janc 2006):

- hot spot is the high value unit with high value neighbours (H-H),
- cold spot is the low value unit with low value neighbours (L-L),
- outlier is the high value unit with low value neighbours (outlier) (H-L), or the low value unit with high value neighbours (outlier) (L-H),
- the unit without significant local autocorrelation.

Local Moran's *I* index was calculated based on formula by Więckowska (2015):

$$I_i = \frac{(x_i - \bar{x})\sum_{j=1}^{n} w_{ij}(x_j - \bar{x})}{\sigma^2} \tag{3}$$

where *n* is the number of spatial units, x_i , x_j is the value of the variable for similar objects, $\bar{x}$ is the average value of the variable for all objects, w_{ij} is the elements of the spatial weights matrix, σ^2 is the variance, $\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$

A row-normalized, direct neighbour weights matrix based on the shared borders criterion was used in the calculations (Herbst and Wójcik 2013, Pietrzykowski 2011, Anselin 1995).

Results

The location quotient for the forest area in the cadastral districts (villages) relative to the total area of the surveyed municipalities is presented in Figure 4. The value of the location quotient increases with a rise in forest density in the analyzed spatial unit. The calculated values of *LQ* indicate that forests are not uniformly distributed in the areas that surround Olsztyn. Forest density was highest in the municipalities situated north and west of the city (Figure 4, red framed). This area borders the Municipal Forest which is situated within the administrative boundaries of Olsztyn. The Municipal Forest is a recreational area with two nature reserves, rivers (the Łyna and the Wadąg) and water bodies. The Municipal Forest is a protected area, which explains higher forest density in that location. Forest density was also higher in the southern part of the rural-urban fringe, but in these locations, forests were somewhat more distant from the urban core (Figure 4, violet framed). This part of the Olsztyn suburban area is characterized by a high rate of development, where large portions of agricultural land are converted into other categories of land use. The cadastral districts situated further away from Olsztyn are areas of high natural value (forests, lakes, and protected areas).

The low values of *LQ* in the districts situated along the eastern and southern boundaries of Olsztyn denote lower availability of forests and, consequently, lower quality of life. In contrast, forest density is high in the western and northern parts of the rural-urban fringe (Figure 4, yellow framed). The forests situated further away from the urban core have a smaller positive impact on the quality of life in the city, and the distance stimulates uncontrolled urban sprawl due to the absence of forests in the immediate vicinity of the city.

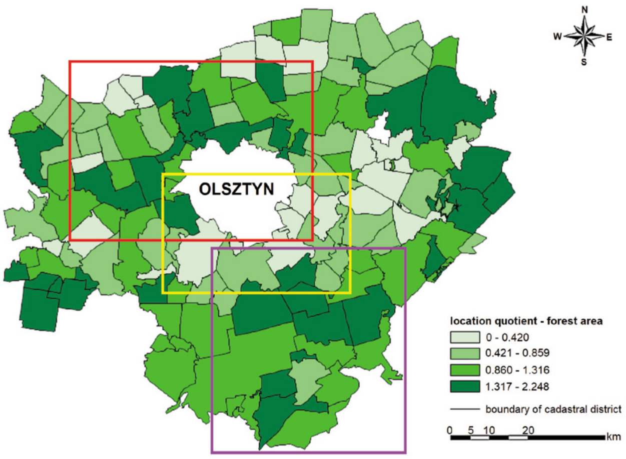

Figure 4. Forest distribution in the cadastral districts of Olsztyn city
Source: Own elaboration based on the Land Inventory kept by the Poviat Center for Geodetic Documentation and Maps in Olsztyn

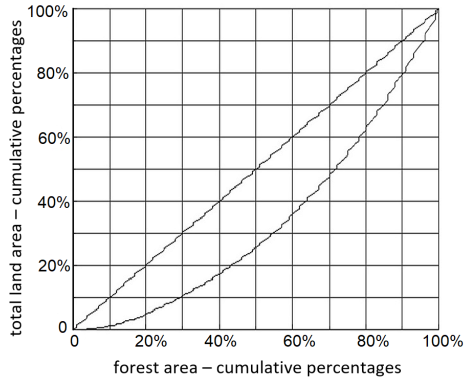

Figure 5. Forest distribution curve in the cadastral districts of Olsztyn city
Source: Own elaboration

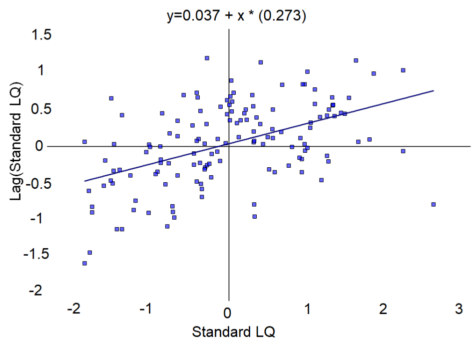

Figure 6. Distribution of Moran's I for LQ variables in suburban cadastral districts of Olsztyn city
Source: Own elaboration

The values of the Gini coefficient, determined with the use of the Lorenz curve (Figure 5), confirm the above observations. A *G* value of 0.333105 points to moderately unequal distribution of forests in the Olsztyn suburban zone.

The Moran's statistics calculated at a significance level of 0.05 are presented in Figure 6. The distribution of points in the scatter plot is relatively even, with a minor increase in concentration in the first (H-H) and third (L-L) quartiles, which denotes a positive correlation. The distribution of points in each quartile of the scatter plot is validated by Moran's *I* of 0.272672, which indicates a weak correlation.

Despite the above, the values of local Moran's *I* suggest the presence of clusters in the Olsztyn suburban zone. Local Moran's *I* statistic was calculated to determine the uniformity of forest distribution on the Olsztyn suburban areas and the presence of correlations between spatial units. Clusters grouping the cadastral districts with similar forest density were identified and correlated with the neighbouring districts. A cluster was defined as a group of the cadastral districts characterized by similar forest cover which are highly unlikely to appear at random. An identified and statistically significant cluster can be analyzed to determine the reasons for its appearance.

The values of local Moran's *I* illustrating spatial correlations between districts based on the distribution of the analyzed variable (location quotient for forests) are presented in Figure 7 and Table 3.

Table 3. Local Moran's *I* statistic for *LQ* variables for suburban cadastral districts of Olsztyn

Local Moran's I_i	
Variable	LQ
Significance	0.05
Number of objects	138
Average I_i	0.270
Standard deviation I_i	0.618
Cardinality (H-H)	10
Cardinality (L-L)	9
Cardinality (L-H)	1
Cardinality (H-L)	1

Source: Own elaboration

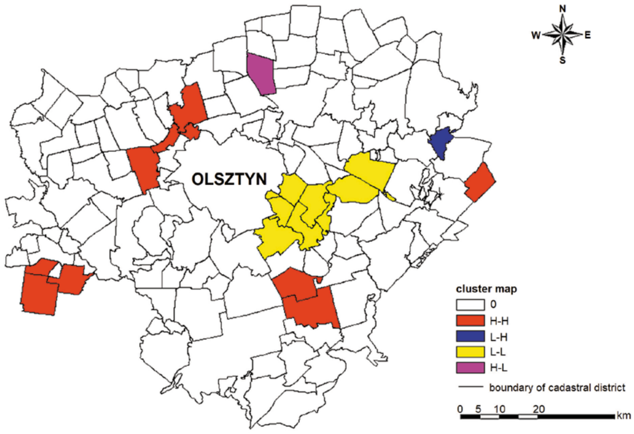

Figure 7. Local Moran's *I* statistic – cluster map of the Olsztyn suburban zone (suburban cadastral districts of Olsztyn city)
Source: Own elaboration

The presence of spatial autocorrelations between the evaluated variables was observed only in selected cases. In most cadastral districts, the analyzed variables were not bound by spatial correlations, as demonstrated by the prevalence of white areas with 0 values in Figure 7. H-H clusters denote districts in the Olsztyn functional urban area which are characterized by high values of the analyzed variable and are surrounded by similar districts. Their location indicates that these clusters are statistically significant and that they contribute to local inequalities. H-H clusters are found mainly in the north-western and southern parts of the analyzed area, which is confirmed by the calculated values of forest distribution and the Gini coefficient. L-L clusters also contribute to local inequalities. They group districts with low values of the location quotient, which are surrounded by similar districts. L-L clusters are situated along the south-eastern boundaries of Olsztyn. Single H-L and L-H clusters were also identified. The remaining units are not bound by significant local autocorrelations.

Discussion

The majority of research studies directly address urban areas (Daniels et al. 2018, Szczepańska and Wasliewicz-Pszczółkowska 2018, Stessens et al. 2017, Comber et al. 2008). Green belts in suburban areas have been analyzed in various contexts, including accessibility, temporal changes, structures and their quality, land-use planning and management policy (Fan et al. 2017, Siedentop et al. 2016, Fitzsimons et al. 2012, Amati and Yokohari 2006). Most authors rely on remote sensing and GIS tools.

Our study shows that in urban areas, green spaces are generally consolidated, well-managed and controlled ecosystems, but they are far more dispersed in suburban areas. This observation is validated by the results of this study which present the distribution of forests around the city of Olsztyn and point to the areas where urban development is limited. These limitations result from legal regulations and conservation measures, including changes in land use, ban on development in forests, establishment of nature reserves and protected areas, as well as growing levels of environmental awareness. These protective measures contribute to the preservation of forests and provide greater control over urban sprawl. Greenbelts are designed to protect compact urban areas and monitor urban sprawl, which has also been demonstrated by other authors (Bengston and Youn 2006, Bengston et al. 2004, Batty et al. 2003, Kühn 2003).

The results correspond to ones of most studies performed in other countries which indicate that green spaces and green belts are unevenly distributed and are gradually built up (Schweizer and Matlack 2014, Boentje and Blinnikov, 2007, Hasse and Lathrop 2003, Matlack 1997). New spatial planning concepts are needed to preserve green belts in suburban areas (Mace 2018, Cadieux et al. 2013). In many cities, new green belts are being developed to accompany various construction projects. Despite fierce competition for vacant land on the developer market, green belts often play a decisive role in urban planning. For this reason, urban development plans should incorporate stable and well-designed green belt systems and new components of urban green space. Such systems should deliver environmental, social and cultural benefits, and they should form corridors that connect green areas in the analyzed cities (Kowarik 2019, Zepp 2018, Chen and Den 2017).

Conclusions

The Olsztyn suburban zone is characterized by dense forests which are the main components of the city green belt. However, green belt components are irregularly distributed, and the densely afforested districts are found both in the direct proximity and further away from the city administrative boundaries. The greatest discontinuity in the green belt structure is noted to the south-east of Olsztyn. As a result, urban sprawl with a high share of multi-family homes, the least desirable housing units, which has been intensified in this part of the suburban zone.

In the analyzed area, urban development is concentrated in the municipalities that are adjacent to Olsztyn in the south and south-east.

The following detailed conclusions can be formulated with regard to the analyzed area:

1. The values of the location quotient in the analyzed cadastral districts and the values of the Gini coefficient

point to moderately uniform spatial distribution of forests in the Olsztyn suburban area. In most cases, the values of indicators representing natural elements are not very high due to rapid urbanization.

2. The municipalities surrounding Olsztyn are characterized by relatively high density of forests which create a green belt. Clusters of districts characterized by high forest abundance are found in the northern, north-western and western parts of the suburban zone in the direct vicinity of the city. In the remaining neighbouring districts, forests are removed further from the urban core.

3. The values (high and low) of local Moran's *I* point to local inequalities in forest distribution. The clusters of the cadastral districts with similar, both high and low, values were identified. Special attention should be paid to the Olsztyn south-eastern boundary which features an L-L cluster and low values of the location quotient. This area directly neighbours the city, and it represents a local discontinuity in the green belt surrounding the urban core. This is an exception because forest density in the studied area is considerably lower in comparison with the remaining areas.

4. The analyzed statistical indicators are useful tools for planning and modifying the spatial distribution of forests in suburban areas. Spatial discontinuities can be minimized and the quality of life can be improved through effective management of forest resources based on analyses and modifications of the presented statistics.

Based on the above conclusions, the following recommendations can be made regarding spatial policy and green belt management:

- forest cover should be maintained at the existing level or increased in districts which are characterized by the highest forest abundance and exert the greatest influence on the neighbouring units (H-H),
- the units with the lowest forest cover (L-L) should not be included in afforestation projects because these areas constitute the land reserve for urban development. Land zoned for development has to be maintained in the suburban areas to prevent the shrinkage of green spaces in cities due to dense development and to counteract leapfrog development,
- forest cover should be levelled out in H-L and L-H clusters to minimize the dispersion of forests and develop a continuous system of green spaces.

The above recommendations can be used in the process of developing local zoning plans and strategic planning documents in suburban municipalities. The formulated guidelines contribute to sustainable planning and development in areas surrounding the urban core.

The example of Olsztyn demonstrates that forests significantly impede housing development and that skillful forest management can influence the form, structure and planning of functional urban areas. The analytical indicators proposed and applied in this study can improve the effectiveness of forest management. These tools can be used to plan the location and size of green belts surrounding urban areas. A well-grounded green belt planning policy contributes to cohesive and sustainable development of suburban areas.

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