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Urban Green Spaces: how geospatial information can help identify diversity. A case study from eastern Lesser Poland

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Abstract. Progressing globalisation and suburbanisation are driving dynamic changes in land management, particularly in suburban zones. Green infrastructure and its impact on human quality of life are playing an increasingly important role in appropriate spatial management, because of human activities that are changing the natural environment. Therefore, monitoring and assessing the proportion of green spaces is essential for environmental, urban and social balance. The purpose of the study is to develop a method for measuring and monitoring the diversity of land cover classes, including green spaces as representatives of natural land cover classes. The proposed method describes the current state of land in quantitative and qualitative terms based on spatial data on land cover. The study employs Shannon's Diversity Index (SHDI) to empirically investigate land cover homogeneity. The intensity of the phenomenon was visualised in space using statistical hot spot analysis. The case study involves two cities in eastern Lesser Poland and districts adjacent to them. The results have demonstrated that the investigated areas have a highly heterogenic land cover. Basic assessment fields have exhibited homogeneity only towards large, green, agricultural, environmentally valuable and, often, protected areas. The results concerning urban green spaces comprise a set of data that constitute a valuable source of information to aid the development of informed urban-planning solutions under the sustainable development paradigm.

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Contents:

1. Introduction

1.1. Impact of human activities in urban areas

Growing populations, progressing urbanisation and economic, social and political changes have contributed to increasing the spatial anthropogenic footprint (Cegielska et al., 2018; Murayama et al., 2021). This is particularly true for large urban agglomerations (Patra et al., 2018) and their suburban zones (Kilper, 2018; Różycka-Czas et al., 2022; Wilkosz-Mamcarczyk et al., 2020). The development of large, densely populated cities that began in the twentieth century has become a global process (Georgi & Dimitriou, 2010). According to the UN (UNFPA, 2011), the expected 2000–2030 population growth of two billion people will concentrate in urban areas. Over 60% of the estimated global population (4.9 billion people) will live in urban areas by 2030 (Alberti et al., 2003). By 2050, the proportion may reach 84% (6.3 billion people) (Rydin et al., 2012). The intensification of urbanisation (Ramachandra et al., 2012) significantly affects the urban microclimate (Georgi & Dimitriou, 2010). Human activities in urbanised areas directly affect land use and land cover (Simwanda et al., 2020). They, in turn, determine biodiversity. Urban natural areas (green sites, forests) can be a bridge reconnecting people to the environment (Chaudhry et al., 2011) and improving the quality of urban life (Cetin, 2015; Szymańska et al., 2015).

1.2. Green urban infrastructure and urban green spaces

The ecological and social importance of green infrastructure increases as cities develop today (Pappalardo et al., 2017; Senosiain, 2020; Iváncsics & Filepné Kovács, 2021). The intensified interest in urban and suburban areas as places of intensive effort for climate and urban resilience (Rogatka et al., 2021) and sustainability action resulted in a number of relevant studies. Also significant is the policy-and-practice discussion on urban nature-based solutions. They can be considered a response to modern environmental and social challenges (Mabon & Shih, 2021).

Urban Green Spaces (UGSs) are referred to as the "lungs of the city" because of their role in attenuating temperature increases (Faqe Ibrahim, 2017) and reducing air pollution and the health issues to which it contributes (Darkwah & Cobbinah, 2014; Wilkosz-Mamcarczyk, 2017; Wolch et al., 2014). They are islands of cool and humidity, in particular in summer, which makes them an important part of the city. In the West, the landscape value of urban and peri-urban agricultural land has long been acknowledged (Lohrberg, 2001), as has its economic potential (Chaudhry et al., 2011). Increasing numbers of urban residents and policy-makers appreciate these benefits. This is reflected in today's spatial planning practices and policies in developed countries, including increased spending on the protection and management of green urban areas (Dorst et al., 2019; Grădinaru & Hersperger, 2019).

UGSs are essential constituents of the urban structure that enhance residents' quality of life and behaviour (Chojecka, 2014). For the purposes of the present research, UGSs include areas within cities and in the suburbs that have been substantially transformed due to anthropogenic pressure.

UGSs and suburban green spaces differ in terms of structure and role. As described above, UGSs provide residents with the opportunity to keep in touch with nature and improve the urban standard of living (Kalfas et al., 2022). Being an interface between the city and the countryside, suburban green spaces on the one hand expand due to urban growth and, on the other, provide a haven for agriculture and natural environment, landscape and cultural heritage (Fernández-Pablos et al., 2021; Lynch, 2021).

The UGS structure is dominated by artificial and semi-artificial features (Gong et al., 2020) including landscaped areas with structural forms of green spaces such as greenbelts, greenways, green-space networks, green ecological corridors, wind corridors and blue-green networks (Lang, 2015). By contrast, suburban green spaces are generally more natural environments with forests, shrubberies and agricultural areas (Belavilas et al., 2012).

1.3. Urban spatial planning and sustainable development spaces

Sustainable development (SD) is considered to be the primary strategy for global social and economic transformation (Shi et al., 2019). According to the definition of SD (WCED, 1987), spatial planning aims to transform the spatial structure so that it responds to social and economic needs while maximally preserving the existing qualities and resources of the natural environment (Wagner, 2016; Piotrowska, 2017;). The idea of resilient and sustainable development has made the issue of environmentally respectful urban planning even more universal and relevant (Affolderbach et al., 2019; Acuto & Leffel, 2021; Chang et al., 2021). Planning consultants need somehow to preserve the "tripartite balance". One of the toughest challenges of urban and suburban planning is to reconcile development with the appropriate shaping and protection of the natural environment (Koreleski, 2009).

If future cities are to become more sustainable, the environmental impact of urbanisation has to be minimised on global and local scales (Mabon & Shih, 2021). In the words of Dixon and Eames (2014), it is no longer a question of "if" but "how" to shift into a more environmentally-friendly economy. This is because proper agglomeration planning can minimise or even reverse the repercussions of urbanisation by integrating built-up and natural areas (Dobbs et al., 2017). Local spatial development plans include principles of environmental protection, public space regulation or preservation of spatial governance. They can provide dos, don'ts, and restrictions for land management (Kukulska & Gawroński, 2017; Balawejder et al., 2021). The provisions provide for the minimum proportion of vegetated areas and green spaces and their protection, which is of particular importance when the quick and chaotic development of cities drives the conversion of natural areas into other functions (Norton et al., 2015).

The practice of urban planning should seek a balance between anthropogenic and natural aspects. Such an integrating approach calls for the early inclusion of environmental aspects in the planning process. Local authorities and urban planning offices need tools to provide a quick and general overview of the current state and to investigate potential planning alternatives (Carsjens & Ligtenberg, 2007).

1.4. GIS for urban planning and urban green spaces monitoring

Space is a highly developed system, particularly in urban and suburban areas. Hence, one has to process diverse datasets to analyse it (Chen & Liu, 2022). GIS can capture and analyse physical, social and economic data concerning regions (Fotheringham & Rogerson, 2013). Then, planners can use GIS spatial query and map tools to design specific development scenarios for a particular space.

The main advantages of GIS for urban planning (Unearth, 2021) include:

- improved mapping and map currency (Moeletsi & Tesfamichael, 2018; Knevels et al., 2019), including increased efficacy of thematic mapping (Grecchi et al., 2013);
- easier access to vital information (Williams et al., 2014);
- improved communication leading to better performance of public administration; and higher quality and efficiency for public services (Navratil, 2020).

Moreover, GISs improve support for strategic decision-making (Unearth, 2021). Thanks to quick and easy access to a variety of spatial data, urban planners can efficiently design multidimensional concepts and strategies (Liu et al., 2020).

In recent years, experts and researchers have used diverse techniques and methods for urban planning and design based on GIS technology. GIS technologies are used to build a virtual urban planning model and improve the effect of urban planning (Zhu & Zhou, 2021). They facilitate the development of urban planning intelligent management (Z. Chen et al., 2021), help create models to reconstruct urban landforms (Wu, 2021) and significantly mobilise public participation in urban planning (Wang et al., 2021). The practical contribution of GIS tools to urban planning is that they offer a resource inventory; with remote images, urban planners can detect the current land use and land cover, as well as follow their evolution (Cegielska et al., 2018). Another rather obvious matter is land-use maps. With the various datasets, users can create layered images. Such visualisations help identify the best locations for individual land components (Hein & Van Mil, 2020) and potential spatial conflicts (Maldonado-Marín et al., 2019). Connectivity measurements make pinpointing specific services or parts of technical infrastructure even more effective (Rusche et al., 2019).

GIS tools are important for environmental impact assessment as well (Lai et al., 2010). They make it possible to estimate the potential environmental impact of urban growth in terms of green urban spaces and their relation with surface temperature (Gomez-Martinez et al., 2021). Research concerning green urban spaces focuses also on assessing and mapping ecosystem services at the city level (Nikodinoska et al., 2018; Vignoli et al., 2021) and the quality of the areas (Z. Yang et al., 2021).

Data and analytical tools are two of the three research components. The third is the methodology for describing the urban structure with the available information (Prastacos & Lagarias, 2016). The indicators need to be calculated to reflect the state or dynamics of changes in a specific spatial feature. Settlement systems are investigated using spatial concentration measures (Arbia & Piras, 2009). They can reflect both the concentration and dispersion of phenomena and objects in space. The results depend not only on the spatial arrangement of the objects but also on the shape and size of basic assessment fields (BAF) (Sudra, 2016; Cegielska, Kukulska-Kozieł et al., 2019).

1.5. Objective of the paper

For the purposes of the present paper, the authors assumed that monitoring and assessing the proportion of natural land cover is essential for environmental, urban and social balance in a region. The creation of future spatial management solutions must take into account environmental scenarios as well, because quantifiable information on urban green spaces is critical for sustainable spatial planning. Land cover diversity monitoring reveals important trends in land use, which facilitates the implementation of reasonable spatial planning at an early stage. In this context, the main objective was to devise and propose a method for measuring and monitoring the diversity of land cover classes (including the share of green spaces) to be used as one of the study analyses involved in preparing future planning documents (in the Polish spatial planning context, particularly for masterplans that present spatial development conditions). Therefore, the objective is also to meet the need for measures that reflect land management in numbers, as postulated in the literature.

The detailed objective of the study was:

1. to determine empirical land cover homogeneity/diversity using Shannon's Diversity Index (SHDI);
2. to determine suburban areas with a considerable proportion of green spaces, including green spaces as representatives of natural land cover classes;
3. to assess the diversity of land cover classes within basic assessment fields and relative to the entire study area;
4. to emphasise the need for natural land cover monitoring;
5. to visualise the issue's intensity (via hot spot analysis);
6. to pinpoint opportunities for GIS tool application in land cover investigations.

The present research is entirely newly developed material. To the best of the authors' knowledge, no studies to date have been published that propose a method for measuring and monitoring the diversity of land cover, while simultaneously employing the SHDI and hot spot analysis. Being a quantitative metric, the SHDI is one of the most popular indicators for landscape quantification. The land cover results it yields may be significantly varied, which hinders correct global conclusions for the entire study area. An additional hot spot analysis of the resulting data paints a better picture of the global intensity and offers "averaged" results. This way, it is possible to identify larger clusters of statistically significant, not isolated, basic assessment fields with low or high SHDI values.

Moreover, there are no large-scale spatial analyses of the diversity of land cover in Poland. What is more, the process of selection of the study area was guided by two principles: the selected part of Lesser Poland should evidently exhibit a high level of anthropogenic pressure on green spaces and fill a geographical gap in the literature. The literature on urbanisation and anthropogenic pressure focuses mainly on other popular areas, such as the Kraków agglomeration or Podhale. In light of the above, the present approach makes the work a novel contribution.

The present study demonstrates trends in the spatial differentiation of urban green spaces at the macro level and investigates the land cover diversity at the macro level. It can provide science-founded guidelines for urban planners and decision-makers regarding identifying future land management directions.

2. Research materials and methods

2.1. Research area

The study area encompassed two cities, Tarnów and Nowy Sącz, together with Tarnowski District and Nowosądecki District around them. The total investigated area was 3,089 km^2 (Fig. 1).

It was selected not by accident. According to Statistics Poland (GUS) (GUS 2021) data, Tarnowski District has a high birth rate of 1.02 per 1,000 residents. The demographic dynamics rate is 0.89 and is similar to the voivodeship average and much greater than the rate for Poland. Nowosądecki District reached the demographic dynamics rate of 4.53 per 1,000 residents. Its population grew 12.2% over 18 years (by 2020). Tarnów and Nowy Sącz are the largest cities in Małopolskie Voivodeship after Kraków. In light of the above, and considering that the Kraków agglomeration has been extensively researched in terms of its urban condition (Cegielska et al., 2019; Barczyk-Ciuła & Satoła, 2021), the authors selected a different study area.

Moreover, the investigated area is home to an environment that is valuable but rarely looked into because of other popular research areas, such as the Kraków agglomeration or Podhale.

2.2. Research procedure and data sources

The input material was vector land cover data models from the Polish database of topographic objects (DTO10k). The other input was vector layers with administrative boundaries from the Polish Record of Boundaries. The data were processed and analysed using QGIS and ArcGIS.

The procedure (from pre-processing to results) is shown in the diagram below (Fig. 2):

Land cover classes from the DTO10k were reclassified to fit the objective and assumptions (second and third detail level). The objects were classified into 11 new classes (Table 1, Fig. 3). The reclassification was performed in the field calculator.

The research procedure involved analysis in basic assessment fields (BAFs). BAFs can be polygons, administrative subdivisions or other variable density grids (Kot, 2015). In the present research, BAFs were tiles of original hexagonal tiling (Fig. 4) with a hexagon area of 1 km^2. Such a BAF has already been employed in scientific research. Note that hexagonal tiling has the lowest ratio of surface to perimeter among all popular fields (squares or triangles) (Parysek, 1982). Note also that analyses using rectangular tiling can often yield ambiguous results, as only four BAFs are adjacent to any single BAF, while for hexagonal tiling the number is six (Birch et al., 2000). According to Birch et al. (2007), such assessment clusters are recommended mainly for visualising spatial phenomena. The cell size of 1 km^2 has been used in the literature (Ellis et al., 2006; X. Li et al., 2016). Too small a cell can yield highly variable results because of an insufficient number of objects with a single BAF. An excessively large cell will shift the focus towards average values. Moreover, the cell size was also selected to match the accuracy of the land cover database used in the study. In principle, the smallest delineated area is 1,000 m^2. Assuming that a 1 km^2 contains only objects with this minimum area, they should amount to 1,000. The authors believe that such circumstances facilitate certain averaging of the result and conclusions, taking into account the spatial extent of the analysis.

In light of the objective of the study, five of the 11 reclassified land cover classes were selected for further analyses (meadows and pastures, forests, wooded and shrubbed areas, Fig. 4). This was done with a semi-automatic procedure (the *select by expression* tool) that allows a logical condition to be created to search the database. With this layer, the authors intersected the vector layer of natural land cover and the hexagonal tiling. This was done using the intersects geoprocessing tool. As a result, the land cover layer was assigned a hexagon ID so that land cover class objects within hexagons could be grouped. For the procedure to continue, it was necessary to calculate the area of each natural land cover class in the BAFs.

2.3. Shannon's Diversity Index (SHDI)

The study employed the Shannon's Diversity Index (SHDI) as one of the most popular indices for landscape quantification (Nagendra, 2002; Uuemaa et al., 2005; Alberti et al., 2007; Xiao & Ji, 2007; Deng et al., 2009; Urbański, 2012).

$$\mathrm{SHDI} = -\sum_{i=1}^{m}(P_i * \ln P_i)$$

where:

Fig. 1. Study area against Małopolskie Voivodeship
Source: Own work

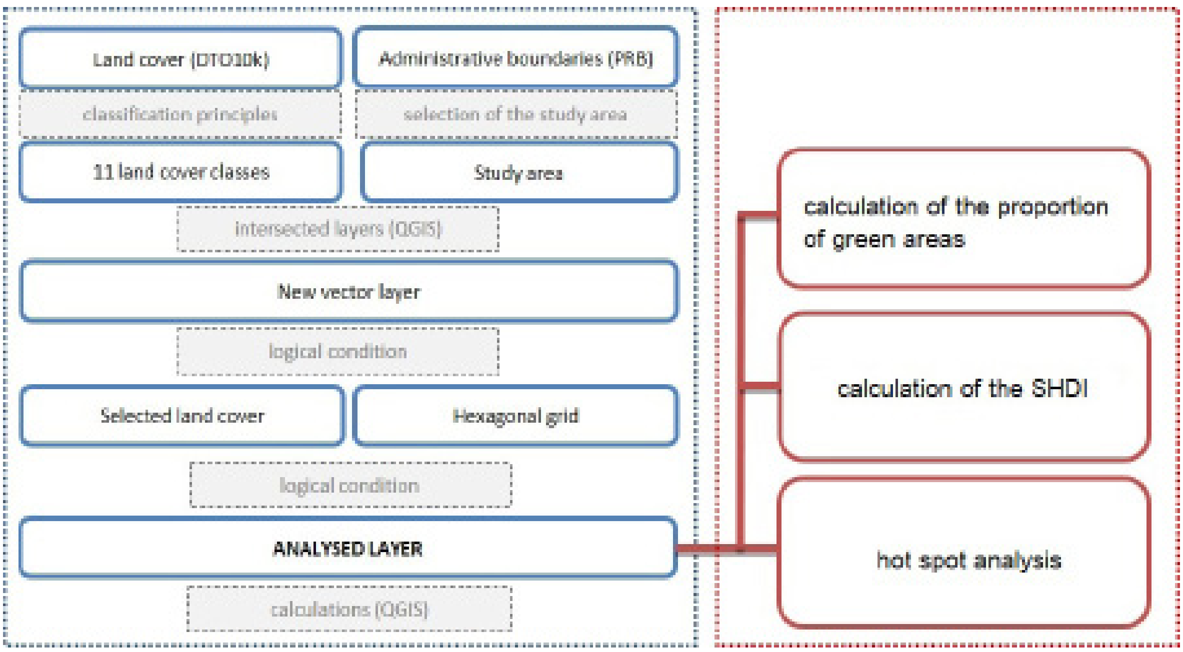

Fig. 2. Diagrammatic representation of the analysis
Source: Own work

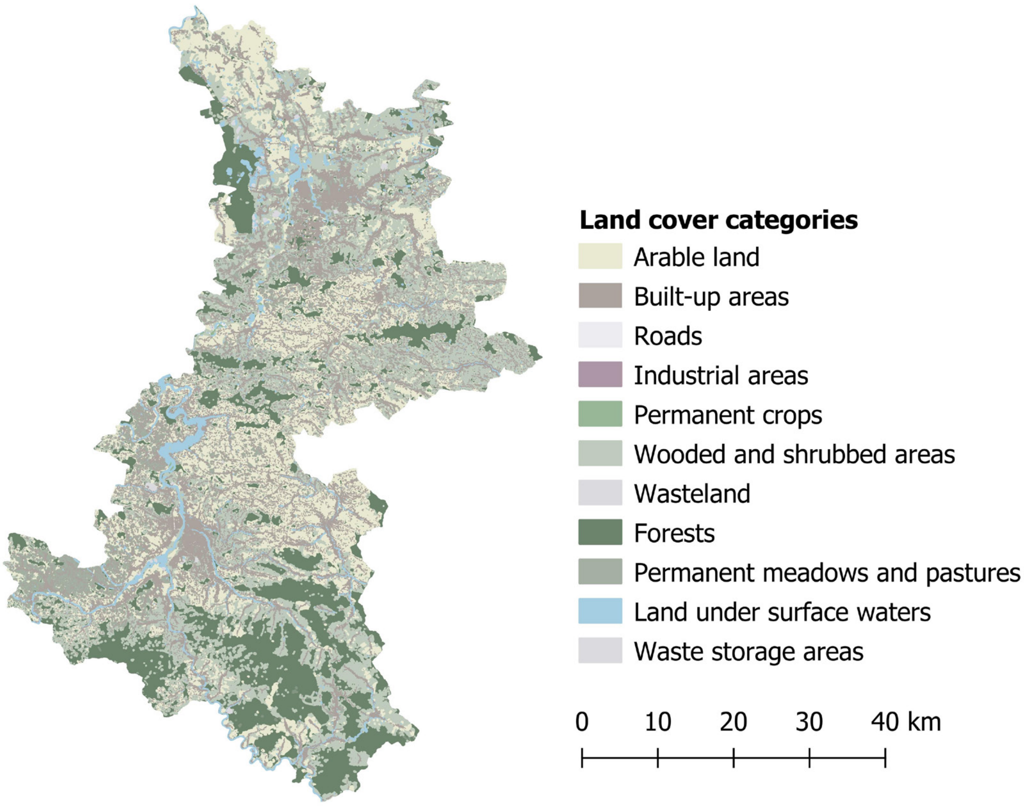

Fig. 3. Land cover categories
Source: Own work

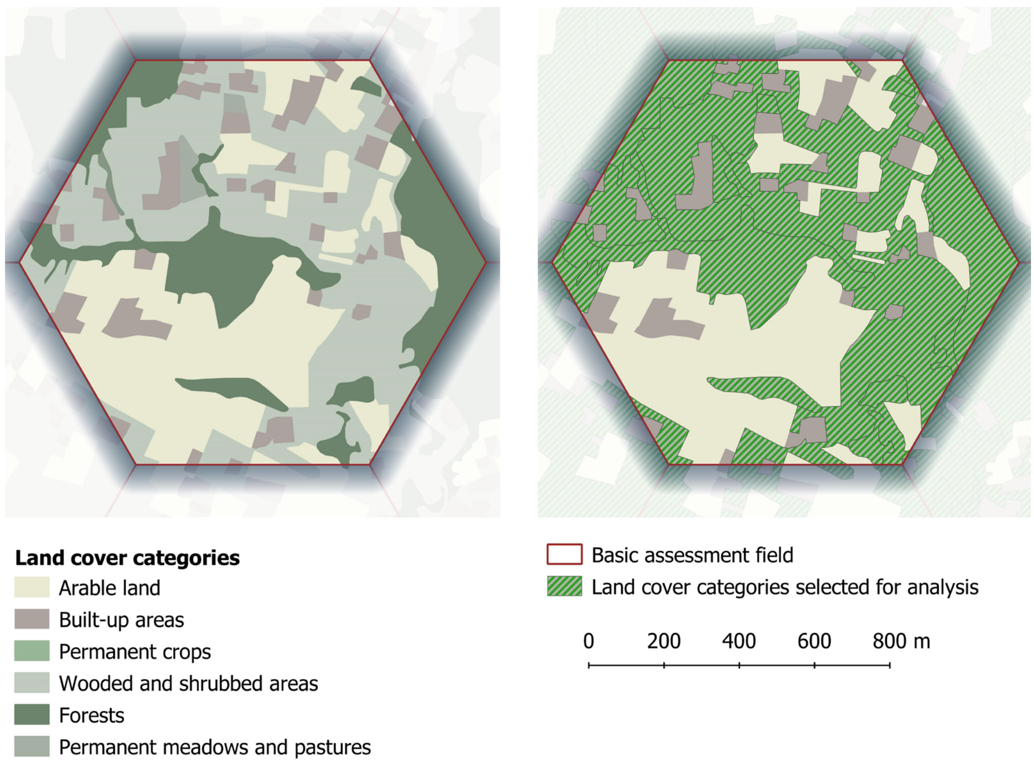

Fig. 4. Land cover classes within hexagons
Source: Own work

Table 1. Reclassification of land cover classes based on DTO10k

Land cover class	DTO10k-code		Object name
Arable land	PTTR	02	crops on arable land
Built-up areas	PTZB	01	multi-family housing
		02	single-family housing
		03	industrial and storage building
		04	commercial and service building
		05	other building
Roads	PTKM	01	area under road
		02	area under railway
		03	area under road and railway
		04	area under airport road
Industrial areas	PTNZ	01	area under technical structures
		02	industrial and storage area
	PTPL	01	square
Permanent crops	PTUT	01	allotment garden
		02	plantation
		03	orchard
		04	forest tree nursery
		05	ornamental and fruit plant nursery
Wooded and shrubbed areas	PTLZ	03	forest cover
	PTRK	02	bushes
Wasteland	PTGN	01	scree, heap, or debris
		02	stony area
		03	sandy or gravelly area
		04	remaining unused land
	PTWZ	01	excavation
		02	dumping ground
Waste storage areas	PTSO	01	area of urban waste storage
		02	area of industrial waste storage
Permanent meadows and pastures	PTTR	01	grassy plants
Forests	PTLZ	01	forest
		02	coppice
	PTRK	01	dwarf mountain pine
Land under surface waters	PTWP	01	sea water
		02	flowing water
		03	still water

Source: own work

P_i – the proportion of the i^{th} class in the landscape, the probability of the i^{th} class,
M – the number of classes in the landscape.

The value of the index increases as the number of land cover classes or types in a given BAF grows and individual classes approach the same proportion (McGarigal & Marks, 1995; Nagendra, 2002; Kot & Leśniak, 2006). The SHDI is 0 when the entire area has only one landscape class. Note that, according to the literature, this index is more sensitive to classes with very small areas (Benito-Calvo et al., 2009; Urbański, 2012). It is a quantitative measure of how many classes (types) there are in a dataset. It is often used to determine biodiversity.

2.4. Hot spot analysis

The last stage was a hot spot analysis, a tool for intensity visualisation (areas with increased occurrence of a phenomenon). The SHDI values were analysed with this method to identify spatial clusters. As the hexagons had the same area and created a continuous plane of adjacent figures, ArcGIS automatically calculated Distance Band as Euclidean distance to be 1,075 m. Fixed Distance Band was used as a conceptualisation of spatial relationships. The hot spot method involves a statistical analysis to define clusters of high- and low-intensity areas. Areas determined with this method exhibit features of statistical significance. For a BAF to be considered statistically significant, it has to have a high value and be surrounded by high-value objects. The areas are identified with the Getis–Ord G_i* statistic (www.desktop.arcgis.com). This approach is an adapted General G-statistic method (Getis & Ord, 2010), a global method for quantifying spatial autocorrelation in an area. It is a local autocorrelation indicator of local spatial autocorrelation differences using statistic calculation for every BAF. This method evaluates how much each cluster is surrounded by clusters that exhibit similarly high or low values (Peeters et al., 2015).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - X \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

where:
x_j – the attribute value of object j,
$w_{i,j}$ – the spatial weight between features i and j,
n – the total number of features $\overline{X}$.

$$X = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (X)^2}$$

The statistical significance is assessed using z and p for each function. The z and p values indicate the location of the phenomenon's high (hot) and low (cold) values. In the case of statistically significant positive values of z, an increase in z reflects the intensification of high values (hot spot). When statistically significant values of z are negative, a decrease in z means the intensification of low values (cold spot). The value of *p* is probability. If *p* is very low, the probability of the spatial pattern being a result of random processes is low as well (www.desktop.arcgic.com).

The hot spot analysis was done in ArcGis – Hot Spot Analysis (Getis-Ord Gi*). Clusters were searched using the value of $\overline{X}$. The results were processed in two variants: (1) calculation of the SHDI for the entire area and (2) for the cities and rural districts separately.

3. Research results

3.1. Proportion of green spaces

The first stage of the analysis was to calculate and visualise the spatial distribution of the proportion of green spaces in BAFs (Fig. 5). Green spaces occupying no more than 38.70% of a BAF (first interval) were found only in cities of Tarnów and Nowy Sącz and in Różanowskie lake (1).

The investigated area demonstrated a tendency towards the second-interval values (38.71%–73.30%) in cities and their suburban zones. Values from this interval form characteristic bands along main roads and the Dunajec River. In Nowosądecki District, these are expressways No. 75 or 87. Values from the last interval where the proportion of green spaces in BAFs exceeds 90.71% also tend to form large enclaves found in protected green areas. The largest clusters were found in the southern part of Nowosądecki District (for example, Popradzki Landscape Park (2), the South Lesser Poland Protected Landscape (3) and their surroundings) and in the southern part of Tarnowski District (for example, Ciężkowicko-Rożnowski Park Krajobrazowy (4), Park Krajobrazowy Pasma Brzanki (5)).

The histogram of the percentage share of green spaces in individual BAFs (Fig. 6) is clearly left-skewed. BAFs with the highest values (90.71%–100.00%) dominated the study area. This fact shows that the area is very attractive in terms of green spaces, including those of the highest order: protected green areas. Areas with nearly 100% green cover dominate.

3.2. Shannon's Diversity Index (SHDI)

The variability of the SHDI was investigated by dividing the resulting values into four classes according to the Jenks natural breaks classification method (Jenks, 1967) (Fig. 7).

The spatial distribution of SHDI values indicates two main trends in the area. The first one is BAF clustering to form enclaves of similar values. See, for example, enclaves of the lowest values reflecting very small variability. The value of 0 occurs when the entire area has only one land cover class. As regards Tarnowski District, it is: the enclave west of Tarnów (the SHDI 0.00–0.33) covering a large and compact forest area (including the Lasy Rodłowskie Preserve (6)); and the enclave south-east of Tarnów covering an area of forests and tree stands near such hills as Ptasia Góra (7), Liwecka Góra (8), Wielka Góra Uniszowska (9), Ostry Kamień (10) and Wielka Góra (11).

Nowosądecki District featured evident enclaves of several tens of BAFs (40–75) with slight land cover diversity (the SHDI also in the first interval) covering a significant portion of the southern part of the district. The area offers a high value in terms of: the landscape, environment and protected sites with numerous landscape parks and their buffer zones, such as the Popradzki Landscape Park (2); areas of protected landscape, such as the South Lesser Poland Protected Landscape (3); and natural preserves (Lembarczek) (12). The area covers such geomorphological mesoregions as Beskid Sądecki and Pogórze Popradzkie.

BAFs with high SHDI values also formed clusters, indicating high diversity of land cover classes or types (0.99–1.54). In Tarnowski District, these enclaves are much smaller and dispersed over the entire district. In Nowosądecki District, they create much larger, clear-cut complexes, mostly north and west of Nowy Sącz. These areas offer blends of green sites and built-up zones. No BAFs tended to form groups within city limits.

The empirical distribution of the SHDI is only slightly skewed. BAFs with the lowest values around 0.0 are relatively numerous. The proportion then drops and rises only from the SHDI close to 0.4.

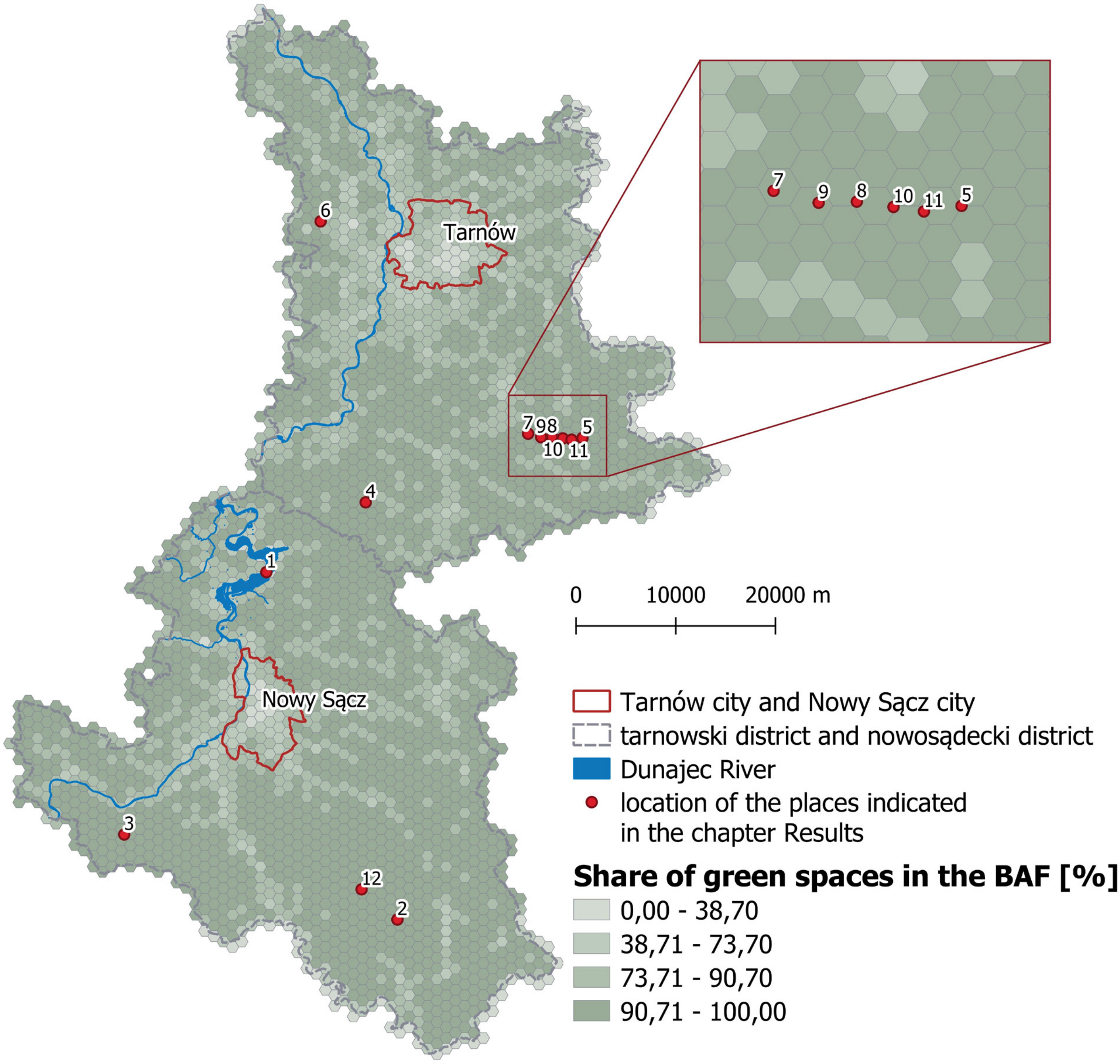

Fig. 5. Share of green spaces in BAFs (%)
Source: Own work

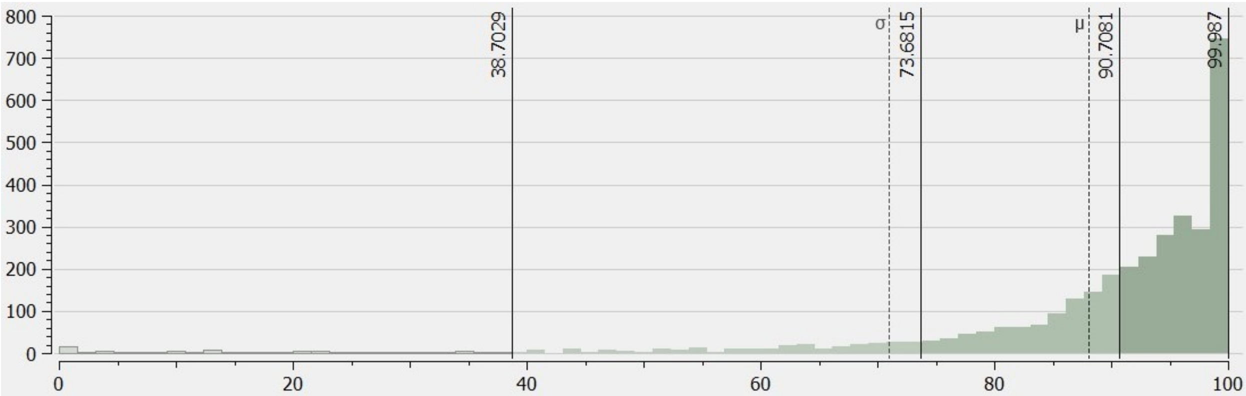

Fig. 6. Histogram of green spaces percentage in BAFs
Source: Own work

From there, as the SHDI value increases, their share in the total number of all BAFs grows. The mode are values from the last interval, close to 1.0. From this point, the proportion of BAFs declines as the SHDI increases.

3.3. Hot spot analysis

A hot spot analysis was performed because of the scattering of BAFs in the study area, mainly in Tarnowski District, Tarnów and Nowy Sącz (Fig. 9, Fig. 10). The results are visualised with a colour gradient. Clusters with higher SHDI are more intensive red, while the lower the SHDI in a cluster, the more intensive blue it is. The more intense the red or blue on the results layer, the greater the certainty that data clustering is not accidental. Areas in grey include BAFs that are not statistically significant (Fig. 6). For them, the probability that spatial relationships among BAFs are random is high. The purpose of this analysis was to present locations where clusters of high and low SHDI occur. Spots marked "Not Significant" demonstrate random SHDI spatial distribution.

Boundaries of clustered BAFs in the hot spot analysis of Nowosądecki District were clearer and better defined but confirmed results from the previous analysis of SHDI (Figure 7). A significant portion of Tarnowski District was classified as "not significant", meaning no statistical significance. The authors defined several hot spots with confidence levels above 90%. These were areas along the Dunajec River, southwest of Tarnów. There were also some cold spots with confidence not less than 90%, coinciding with the west and southeast green areas of Tarnów (green spaces around the hills referred to in the previous section) identified in the previous analysis.

4. Discussion

4.1. Urban green space planning and management

The area and role of UGS increase as cities and large urban agglomerations grow today. Hence the relevance of research and analyses in this domain. Only research with up-to-date data that comprehensively represent the condition and occurrence of such areas and their spatial distribution can contribute to a rational establishment of new enclaves and protection of existing areas. This matter is significantly impacted by spatial policies, which respond to social and economic needs while maximally preserving the existing natural qualities and resources. Undoubtedly, progress will lead to the development of new spaces. Therefore, one of the toughest challenges of urban and suburban planning is to reconcile their development with appropriate shaping and protection of the natural environment. Proper agglomeration planning can minimise or even reverse the repercussions of urbanisation by integrating built-up and natural areas (Dobbs et al., 2017).

A comparative analysis of 23 European cities by Baycan-Levent and Nijkamp (2009) demonstrated that, regardless of policy differences, the key factors in urban green space planning and management are the proportion of green areas in urban land use and changes in this proportion over time, the level of involvement of city administration, and citizen participation. Darkwah and Cobbinah (2014) also acknowledged the role of urban residents in the dynamic process of green space management, especially in recent years, when people started to appreciate the need for contact with nature. As a result, it increased the weight of landscape qualities

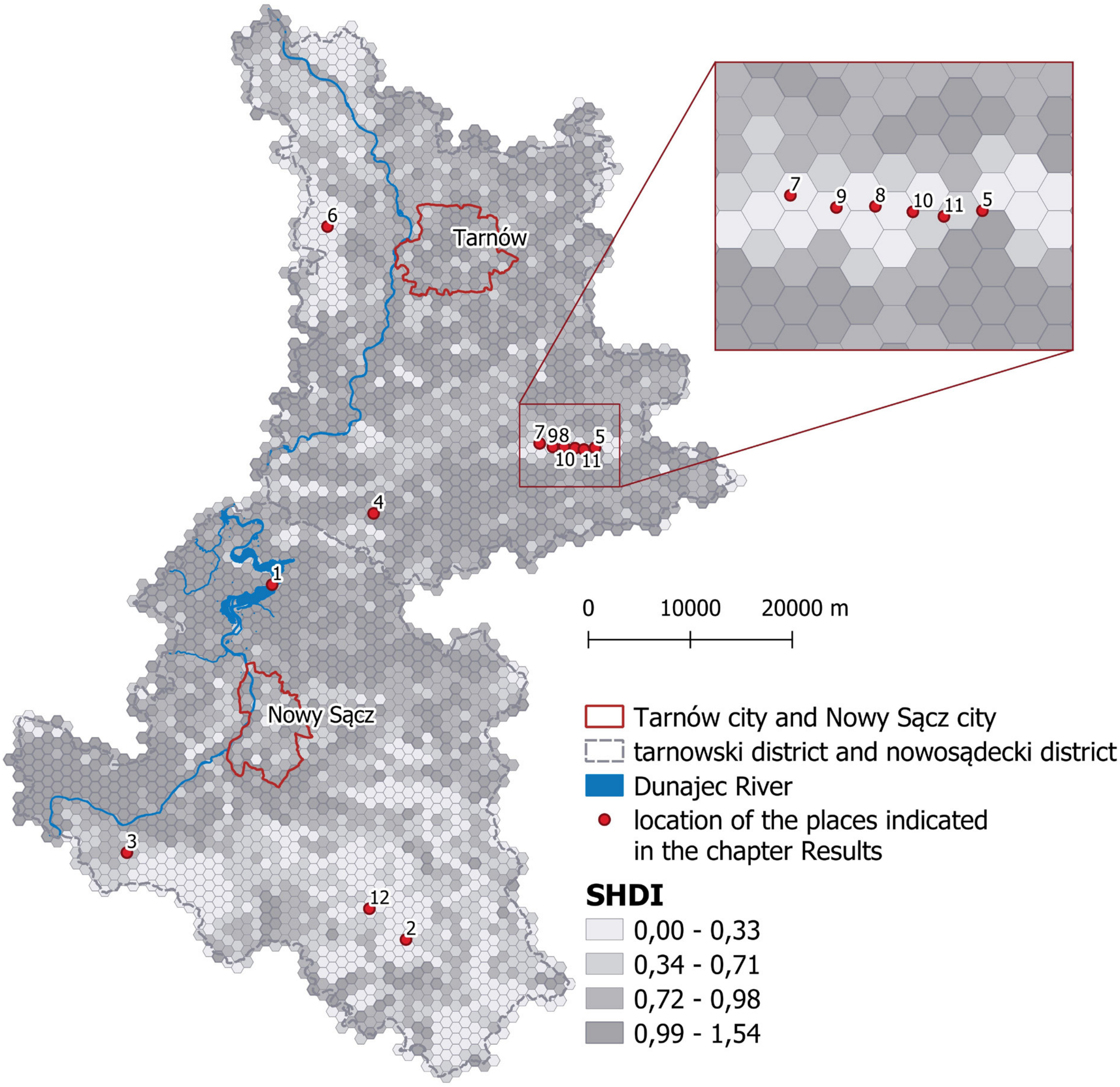

Fig. 7. SHDI values
Source: Own work

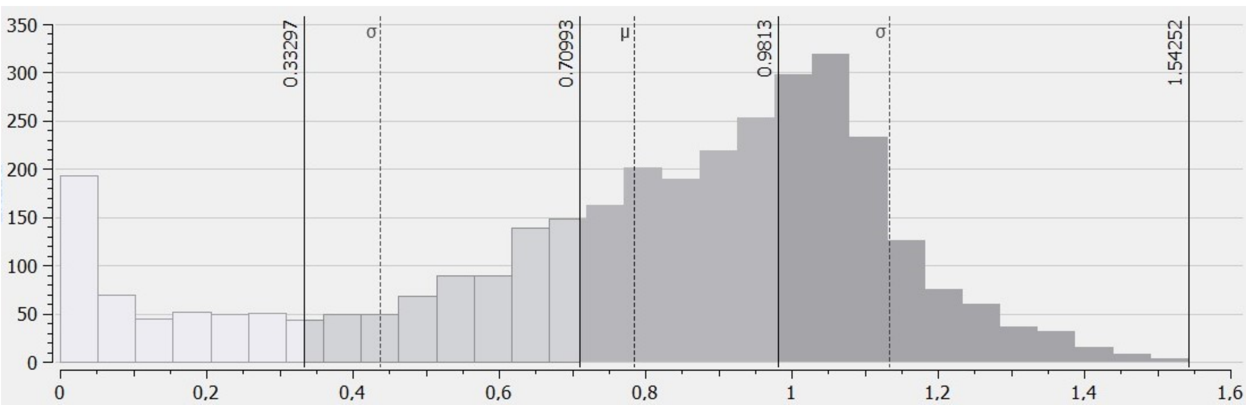

Fig. 8. SHDI histogram
Source: Own work

and environment quality when selecting the place to live (Chaudhry et al., 2011), which drove up property prices near green spaces (Georgi & Dimitriou, 2010; Darkwah & Cobbinah, 2014).

Green spaces can fit into urban and suburban planning in various ways. Sutkowska (2006) discussed Hamburg, one of Germany's greenest cities, where a system of defensive works and moats was transformed into green spaces. Yang et al. (2009) pointed to Rome, where the impact that orchards around the city had on air quality was noted. Other examples of projects in European cities were discussed by Szczepanowska (2012). González-García and Sal (2008) discussed León (Nicaragua), where urban gardens control adverse climate conditions and the increase in vegetation biodiversity. Seeliger and Turok (2015) presented South Africa with its Green Building Council of South Africa, which promotes "green buildings".

4.2. GIS in urban green space research

The potential for using GIS in urban research is significant (Mondal et al., 2017; Murayama et al., 2021; Wnęk et al., 2021) – also regarding green space analysis (Cetin, 2015) and Polish cities (Antczak, 2017). With the latest technologies, researchers can analyse anthropogenic areas and the benefits of UGS (Vich et al., 2019). These tools help

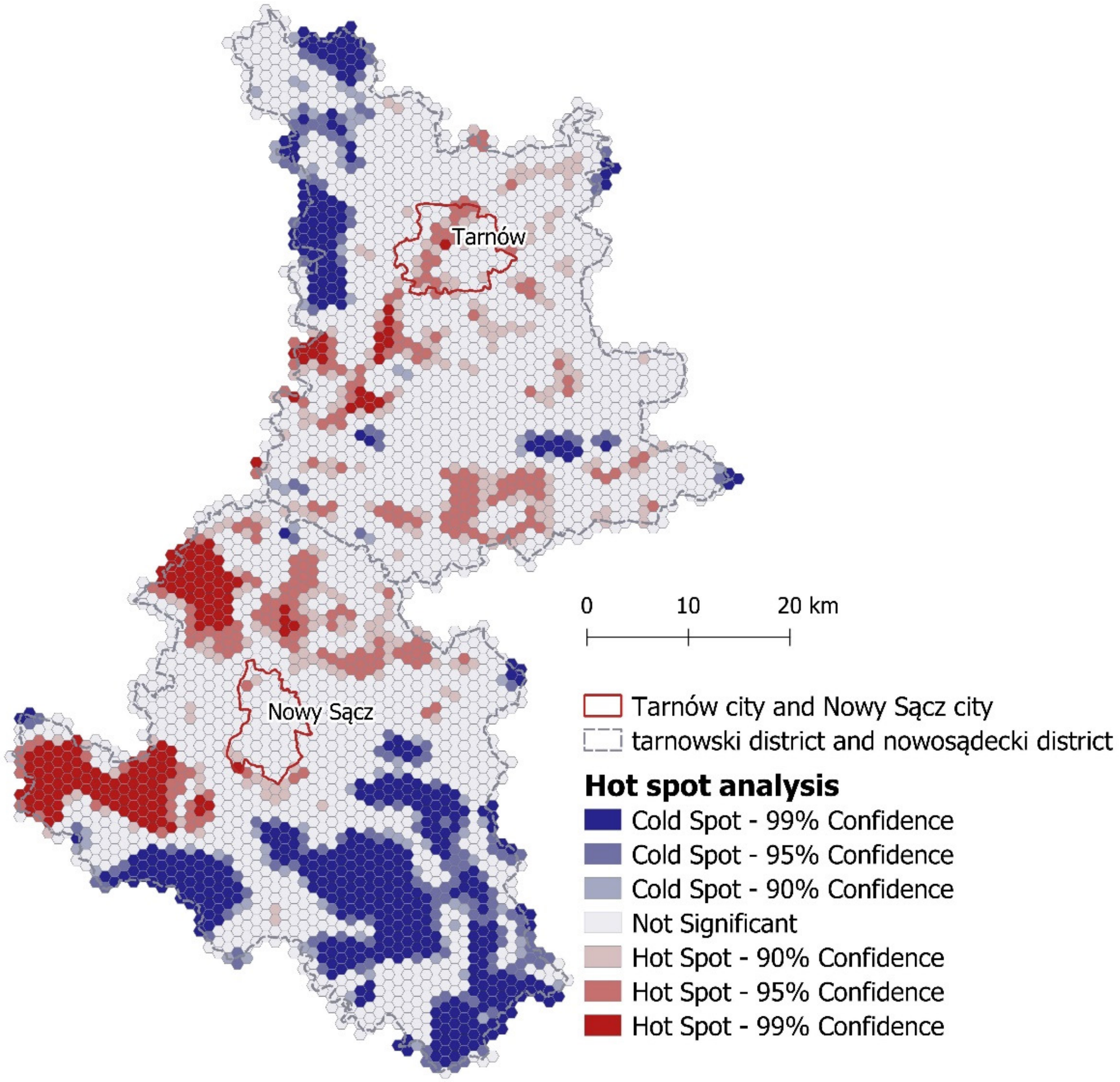

Fig. 9. Hot spot analysis
Source: Own work

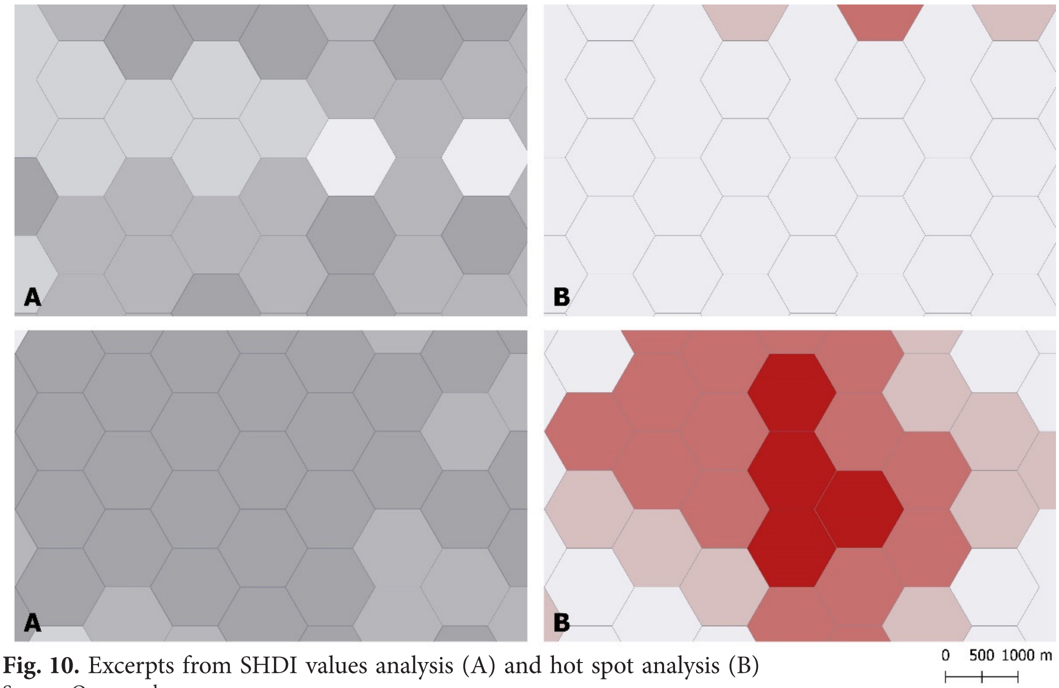

Fig. 10. Excerpts from SHDI values analysis (A) and hot spot analysis (B)
Source: Own work

reliably represent the current state of urban green space use. Their proximity is the traditional metric of greenness exposure, which today is measured precisely and comprehensively with GIS solutions (Koohsari et al., 2015).

The intensity of phenomena can be quantified, changes monitored and models of future transformations built thanks to a combination of such methods as statistical analysis and GIS research tools (Jat et al., 2008). Cao et al. (2017) demonstrated that GIS tools could help describe space in terms of land use structures. Moreover, a literature review indicated that various analyses of changes in the spatial distribution of UGS help identify correlations between objects, trends and dynamics of transformations. This knowledge is indispensable for rational spatial management, which is founded on current development trends and spatial standards. Furthermore, it paves the way for rational planning of future land use (Ramachandra et al., 2012), the *sine qua non* for conformity with sustainable development principles (Megahed et al., 2015).

According to Lang et al. (2008), the need to collect quantifiable information on UGS for sustainable spatial planning is real. The combination model of the SHDI and hot spot analysis proposed here is a tool that can aid planning decisions. This model can assess and compare districts (or other assessment fields) in terms of the number, spatial distribution and types of land cover structures, while identifying the level of intensity or shortage of UGSs. It reflects the diversity of land use types and their configurations, so it can objectively manifest the quality of the space, including UGS in the analysed areas. Therefore, the model can be used to design future scenarios for spatial management that will be most consistent with sustainable development principles.

4.3. Landscape metrics and hot spot analyses in urban green space research

Landscape metrics are relatively popular measures that help identify and assess the intensity of spatial phenomena. They are useful in landscape fragmentation and change analyses (Southworth et al., 2002), landscape aesthetic quality analyses (Tenerelli et al., 2017), urbanscape analyses (Dietzel et al., 2005; Sofia et al., 2016), anthropogenic landscape change analyses (Jaeger, 2000; Prastacos et al., 2012), or environment quality management, planning, and monitoring analyses (Botequilha Leitão & Ahern, 2002).

The research by Kong & Nakagoshi (2006) is of value here as well. They developed a new method for quantifying and capturing changes in green space patterns through a case study of Jinan City, China, from 1989 to 2004. They also employed GIS tools to quantify local urban green spaces. Their results confirmed that a significantly altered green space pattern could be quantified using landscape metrics. When considering the possibility of using landscape metrics to monitor urbanscape changes and assess the condition of urban green spaces, one should not forget the study on the Klang Valley by Chan and Vu (2017). This analysis used landscape metrics to describe the composition and configuration of classes within a landscape. Nasehi and Imanpour namin (2020) assessed urban green space fragmentation with landscape metrics in Teheran. UGS can also be investigated quantitatively. Kong et al. (2005) combined this approach with gradient analysis to look into the city of Jinan (China). In the present study, UGSs were distributed unevenly, and some areas exhibit significant SHDI differentiation; similar results of UGS analysis were offered by M'Ikiugu et al. (2012), who used landscape metrics and GIS tools to identify potential expansion spots. They selected the central part of Nairobi as a representative sample. It turned out to be unevenly covered in UGS.

When discussing spatial metrics, one has to mention that many of them are interrelated (Riitters et al., 1995), which necessitates an initial selection at the research planning stage (Affek, 2016). In the present study, the SHDI metric was chosen because of its popularity in similar research (da Silva et al., 2019; Zhao et al., 2019). Moreover, the SHDI is among the most popular indices for landscape quantification (Alberti et al., 2007; Xiao & Ji, 2007; Deng et al., 2009; Urbański, 2012). Its value increases as the number of land cover classes or types in the BAF grows, and individual classes approach the same proportion (Nagendra, 2002; Kot & Leśniak, 2006). SHDI equals 0 when the entire investigated area has only one landscape class, but it grows with the growing number of patches (Pukowiec-Kurda & Sobala, 2016). Note that, according to the literature, this index is more sensitive to classes with very small areas (Benito-Calvo et al., 2009; Urbański, 2012).

Researchers employ other diversity indices as well. For example, there is the Shannon–Wiener index (Spellerberg, 2008; Lin et al., 2011; Dronova et al., 2016). The index gives very good results in comparative research on two or more environments. Another index is the Landscape Shannon Index (LSHD) used by Gao et al. (2020) to indicate the level of landscape diversity. In turn, Shannon entropy can be used to investigate the concentration of anthropogenic land cover elements (Cegielska et al., 2019) or monitor urban growth and identify urban growth type (Dhanaraj & Angadi, 2020). Yet another index is Simpson's Diversity Index (SIDI) and its reverse, Simpson's dominance, which reflect biodiversity. They are most commonly used to assess the biodiversity of habitats but have more applications as well. Research by Kubacka and Smaga (2019) is interesting in this context. They used the SIDI as an index to assess the dynamics of changes in CORINE Land Cover classes in areas of the Natura 2000 ecological network. Another example is the research by López et al. (2020), who assessed changes in the composition and configuration of the landscape in the tropical Andes in Southern Ecuador from 1989 to 2016 using the SIDI and Shannon's Evenness Index, among others.

Hot spot analyses are just as popular as landscape metrics (Xu et al., 2019; Zhang et al., 2019; Q. Li et al., 2021; Manton et al., 2021). Based on temperature data, Goswami et al. (2013) identified urban hot spots in Kamrup Metro District of Assam (India). It is true that land cover type significantly affects urban temperature, leading to urban heat islands in highly urbanised areas. UGSs are believed to be the right way to reduce its effects and ensure comfortable conditions for people living nearby (Aram et al., 2019). The present study's authors decided to conduct the hot spot analysis because of the large number of BAFs and the probability of obtaining significant result dispersion. The aim of the hot spot analysis was to identify larger clusters of statistically significant, not just individual, isolated, BAFs with low or high SHDI values.

5. Conclusions

In general, UGS are essential constituents of the urban structure that enhance residents' quality of life and behaviour. Moreover, as modern cities and suburbs grow, so does the role of green infrastructure and urban green spaces. Hence the importance and necessity of monitoring these areas.

The authors suggest environmental analyses that take into consideration green spaces when planning and designing urban structures and urbanscapes. The present study combines an analysis of urban green space diversification with the identification of areas (enclaves, clusters) of statistical significance regarding the SHDI. The present study is the first one to propose a quantitative assessment of land use quality, including UGSs, at a regional scale. It presents trends in spatial differentiation of land use types and identified significant clusters of green spaces.

The results of the analysis indicate that:

1. an analysis with the SHDI landscape metric combined with a hot spot analysis facilitates the generalisation of results of studies

on large areas with numerous fields of estimation. It is therefore recommended for regional research;

2. the present study yielded two variants of results in terms of how the spatial structure of SHDI values behaved:
   - individual BAFs were dispersed and did not form larger enclaves of hexagons with similar SHDI values (mostly Tarnowski District, Tarnów, and Nowy Sącz);
   - individual BAFs tended to aggregate into large-area, multi-object enclaves of similar SHDI values (mainly Nowosądecki District due to large, green, agricultural, environmentally valuable and often protected areas);
3. the hot spot analysis helped verify the statistical significance of the results and “smooth out” significant diversities in BAF values;
4. hot areas with high SHDI values are those where vegetation was shaped artificially (hence the diversification);
5. areas identified as cold with low SHDI are those where vegetation makes uniform patches of land cover (such as preserves or national parks);
6. areas of Tarnów and Nowy Sącz did not exhibit any statistically significant diversity.

Not only does the proposed study take into consideration the proportion of green spaces in basic assessment fields, but it also focuses on the diversity of land cover types in the field. The results facilitate a more objective assessment of the quality of land use, including the significance of the UGS share in land cover, offering urban planners details on the distribution of compact UGS clusters. Such an analysis provides powerful support to decision-makers regarding planning solutions because it makes use of easily available data (DTO10k data are open data in Poland), opensource software and simple analytical methods.

The present research on UGSs yielded numerous insights that can be used for new urban policies, both in Poland and internationally. The generated hot spot map can guide future choice of areas earmarked for UGS or identification of places where no development should be undertaken due to their high urban green space potential. Such projects could be shifted to areas of low urban green space potential.

The results and conclusions they support are important to local or regional authorities, the EU Green Deal and climate neutrality. Moreover, it is without doubt a significant starting point for future research on the spatial dimension of the urban and suburban landscape and change trends in it.

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