



Evaluation of the location of cities in terms of land cover on the example of Poland

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Abstract

The increasing availability of remote sensing materials of varying spatial resolution inclines to look for methods enabling their use, both at planning the spatial structure of particular urban centers and shaping the global urban development policy on the national level. Urban development valorization should include the evaluation of urban greening while taking into account the surrounding landscape. Therefore, this work aimed at developing a method which would consider those two elements. By using the proposed method, all cities of Poland within their administrative boundaries were classified into generalized types. They are characterized by cities' location in relation to the dominant landscape background which can be helpful in planning the actions in relation to developing the urban greening, as well as evaluating of the quality of life of the residents at the national level. Due to the landscape element, the decline in the quality of life of residents may concern a large group of cities located within the anthropogenic and agricultural landscape as well as the urban and agricultural, where the harmful effects of pollution from residential energy, industry, and farming often overlap. The method presented in this work can be used in relation to cities in other countries or to larger areas, enabling comparison between them.

Keywords Urban greening · Lands cover · Cities in ecology · Quality of life · Geographic information system

Introduction

Associating the urban areas with the surrounding landscape is one of the elements which should be taken into consideration while valorizing the cities in terms of quality of life of their residents (Hobbs 1997; Kuo 2003; Arnberger 2006; Matsuoka and Kaplan 2008). This approach is incorporated into the concept of shaping the city's spatial policy, referred to as “the city in ecology,” (Naess 2001; Hulicka 2015) where the city is part of a larger ecosystem and where the relationship between the city and its surroundings should be taken into account when planning spatial development.

Sustainable urban development concepts should therefore take into account not only the increase in natural diversity, the development of urban green areas, the structure of the use of land forms (Bjerke et al. 2006; Ahern et al. 2014; Mierzejewska 2015) and landscape values (Myga-Piątek 2010; Basten 2011), but also consider the impact of the way of use of suburban areas which affect the air quality and health of cities residents (Miller and Hobbs 2002; Wolch et al. 2014).

Planning sustainable development of urban centers should include areas outside of their borders, also because of their environmental, climatic (Li et al. 2005; Escobedo et al. 2011), and recreational role (Stigell and Schantz 2015; Mierzejewska 2015a). This tendency includes the so-called concept of green infrastructure, based on the idea of joining parks and other green areas through the system of corridors (Collinge 1998; Hidding and Teunissen 2002). Its aim is to improve the quality of life of urban citizens, protect landscape, and preserve biodiversity, as well as to prevent excessive greenery path insulation (Collinge 1996; Benedict and McMahon 2002; Bruszevska 2013). Additionally, when planning the proper system of urban greening, European Environment Agency (2011) recommends including areas outside of the administrative

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boundaries of cities. The first stage of action should include the analysis of the diversity of green areas within the city borders and their nearest peripheries. The next step should include such elements as; forest parks, lakes, rivers, agricultural areas, urban forests, and should consider the connection of a city to the surrounding landscape.

What should be sought are external connections that can fulfill essential ecological functions such as natural migration corridors and ecological islands (Ahern et al. 2014). It is particularly important in times of strong urbanization of suburban areas (Antrop and Van Eetvelde 2000; Antrop 2004; Xiao et al. 2006) as well as the increasing devastation of the landscape within these areas (Drapella-Hermansdorfer 2005; Źarska 2005; Troy et al. 2007). Therefore, the protection of suburban areas should be an integral part of the comprehensively understood problems of urban protection and should be carried out on a broader scale of landscapes (Źarska 2005; Solon et al. 2015).

The problem of the impact of land use on the health of residents is of increasing public concern. Especially, in the face of emerging numerous works documenting the growth of mortality rates due to pollutants coming from the areas used for agriculture (Lelieveld et al. 2015). Paradoxically, small towns located within the boundaries of agricultural landscapes can be subject to various air pollutants from farming (Pope and Dockery 2006; Balarasa et al. 2007; Beelen 2014; Lelieveld et al. 2015). These reports confirm the necessity of searching for new methods of determining relations of urban areas with the landscape surrounding the city (Vuilleumier and Prelaz-Droux 2002).

The availability of remote sensing materials facilitates analysis of this type, especially in relation to selected cities (Feranec et al. 2000; Zhang et al. 2004; Balrama and Dragicević 2005; Xiao et al. 2006; Feranec et al. 2007; Kong et al. 2007; Bagan and Yamagata 2012). However, when assessing a large and size-differentiated group of cities, for example, on the national level, a number of difficulties can be encountered. These difficulties relate to data generalization and the necessity for systematizing relations between a city and its surroundings (Runge 2012). The use of the method determining the dominant landscape background seems to be helpful in achieving this aim (Pieńkowski and Podlasiński 2017). This method helps to generalize the land cover type within the city along with neighboring areas. In addition, it facilitates choosing the connections which condition important ecological functions, including the existence of ecological corridors and islands. This is particularly important in times of strong urbanization of suburban areas neighboring with large cities (Cook 2002; Opdam et al. 2006; Bryant 2006; Mierzejewska 2015; Drapella-Hermansdorfer 2005; Nowak et al. 2010). Applying this method also allows determining the location of cities in terms of the landscape and dividing them which is presented in this work.

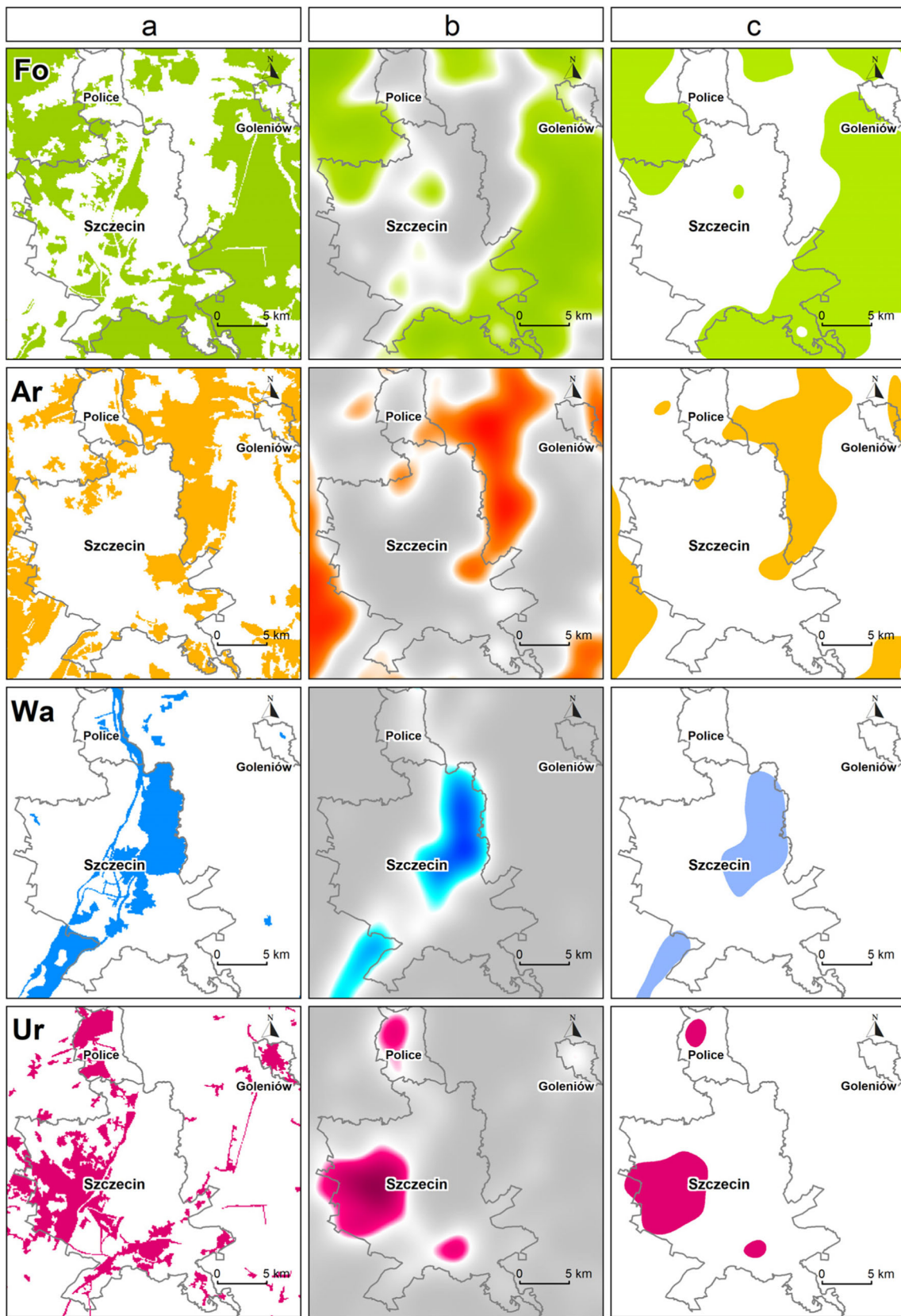
Fig. 1 Stages determine the areas defining the dominant land use (> 50%) for example surroundings of Szczecin city. **a** – distribution the type of land use (part of the map Corine Land Cover 2006), **b** – “A” map after filtration (2 km radius), **c** – “A” map with overlaid areas illustrating the limits of the dominant land use (> 50%). Fo – forest landscape, Ar – agricultural landscape, Wa – water and wetland landscape, Ur – urban landscape

Material and method of landscape background determination

Data on the location and surface of the cities were gathered based on publicly available spatial Corine Land Cover (Hościło and Tomaszewska 2014) and statistical data (GUS 2016). The Corine Land Cover database was used, from which four types of land covers were identified: agricultural areas, urban areas, forests, and waters with wetlands. Green urban areas and sport and leisure facilities, which are part of Corine Land Cover’s artificial surfaces level, have been included to the forest areas.

In this work, maps of Polish landscape backgrounds were used based on the calculations carried out according to the Pieńkowski and Podlasiński methodology (Pieńkowski and Podlasiński 2017). For the generalization of land cover forms, a method based on spatial moving average (*moving windows*) was used, the modification of which was applied in this paper (“*Resampling Filter*” module in the SAGA GIS program). It is assumed that the dominance of a given type of use is determined by the value of the raster attribute. It is obtained on the basis of the use of filtration module, and it falls within the range of 0 to 100%, where a zero value means no impact of a given landscape category, and a 100% value means total land cover for this category. The areas where the attribute value is over 50% were considered the dominant landscape background.

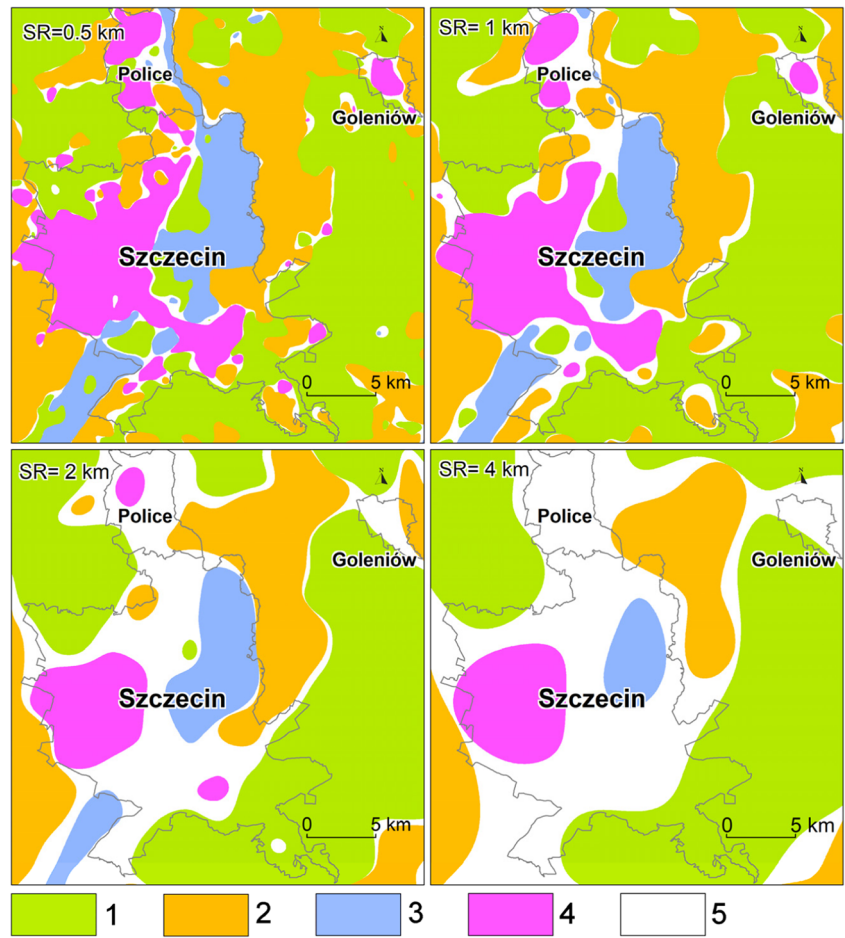
A filtration process was carried out for all four selected forms of land cover (Fig. 1b). Then, for each of them, areas for which the raster attributes are above 50% were set (Fig. 1c). Zones of dominant landscape background were created by overlaying these areas (Fig. 2). For each of four search radii used in the work (0.5, 1.0, 2.0, 4.0 km) a map was obtained of the dominant land cover (hereinafter referred to as the landscape background). The dominance of a given form of use (>50%) at a given radius was taken into account – as well as areas where none of the forms of use accounted for more than 50% (mixed use). When choosing the search radius, it was suggested to use, i.a. an average diameter of national cities, which in Poland is 2 km; an average walking distance, estimated at 2.5–3 km (Stigell and Schantz 2015); as well as the distance of pollution effect coming from agricultural sources (Asmann et al. 1998, Sutton et al. 2003). Some authors in the analysis of the influence of the landscape on the city take into account the area surrounding it, using a specified buffer size (Bagan and Yamagata 2012). However, the use of landscape background and the accepted



degree of blurring (search radius) facilitates generalization degree of the data and allows for the simultaneous capturing

of interaction between different ways of land cover within the city boundaries and beyond them.

Fig. 2 Zones of landscape background for example surroundings of Szczecin City at different search radius (SR). 1 – forest landscape, 2 – agricultural landscape, 3 – water and wetland landscape, 4 – urban landscape, 5 – mixed landscape



All cities of Poland are classified according to their location in terms of the landscape background. Four groups were

distinguished from among 928 Polish cities, depending on the landscape background (forest, agricultural, urban, water

Fig. 3 Examples of the cities' location in terms of landscape background (search radius 2 km): **a** agricultural, **b** forest, **c** water and wetland, **d** urban, **e** mixed landscape

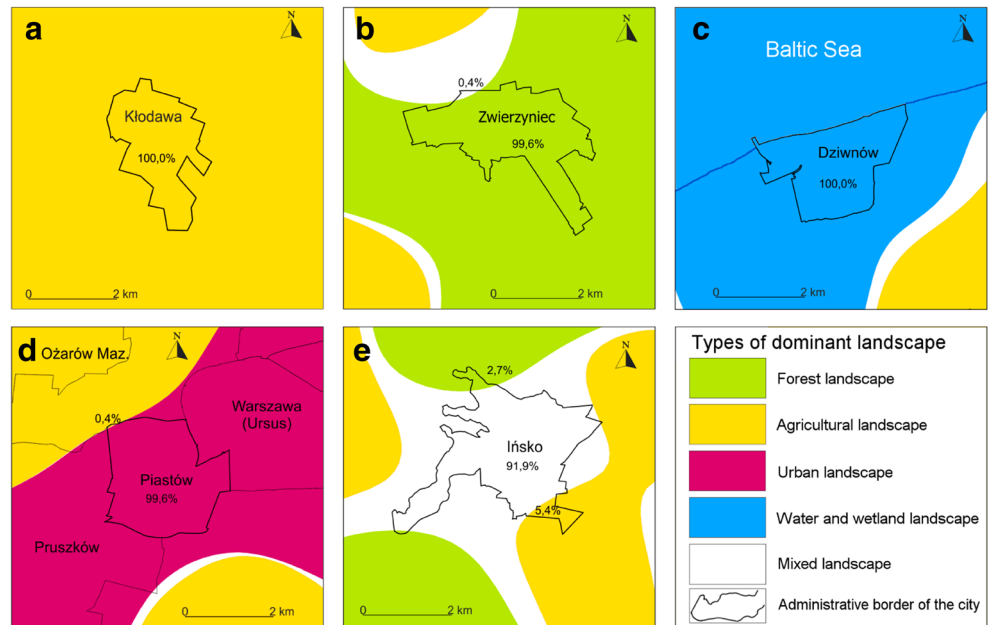


Fig. 4 Examples of the differentiated location of cities in Poland in terms of the landscape background with their graphics presentation including four ranges of search radius (SR rings: 0.5, 1.0, 2.0, 4.0 km); within the administrative boundaries of the city (a) and boundaries of dense urban buildings (b). Color explanations see Fig. 3

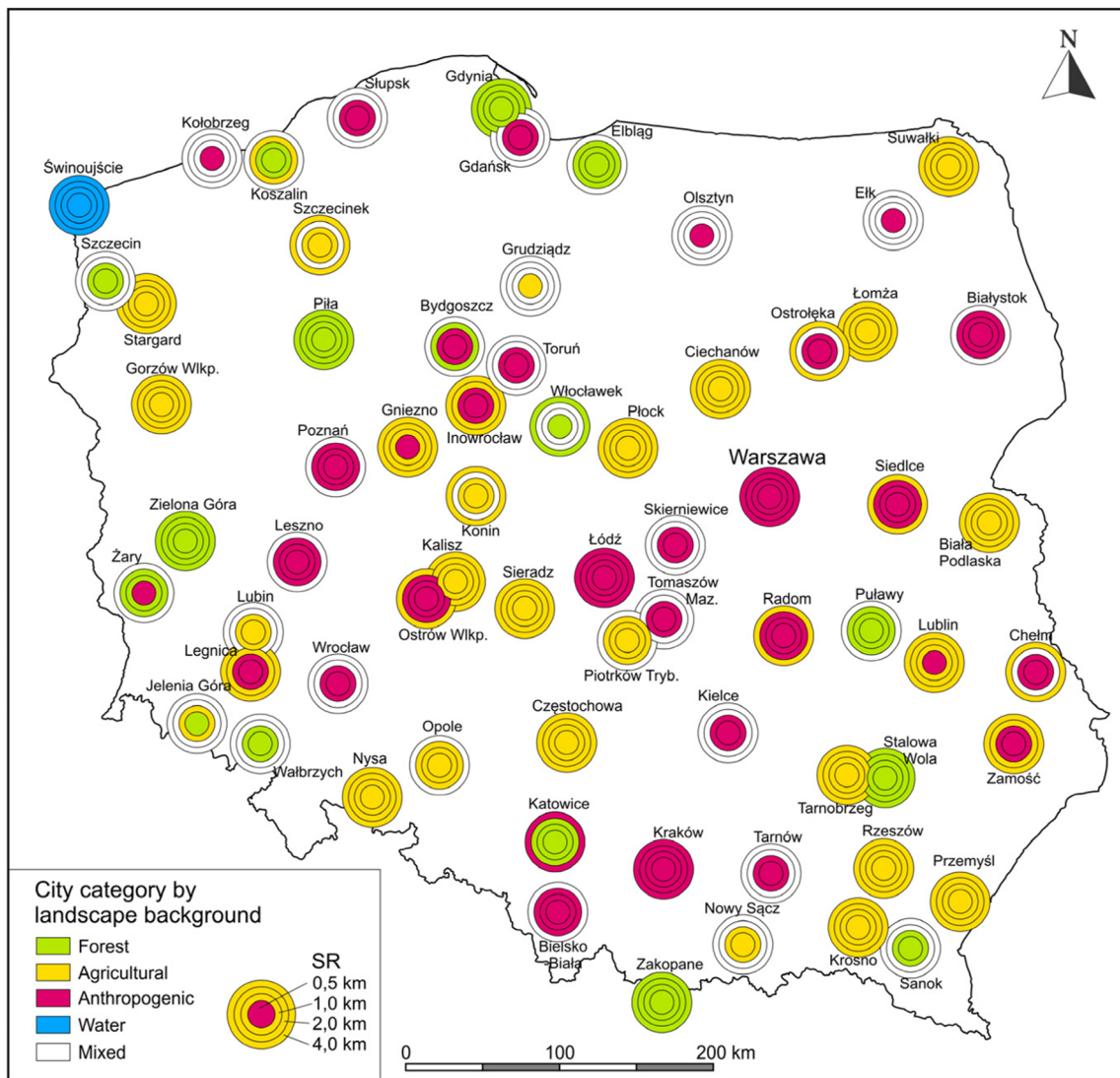
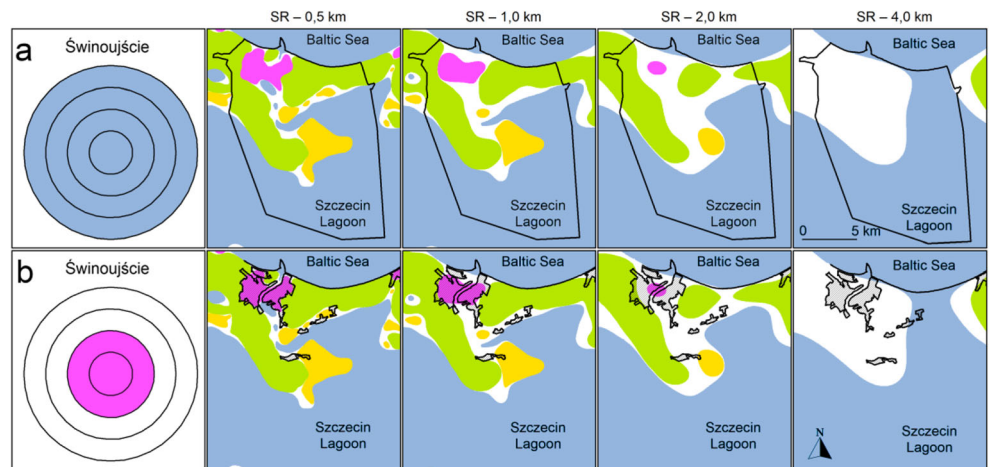


Fig. 5 Example of graphical presentation of heterogeneous landscape background of selected cities in Poland (>40 thousand residents) designated within their administrative boundaries

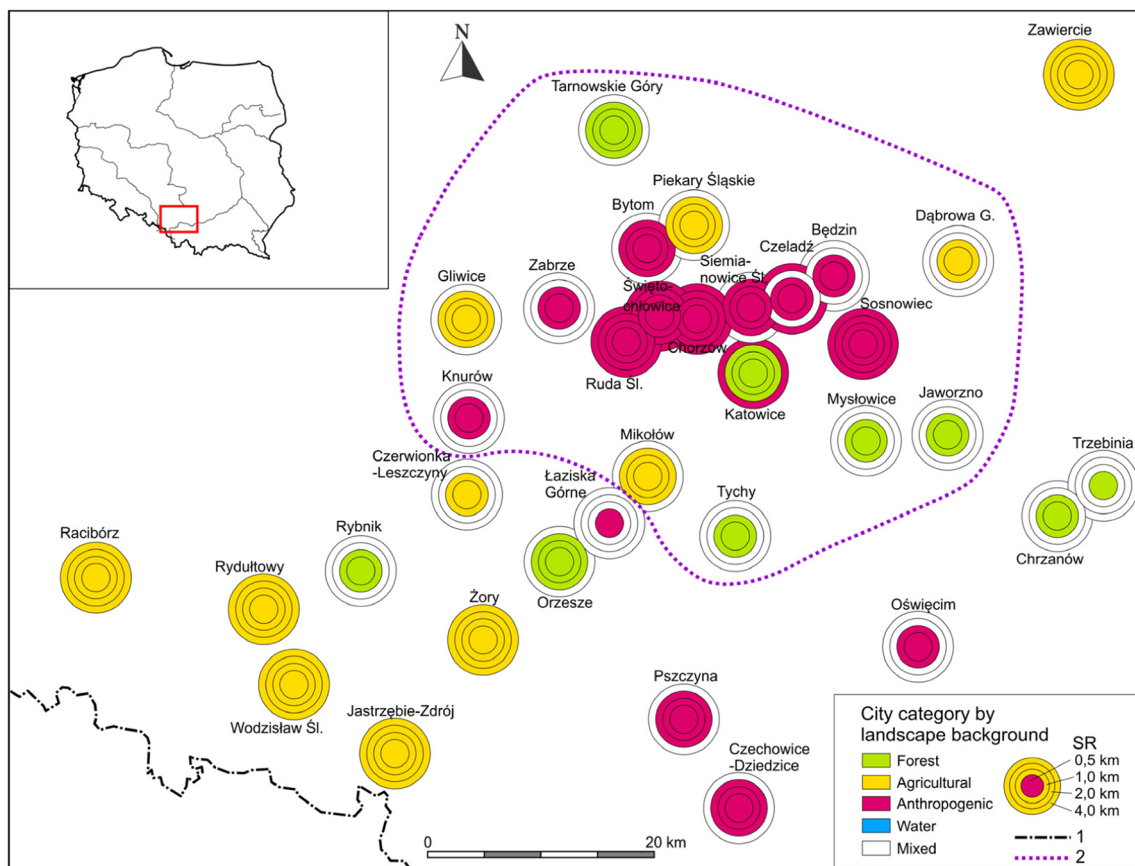


Fig. 6 Example of graphical presentation of the heterogeneous landscape background of the cities of Upper Silesia, designated within the administrative boundaries of 1 – state boundaries, 2 – the Upper Silesia boundaries

and wetlands). Also, an additional group with a predominantly mixed background was distinguished (where there are at least three types of coating with a similar degree of coverage). Examples of the cities located in the background of the dominant land cover are presented in Fig. 3.

When classifying the cities into population, a simplified distinction according to Szymańska (2007) was used. When it comes to cities, they were divided into five groups based on their surface (<10, 10–20, 20–50, 50–100, >100 km²).

Due to the fact that within the administrative boundaries of cities in Poland, undeveloped areas (such as urban forests, parks, lakes or fields) may have a significant share, the determination of the location of the city in terms of the landscape background was made both with respect to administrative boundaries and to the built-up areas, in which the majority of the city's inhabitants live.

Given that landscape background presented in the work depends on the radius search, its four dimensions were selected. They can approximately correspond to the range of direct impact of land use on the quality of life of urban residents, presented in the literature. Examples of the differentiated location of cities in Poland in relation to the background in selected radius searches (0.5, 1.0, 2.0, 4.0 km) with their

graphic presentation are shown in Fig. 4. Other rings of circles show the dominant land cover (landscape background) in range of four search radii. Moreover, the figure explains the problem resulting from the fact that within the administrative boundaries of cities significant areas prevail there: urban forests, surface waters, and even arable land. Not taking these elements into account would often lead to oversimplification of the inference, especially regarding quality of life of residents in large urban centers. To avoid this, applied were two ways of evaluating the city's position in terms of the landscape background. The first one includes the qualification of the city carried out within its administrative boundaries. The second one (used in the subchapter *The heterogeneity of the city landscape background within built-up areas*) includes only the area of dense urban areas. The need to do so relates particularly to larger cities. In relation to smaller cities (<20 thousand residents), the dominant landscape background of surrounding areas so strongly affects the area of the city that some of forest and water areas within the city are of little value at its qualification to a dominant landscape background.

Świnoujście is an example of a city illustrating the need of such approach. This is linked with the fact that within the administrative boundaries of Świnoujście, there are large areas

Table 1 The number of Polish cities in given landscape types

Type	Subtype	Class	Number of cities					Total	
			Size ranges [km ²]						
			<10	10–20	20–50	50–100	>100		
Urban landscape									
U	U4	U4	1	5	2	4	6	18	
		U3/a1	0	5	6	0	2	13	
		U/a	U2/a2	15	18	9	1	0	43
	U/a	U1/a3	25	11	6	1	2	45	
		U3/m1	2	4	7	1	4	18	
		U/m	U2/m2	6	18	18	1	2	45
	U/m	U1/m3	4	4	4	1	0	13	
		U3/f1	0	0	0	0	0	0	
		U/f	U2/f2	2	1	0	0	0	3
U/f	U1/f3	3	0	1	1	0	5		
	Agricultural landscape								
	A	A4	A4	229	163	99	17	1	509
A/m			A3/m1	8	5	6	2	1	22
A2/m2			0	6	4	0	1	11	
A/m		A1/m3	5	1	1	0	0	7	
		A3/f1	4	3	1	0	0	8	
		A/f	A2/f2	5	2	1	0	0	7
A/f		A1/f3	2	2	0	1	0	5	
		Forest landscape							
		F	F4	F4	7	19	28	18	4
F3/m1	2			1	2	5	0	10	
F/m	F2/m2			2	5	8	1	1	17
F/m	F1/m3		0	3	1	0	1	5	
	F/a		F3/a1	3	2	5	1	0	11
	F2/a2		2	3	0	1	0	6	
F/a	F1/a3		2	1	0	0	0	3	
	F/w		F2/w2	0	1	1	0	0	2
	F/u		F3/u1	0	0	0	0	1	1
Water and wetland landscape									
W	W4		W4	2	0	1	0	2	5
			W/a	W3/a1	0	1	0	0	0
		W2/a2	2	1	1	0	0	4	
	W/m	W2/m2	0	1	0	0	0	1	
		W1/m3	1	0	0	0	0	1	
Mixed landscape									
M	M/x		11	0	1	0	0	12	
Total			345	286	213	56	28	928	

of waters along with numerous small islands and forests (altogether, their area constitutes 72.8% of the city’s area), while the built-up area occupies only 10% of its area. While qualifying the location of the city in terms of the dominant landscape, which takes into account the course of its

administrative boundaries; the city, regardless of the search radius, is located in a water and wetlands landscape (Fig. 4a). When only taking into account the built-up area, in the first two radii, the dominant is an anthropogenic landscape (Fig. 4b). However, the presented example of a city is an outlier as in most analyzed cities the differences resulting from two different methods of calculation are not so clear.

To summarize the aforementioned problem, the first of presented methods informs within which dominant landscape the entire area of the city is located (taking into account its administrative boundaries). The second method informs us within which landscape the dense urban buildings area is located. It seems that for the general division of the cities in terms of the surrounding landscape background it is more appropriate to operate with the administrative boundaries (which has been applied in this work), while for the attempt to determine the direct impact of the landscape on the quality of resident’s life, it is appropriate to narrow the analysis to built-up areas.

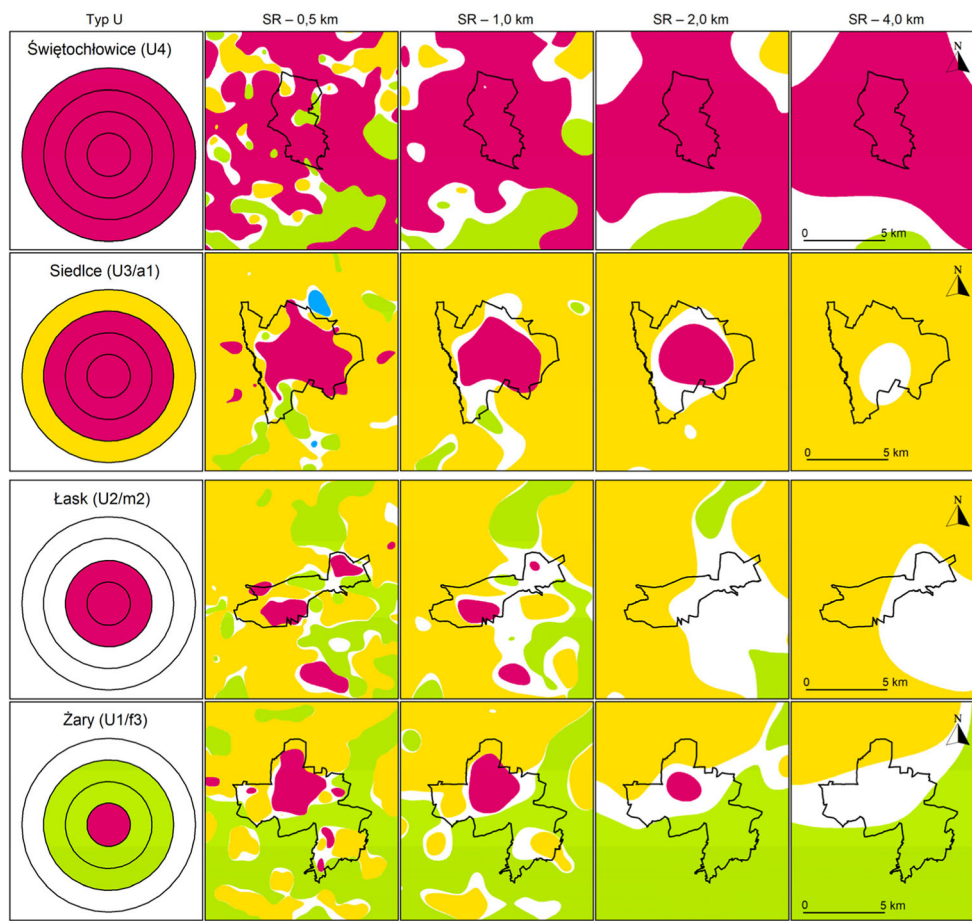
Application of the method in the classification of Polish cities

Using the criteria presented in this methodology, the cities are located within the differentiated background, which largely reflects the agro-forest nature of the country. Poland is dominated by agricultural land, which constitutes 59.8% of the country’s surface, and then, by forests, which constitute 32.7%.

The differentiation of location of chosen cities in terms of landscape background regarding administrative boundaries is presented in Figs. 5 and 6. The first one shows the diversity of the landscape background of the selected Polish cities with more than thousand residents. The second one takes into account the densely populated area of Upper Silesia, including Katowice urban area, which is characterized by a large variety in terms of industrialization and the nature of land use.

Keeping in mind the interaction between urban areas and the surrounding areas, all Polish cities were divided within their administrative boundaries because of their dominant landscape background. It includes the structure of the land cover within the city area as well as the area outside its boundaries. The distinguished types include five types of landscape (including the mixed landscape), four search radii, and their organized combinations. The number in a given type, subtype, and class, depending on the size of the city is shown in Table 1. Type of the city was determined by the dominant landscape within the administrative boundaries, calculated with the smallest search radius (0.5 km). Including this radius, 22% of Polish cities were accounted for in the urbanized type (U). Cities of the agricultural type (A) constitute the largest group (61%), which relates to the dominant share of agricultural land within the country’s landscape. Cities of the forest

Fig. 7 Example of determining types of cities with dominant anthropogenic land cover depending on adopted search radius. Color explanations see Fig. 1. SR – search radius



type (F) constitute a much smaller amount (14%) than the share of the whole country's use would indicate. The remaining 3% are cities of the water (W) and mixed type (M).

The use of larger radius qualified the city for the subtypes and classes (Fig. 7). The first of presented groups are the cities of the urban type (U). Among them there is U4 subtype, in which the anthropogenic cover dominates within all four search radii (0.5 km–4 km). It includes 6 of the biggest Polish cities in terms of population, with over 500 thousand of residents (e.g. Warsaw, Cracow, Poznań) and 12 smaller cities with a varied area located in agglomeration: Silesian (e.g., Bytom, Chrzanów, Zabrze) and Warsaw (e.g., Piastów, Prószków, Ząbki). Smaller cities in this subtype are areas affected by the impact of the anthropogenic landscape of the neighboring bigger cities.

Distinguished was the (U/a) subtype in the urbanized type (U), which is dominated by the agricultural landscape when a larger search radius are used. Depending on the number of search radii, in this subtype three classes were distinguished: U3/a1, U2/a2 and U1/a3. In total, there are 101 cities in this subtype, with five having more than 100 thousand residents (e.g. Lublin – U3/a1, Legnica U2/a2, Częstochowa – U1/a3).

The largest group in this subtype consists of 40 cities below 10 km² (e.g.: Płoty – U2/a2, Kruszwica – U1/a3).

Another subtype (Uf) consists of cities dominated by the forest landscape when increasing the search radius. These are usually small cities located close to large forest complexes. Examples of cities belonging to this subtype are Kartuzy (U1/f3) and Mirosławiec (U2/f2).

A significant number of cities (76) was classified to an Um subtype. This group includes large cities in terms of population and surface area, where administrative boundaries outside urbanized areas are more diversified in terms of land use (e.g., Bydgoszcz, Gdańsk – U3 m1, Szczecin, Kielce – U2 m2, Olsztyn – U1 m3), as well as 63 cities of less than 50 km² (Słupsk – U3 m1, Ełk – U2 m2, Brzesko – U1 m3). Examples of cities belonging to selected types are presented in Fig. 8.

Selected groups of cities, including landscape background, can be helpful in shaping their spatial policy in relation to green areas because they include both the existing structure of urban greening and land cover outside the city borders. Consideration of four different search radii allows for assessment of a wider spatial spectrum of interactions



Fig. 8 An example of locating cities within the diversified landscape background. **a** Kłodawa (A4), **b** Kępice (F4), **c** Piastów (U4), **d** Jastarnia (W4). Source: Google Earth

between the land cover of a city and its surroundings. This is particularly important when implementing objectives of the policy of sustainable development of urban areas, in relation to creating greenery system connected with neighboring areas of cities.

Taking into account the formation of urban greenery, particular attention should be given to the type of urbanized cities (U), especially to relatively few cities in class U4 (18 cities), in which 25% of the Polish urban population lives. In addition to large cities, which are characterized by high levels of urbanization, lowering the quality of life of residents may concern relatively numerous group of smaller cities with a dense urban area, which with a larger search radius are located within the agricultural landscape (U3/a1, U2/a2, U1/a3) or regardless of the radius, belong

to the (A4) type. These cities are heated primarily by coal, which causes severe air pollution from low emission (Kuceba and Kulej–Dudek 2016; Bell et al. 2006). Also, the chemical agents coming from agricultural areas have an impact on the quality of life. Altogether, in those four distinct groups resides more than 63% of the population.

Much better conditions are in the cities surrounded by forests, including cities of F type and U/f, A/f and M/f subtypes, due to their location in the landscape. Altogether, in this type and three subtypes lives 14% of the urban population. With the exception of Silesian cities, most of them (especially of the F type) are cities of touristic and recreational character. Examples of Polish cities according to the adopted classification are presented in Table 2.

Table 2 Examples of classification of selected Polish cities including their surface (cities size)

Type	Cities size [km ²]	The number of cities in the selected type	Name of the cities including class symbol
U	>100	16	Warsaw (U4), Cracov (U4), Łódź (U4), Gliwice (U1/a3)
	50–100	10	Sosnowiec (U4), Ruda Śląska (U4), Tychy (U2/m2), Grudziądz (U1/a3)
	20–50	53	Chorzów (U4), Siedlce (U3/a1), Tczew (U2/a2), Żary (U1/f3).
	10–20	66	Piaseczno (U4), Świętochłowice (U4), Wieliczka U3/a1, Łask (U2/a2).
	<10	58	Piastów (U4), Płoty (U2/a2), Mirosławiec (U2/f2), Żnin (U1/a3).
A	>100	3	Rzeszów (A4), Dąbrowa Górnicza (A2/m2), Jelenia Góra (A3/m1)
	50–100	20	Gorzów (A4), Kalisz (A4), Opole (A3/m1), Pieszycy (A1/f3)
	20–50	112	Łomża (A4), Jasło (A4), Boguszów–Gorce (A2/f2), Wąlczy (A2/m2)
	10–20	182	Koło (A4), Łañcut (A4), Lesko (A2/f2), Kościerzyna (A2/m2)
	<10	253	Łęczycy (A4), Choszczno (A4), Sejny (A4), Supraśl (A2/f2)
F	>100	7	Piła (F4), Wisła (F4), Katowice (F3/u1), Jaworzno (F2/m2)
	50–100	26	Augustów (F4), Zakopane (F4), Elbląg (F3/m1), Orzesze (F3/m1)
	20–50	45	Żagań (F4), Wejherowo (F4), Hel (F2/w2), Chrzanów (F2/m2)
	10–20	35	Pionki (F4), Rzepin (F4), Biały Bór (F2/a2), Łeba (F2/w2)
	<10	18	Bardo (F4), Tuczno (F4), Ulanów (F3/a1), Iwonicz Zdrój (F3/m1)
W	>100	2	Świnoujście (W4), Krynica Morska (W4).
	50–100	–	–
	20–50	2	Nowe Warpno (W4), Otmuchów (W2/a2)
	10–20	3	Wolin (W3/a1), Myślibórz (W2/a2), Sława (W2/m2)
	<10	5	Jastarnia (W4), Dziwnów (W4), Moryń (W2/a2), Ińsko (W1/m3)

Conclusion

The method of raster data generalization presented in this work allows for determining the location of cities in relation to land cover forms, as well as to divide them. This facilitates the assessment of the potential impact of land cover on the quality of life of the residents on a national scale. It takes into account the structure of land cover within the city as well as areas outside its boundaries.

The method was used, among others, when classifying all of 928 Polish cities in the administrative boundaries, including five forms of dominant landscape and four search radii. The type of city was determined by the dominant landscape within the administrative boundaries, calculated with the smallest

search radius. Presented division allowed for selection of a group of cities in case of which particular attention should be paid to the way of shaping green urban areas in the context of their inhabitants' life quality. These groups include cities of the urbanized type (U), especially relatively small cities in U4 class, which are inhabited by 25% of Poland's population. Declining of the residents' life quality may concern also a large group of smaller cities in terms of area with densely built-up cities situated in agricultural or urbanized agricultural landscapes where there is a likelihood of harmful impact of the industry, residential energy, and air pollution from farming. Altogether, over 63% of the urban population lives in groups A4, U1/a3, U2/a2, U3/a1. Potentially the best conditions, due to the location in the landscape, have cities surrounded by

forests, which are inhabited by 14% of the urban population. With the exception of Silesian cities, most of them are of touristic and recreational character.

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