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An evaluation of urbanisation processes in suburban zones using land-cover data and fuzzy set theory

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Abstract. The aim of this article was to evaluate urbanisation processes in space using the CORINE Land Cover (CLC) databases. The study was conducted in the rural municipality of Dywity in the direct vicinity of the city of Olsztyn. Basic concepts and methods for evaluating urbanisation processes were determined based on a review of the literature. The article addresses issues related to spatial management and GIS as a data source and a tool for analysing land management activities. The search for new methods for evaluating spatial management and spatial processes plays a particularly important role in rapidly urbanising areas. The study explored the applicability of GIS as a data source and a tool for evaluating urbanisation processes in studies that rely on modern methods such as fuzzy set theory. The intensity and dynamics of urbanisation processes were evaluated based on changes in land cover with the use of CLC databases.

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1. Introduction

According to the United Nations World Urbanisation Prospects report (2019), urban dwellers accounted for 55% of the global population in 2018. By 2050, the percentage of the urban population is projected to grow to 68% (United Nations, 2019). It should be noted that this level has already been achieved in the European Union, where more than two thirds of the population reside in cities, and the percentage of the urban population continues to increase (Bajwa et al., 2015).

The steady rise in the global population is contributing to the development of various types of human settlements (Albino et al., 2015). In consequence, spatial processes such as migration and spatial diffusion are increasingly leading to important qualitative changes (Sun & Ongsomwang, 2020). The agrarian structure of settlements is being gradually replaced by industrial structures (Bruegmann, 2015). Changes are also observed in population density, leading to the formation of larger population clusters (Streule et al., 2020). These processes modify demographic and social structures in both rural and urban areas (Montgomery et al., 2013). The described changes are clearly reflected in land cover and the organisation of space (Rimal et al., 2018). These transformations are referred to as “spatial urbanisation” (Romano et al., 2017). This process induces changes in economic space to accommodate urban characteristics and functions (Dijkstra et al., 2018). The result is semi-urbanisation, i.e. the evolution of urban features in agricultural areas. Therefore, this process is associated with transformations of spatial structures (Dijkstra & Poelman, 2014).

In general, suburbanisation most often affects pre-urban zones that complement the urban fabric, as well as suburban zones where non-urban areas are subjected to urbanisation pressure (Cieślak et al., 2016). Suburban zones created in the suburbanisation process are unstable areas that bring change to all aspects of human life and activity (Cieślak et al., 2020). In these areas, new structures merge with the old architecture or are completely dispersed. Most suburban dwellers commute daily to work in the city (Hochstenbach & Musterd, 2018). Suburban homes usually resemble urban villas, and they are built to a higher standard than typical rural homesteads (Parsons et al., 2019). New housing development is also characterised by higher density and the absence of farm buildings (Cieslak et al., 2019). Suburbanisation increases public spending on transport, infrastructure and public institutions (Cieślak & Szuniewicz, 2015). These processes lead to changes not only in land cover, but also in the organisation and management of space, and they pose an immense challenge for the authorities of the adjacent rural municipalities that are usually most affected by suburbanisation (Rietkerk & van de Koppel, 2008; Butt et al., 2015; Mikhaylov, et al. ,2021). An analysis of the rate of the above processes is an important element of spatial management, which makes it possible to prepare for successive stages of suburbanisation (Barros et al., 2018). Spatial analyses and geographic information systems (GIS) significantly facilitate assessments of urbanisation processes (Espinosa et al., 2016). The availability of GIS databases supports observations and analyses of spatial processes (Dai et al., 2001). The major problem of rapidly changing suburban areas is the difficulty in monitoring these changes. Progressive land fragmentation and shifts in land use have led to irreversible changes, which are rarely in harmony with the locally defined spatial policy. We frequently have to cope with low levels of awareness that some forms of land use are disappearing and others, not the most desirable ones, are emerging. Seeking tools that will enable the assessment and thus monitoring of these transformations with the use of spatial information is very desirable.

In view of the above, the main aim of this study was to determine the applicability of the CORINE Land Cover (CLC) database for tracking urbanisation processes in space. For the purpose of this study, the author's synthetic urbanisation index based on land-cover data from the CLC database was determined. The *WU* index represents the area occupied by each land-cover type, weighted by the extent of anthropogenic modification, and defining the proportion of urban land-use types (*wp*). A merit of the article is that it indicates a procedure that uses increasingly abundant spatial databases for a quick evaluation of spatial changes, which can be conducted on a local scale. The studied object was the rural municipality of Dywity, which is adjacent to Olsztyn, the capital city of the Voivodeship of Warmia and Mazury. Land cover in Dywity was investigated using the CLC database. The collected data were analysed to determine changes in land use and land cover in the studied municipality.

2. Sources of data

2.1 Characteristics of the studied area

The studied area was the municipality of Dywity in Olsztyn county. This rural municipality is situated in the direct vicinity of Olsztyn, the capital city of the Voivodeship of Warmia and Mazury (Fig. 1) (LOCAL DEVELOPMENT PLAN 2004).

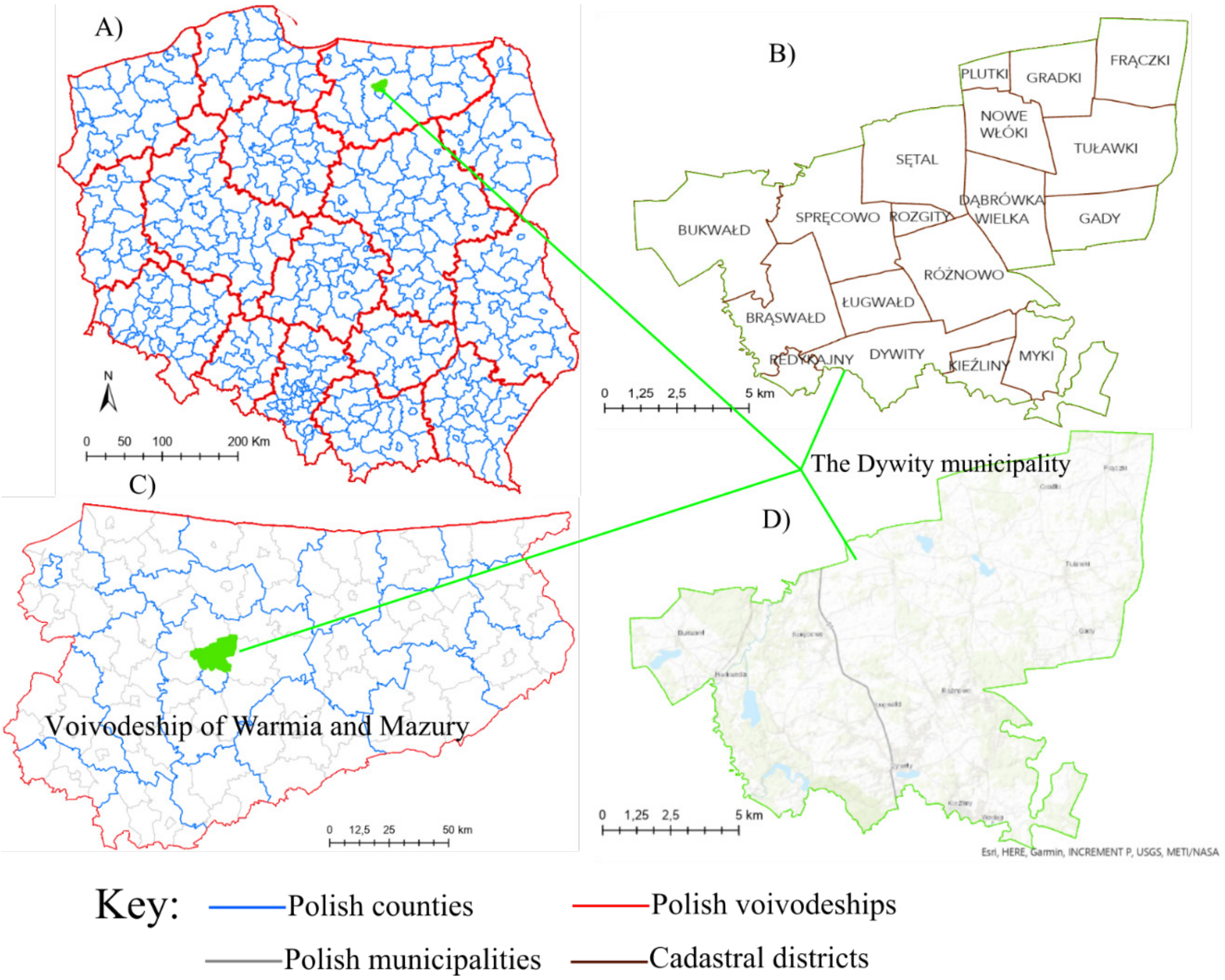

Fig. 1. Polish voivodeships on a map of Poland (A); map of Dywity municipality divided into cadastral districts (B); Dywity on a map of municipalities in the Voivodeship of Warmia and Mazury (C); topographic map of Dywity municipality (D)
Source: author's own work.

In addition to the urban municipality of Olsztyn, Dywity borders five other municipalities: Dobre Miasto, Jeziorany, Barczewo, Jonkowo and Świątki. The settlement network in Dywity comprises variously sized villages as well as dispersed and isolated farmsteads. Most of the studied municipality has a regular settlement pattern. The only exception is the southern part of Dywity, which is directly adjacent to Olsztyn. This part of the municipality has well-developed infrastructure, which contributes to the rapid development of single-family houses, services and retail outlets (Plan Rozwoju Lokalnego Gminy Dywity, 2004).

Dywity comprises 19 cadastral districts: Bukwałd, Dywity, Gady, Gradki, Rozgity, Frączki, Ługwałd, Nowe Włóki, Redykajny, Tuławki, Brąswałd, Sętal, Zalbki, Myki, Dąbrówka Wielka, Kieźliny, Plutki, Spręcowo and Różnowo. The cadastral districts Redykajny, Dywity, Kieźliny and Zalbki are directly adjacent to Olsztyn. Dywity municipality has an area of 161.13 km^2 and a population of 11,697 (https://bdl.stat.gov.pl/BDL/, accessed on 18 January 2020). Population density equals 73 persons per km^2 and continues to increase each year. The changes in the demographic structure of Dywity between 2000 and 2018 are presented in Table 1. The time frame of the study was driven by access to Corine Land Cover data. Data from CLC databases are released every six years. The most up-to-date database available is the land cover data for 2018.

Population and population density increased steadily in each year of the analysed period (2000–2018) without major surges or lags. The observed population growth can be attributed to the proximity of Olsztyn city and national road No. 51. The magnitude and steady rate of population growth contribute to changes in land use and, consequently, land cover, which is the main object of analysis in the present study.

2.2. CORINE Land Cover

The CORINE (Coordination of Information on the Environment) Land Cover database is a thematic component of the CORINE programme and one of the richest sources of land cover data. The programme was initiated by the European Commission in 1985 (GIOS; 2019).

Table 1. Demographic changes in Dywity municipality in 2000–2018

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Population density (persons /km^2)	48	49	50	52	54	56	58	60	61	63	65	66	67	68	69	70	71	72	73
Population (‘000)	7.8	7.8	8.1	8.3	8.7	9.1	9.3	9.6	9.9	10.1	10.4	10.6	10.8	11.0	11.1	11.3	11.4	11.5	11.7

Source: author’s own work.

Table 2. Overview of satellite data used for land-cover interpretation in Poland

Reference Year	Source data
CLC 1990	Landsat 4/5 TM Images from 1 period
CLC 2000	Landsat 7 ETM Images from 1 period
CLC 2006	SPOT-4/5, IRS P6 LISS III Images from 2 periods
CLC 2012	IRS P6 LISS III,RapidEye Images from 2 periods
CLC 2018	Sentinel-2A/B, Landsat 8 Images from 2 periods

Source: author’s own work.

Land cover data were accumulated in the CLC database to harmonizise the environmental policies of the European Union Member States. Satellite images, aerial images and topographic maps are the main sources of land-cover data (Büttner et al., 2004; Cieślak et al., 2018). In Poland, the datasets are derived free of charge from the Chief Inspectorate of Environmental Protection (GIOŚ; 2019). Poland has participated in all previous editions of CORINE Land Cover projects. Source data used in construction of CLC databases are presented in Table 2 (Bielecka et al., 2020).

The nomenclature in the CLC database relies on three hierarchical levels that are characterised by different accuracies of land-cover data. The first level is the most general, and it consists of five major categories representing the main land-cover types on the Earth:

1. Artificial surfaces – built-up areas, including residential areas, commercial and industrial areas, mines and green urban spaces.
2. Agricultural areas – arable land, permanent crops, meadows, pastures and land principally occupied by agriculture with significant areas of natural vegetation.
3. Forests and semi-natural areas – forests, shrubs and open areas with little or no vegetation.
4. Wetlands – inland marshes, peat bogs, salt marshes, salines and intertidal flats.
5. Water bodies – inland waters and marine waters (Cieślak et al., 2020).

The second level is more detailed, and it comprises 15 land-cover types (on a scale of 1:500 000 to 1:1 000 000). The third level contains the most detailed data, and it features 44 land-cover classes. Land-cover maps developed based on third-level data in the CLC database had to meet the following requirements: map scale – 1:100 000, the minimum mapping area – 25 hectares for surface features and 100 m for linear features, the minimum spatial resolution for distinguishing different land cover types – 100 m (I. Cieślak et al., 2017).

3. Methods

3.1. Research methodology

The aim of the study was to determine the applicability of the CLC database for tracking urbanisation processes in space. This research objective was pursued in a study of the Dywity municipality. Changes in land-cover types in the evaluated municipality were analysed using the ArcGIS for Desktop program and public-domain spatial data. These resources included land-cover/land-use data for Europe released by the Polish Chief Inspectorate of Environmental Protection under the European CORINE Land Cover programme (CORINE Land Cover, n.d.). The studied area was narrowed down based on information about the administrative division of Poland published by the Head Office of Geodesy and Cartography. Based on these resources, the boundaries of the Dywity municipality were identified, and land-cover/land-use data were adjusted to the identified boundaries.

Changes in land cover were monitored over time by analysing the four most recent CLC databases that were released in 2000, 2006, 2012 and 2018. Land-use maps were generated for the corresponding years based on level 3 CLC data and the appropriate colour codes in the CLC database.

The determination of the extent of anthropogenic modification *wp* proved to be problematic in the calculation of the urbanisation index. To resolve this problem, the area and degree of membership of various land-cover types in the urban function were calculated with the use of fuzzy set theory (Zadeh, 2011). According to fuzzy set theory, every land-cover type in the studied municipality was assigned a value denoting the proportion of urban land-use types (*wp*) and the extent of anthropogenic changes in land cover (Ahmed et al., 2013). Every element in a fuzzy set is assigned a value in the range of <0;1> (Cieślak, 2012). The value was assigned based on studies of the affiliation of different land-cover forms to urban and rural land use. The research addressed the identification of urban transition zones (Biłozor; 2004). Survey methods were used for the study. A group of 50 spatial and environmental specialists determined the intensity of anthropogenic land transformation of a particular land cover. Respondents were asked to select which of the following land-use types was "more transformed" than the others. The results of the survey were used to develop a fuzzy model of land transformation. The questionnaire consisted of a comparison matrix in which respondents identified the intensity of anthropogenic elements on a particular site, described by a specific land use ("←", "O", or "↑" for which the values were 2-1-0, respectively). The totals of values derived from all surveys were averaged and then used to calculate a value denoting the proportion of urban land-use types (*wp*) (Biłozor et al., 2020).

Urbanisation processes, particularly in municipalities situated in the direct vicinity of large and dynamically developing regional capitals, were described with the use of a synthetic urbanisation index based on land-cover data from the CLC database. The *WU* index represents the area occupied by each land-cover type, weighted by the extent of anthropogenic modification, and defining the proportion of urban land-use types (wp). The *WU* index was calculated with the following formula:

$$WU_R = \frac{\sum_{i=1}^{N} \ (wp_{n_i} \ * \ P_{n_1})}{P_g} * 100$$

where:
WU_R – urbanisation index at time *R*;
N – number of land-cover types in a given year;
wp – extent of anthropogenic modification;
P_n – area occupied by a given land-cover type;
n_i – number of land-cover class in the CLC database;
P_g – area of municipality

The urbanisation index can take on values in the range of 0 to 100, where 0 denotes rural areas and 100 is a theoretical value that could be obtained in areas featuring only land-cover types that are indicative of urban land-use patterns.

3.2. An evaluation method based on fuzzy sets

Various methods have been developed for evaluating changes in land use and land management. Some of these methods rely on the fuzzy set theory developed by Lotfi Zadeh in 1965. A fuzzy set is a class of objects with a continuum of grades of membership. It is characterised by a membership function that assigns to each object a grade of membership ranging from 0 to 1 (Biłozor, 2012). Fuzzy sets are a good starting point for building conceptual frameworks that, in many respects, overlap the frameworks that are developed for classic sets. However, fuzzy sets are more generalised than classical sets, and they have a broader range of applications, in particular in the fields of pattern classification and data processing (Zimmermann, 2010).

Fuzzy sets have been used to analyse the rural–urban continuum by identifying and defining land-use types in the rural–urban fringe (usually a large city) (Biłozor et al., 2020). In this method, the degree of membership of land-use types in a set of urban functions was evaluated, and the spatial range of urban land-use types was determined (Biłozor et al., 2019). Areas in the range of <0.3; 0.5> do not have clearly identified functions, and they are referred to as transition zones.

4. Results

4.1. Analysis of land-cover types in the Dywity municipality

The changes in the proportions of various land-cover types over time were determined by generating four maps of the Dywity municipality based on the results of cartographic inventories conducted under the CLC program in 2000, 2006, 2012 and 2018 (Fig. 2).

Only 13 out of the total of 44 land-cover classes in the CLC database were identified in Dywity, and they are presented in Table 3. The following land-cover types were identified: inland marshes, water courses, non-irrigated arable land, transitional woodland-shrub, broad-leaved forests, coniferous

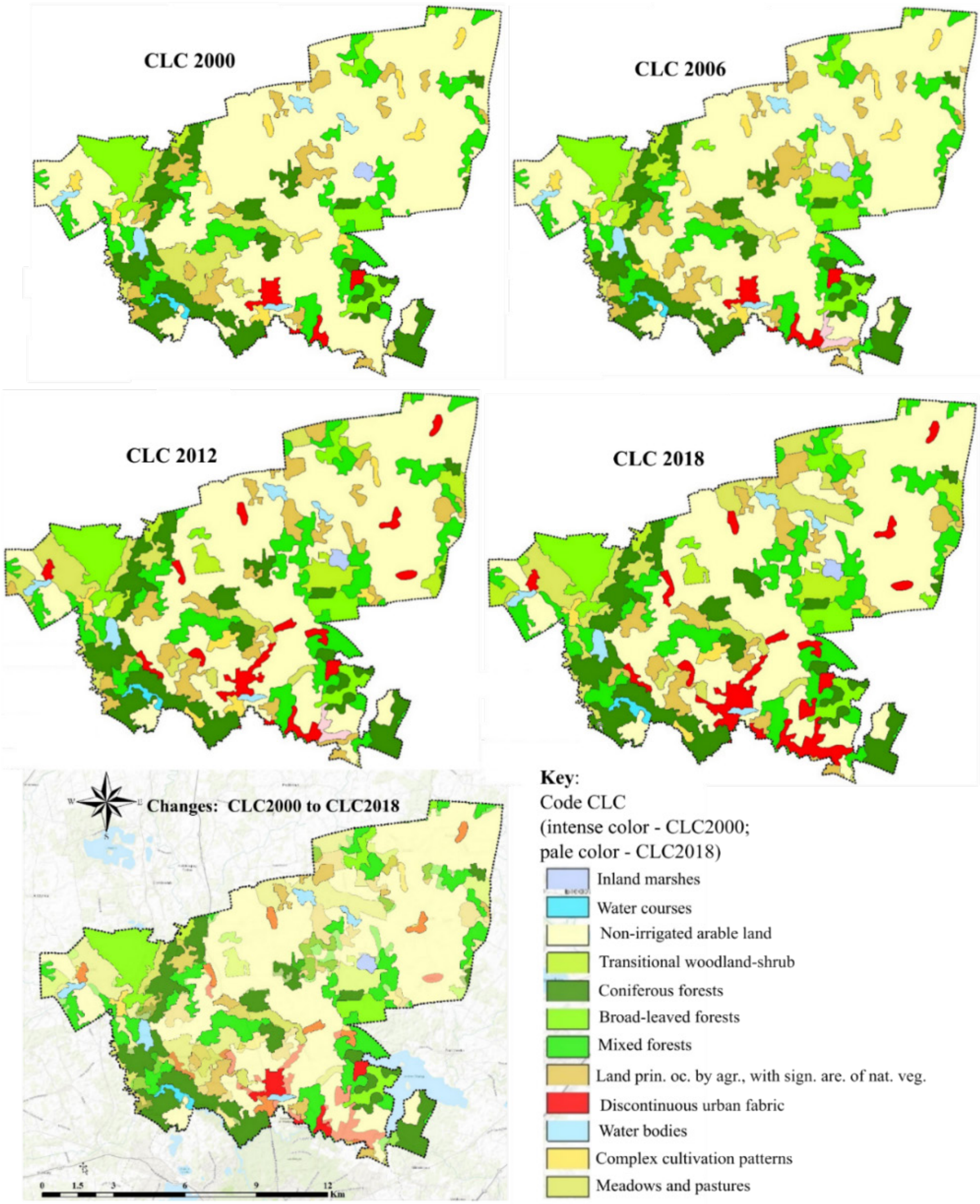

Fig. 2. Land-cover maps generated for Dywity municipality based on results of CLC inventories in 2000, 2006, 2012 and 2018

Source: author's own work.

forests, mixed forests, land principally occupied by agriculture with significant areas of natural vegetation, discontinuous urban fabric, water bodies, complex cultivation patterns, meadows and pastures, sport and leisure facilities.

The presented maps were generated based on CLC inventory data. Spatial data were converted to the ETRS_1989_Poland_CS2000_Zone_7 coordinate system to ensure that land-cover patterns are accurately reflected in the maps. Land-cover types were colour coded according to CLC guidelines and presented in the map key in Figure 2. The generated maps present land-cover types identified at four points in time separated by six-year intervals. The spatial distribution of land-cover types was analysed in each map, and changes relative to the previous time point were determined. The maps presenting data from the first and last years of the analysed period (2000 and 2018) were compared to facilitate the identification of long-term changes.

A comparison of the maps revealed considerable changes between the first and last year of the analysed period. Certain features could not be identified in a comparison of maps generated in six-year intervals. The most notable change was the increase in diversity of land-cover types. These changes took place at the expense of arable land, whose area was drastically reduced.

An increase was observed mainly in the area of forests (north-eastern part of the municipality), meadows and pastures (large such features in the western and northern parts of the municipality) and, above all, discontinuous urban fabric. The existing areas with urban land cover were expanded, and many new dispersed clusters emerged across the entire municipality. The most extensive changes were observed in the proximity of the urban core, which points to the rapid progression of urbanisation in the studied area.

Table 3. Land-cover types in Dywity municipality based on CLC data for 2000–2018

		2000		2006		2012		2018	
No.	Land cover type	Number of sites	Area (ha)	Number of sites	Area (ha)	Number of sites	Area (ha)	Number of sites	Area (ha)
1	Inland marshes	1	46.55	1	46.55	1	49.95	1	50.71
2	Water courses	1	49.45	1	49.45	1	49.45	1	58.13
3	Arable land	7	9367.85	10	9024.38	12	7573.02	15	6943.33
4	Transitional woodland-shrub	1	40.54	4	425.16	7	586.81	6	566.15
5	Coniferous forests	17	1722.07	17	1724.52	17	1753.72	17	1832.33
6	Broad-leaved forests	7	939.88	8	971.31	8	976.66	9	1030.40
7	Mixed forests	26	1676.32	27	1710.70	28	1983.17	29	2138.91
8	Sport and leisure facilities	0	0.00	1	71.20	1	71.20	0	0.00
9	Agricultural land	17	825.05	19	1016.67	25	1158.78	16	969.32
10	Water bodies	6	196.70	6	196.69	6	196.69	6	197.08
11	Discontinuous urban fabric	4	185.77	4	217.53	14	553.82	15	834.19
12	Complex cultivation patterns	11	327.90	12	375.60	6	220.39	4	148.23
13	Meadows and pastures	6	735.04	5	283.35	14	939.42	17	1344.31
	TOTAL	104	16113.10	115	16113.10	140	16113.10	136	16113.10

Source: author's own work.

4.2. Statistical analysis

The results of the cartographic analysis were processed statistically to identify general trends and the direction of changes in land use. The maximum, average and minimum areas of all land-cover types in the analysed municipality are presented in Table 3.

The most extensive changes in the studied period were evaluated in the first step of the analysis. A new function – sport and leisure facilities – was introduced during the 18-year period of analysis, and it was recorded in the CLC inventory in 2006 and 2012. However, this function was no longer present in the most recent inventory of 2018. The greatest change was noted in the area of non-irrigated arable land (referred to as arable land in Table 2) which decreased from 9367.85 ha in 2000 to 6943.33 ha in 2018, i.e., by 2424.52 ha. This indicates that the area of arable land decreased by 25.88%. Land fragmentation more than doubled in the studied period, from seven objects in 2000 to 15 objects in 2018.

In turn, the area of transitional woodland-shrubs increased considerably in the studied period. In 2000, the transitional woodland-shrub and shrubs occupied only 40.54 ha, and their area increased already in 2006. The area of this land cover class increased more than ten-fold over a period of six years. This increase was less spectacular in successive years, and in 2018 the area of transitional woodland-shrubs decreased by 20 ha relative to 2012. Despite the above, the area occupied by this land cover type increased nearly 14-fold (by 1396.52%) between 2000 and 2018. The above can be attributed to the municipality's environmental policy, which promotes afforestation. These measures increased the area of all types of forests. The area of broad-leaved and coniferous forests increased by 9.63% and 6.40%, respectively, whereas the area of mixed forests increased by 27.60% in the analysed period. The expansion of broad-leaved and mixed forests points to the afforestation of new areas.

Interesting trends were noted in the discontinuous urban fabric class. In this land-cover type, an increase was observed not only in the number of objects, but also in their total area. The area continued to expand steadily, whereas the number of objects remained unchanged in the first years of the analysed period. In 2012, the number of objects increased rapidly from 4 to 14. Only one new object was noted in 2018, but the area occupied by discontinuous urban fabric continued to increase at a rate equally as high as in 2012. The difference between years reached only 55.92 ha, which indicates that new buildings were initially dispersed. They were developed in new, isolated locations, which increased the number of objects on the map. The existing urban fabric was expanded between 2012 and 2018, but the corresponding increase (280.37 ha) did not lead to fragmented development. The area occupied by scattered housing increased by 349% between 2000 and 2018, which marks more than a three-fold increase in urbanised areas over a period of 18 years.

A considerable increase was also observed in area of meadows and pastures. Despite an initial decrease in this land-cover class, meadows and pastures were enlarged in successive years of the studied period. The area of meadows and pastures in the Dywity municipality nearly doubled (82.9%) between 2000 and 2018.

The area of inland marshes, water courses and water bodies did not change significantly in the evaluated period, and it remained stable in some years. The observed changes resulted from the expansion of wetlands in the adjacent areas, which is a slow process.

The last land-cover class included in the analysis was that of complex cultivation patterns. A minor increase in this land-cover type was initially observed, but it was followed by a steady decrease in successive years. Overall, the area of complex cultivation patterns decreased to 54.79% of the initial value.

The data presented in Table 3 have been visualised in a bar chart (Fig. 3) to better illustrate the changes in land cover in the Dywity municipality in the studied period.

The area of the vast majority (9 out of 13) of land-cover types in the studied municipality increased relative to the first analysed time point. This increase took place at the expense of arable land, as previously discussed. Arable land occupies a large part of the municipality's territory; therefore, its percentage proportion did not decrease significantly.

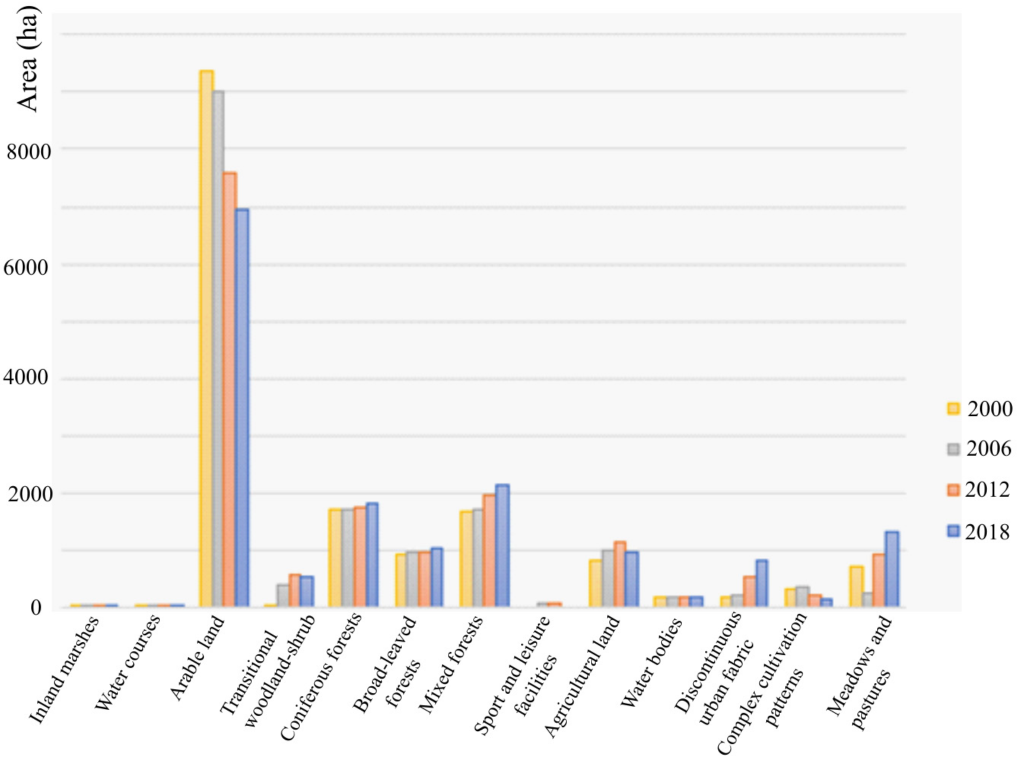

Fig. 3. Land-use types in Dywity municipality
Source: author's own work.

However, the observed decrease was considerable when measured in hectares. More than 2424 ha of arable land was lost in Dywity. The area of complex cultivation patterns, and sport and leisure facilities also decreased. In the latter class, the noted changes were not caused by economic factors such as the acquisition of new land for development, but they resulted from the local government's decision to cut spending on certain social and economic functions.

4.3. Calculation of the urbanisation index based on CLC data

The identified changes in the location and area of various land-cover types were used in further analysis to evaluate urbanisation processes in space.

The degree of membership of the analysed land-cover types was determined based on a review of the literature (Biłozor, 2012). The urbanisation index assigning process has been described in chapter 3.1. The values used in the calculation of this index are presented in Table 4.

To improve the clarity of the presentation, the degree of membership of various land-cover types in urban and rural functions was illustrated using maps. The maps were presented in the form of a cartogram to illustrate the membership of land-cover classes in the urban function in the studied municipality.

Ultimately, the values of the *WU* urbanisation index were calculated based on the degree of membership of different land-cover types in the urban function. The index was calculated for the entire municipality for four points in time, based on the availability of CLC databases. The maps illustrating the membership of the analysed land-cover types in the urban function are presented in Figure 4.

Four indicators representing the degree of membership in the urban function were determined in the Dywity municipality. The degree of membership was lowest at 0.13 in the vast majority of the cases. Very few areas were characterised by a high degree of membership in the urban function.

In 2006, the spatial distribution of land-use classes remained nearly unchanged relative to the previous period of the analysis. An additional class with a high degree of membership in the urban function was identified. A clear increase was observed in land-cover classes whose membership in the urban function was calculated at 0.20.

Several new areas with the highest degree of membership in the urban function were identified in 2012. In 2018, in the southern part of the studied municipality, an increase was observed in land-cover

Table 4. Degree of membership of land-cover types in urban and rural functions

No.	Land-cover type	Degree of membership in urban function	Degree of membership in rural function
1	Inland marshes	0.20	0.80
2	Water courses	0.20	0.80
3	Arable land	0.13	0.87
4	Transitional woodland-shrub	0.20	0.80
5	Coniferous forests	0.20	0.80
6	Broad-leaved forests	0.20	0.80
7	Mixed forests	0.20	0.80
8	Sport and leisure facilities	0.66	0.34
9	Agricultural land	0.13	0.87
10	Water bodies	0.20	0.80
11	Discontinuous urban fabric	0.69	0.31
12	Complex cultivation patterns	0.16	0.84
13	Meadows and pastures	0.13	0.87

Source: author's own work.

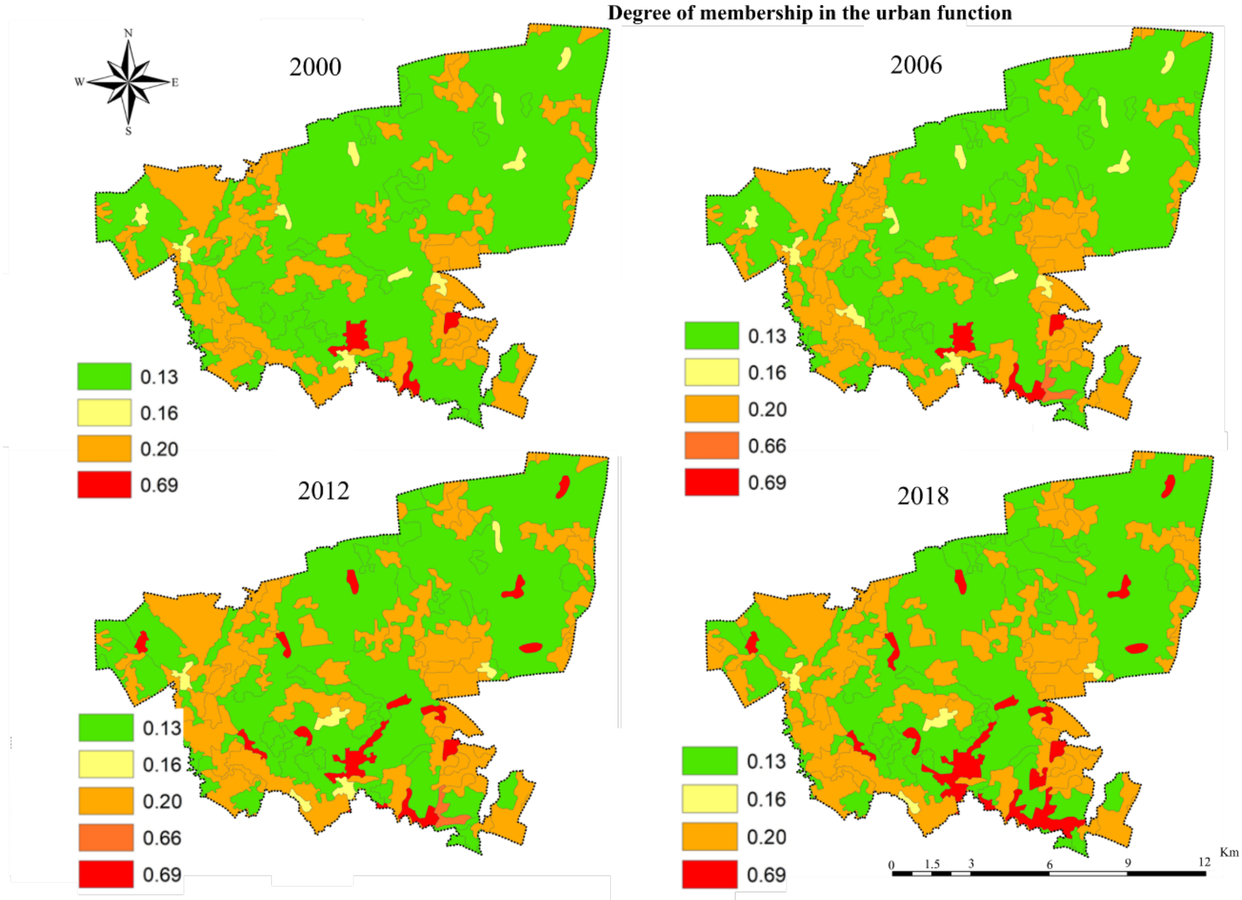

Fig. 4. Spatial distribution of membership of land-cover types in the urban function in 2000, 2006, 2012 and 2018
Source: author's own work.

Table 5. Urbanisation index

Year	2000	2006	2012	2018
WU	15.74	16.29	17.63	18.48
Change in *WU* between successive years	-	3%	8%	5%
Change in $WU_{2000\text{-}2018}$	17%			

Source: author's own work.

types where the degree of membership in the urban function reached 0.69, relative to the previous analysed time point.

The *WU* urbanisation index was calculated for 2000, 2006, 2012 and 2018 to determine the rate of urbanisation processes in the Dywity municipality. The final values of the *WU* index in each studied year, changes across years, and the overall change between 2000 and 2018 are presented in Table 5.

5. Summary

As expected, the value of index *WU* continued to increase throughout the analysed period. The smallest increase was noted in the first years of the study, whereas the greatest difference was observed between 2006 and 2012. In general, the values of the *WU* index were relatively low. However, it should be noted that the value of the urbanisation index generally ranges from 30 to 40 for cities such as Olsztyn. The steady increase in *WU* index values points to progressing urbanisation in Dywity, which can be directly correlated with the municipality's development due to its location in the vicinity of Olsztyn – a large urban centre. Discontinuous urban fabric was characterised by the highest degree of membership in the urban function; therefore, an increase in this land-cover class directly influenced the values of the urbanisation index. The overall increase in *WU* index value between 2000 and 2018 reached 17%, which points to a relatively high rate of urbanisation. Progressing land development in rural areas can be attributed to the suburbanisation of Olsztyn. The land-cover maps for the Dywity municipality based on CLC data for 2000 and 2018 (Fig. 2) clearly illustrate this process.

6. Conclusions

The aim of this study was to determine the applicability of the CLC database for tracking urbanisation processes in space. Basic concepts and methods for evaluating urbanisation processes were defined based on a review of the literature. Selected methods were tested in the rural municipality of Dywity located in the direct vicinity of Olsztyn, the capital city of the Warmia and Mazury Voivodeship. Land-cover types in Dywity were studied using the land-cover/land-use classes in the CLC database. The results were used to track changes in land use. The resulting data were subjected to statistical and spatial analyses.

The studied municipality has an area of 161.13 km^2. Thirteen out of the 44 land-cover classes in the CLC database were identified in Dywity. Considerable land fragmentation was observed in the analysed municipality across the years, particularly in arable land, meadows and pastures, transitional woodland-shrub and discontinuous urban fabric. In all of the identified land-cover types, the number of objects doubled or even tripled in the studied period. The highest increase in area was noted in meadows and pastures. A high, although less spectacular increase was also observed in the area occupied by scattered housing. The area of transitional woodland-shrub increased several times. These changes decreased the area of non-irrigated arable land.

The urbanisation index *WU* was proposed by the authors to evaluate the ultimate degree of urbanisation in Dywity. The index was calculated based on the area occupied by different land-cover types and the degree of their membership in the urban function. The values of these variables were then summed up and divided by the area of the studied municipality. The proposed index was calculated using fuzzy set theory and indicators of membership of the identified land-cover types in the urban function. The *WU* index was calculated for four time points at equal time intervals: 2000, 2006, 2012 and 2018. The value of the *WU* index increased steadily in the evaluated period, which points to progressing urbanisation in the Dywity municipality. The index can also be calculated in a similar way for other municipalities and subsequent time periods. The research on the value of this index and its dynamics will be the subject of further studies by the authors

The results of the study clearly indicate that the CLC inventory is a useful resource for investigating urbanisation processes. The CLC database is an important source of information about changes in land use, specifically in areas where these changes proceed rapidly. It should be noted that urbanisation processes are most effectively captured in analyses of long-term trends. The fact that CLC databases covering six-year intervals were analysed in the study did not pose a significant obstacle. As demonstrated on the example of Olsztyn, the *WU* index can be a useful tool for evaluating suburbanisation processes. It can also be deployed by the local government and planning authorities to monitor urbanisation, which is a very important consideration in the face of the growing demand for residential land..

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