

Article

# The Intensity of Urban Sprawl in Poland

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**Abstract:** The issues of urban sprawl are current in both global research as well as the sphere of activities by public authorities in developed and developing countries. Urban sprawl is a phenomenon that goes beyond the administrative boundaries of cities, which forces monitoring of the phenomenon on a wide territorial scale, i.e., regional and national. However, assessing the level of urban sprawl on such a scale still remains a research challenge in many countries. Poland is such an example, where there is a deficit in assessing the level of the phenomenon, its spatial specificity, as well as comparisons between other national urban areas. The presented research uses the urban morphology method to assess urban sprawl in Poland. The method assumes the use of square grids and building locations for the quantification of sprawl. Based on the 14 urban areas that aggregate 296 communes, it was pointed out that the level of urban sprawl in Poland is moderate. The results indicate that there is not a significant sprawl or compact structures.

**Keywords:** urban sprawl; urban morphology; grids; spatial policy



**Citation:** Lityński, P. The Intensity of Urban Sprawl in Poland. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 95. <https://doi.org/10.3390/ijgi10020095>

Academic Editors: Wolfgang Kainz and Jean-Claude Thill

Received: 21 December 2020

Accepted: 19 February 2021

Published: 21 February 2021

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## 1. Introduction

Since the second half of the last century, there has been a dynamic development of cities, which play an increasingly important social and economic role, but also occupy a greater amount of land [1]. The physical dimension of cities does not correspond to administrative borders anymore, but together with the surrounding communes, they create functional areas (agglomerations and metropolises) where socio-economic activity is concentrated [2]. Changes in the functioning of urban areas caused a loss of control within some development processes, resulting in a disturbance of the functional and spatial structure of both cities and the surrounding communes [3,4]. Therefore, urban sprawl has become an important research problem in terms of conceptual, efficiency, and governance dimension [5,6].

Differences in socio-economic and territorial conditions between continents, countries, and regions play a fundamental role in shaping the settlement structure, including urban sprawl. The differences result from economic factors, planning tradition, population changes and the availability of land for development. Therefore, the discussion on urban sprawl may be ineffective if the experience of other countries are directly adopted. In European literature, a significant interest in post-socialist suburbanization is observed [7–9]. Systemic changes related to the transition from centrally controlled to a free market economy had a significant impact on the spatial transformations of cities [10]. Among the leading spatial processes was the uncontrolled suburbanization due to the dispersion of urban functions beyond the boundaries of the compact city. Urban sprawl was the dominant model of spatial growth in post-socialist metropolitan areas and medium-sized urban areas [11–19]. The specificity of urban sprawl was expressed in the chaotic location of new buildings.

Despite numerous studies on the identification of urban sprawl, there is a gap in the methodical approach as to the exact measurement of urban sprawl. However, there are methods for assessing the urban morphology in light of sprawl features, but they are used in relation to previously delimited metropolitan areas, which exposes the research

to errors. However, there is the possibility of delimitation of urban sprawl, however after determining the possible range of the phenomenon, the research is not continued, taking into account the morphology. There is therefore a need to apply morphological methods to areas delimited in terms of the extent of urban sprawl. The absence of specific quantification of urban sprawl phenomena results in the lack of a theory explaining their effects as well as the lack of effectiveness of territorially targeted public policies. Therefore, for many years, the demand for analyzes assessing the spatial structure of urban areas has been reported in Poland. The essential national strategic documents indicate the desirability of creating a system for monitoring and diagnosing the spatial structure of urban areas, e.g., the Concept of the National Spatial Planning 2030, Poland [20].

The identified research gap formulates the research hypothesis. The hypothesis assumes that urban sprawl in Poland represents a moderate level of intensity. To verify the hypothesis, it is necessary to adopt two main research objectives, which include: The use of the urban morphological method based on the distribution of buildings to assess the specificity of urban sprawl in Poland; and the use of the morphological method, in relation to areas delimited in terms of the phenomenon of urban sprawl.

The structure of the article includes: A literature review, which developed the essence of urban sprawl and the methodological aspects of its measurement. The mentioned research gap, which sets the two research objectives, was also explained. A research method based on the approach of Galster et al. [1]. This chapter explains that the method has been adapted to the specificity of Polish spatial processes as well as legal conditions and the metric system. The method was also developed with recommendations defined in the original study by Galster et al. Outcomes, which present the results of the assessment of urban sprawl in Poland. A discussion explaining the impact of changes in the original morphological method on Polish conditions, and comparing the research results with other studies. The Conclusions Section presents the importance of the research results for public policy, in particular for monitoring spatial changes in Poland and for the implementation of the national spatial policy.

## 2. Literature Review

### 2.1. *The Essence of Urban Sprawl*

Slavati and Morelli [21] review the differentiated definition of urban sprawl. Among the examples of definitions, it can be pointed out that urban sprawl is greedy, egoistic and incompetent in the use of land characterized by uninterrupted monotonicity of development, which is not spatially continuous [22]. Another example indicates a way of spatial growth of a city or metropolis characterized by low building density, dependence on a car and generally new buildings surrounding degraded cities [23]. In turn, Bogart [24] contests the use of the term urban sprawl, claiming that it is a change in the spatial structure of the metropolitan area and proposes the term trading places. In the international discussion, Galster et al. [1] and Bhatta [25] criticizes the terminological ambiguity of urban sprawl as a term, indicating that there are even without any description that approximates this issue of urban sprawl.

In the second decade of the 21st century, however, there is consistency in defining urban sprawl, as a chaotic change in the spatial structure of suburban communes, which arose as a result of the intensification of suburbanization, with a low degree of control of these processes by spatial policy [26–28]. The essence of the term urban sprawl is to understand what a chaotic change in the spatial structure is. It is a question relating to the morphological features of suburban space. Wilson et al. [3] and Galster et al. [1] indicate that urban sprawl is usually described as a loose form of housing, both on the edge of cities and in the suburban zones. This development is low, with a clear lack of a center. At the same time, the buildings are characterized by a lack of spatial continuity. This lack of building continuity is often termed leapfrog, which is supposed to depict housing development inside agricultural areas, creating a patchwork not resembling a compact city. Suburban buildings are also characterized by functional segregation or homogeneity [1].

In relation to Poland and the historical context of urban sprawl, it should be pointed out that the process of urban expansion was not planned and uncontrollable. As Martyniuk-Pęczek et al. [29] noticed, after the transition of the Polish economy from a centrally planned to a free market system, the areas surrounding the city have become an attractive investment offer for individual stockholders. The intensification of suburban migration processes resulted from the poor condition of housing [7,10,11]. In the first half of the 1990's, mandatory spatial planning was abolished due to the ideological negation of solutions used in socialism, regardless of their legitimacy and effectiveness. However, mandatory spatial planning was then used even in Western European countries. A little later, in 2003, new legislation was introduced, resulting in further erosion of public control over space. As indicated by Kowalewski and Nowak [30], half of the investments in Poland were implemented in areas without local spatial plans. In areas without local spatial development plans, a building permit in the form of an administrative decision was issued by one public official. The issuing of administrative decisions caused a wave of corruption in local government administration [31]. Śleszyński [32] notes that the next stage of suburban migrations took place in the period between 2006 and 2012 and was associated with Poland's accession to the EU.

In Poland, the term urban sprawl is used interchangeably as the uncontrollable spatial growth of a city. In relation to explaining the specificity of urban sprawl as a spatial phenomenon, attention should be brought to three categories: planned, spontaneous, and uncontrollable [33]. The first is the planned category, which concerns the achievement of the set goals, and in the case of space, it is the implementation of the spatial development plan. Spontaneous spatial category is the voluntary location decisions made at the level of a single entity [33]. This location is conditioned by economic factors as well as individual needs (e.g., the next family life cycle and change in housing preferences). In contrast, uncontrollable as a category is defined as tendencies in the development of space of high strength and lack of controllability [34]. The differences between the idem boil down to the scale, i.e., the subjects of spontaneity are individuals or micro-communities, while the uncontrollable description is attributed to social groups or larger territorial communities. Uncontrollable spatial phenomena are generally conscious and voluntary actions undertaken to satisfy the individual needs of entities like households [35]. The majority of uncontrollable phenomena is assessed negatively because of the deviation from the idea of planning, optimization and rational operation. A planned space is one that was created according to the adopted plan, a vision that ensures order. However, the space created as uncontrollable was chosen, designated and built up, as the sum of individual activities of the residents. Therefore, the uncontrollable of the location of buildings can be applied not only to the process, but also to the current state of the space development in which the process is observed.

Uncontrollable urban growth has the features of an amorphous space structure, which is a form of coexistence [29,36–38]; new residential buildings with old agricultural buildings, and underdeveloped housing structures with unsettled wasteland zones. The housing located in the suburbs, creates urbanization pressure. In addition, investments had developed along the original communication routes, forming the so called ribbon development [39]. In Poland, unlike in Western countries, urban sprawl is a relatively new phenomenon that overlaps with the processes of systemic transformation. The deficiency of knowledge along with the lack of use of public sector space management instruments results in a morphological absence in the compactness of space.

## 2.2. *The Measurement of Urban Sprawl*

Gervasoni et al. [40] draws attention to the historical context of research on urban sprawl in an international dimension, which distinguishes three periods: early studies, the 1990s and the beginning of the 21st century. Early studies focus on the specific features of suburbs' development. Harvey and Clark [41] state that this phenomenon is observed on the outskirts of the city on undeveloped or agricultural land and manifests itself in the development of low-density buildings, ribbon development or the leapfrog characteristic.

In the nineties, new aspects related to diversified land use were introduced. Diversified land uses were related to residential, service, office, retail and industrial areas. Urban sprawl was defined as a dysfunctional combination of land uses, i.e., homogeneous land uses that are distant from one another. The cause of the dysfunctional combination of land use was the lack of planning and coordination of spatial processes by public authorities [42]. This decade also links urban sprawl with social segregation and car dependence [43]. The beginning of the 21st century introduced the development of the Internet, and further access to databases, combined with the development of quantitative methods and computer conversion capabilities [40]. In Europe, the Corine Land Cover Program was launched, which applied a method for land cover data collection based on a hardcopy inventory from satellite image printouts [44]. An important part of the research focuses on quantifying techniques for measuring urban dispersion by using the Geographical Information Systems data, such as remote sensing images. The availability of satellite images from different time series enabled tracking of land use changes [45,46] or presented dynamics of urban development, including urban sprawl [4,47].

Parallel to remote sensing methods, Galster et al. [1] emphasize that urban sprawl is a collection of many negatively assessed features of spatial development. Therefore, they point to eight dimensions of spatial disorder: low building density, lack of spatial continuity, lack of concentration of buildings, lack of buildings' clustering, spatial decentralization, polynuclearity, lack of land-use mix, and lack of proximity. Arribas-Bel et al. [26] continue the multidimensional perception of urban sprawl. They see the quantification of the phenomenon in light of the eight indicators highlighted by Galster et al. [26] as one of the more important and accurate contemporary approaches of specification and measurement of urban sprawl. Arribas-Bel et al. [26] pointed the application of this approach [48–50] and develop the method of introducing a hierarchy of features of the phenomenon. First of all, the categories of urban morphology: scattering, connectivity, accessibility and open spaces. These are the features of the arrangement and coherence of the urban area, answering the question: What is the current spatial structure? Secondly, the categories of the internal composition of the area are indicated, i.e., density, spatial decentralization and land-use mix, which are a refinement of urban morphology, indicating how the spatial structure is filled.

In the Polish literature on urban sprawl, Lisowski and Grochowski [51] recognize the advantages of Galster's approach to measuring urban sprawl as a method that presents various features of the phenomenon. In Poland, however, this method is not widely used due to the requirements for input data as well as methodical and empirical processing. It is necessary to use two grids of squares: 1 mil<sup>2</sup> and  $\frac{1}{4}$  mil<sup>2</sup>. These grids are applied to the map of the previously designated area and buildings are counted in the following squares. Based on the recognition of the number of buildings in subsequent squares, the specificity of space composition is quantified using the mentioned indicators. Galster et al. [1] define and calculate the urban sprawl features in designated metropolitan areas of the United States. However, they listed the necessary directions for further development of the method, among which three postulates require particular attention:

1. The need to develop a method for determining the territorial extent of urban sprawl; they use, in their research, the metropolitan areas from US public statistics, while indicating that they are not an ideal delimitation for studying the subject;
2. Precise definition of the so-called developable land (DL). This area is an important category underlying the whole method; it is used instead of the total area when calculating the indicators. DL subtracts the surface on which, for various reasons, buildings cannot be built (e.g., rivers), thus giving a more accurate evaluation of the space structure;
3. With consideration to expanding the indexation of urban sprawl; the authors of the study use the Z-score for synthesizing morphological variables into one urban sprawl index.

Delimitation of urban sprawl is a complex study due to the dynamic specificity of the phenomenon. Referring to the geographical scope of the process, which at different periods of time changes outwardly from the core. In general, empirical studies assumed the boundaries of metropolitan areas as a test area in which the morphology methods are applied. These areas are convenient for researchers, due to the availability of properly aggregated data, but at the same time show the shortcomings of overestimating the range of urban sprawl. This drawback is not clearly assessed in a negative light, as the overestimation eliminates the risk of adopting the phenomenon boundary too narrowly. However, the inclusion of peripheral communes in a metropolitan area may slightly disturb the assessment [52–55]. In the research, there are therefore arbitrary approaches to the demarcation of boundaries that go beyond the urbanized area at a heuristically determined distance, in order to capture the disorder of the spatial structure. Such an approach may, however, ignore places beyond the arbitrary demarcation line, which are sufficient from the point of view of urban sprawl, i.e., they show satisfactory functional connections with the core and the associated space changes.

Considering Galster's approach, the legitimacy of using morphological indicators in relation to Poland should be considered. The basic indicator in this method is building density. In the research on both the delimitation and spatial specificity of spontaneous urban growth, the most commonly used measure is also the density of housing, employment, services, etc. [52,54,56,57]. Additionally, in Poland, urban sprawl is defined as areas of low building density [32]. Pieniążek and Rogalińska [58] review methodological approaches and conclude that Polish building density is a common measure of urban sprawl, but there is a gap in the more comprehensive approach regarding urban sprawl. They note that, in Polish conditions, i.e., data available in public statistics, sprawl assessment is currently problematic and is limited to population processes related to migration, changes in the level and structure of the population, and related building growth. After all, these processes may signal the possibility of urban sprawl, or otherwise determine its delimitation. However, they do not specify the morphology or composition of the spatial structure of the suburbs, which is the essence of studying sprawl. Hence, additional Galster indicators reflecting composition should be discussed.

Continuity is the degree to which space has been built up in a spatially adjacent manner. Lack of spatial continuity in Poland is perceived as a feature of urban sprawl [58]. However, it is problematic that the lack of continuity does not always have to mean that the space is amorphous. Planned development with designated areas with high density, divided by a river or a lake, will not represent an uncontrollable developed spatial structure. This problem, however, can be eliminated in the method through proper definition and adoption in DL calculations. In which case, undeveloped areas are subtracted from the research due to objective physical and legal limitations.

Concentration is a measure that should accompany the interpretation of density. The density indicators do not specify the spatial distribution of buildings, while the concentration distinguishes those areas where most buildings are located in a low number of smaller areas with a relatively high density, than those where the buildings are evenly distributed throughout the space. In Poland, the term concentration is not commonly used in the literature, but this indicator reflects the spatial structure of a ribbon character well. The ribbon structure (i.e., the development of areas along communication routes) is described as a common type of development for rural communes in Poland where suburbanization processes take place [51,59,60].

Clustering is also a measure that accompanies density, but is also complementary to concentration. Clustering is the degree of development of 1 mil<sup>2</sup> in such a manner that the buildings are grouped together in only one of  $\frac{1}{4}$  mil<sup>2</sup>. Thus, clustering indicates the structure of space, which is dense, adjacent, but at the same time arranged into compact housing estates. The lack of clustering of suburban housing estates in Poland is also perceived by town planners as a symptom of urban sprawl [61]. However, clustering can be a measure of leapfrog. In the interpretation of clustering, therefore, a situation may arise



where high values indicate a grouping of buildings, which is a positive phenomenon, and leapfrog, which is a negative phenomenon in the context of urban sprawl. Hence, it seems that, when assessing urban sprawl, clustering must be combined with concentration. If both measures are high, then there is no urban sprawl. At a low concentration, whether the clustering is high or low, one will recognize sprawl.

Centralization is the degree to which buildings are located close to the center of the city. It should be noted that the loss of spatial centralization, i.e., spatial decentralization, is one of the most frequently raised problems of urban sprawl in Poland and in the world [23,29,32,58]. Decentralization causes longer travel distances in an urban area and inefficiencies in land use.

Nuclearity is the degree to which a study area exhibits a multiplicity of centers. According to Galster et al. [1], the previously considered spatial centralization is a measure that accurately reflects monocentric urban areas. Lisowski and Grochowski [51] believe that, in Poland, nuclearity is debatable because polynuclearity reduces the distance of commuting. Martyniuk-Pęczek et al. [29] came to similar conclusions. In Polish conditions, therefore, nuclearity can be omitted as a feature of urban sprawl.

There are two more measures in Galster's approach, which are similar in meaning. The first is mixed use: the degree to which land with mixed use exists in a small unit of space; the second is proximity, i.e., the degree to which land with various uses is adjacent to the area covered by the analysis. The differences come down to the fact that proximity is based on the measurement of distance, and mixed uses the coexistence of two types of buildings in a small spatial unit. Conceptually, the differentiation of mixed use and proximity assesses the relationship between places of residence to workplaces, and urban sprawl is related to remoteness. However, it should be noted that distance is also used in the centrality measurement, so that the interpretation of proximity measurement does not enrich the assessment of urban sprawl. In Poland, the problems of remoteness of places of residence from work places are not exposed. The problem is rather the random location of residential buildings on agricultural land [62–64]. This phenomenon is called urbanization pressure. Therefore, in Polish conditions, mixed uses can be changed to an assessment of the extent to which residential and agricultural buildings function in a small spatial unit. Such a measure would reflect the urbanization pressure defined by Polish researchers.

There is a gap in the methodical approach as to the exact measurement of urban sprawl. On the one hand, there are methods for assessing the urban morphology in light of sprawl features, but they are used in relation to previously delimited metropolitan areas, which exposes the research to errors. On the other hand, there is the possibility of delimitation of urban sprawl, but after determining the possible range of the phenomenon is not continued with morphological research. There is therefore a need to apply morphological methods to deliberately designated areas.

In noting the gap in current research on urban sprawl, however, it should be pointed out that research on the phenomenon can be divided into two categories. The first is local research dedicated to individual areas based on the proprietary of the authors' methods, which are often advanced using geostatistic tools [65,66]. Their advantage is the knowledge of the broader context of the phenomenon and spatial specificity that enriches the inference. However, the burden here is the lack of comparability between other national or international analyzes of urban areas. The second is a national study analyzing a significant part of urban areas according to one method [67]. The values of these approaches are contrary to local methods. Among the macro-scale studies, the OECD Report [68] draws attention, which attempts to identify the phenomenon of urban sprawl in 1156 urban areas of 29 OECD countries, including Poland. The conclusions formulated in the Report [68] indicate that Polish urban areas are characterized by higher density, less polycentric character and more fragmentation than the average of OECD countries. In the period 1990–2014 polycentricity, spatial decentralization and fragmentation increased, and this was mainly in the period 1990–2000. However, the population density of urban areas dropped sharply (by 21%) and this decrease occurred primarily after 2000. The advantage of the study is

the possibility of comparison between many countries and methodological advancement. The disadvantage of these results can be found in the input data based on the spatial distribution of the population. It should be noted that urban sprawl is primarily a spatial category, i.e., expressed in the land use footprints.

Therefore, the identified research gap allows us to formulate the research hypothesis. The hypothesis assumes that urban sprawl in Poland represents a moderate level. To verify the hypothesis, it is necessary to adopt two main research objectives, which include: The use of the urban morphological method based on the distribution of buildings to assess the specificity of urban sprawl in Poland; and the use of the morphological method, in relation to areas delimited in terms of the phenomenon of urban sprawl.

### 3. Materials and Methods

To achieve objective 1, a modified method was used, which was originally presented by Galster et al. [1]. This method was adapted to Polish conditions. It refers to an adaptation of morphological indicators to the specifics of the Polish suburban zone development processes, as well as Polish legislations. Among the modifications of morphological indicators, the land-use mix indicator has been changed. Galster et al. [1] calculated it as the relation between business and residential buildings. Based on Polish literature, in the presented study, this indicator has been included as a relation of residential and agricultural development, thus identifying the urbanization pressure on agricultural areas. Hence, the original name of the land-use mix indicator has been replaced by a new name, i.e., urbanization pressure. In addition, Galster did not calculate the continuity indicator, while in this study the calculation of this indicator was undertaken because it reflects the ribbon's spatial structure well. In Poland, the ribbon structure, i.e., the development of areas along communication routes is described as a common type of development for rural communes where suburbanization processes occur. At the same time, the calculation of proximity indicators was abandoned due to the potential duplication of significance with the indicator of urbanization pressure, and nuclearity due to the study of monocentric areas only. In addition, the method was adjusted to the Polish metric system. The method was also adapted to the input data, instead of satellite images, address data from the Central Center for Geodetic and Cartographic Documentation, Poland (CCGCD) was used. This data pertains to specific buildings location along with a description of its specificity; this data also indicates the legal status and function of land.

The method used to evaluate urban morphology consists of several steps, which can be summarized as follows:

1. The basis for the analysis is a map of the area including the description of lands and location of buildings from the CCGCD. Maps were used for the two periods of 2015 and 2017 to capture short-term spatial changes;
2. Two square grids with a side of 1 km and 500 m were covered on the map of the examined areas, taking into account the location of buildings. The procedure for this step is indicated in Table 1;
3. The spatial structure of the studied area is quantified through the prism of combining the distribution of squares with different numbers of buildings. This quantification was made based on the indicators set out in Table 2. ArcGis and Excel software were used. The calculations were carried out in relation to the centroids of each grid: for 2015, it was 34,169 grids with a side of 1 km and 96,452 grids with a side of 500 m; for 2017, it is 34,254 grids with a side of 1 km and 96,985 grids with a side of 500 m.
4. Construction of a synthetic measure assessing the degree of urban sprawl.

**Table 1.** Procedure of GIS analyzes performed in the second step.

Description	Program
Preparation of a squares grids of 1 km and 500 m sides for each grid for the whole country; squares grids were superimposed in such a way that each grid of 1 km <sup>2</sup> contained 4 grids with a side of 500 m.	ArcGis
Loading the layer with the location of buildings from the CCGCD database.	Spatialite
Analysis of the number of buildings in square grids.	Spatialite
Aggregation of layers to be deducted under DL.	QGIS
Intersection of DL layers with a square grid taking into account the number of buildings.	QGIS
Joining the square grid layers with the DL area and calculating the DL area.	Spatialite
Connecting the aggregate layer of buildings with individual communes and urban areas.	ArcGis
Converting the polygon layer of buildings to point layer, resulting in working layers	ArcGis

**Table 2.** Urban morphology indicators.

Morphological Indicator	Formula
Density	$D_{iu} = T_{iu}/A_u = \sum_{m=1}^M T_{im}/A_u$
Urbanization pressure	$UP(j \rightarrow i) = \sum_{m=1}^M (D_{im}[D_{jm}/T_{ju}])/D_{iu}$ [min = 0; max = max $D_{im}$ observed in each area occupied by j]
Continuity	$C_{iu} = \sum_{s=1}^S [D_{is} > 5 \text{ buildings} = 1; \text{otherwise} = 0]/S$ , [min = 0; max = 1],
Concentration	$COV_{iu} = (\sum_{m=1}^M [D_{im} - D_{iu}]^2/M)^{\frac{1}{2}} / [\sum_{m=1}^M D_{im}/M]$
Clustering	$CLUS_{iu} = [\sum_{m=1}^M (\sum_{s=1}^4 [D_{is} - D_{im}]^2/4)^{\frac{1}{2}}/M] / [\sum_{m=1}^M D_{im}/M]$
Decentralization	$CBD(\text{dist}) = [T_{iu} * (A^{\frac{1}{2}})] / [\sum_{m=1}^M F[k,m]*T_{im}]$

Notes: i—adopted type of land use or specific space observation, i.e. residential use (buildings); j—agricultural land use (buildings); u—the biggest spatial unit adopted in the analysis, urban area; m – mid-size spatial unit: 1 km<sup>2</sup>; 1, 2, . . . , m, . . . , M of mid-sized spatial units constitute the urban area u; s – the smallest spatial unit: 1/4 km<sup>2</sup>; 1, 2, . . . , s, . . . , S of the smallest units constitute the urban area u;  $D_{iu}$ —density of the ith land use (buildings) in DL for the urban area  $D_{iu} = T_{iu} / A_u$ ;  $D_{is}$ —density (of buildings) of the ith land use in the surface area of the sth spatial unit  $D_{is} = T_{is}/A_s$ ;  $D_{im}$ —density (of buildings) of the ith land use in the surface area of the mth spatial unit;  $Dim = T_{im} / A_m$ ;  $D_{jm}$ —density of the jth land use (agricultural buildings) in the surface area of the mth spatial unit;  $T_{iu}$ —total number of observations of the ith land use in the urban area u;  $T_{im}$ —total number of observations of the ith land use in the area of the mth spatial unit;  $T_{ju}$ —total number of observations of the jth land use (agricultural buildings) in the urban area u;  $T_{ia}$  – total number of observations of the ith land use in the central area;  $T_{ie}$ —total number of observations of the ith land use in other cores e;  $A_u$ —total surface area of DL in the urban area u;  $A_u = \sum_{m=1}^M P_m * A_m$ ;  $A_m$ —total surface area of DL in the m-th spatial unit w;  $F[k,m]$ —distance between centroids of the geographical grid k and m;  $P_m$ —percentage of the m-th spatial unit in u. Source: own based on Galster et al. [1]

In addition to the above-mentioned adaptations of the method to Polish conditions, the research developed a morphological method in the directions recommended by Galster et al. [1]. Firstly, the method was applied to a delimited urban area according to the urban sprawl risk (postulate 1). Secondly, the method was developed to precisely define DL (postulate 2). Third, the measures of indexing urban sprawl were expanded (postulate 3).

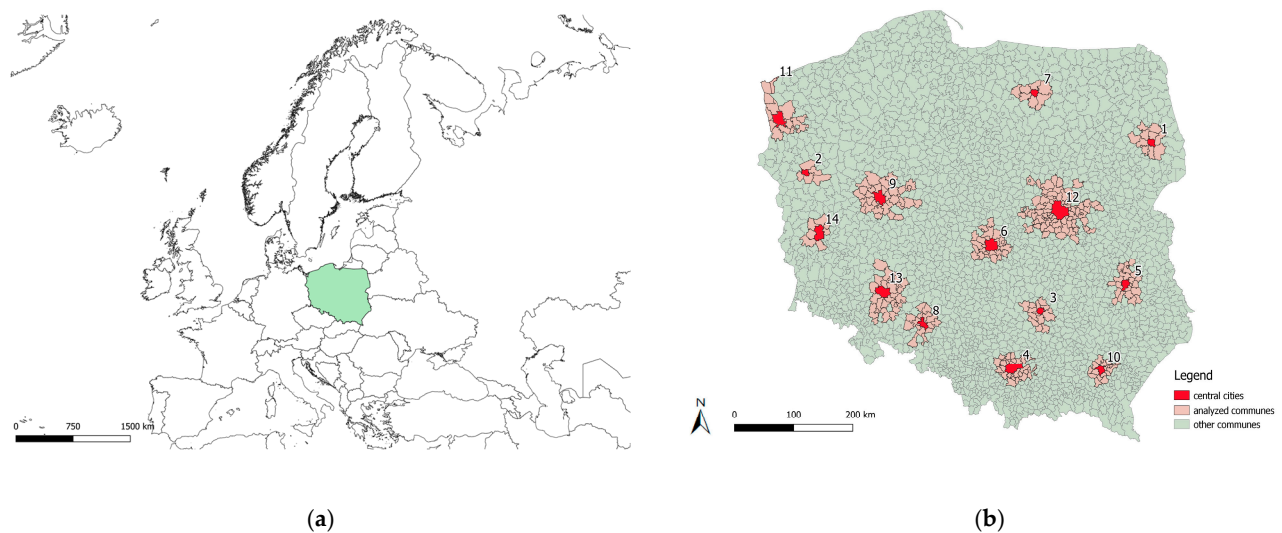
It should be noted that postulate 1 is directly related to research objective 2. Delimitation of urban sprawl is a broad research undertaking that goes beyond the possibilities of presentation in one article with morphological research. Therefore, the method presented in a separate study in Reference [27] was used. This is the author's methodological concept in the field of delimitation of urban sprawl based on the statistical operationalization



of the definition of urban sprawl: “chaotic changes in the spatial structure of suburban communes resulting from the intensification of suburbanization, with a low degree of control of these processes on the part of spatial policy”. Operationalization involves the allocation of indicators describing the three components of the definition:

1. Development processes: new completed building structures, number of apartments per 1k residents;
2. Migration processes from the city: registrations from city, balance of internal migration, newly registered business entities;
3. Control degree of spatial processes by public authorities: administrative decisions on construction conditions, coverage of Land Spatial Development Plans.

In this article, the research range is a suburban area of all cities in the capitals of regions in Poland that are monocentric. Therefore, morphological analysis covered 296 communes surrounding the most important monocentric central cities in Poland. The research area is shown in Figure 1.



**Figure 1.** Research area: urban areas in Poland: (a) Location of Poland in Europe; (b) Analyzed urban areas in Poland: 1. Białystok, 2. Gorzów, 3. Kielce, 4. Kraków, 5. Lublin, 6. Łódź, 7. Olsztyn, 8. Opole, 9. Poznań, 10. Rzeszów, 11. Szczecin, 12. Warszawa, 13. Wrocław, and 14. Zielona Góra.

In reference to postulate 2, i.e., DL, is an area without natural features or barriers preventing development. In the original study, conducted in American conditions, a net land area available in statistics was used. On the basis of the net land area the non-DL was identified [48]. The authors note, however, some shortcomings for the undeveloped but buildable area that plays a key role in the method. There was no distinction between usable land and similar-looking but inaccessible land that is reserved for parks or protected nature areas. However, in this study, it was proposed that the DL exclude the surface of roads, waters, and protected areas. Thus, in the calculation of indicators, the DL for Polish conditions was calculated in each of the squares of the grid with a side of 1 km and 500 m by subtracting it from the total surface of the squares, the area designated by the buffer around: national, provincial, poviát and municipal roads; rivers, streams, all flowing and standing waters; protected areas, including national parks and reserves. The buffers have been designated as the distance: for roads, 5 m from the road line; for protected areas, 12 m from the boundary of the area; and for rivers, half the width of the river indicated in the layer attribute table in the CCGCD data. Under Polish legal regulations, construction investments cannot be carried out in the mentioned areas [69]. However, in different areas, examples of implementation of construction investments can be found despite the fact that seemingly such areas cannot be used to be built on (e.g., agricultural land, and forests).

With reference to postulate 3, it should be clarified that Galster et al. [1] should build a composite index based on the Z score by adding up standardized morphological indicators. The name Z score was left in the present study, but the sum of the unified variables was used to determine the urban sprawl index. The calculated index based on the Z score is presented in the formula:

$$Z \text{ score}_i = \sum_{j=1}^m \left( \frac{z_i}{z_{max} - z_{min}} \right)$$

As the interpretation of indicators of urban morphology indicates that the higher their value, the more positive the organization of space, thus each indicator was treated as a stimulant. The exception is the indicator of urbanization pressure, in which interpretation is the opposite; therefore, this indicator was included in the equation with a negative sign. Consequently, the interpretation of the index based on the Z score indicates that the lower its value, the higher the degree of urban sprawl, i.e., negatively assessed spatial development in the suburban area.

Parallel to the Z score index, four other approaches were proposed based on the measures: Bray-Curtis, Perkal, Hellwig, and Model. Formulas for additional four synthetic measures are presented in Table 3.

**Table 3.** Formulas for synthetic methods used to calculate the urban sprawl index.

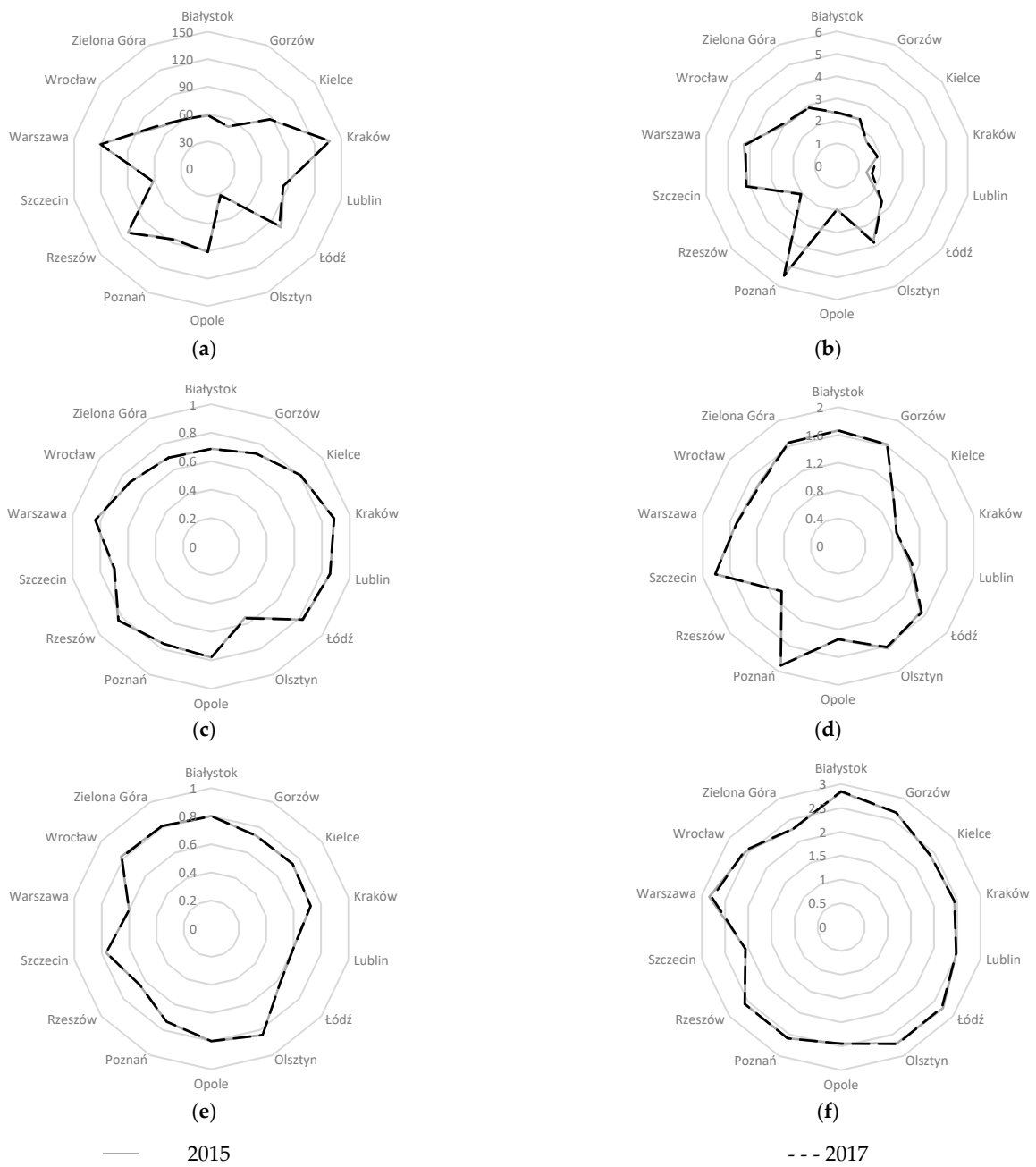
Bray-Curtis (BC <sub>i</sub> )	Perkal (P <sub>i</sub> )	Hellwig (H <sub>i</sub> )	Model (M <sub>i</sub> )
formula			
$BC_i = 1 - \frac{\sum_{j=1}^m  z_{ij} - z_{kj} }{\sum_{j=1}^m (z_{ij} + z_{kj})}$	$P_i = \frac{1}{p} \sum_{j=1}^p z_{ij}$	$P_i = \frac{1}{p} \sum_{j=1}^p z_{ij}$ $c_{ik} = \left[ \sum_{j=1}^m (z_{ij} - z_{kj}) \right]^{\frac{1}{2}}$ $c_0 = 2s_j + \frac{1}{p} \sum_{j=1}^p c_{ik}$	$M_i = \frac{1}{p} \sum_{j=1}^p z_{ij}$
normalization			
$z_{ij} = \left( \frac{x_{ij}}{x_{max} - x_{min}} \right)$	$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j}$ or $z_{ij} = \frac{\bar{x}_j - x_{ij}}{s_j}$	$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j}$	$z_{ij} = \frac{x_{ij}}{x_{max}}$ or $z_{ij} = \frac{x_{min}}{x_{ij}}$

Notes:  $z_{ij}$ —normalized variable;  $x_{ij}$ —value of  $j$  for object  $i$ ;  $\bar{x}_j$ —average value of  $j$  variable;  $s_j$ —standard deviation of the variable  $j$ ;  $k$ —hypothetical urban area in which the indicator assumes the most desirable values;  $p$ —number of partial indicators.

Comparison of the results of five measures will determine the choice of one that was used for the ranking assessing urban areas in terms of urban sprawl. At the same time, it should be noted that there may be different positioning of urban areas between rankings based on different synthetic measures. Such variation is normal and results from different normalization procedures when calculating synthetic indicators. Therefore, a matrix of determination coefficients ( $R^2$ ) between synthetic methods was proposed to choose the most-accurate synthetic method. An important feature of the coefficient of determination is additivity. Therefore, the highest sum of  $R^2$  for the last of the analyzed years was used to select the most accurate method of synthetic assessment of urban sprawl.

#### 4. Results

Figure 2 and Table 4 present the results of morphological indicators for the analyzed areas for two years. The analyzed areas are not very morphologically diverse, which can be seen by the standard variation index ( $V$ ). Only building density ( $D_{iu}$ ) and urbanization pressure ( $UP(j \rightarrow i)$ ) are areas that are moderately different. However, the remaining morphological indicators show low morphological diversity between areas.



**Figure 2.** Values of morphological indicators for 2015 and 2017: (a) Density— $D_{iu}$ ; (b) Urbanization pressure— $UP(j \rightarrow i)$ ; (c) Continuity —  $C_{iu}$ ; (d)— Concentration— $COV_{iu}$ ; (e) Clustering— $CLUS_{iu}$ ; and (f) Decentralization— $CBD(dist)$ .

**Table 4.** Descriptive statistics values of morphological indicators for 2015 and 2017.

Urban Area	$D_{iu}$		$UP(j \rightarrow i)$		$C_{iu}$		$COV_{iu}$		$CLUS_{iu}$		$CBD(dist)$	
	2015	2017	2015	2017	2015	2017	2015	2017	2015	2017	2015	2017
Variation (V)	0.3410	0.3351	0.3987	0.3873	0.1118	0.1105	0.2174	0.2145	0.1098	0.1085	0.0811	0.0789
Min.	31.4029	32.2860	1.3543	1.6089	0.5532	0.5599	0.8603	0.8626	0.5993	0.6009	2.0597	2.0627
Max.	136.8412	137.0758	5.4117	5.4634	0.8867	0.8873	1.9072	1.9098	0.8389	0.8397	2.8406	2.8483

Based on Table 4, a general assessment of Polish urban areas in terms of individual characteristics of urban sprawl can be made. Thus, in terms of density, the worst situation is observed in the Olsztyn area, which has the lowest building density. Additionally, the Olsztyn area shows the lowest level of spatial continuity of this development. In turn, the least concentrated area is Kraków. In regards to clustering of dense settlements, the Warszawa area has the lowest degree of compactness. However, in terms of the distance between buildings and the central city, the Szczecin area exhibits the highest decentralization. The Poznań area shows the highest level of negatively assessed urbanization pressure on agricultural areas.

The morphological indicators, synthesized form the urban sprawl index, which indicates the level of unfavorably valued spatial structure attributed to the urban sprawl. Table 5 presents various urban sprawl indexes based on standardized data. The construction of indexes takes into account the diverse nature of indicators, the interpretation of which refers to a stimulant or destimulant. In this light, this time the interpretation of all indexes is the same and indicates that the lower the value, the greater the urban sprawl.

**Table 5.** Urban sprawl indexes according to selected methods for 2015 and 2017.

Urban Area	$Z\ Score_i$		$BC_i$		$P_i$		$H_i$		$M_i$	
	2015	2017	2015	2017	2015	2017	2015	2017	2015	2017
Białystok	11.7593	11.8373	0.9557	0.9566	0.2796	0.2986	0.2787	0.2739	0.7674	0.7837
Gorzów	11.2597	11.3323	0.9326	0.9331	0.0203	0.0254	0.2437	0.2376	0.7408	0.7565
Kielce	10.7777	10.8646	0.9239	0.9265	-0.0528	-0.0372	0.1584	0.1511	0.7672	0.7913
Kraków	11.3861	11.4616	0.9496	0.9518	0.3008	0.3160	0.1913	0.1804	0.8174	0.8400
Lublin	10.3998	10.5483	0.9131	0.9130	-0.1114	-0.1311	0.0680	0.0842	0.7882	0.7895
Łódź	11.6314	11.6638	0.9451	0.9437	0.2556	0.2352	0.3504	0.3393	0.7861	0.7972
Olsztyn	11.4083	11.5325	0.9043	0.9044	-0.3924	-0.3765	0.1105	0.1179	0.6708	0.6813
Opole	11.4450	11.5063	0.9500	0.9509	0.2264	0.2315	0.2903	0.2794	0.7927	0.8123
Poznań	12.6317	12.7571	0.9248	0.9235	-0.0766	-0.0730	0.5422	0.5369	0.7534	0.7604
Rzeszów	11.0843	11.1563	0.9308	0.9317	0.0867	0.0898	0.2231	0.2154	0.7765	0.7942
Szczecin	11.2938	11.3739	0.8887	0.8865	-0.5432	-0.5710	0.1732	0.1565	0.6943	0.7017
Warszawa	12.2846	12.2716	0.9356	0.9321	0.1588	0.1258	0.4561	0.4455	0.7749	0.7797
Wrocław	11.6752	11.7855	0.9376	0.9378	0.0509	0.0610	0.3453	0.3514	0.7409	0.7530
Zielona Góra	11.2538	11.3330	0.9184	0.9196	-0.2026	-0.1943	0.2139	0.2032	0.7219	0.7364

Indexes enable the comparison of urban areas with each other as well as positioning in terms of urban sprawl. In this way, it is possible to create a ranking of areas with the largest spatial disorder. The rankings are created in this case as part of a specific method and not between methods. Table 6 presents, therefore, for the two analyzed years, rankings determined by synthesis methods. For each of the proposed indexing methods, #1 is assigned to the area with the lowest level of urban sprawl. The lower the rankings, the higher the degree of urban sprawl.

**Table 6.** Ranking: list of urban areas by order of index.

#	Z Score <sub>i</sub>	BC <sub>i</sub>	P <sub>i</sub>	H <sub>i</sub>	W <sub>i</sub>
<b>2015</b>					
1	Poznań	Białystok	Kraków	Poznań	Kraków
2	Warszawa	Opole	Białystok	Warszawa	Opole
3	Białystok	Kraków	Łódź	Łódź	Lublin
4	Wrocław	Łódź	Opole	Wrocław	Łódź
5	Łódź	Wrocław	Warszawa	Opole	Rzeszów
6	Opole	Warszawa	Rzeszów	Białystok	Warszawa
7	Olsztyn	Gorzów	Wrocław	Gorzów	Białystok
8	Kraków	Rzeszów	Gorzów	Rzeszów	Kielce
9	Szczecin	Poznań	Kielce	Zielona Góra	Poznań
10	Gorzów	Kielce	Poznań	Kraków	Wrocław
11	Zielona Góra	Zielona Góra	Lublin	Szczecin	Gorzów
12	Rzeszów	Lublin	Zielona Góra	Kielce	Zielona Góra
13	Kielce	Olsztyn	Olsztyn	Olsztyn	Szczecin
14	Lublin	Szczecin	Szczecin	Lublin	Olsztyn
<b>2017</b>					
1	Poznań	Białystok	Kraków	Poznań	Kraków
2	Warszawa	Kraków	Białystok	Warszawa	Opole
3	Białystok	Opole	Łódź	Wrocław	Łódź
4	Wrocław	Łódź	Opole	Łódź	Rzeszów
5	Łódź	Wrocław	Warszawa	Opole	Kielce
6	Olsztyn	Gorzów	Rzeszów	Białystok	Lublin
7	Opole	Warszawa	Wrocław	Gorzów	Białystok
8	Kraków	Rzeszów	Gorzów	Rzeszów	Warszawa
9	Szczecin	Kielce	Kielce	Zielona Góra	Poznań
10	Zielona Góra	Poznań	Poznań	Kraków	Gorzów
11	Gorzów	Zielona Góra	Lublin	Szczecin	Wrocław
12	Rzeszów	Lublin	Zielona Góra	Kielce	Zielona Góra
13	Kielce	Olsztyn	Olsztyn	Olsztyn	Szczecin
14	Lublin	Szczecin	Szczecin	Lublin	Olsztyn

According to the adopted methodological assumptions, the selection of the ranking is based on the highest sum of ( $R^2$ ). The matrix of ( $R^2$ ) is presented in Table 7. The most satisfactory results are provided by the Perkal ( $P_i$ ) method. Therefore, for the purpose of creating the final ranking, it was decided to choose indexing using this method.

**Table 7.** Matrix of determination coefficients ( $R^2$ ).

Method	Z Score <sub>i</sub>	BC <sub>i</sub>	P <sub>i</sub>	H <sub>i</sub>	W <sub>i</sub>
Z score <sub>i</sub>	-	0.2070	0.0017	0.0533	0.0473
BC <sub>i</sub>	0.2070	-	0.0907	0.0017	0.0026
P <sub>i</sub>	0.0017	0.0907	-	0.6435	0.0804
H <sub>i</sub>	0.0533	0.0017	0.6435	-	0.0804
W <sub>i</sub>	0.0473	0.0026	0.0804	0.0804	-
Sum	0.3093	0.3019	<u>0.8163</u>	0.7789	0.2107

The index built on the basis of the Perkal method takes values from  $-3$  to  $3$ . Urban areas with a high degree of spontaneous spatial structure will show values below  $0$ , areas with a moderate degree of phenomenon will oscillate around  $0$ , and areas with a relatively low degree will have values above  $0$ . Similar areas are considered to have similar index values.

Table 8 presents the ranking of urban areas in terms of urban sprawl based on the Perkal method. The left side of the table indicates the place of a specific urban area in the ranking in two years 2015 and 2017. The values of the urban sprawl index are also presented. The higher the position in the ranking, the lower the degree of urban sprawl;



the lower the position, the higher the degree of the phenomenon. The right side of Table 7 assesses the direction of spatial changes. Positive evaluation (P) refers to areas in which the spatial structure is improved. In other words, urban sprawl is reduced by locating new buildings in a compact way, near existing buildings. Negative evaluation (N), however, indicates negatively assessed processes of locating new buildings dispersed and away from existing settlements. In addition, it should be noted that inferences about spatial changes based on two recent years should be carried out carefully. The values of changes indicated in Table 7 do not prejudice the absolute assessment of the dynamics of spatial processes; they only indicate the possibility of emerging directions of transformation of the spatial structure, and above all, they inform about the degree of index change within two years.

**Table 8.** Ranking of urban areas in terms of urban sprawl.

Index 2015	Urban Area	Ranking *	Urban Area	Index 2017	Shift	Evaluation **
0.3008	Kraków	1	Kraków	0.3160	0.0152	P
0.2796	Białystok	2	Białystok	0.2986	0.0189	P
0.2556	Łódź	3	Łódź	0.2352	−0.0204	N
0.2264	Opole	4	Opole	0.2315	0.0051	P
0.1588	Warszawa	5	Warszawa	0.1258	−0.0330	N
0.0867	Rzeszów	6	Rzeszów	0.0898	0.0031	P
0.0509	Wrocław	7	Wrocław	0.0610	0.0101	P
0.0203	Gorzów	8	Gorzów	0.0254	0.0051	P
−0.0528	Kielce	9	Kielce	−0.0372	0.0156	P
−0.0766	Poznań	10	Poznań	−0.0730	0.0036	P
−0.1114	Lublin	11	Lublin	−0.1311	−0.0197	N
−0.2026	Zielona Góra	12	Zielona Góra	−0.1943	0.0083	P
−0.3924	Olsztyn	13	Olsztyn	−0.3765	0.0159	P
−0.5432	Szczecin	14	Szczecin	−0.5710	−0.0278	N

Notes: \* the lower the rank, the higher the urban sprawl; \*\* P—positive; N—negative.

In the overall evaluation, the urban sprawl index in the analyzed urban areas in 2017 ranges between  $-0.57$  and  $+0.32$ , on a scale of  $-3$  to  $+3$ . In this approach, the suburban area of the Polish regional capitals is characterized by a moderate degree of the spatial structure disorder. There are no areas with a compact structure, there are also no areas with an absolute high degree of space structure disorder. The small range between the extreme index values also indicates a similarity in the urban sprawl level of the studied areas. These results confirm the previously indicated assessment based on (V).

The urban areas with the lowest degree of the analyzed phenomenon are primarily Kraków and Białystok, showing in 2017 the index of  $0.32$  and  $0.30$ , respectively. Whereas the highest degree of urban sprawl can be attributed to the areas of Szczecin ( $-0.57$ ) and Olsztyn ( $-0.38$ ). It should also be noted that the more compact areas (Kraków and Białystok) are additionally accompanied by positively valued changes in the structure of space between 2015 and 2017. In turn, negative spatial processes are observed in the area with the highest level of urban sprawl (Szczecin). This is proved by the differences between the indices (right side of Table 8), which in the case of Kraków and Białystok is  $+0.02$ , while in the case of the Szczecin area, it is  $-0.03$ .

It is also worth pointing out, as an interesting case, the largest urban area studied, i.e., Warszawa, which is the capital of Poland. In a short period of time, i.e., two years, it showed noticeably adverse changes in the level of the urban sprawl index ( $-0.033$ ). The reason was the growth of buildings in dispersed locations, which in effect lead not to a compact, but rather a spontaneously built-up spatial structure. Therefore, in an equally designated urban area in two years of analyzes, the increase in development could be interpreted as the density of development (assuming a simple measure of the ratio of number of buildings and the area), yet in reality it does not lead at all to a denser development of space. On the contrary, it results in the formation of a structure with negatively valued features, i.e.,

thickening of buildings by locating a new one away from the existing settlements. A similar situation was also observed in the areas of Łódź, Szczecin and Lublin.

## 5. Discussion

### 5.1. The Sum of the Method

The research hypothesis assumed that urban sprawl in Poland represents a moderate level. This hypothesis was verified positively, because the results of studies using the square grid and building locations indicate that, in Poland, the synthetic index of urban sprawl is in range (−0.57; +0.32) and on the scale (−3; +3).

In the broad evaluation of the spatial structures within Polish urban areas, the arrangement of space is expressed in a restrained distance from the core city. The buildings are located with a moderate degree of spatial continuity, while at the same time focused on relatively small areas. The internal composition, indicating the fulfillment of the described arrangement of the spatial structure, indicates that Polish urban areas are fairly densely built-up, and the way of grouping buildings into compact settlements can be assessed as average. At the same time, the location of buildings is associated with a high degree of proximity of residential and agricultural buildings. The presented results of urban sprawl evaluation allow for their presentation in the context of the current state of research. For example, in the OECD Report [68], which deals with issues of assessing the spread of cities of OECD countries. This report indicates that Polish urban areas are less fragmented than the OECD average, which can also be confirmed through the prism of continuity, concentration and clustering indicators. However, the report does not attempt to assess the specificity of spatial development, i.e., its filling, and the presented research shows high urbanization pressure in agricultural areas.

The research proposed in the article located in a group of measurements identifies the degree of dispersion of buildings in urban space based on morphological methods. The use of research on the morphological approach present in the international literature forces us to adapt and further develop the methods. The method was adapted to the specificity of Polish urban sprawl by determining the urbanization pressure index and the calculation of the continuity reflecting the ribbon development. One of the most important categories of morphological methods is the area in relation to which morphological indicators are calculated (DL). The presented methodological proposal adapts the category of DL to Polish conditions. In practice, the specifics of the functioning of Polish legislative systems does not protect many types of areas that have a function other than construction in buildings (e.g. landscape and agricultural parks). Thus, based on the Polish CCGCD documentation, it was proposed that the DL excludes the surface of roads, waters and protected areas. With respect to national, regional, county and commune roads (streets, rail and airport), the subtraction area was calculated by determining buffers in the GIS software. In terms of water, the DL omits designated buffers for rivers, flowing and standing waters. Whereas, for protected areas only, the areas of national parks and reserves are deducted as well. The suggested approach seems to enrich the proposals of Galster et al. [1], which uses satellite images, while admitting the issues around the need to identify national parks and reserves.

Another dimension of the method development concerns the indexation of urban sprawl. The presented study meets the postulates for indexation development, not only by modifying the normalization of the Z score index primary data, but also by using and evaluating four other approaches to synthesizing morphological variables. Therefore, apart from the index mentioned, the following measures were also used: Bray-Curtis, Perkal, Hellwig, and Model. Studies have shown the usefulness of the Perkal method for evaluating urban sprawl in Poland.

### 5.2. The Policy Implications

For Polish spatial policy, the results can be particularly useful. The proposed approach may not only give foundations for the system of monitoring spatial changes of urban

areas in Poland, but also set the objectives of national spatial policy. An example of such objectives can be:

- Preventing the location of new buildings resulting in lowering the density of the developable land in the commune (goal: high density);
- Stimulating the building continuity improvement in communes by supporting the location in undeveloped spaces between the existing buildings (goal: high spatial continuity);
- Preventing the location of buildings in a long distance from the existing, stimulating the development of buildings in the vicinity of other buildings (goal: high concentration of buildings);
- Preventing the situation of individual investments in previously undeveloped areas, and equipping the commune authorities with instruments for coordinating individual investments aimed at grouping new buildings into compact settlements (purpose: high clustering of buildings);
- Tightening the above-mentioned objectives along with the distance from the core city. While in the communes directly adjacent to the core city, the stimulating instruments for the location could be dominated in a dense, continuous and spatially focused manner, as well as grouped in compact settlements, in the subsequent communes' restrictions on new housing would be imposed (objective: prevention of spatial decentralization);
- Preventing the location of residential development in areas used for agriculture and stimulating the location near existing residential buildings or jobs (purpose: lowering urbanization pressure).

The presented examples of spatial policy objectives do not exhaust the possibilities of creating public interventions based on the results of the presented study. They only signal the possibility of operational use of research results in the practice of Polish spatial policy.

### 5.3. The Method Limitations

The research presented here develops the current state of knowledge about the processes of urban sprawl, especially in Poland. Like a large part of the original concept, it may, however, have some limitations that would have to be overcome, given the ability to formulate conclusions more broadly. At the same time, these restrictions set the direction for future research. The first of the limitations seems to be the time horizon for measuring changes in spatial structure (2015, 2017). However, due to the specificity of data archiving in Poland, it was not possible to obtain further sets of data. The second limitation, which seems to be acceptable at the current stage of development of the morphological method and access to data, is the issue of building types counted in a square grid. Single and multi-family buildings are represented by one point with type designation. However, there is no data on the number of apartments. The third limitation is the size of the grids. In the research for Poland, the grids were reduced in relation to the American research from 0.5–1.0 miles to 0.5–1.0 km. Nevertheless, future research directions may focus on smaller grids and verify the results with the presented research. Such studies would provide an answer to the question of whether smaller grids provide more precise results.

## 6. Conclusions

The presented method, and especially the results, can be an exemplification for a system of monitoring the spatial transformation of urban areas, which would identify the growth of urban sprawl. There are areas in Poland (Warszawa, Łódź, Szczecin, and Lublin) in which noticeably adverse changes in the level of urban sprawl were observed during a period of only two years. The reason being that the growth of buildings in dispersed locations leads not to a compact, but rather spontaneously built-up spatial structure. It should be noted that, in an equally delimited urban area in the two years, the increase in development could be interpreted as the density of development, but in reality, it is not the case. Newly built construction does not lead to denser development. On the contrary,

it results in the formation of a structure with negatively valued features like less dense development because of locating buildings far from old settlements.

The above conclusions result directly from the presented research, but research conducted in other countries confirms the existence of negatively assessed changes in suburban space. Hence, the importance of the research results can be observed not only in the Polish practice of spatial management, but also in the international dimension. The presented indicators enabling monitoring of spatial changes can become the basis for monitoring systems for spatial policies in the local, national and also international dimension.

In addition, presented research results enrich the possibilities of formulating spatial policies whose primary purpose is to ensure spatial order at the national and regional level. Processes taking place in large urban areas require coordination by dedicated public authorities, due to the specificity of instruments for influencing space. It is noted here that the possibility of using instruments cannot be limited by the administrative boundaries of communes, as spatial processes do not honor administrative boundaries. Therefore, the effectiveness of spatial instruments is significantly limited by the possibility of their use within administrative boundaries. Therefore, for the effectiveness of coordinating spatial processes, the intervention zone, whose boundaries are determined by problems rather than administrative borders, is more important. The operational usefulness of the proposed morphological method in determining such a zone should be noted here. The method of using a square grid makes it possible to identify, with an accuracy of 500 m, the chaotic areas requiring necessary actions, and areas with a coherent spatial structure.

**Author Contributions:** Conceptualization, Piotr Lityński; Methodology, Piotr Lityński; Software, Piotr Lityński; Validation, Piotr Lityński; Formal Analysis, Piotr Lityński; Investigation, Piotr Lityński; Resources, Piotr Lityński; Data Curation, Piotr Lityński; Writing-Original Draft Preparation, Piotr Lityński; Writing-Review & Editing, Piotr Lityński; Visualization, Piotr Lityński; Supervision, Piotr Lityński; Project Administration, Piotr Lityński; Funding Acquisition, Piotr Lityński. Author has read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Science Centre, Poland under Grant no. UMO-2016/23/D/HS4/02961, (“Financial Mechanisms in the Economy Resulting from the Phenomenon of Urban Sprawl”). Spatial data were generated at the Central Center for Geodetic and Cartographic Documentation, Poland-license DIO.7211.511.2017\_PL\_N.

**Conflicts of Interest:** The author declares no conflict of interest.

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