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Comparison of indexes for automatic mapping of built-up areas – a case study of Gliwice

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Abstract:

The built-up index was developed to "mapping" built-up areas using publicly available satellite images. However, its biggest problem is not distinguishing between built-up areas and bare soils. This distinction is fundamental to automatic mapping. Therefore, numerous approaches to delimitation appear in the literature, proposing different solutions to eliminate errors during the automatic process. The study aimed to select the most appropriate built-up index for automatic delimitation of areas related to the Upper Silesian Conurbation. Preliminary work was based on a literature review of the use of various built-up indexes. In the next step, the most useful indicators in the context of automatic delimitation of these areas were selected. In this work, comparative analyses of the built-up indexes proposed in the literature were carried out on the example of the city of Gliwice so that their usefulness and adequacy for the delimitation of built-up areas in the Upper Silesian conurbation could be determined. Analyses were carried out using open spatial data and using GIS tools such as ArcGIS and SAGA. Indicators were calculated using selected Landsat 7 and Landsat 8 satellite images. From the indicators selected, the MBUI appear to be the most useful, besides the basic one i.e., widely used in development delimitation calculations, NDBI. However, each of these indicators has weaknesses that cause the automatic delimitation process generate some errors. There should therefore be further research in this area.

Keywords: built-up area; indexes; automatic mapping; GIS

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1. Introduction

Urban expansion is a process that is associated with fragmentation, degradation, decline in biodiversity and, consequently, loss of green areas, including agricultural areas [1–3]. An example of such processes are the cities of the Silesian Voivodeship, especially those belonging to the Upper Silesian Conurbation, where the phenomena of the loss of open green areas in favour of built-up areas can be observed for many years [4]. This is particularly the case in suburban areas where, for example, agricultural land is being replaced by areas of single-family and multi-family housing and industrial and commercial areas [5, 6].

In 2020 and 2021, a two-year study was undertaken at the IETU titled: "Analysis of the correlation between the soil sealing and the increase in the intensity of development and the decline of open green areas" which aimed to study and identify the scale and rate of disappearance of green areas (especially forest land and agricultural land) in the Upper Silesian Conurbation [7]. Preliminary analyses showed that of the 19 cities, the largest declines in this type of area are in the areas of Gliwice, Sosnowiec and Chorzow. In the further stages of the work, analyses of 3 consecutive editions of the Urban Atlas (2006, 2012 and 2018) [8], which is one of the services of the Copernicus project, showed on the one hand, the highest loss of green areas and, on the other hand, an increase in industrial, commercial areas and urban fabric.

This research has made it possible to trace certain trends and changes in the city's spatial structure. The fixed methodology of creating the Urban Atlas is an additional ad-vantage of the service. However, the analyses carried out do not allow detailed and up-to-date analysis. In the study of changes in the urban environment, this is of great importance, for example, in the diagnosis of the state of the city to manage its space and resources, or in the analyses required for selecting adaptation measures to climate change. To carry out an analysis close to the actual and current conditions in the city, one can use the developed various types of indexes, which are calculated based on current and publicly available satellite images. One of them is the NDBI index, which was developed to "map" built-up areas. However, its huge weakness is that it does not distinguish between built-up areas and uncovered soils [9–11]. This was fully confirmed by the analyses conducted as part of the aforementioned two-year statutory work. The distinction between the two areas is fundamental. Often areas of uncovered soils are agricultural areas and should not be classified in the same group as built-up areas, as this completely distorts the analyses giving a false picture of the boundaries of built-up areas. Consequently, the statistics performed based on GIS tools are also subject to error.

Objective and scope of work

The purpose of the study was to review the development indicators proposed in the literature and select them for further work. Initial work consisted of a review of the mainly English language literature in available online databases for the use of various development indicators. In the next step, such indicators were selected that can be most useful in the context of delimitation of areas with similar conditions to the city of Gliwice, i.e. a relatively compact and concentrated urban fabric with so-called open areas in the suburbs, including areas of arable land and bare lands. In the study, comparative analyses of the development indicators proposed in the literature were performed on the example of the city of Gliwice so that their suitability and adequacy for development delimitation could be determined.

The analyses were carried out using GIS tools: ArcGIS and an open-source geographic information system (GIS) SAGA which is based on the GNU General Public License mainly [12]. The indicators were calculated using selected Landsat 7 and Landsat 8 satellite images. The images were selected so that they could be compared with 3 editions of the Urban Atlas from the years: 2006, 2012 and 2018 to calculate basic statistics.

2. Materials and Methods

The literature review was based on peer-reviewed journals, books and conference proceedings. The main source was the Elsevier database supplemented by other available databases, i.e. scopus.com, webofknowledge.com and springer.com or sciencedirect. These resources were analysed for proposed modifications to "build-up indicators". The selection of indicators for calculating development was carried out using an expert method, based on the similarity of the nature of the city's development and open areas.

An analysis of the literature showed that the problem of distinguishing built-up areas from areas of bare land for automatic delimitation of the former has been addressed by many authors. One of the first indicators for the delimitation of built-up areas that could be traced in available sources is the Urban Index (UI), which was proposed by Kawamura M. [13]. However, the most basic and widespread index for development delimitation is the Normalized Difference Built Index (NDBI) proposed by Zha et al. [9]. The aforementioned indices do not distinguish between built-up areas and uncovered soils. Xu (2008) therefore proposed a modification of the built-up index, the so-called Index-based Built-up Index (IBI) based on the Soil Adjusted Vegetation Index (SAVI) and Modified Normalized Difference Water Index (MNDWI) [14]. The SAVI is used to identify different types of vegetation [15, 16], while the MNDWI identifies water areas from satellite imagery [17, 18].

In 2010, Lee et al. proposed another index for development delimitation: the Built-up Index (BUI) as a standard method for classifying development [19]. A further modification was proposed by As-syakur et al, (2012) in the form of the Enhanced Built-Up and Bare-ness Index (EBBI) for more accurate and simultaneous delimitation of built-up and undeveloped areas using a single formula [20].

Another index was developed by Sinha et al, (2016) - the New Built-up Index (NBUI) [21]. The idea of this index is based on the complexity of the urban area ecosystem, which consists of four main elements: impervious surface, green vegetation, exposed soil, and water bodies. The tool is based on three indices, i.e. EBBI adjusted by soil-adjusted vegetation index i.e. Soil-Adjusted Vegetation Index (SAVI) and Modified Normalized Difference Water Index - Modified Normalized Difference Water Index (MNDWI). Prasomsup et al, (2020) in turn proposed a modification of the existing BUI index: Modified Built-Up Index (MBUI), which integrates BUI with MNDWI [22]. In addition, many other modifications have been made to indicators for delimiting greenery, water and exposed soil, and proposals for various combinations of individual indicators have been made, including Tin and Muttitanon, (2021) [23] and Ukhnaa et al, (2019) [24]. After a preliminary analysis of the literature, it can be concluded that the problem of proper classification of urban built-up areas still exists and has not been fully solved. To sum up after reviewing the available literature, the following indicators have been selected that may be useful for delineating built-up areas: NDBI - as a basic indicator, UI, IBI, EBBI, NBUI, MBUI. To calculate the more complex NBUI and MBUI indicators, the intermediate indicators, which are their components, i.e., MNDWI and SAVI, were calculated. In addition, the NDBaI index, which is used to delimit exposed soils, and NDVI, a vegetation index, were calculated. It should be noted that SAVI and NDVI are similar indexes in nature and use. Ray, for example, distinguishes between the two in that SAVI ap-plies to an area with a vegetation cover of only 15 percent, while NDVI applies to areas with more than 30 percent [25]. Some of the indicators listed above are well analysed on various examples of cities. In this regard, the literature is rich. In the cases of NDBI, EBBI, IBI, UI and NDBaI (exposed soil index), the values based on which the delimitation of individual areas is performed are indicated. They are based on studies of urbanised cities carried out by the authors of each indicator [20, 26]. These values are summarised below in Table 1.

Table 1. Summary of the values of the indicators on which the delimitation of built-up areas and uncovered soils is based

Index	Unbuilt areas	Built-up areas	Areas of bare soils
NDBI	-*	0,100-0,300	>0,300
EBBI	<0,1	0,100-0,350	>0,350
IBI	<0,018	0,018-0,308	>0,308
UI	-	>0**	-
NDBaI	-	-	>-0,150

* no value in the table means that the indicator is not used to delimit other areas beyond those indicated

** the UI indicator delimits only built-up areas. It interprets them as all values greater than zero

It should be emphasised that the cities analysed in the literature tend to belong to highly urbanised areas, much more so than in the cities of Upper Silesia. Therefore, it would be appropriate to test the relevance of the indications given in Table 1 based on cities with slightly lower rates of development.

An important step in the work was the selection of satellite images. The sources of these images were the satellites Landsat 7 and 8. Landsat 7 images have been available since 1999. However, in 2003 there was a failure of the SLC (Scan Line Corrector) and the images after that time have data gaps [27]. It is possible to remove these errors by applying an appropriate mask to the raster, but for statistical analysis, they are of little use and were not downloaded from online resources. In collecting the scenes, the existing IETU GIS re-sources were used first and the United States Geological Survey (USCG) search engine second [28, 29]. Scenes retrieved from the website were selected according to basic criteria:

- cloud cover of no more than 10%, so as not to cover the study area,
- the time of taking the photo is summer, i.e. from June to August.

An additional, though no less important, search criterion was the path and row of WRS, respectively: 189 and 025, so that the selected raster covered the entire study area. Thus, scenes from the following dates were selected:

Landsat 7: 2000.08.02, 2000.08.18, 2002.06.05, 2002.08.24.

Landsat 8: 2015.07.03, 2015.08.20, 2016.07.21, 2019.08.31, 2022.06.20

For calculating chosen indexes different spectral bands are needed, which means different channels (bands) acquired from the satellite. In Landsat 7 and Landsat 8, the bands included in the formulas given below (from 1 to 6) have a different number and a slightly different wavelength, and in addition, the thermal and panchromatic bands have a different resolution than the others. In general, it can be summarised that the Landsat 7 satellite consists of 8 spectral bands, with a resolution of 30 m for bands 1 through 7 and 15m for the panchromatic band (Table 2). The Landsat 8 satellite, on the other hand, consists of 9 spectral bands (Operational Land Imager) and 2 thermal bands (Thermal Infra-red Sensor, or TIRS for short) - bands 10-11. The resolution of bands 1-7 and 9 is 30 m, the panchromatic band has a resolution of 15 m and the thermal bands 30 m (Table 3). The approximate size of the scene in both satellites is 170 km from north to south and 183 km from east to west.

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Table 2. Characteristics of the individual bands of the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite [30, 31]

Landsat 7	Wavelength (micrometres)	Resolution (metres)
Band 1 - BLUE	0.45-0.52	30
Band 2 - GREEN	0.52-0.60	30
Band 3 - RED	0.63-0.69	30
Band 4 – NIR (Near-infrared)	0.77-0.90	30
Band 5 - SWIR 1 (Short Wave Infrared)	1.55-1.75	30
Band 6 - Thermal	10.40-12.50	60 (30)
Band 7 - SWIR 2	2.09-2.35	30
Band 8 - Panchromatic	0.52-0.90	15

Table 3. Charristics of the different bands of the Landsat 8 Operational Land Imager (OLI) satellite

Landsat 8	Wavelength (micrometres)	Resolution (metres)
Band 1 – Ultra Blue (Coastal aerosol)	0.43-0.45	30
Band 2 - BLUE	0.45-0.51	30
Band 3 - GREEN	0.53-0.59	30
Band 4 - RED	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

The selected indicators for development delimitation are calculated according to the following formulas:

$$NDBI = \frac{SWIR1-NIR}{SWIR1+NIR} \quad \text{reference: [9]} \tag{1}$$

$$UI = \frac{SWIR2-NIR}{SWIR2+NIR} \quad \text{reference: [13]} \tag{2}$$

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$$IBI = \frac{\frac{2*SWIR_1}{SWIR_1+NIR} - \left[\frac{NIR}{RED+NIR} + \frac{GREEN}{GREEN+SWIR_1}\right]}{\frac{2*SWIR_1}{SWIR_1+NIR} + \left[\frac{NIR}{RED+NIR} + \frac{GREEN}{GREEN+SWIR_1}\right]} \quad \text{reference: [14]} \tag{3}$$

$$EBBI = \frac{SWIR1-NIR}{10*\sqrt{SWIR1+TIRS1}} \quad \text{reference: [20]} \tag{4}$$

$$NBUI = EBBI - (SAVI + MNDWI) \quad \text{reference: [21]} \tag{5}$$

where:

$$SAVI = \frac{NIR-RED}{(NIR+RED+L)} * (1 + L) \quad \text{reference: [15]}$$

*L – canopy background adjustment factor (*In areas with no vegetation cover L=1, in areas with moderate vegetation cover density L=0.5, and in areas with very high vegetation cover density L=0 [15, 32]. For the analysis, the factor was assumed to be 0,5).

$$MNDWI = \frac{GREEN-NIR}{GREEN+NIR} \quad \text{reference: [17]}$$

$$MBUI = (NDBI - NDVI) - MNDWI \quad \text{reference: [22]} \tag{6}$$

where:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad \text{reference: [33]}$$

MNDWI – as in (5)

$$NDBaI = \frac{SWIR1-TIRS1}{SWIR1+TIRS1} \quad \text{reference: [34]} \tag{7}$$

$$BUI = NDBI - NDVI \quad \text{reference: [19]} \tag{8}$$

For preliminary studies, i.e. comparison of indicators and selection of the most suitable for delimitation of built-up areas modification of NDBI indicator, a scene from Landsat 8 satellite from August 31, 2019, Level 1 (Level 1 - L1) i.e. raw image data without correction was selected. The scene was processed. In the first step, the scene was corrected using the reflection coefficient at the so-called level above the atmosphere (TOA) calculated according to the Landsat 8 (L8) Data Users Handbook (2019) [35]. For Landsat 8 satellite it is calculated according to the formula:

$$\rho\lambda' = M_\rho * Q_{cal} + A_\rho \tag{9}$$

where:

$\rho\lambda'$ - TOA Planetary Spectral Reflectance, without correction for solar angle,

M_ρ - reflectance multiplicative scaling factor for the band,

A_ρ - reflectance additive scaling factor for the band,

Q_{cal} - level 1 pixel value in DN

Separately, a correction is done for the TIRS thermal bands. For them, the spectral radiance (L_λ) was calculated according to the formula:

$$L_\lambda = ML * Qcal + AL \tag{10}$$

where:

L_λ - spectral radiance (W/(m^2 * sr * µm)),

ML - radiance multiplicative scaling factor for the band,

AL - radiance additive scaling factor for the band,

Q_{CAL} - level 1 pixel value in DN.

In the second step, the top of atmosphere brightness temperature -T is calculated from the luminance spectral value according to the formula:

$$T = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{11}$$

where:

T - top of atmosphere brightness temperature (K) where:

L_λ - TOA spectral radiance (Watts/(m^2 * srad * µm))

K_1 and K_2 - band-specific thermal conversion constant K_1 and K_2 from the metadata for Landsat 8.

The correction was carried out in the Saga 8.5.0 program (Figure 1), and the individual scenes needed for calculations were trimmed to the Gliwice city limits. After the process of preparing the scenes, the calculations and analysis proceeded.

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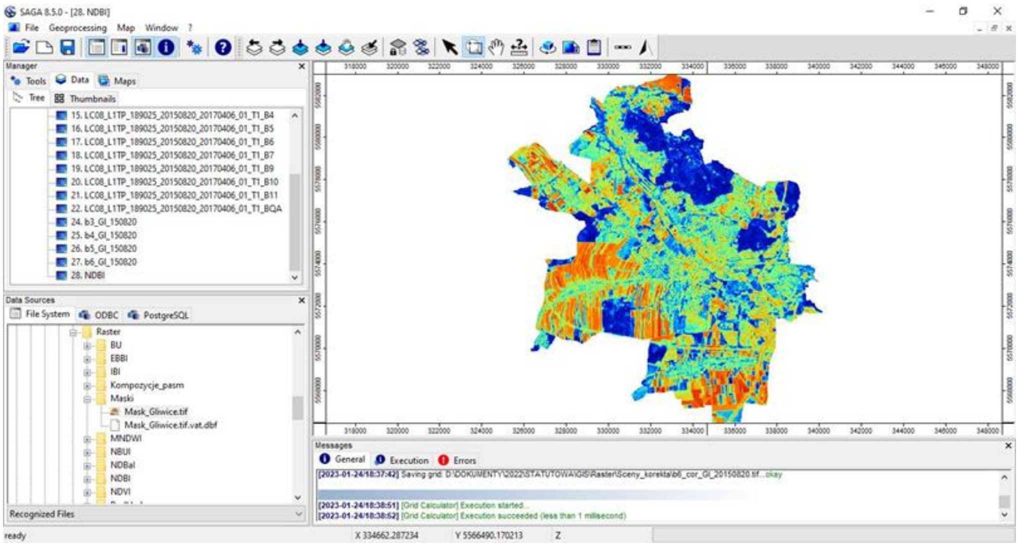

Fig. 1. Calculation of NDBI index in the SAGA program using Landsat 8 satellite bands as of 2015.08.20 as an example [SAGA - print screen of the example user interface]

3. Results of spatial analysis and discussion

In the next step of analyses, correlations between individual development indicators were calculated and checked. The result is summarised in Table 4.

Table 4. Correlation between individual development indicators

	BUI	EBBI	IBI	NBUI	MBUI	NDBI	UI
BUI		0,8458	0,8107	-0,0116	0,8857	0,8269	0,7532
EBBI			0,9544	0,2625	0,9147	0,9604	0,3829
IBI				0,1974	0,9688	0,9968	0,3870
NBUI					0,16572	0,1762	-0,0116
MBUI						0,9716	0,5752
NDBI							0,4059
UI							

The various modifications of the NDBI development index such as EBBI, IBI or MBUI have a high correlation with each other, so they show considerable similarity. In some cases such as the NBUI index, the result of a negative correlation indicates errors in calculations or the formula taken from the literature, since the indicators for development delimitation should be more or less correlated with each other. Errors in formulas, for example, are not uncommon, despite these being peer-reviewed publications. In one such case, the error was spotted and corrected during the analyses performed. However, in this case, the reasons for such a negative correlation were not analysed because error analysis was not the purpose of the work.

The NDBI, MBUI, EBBI and IBI indicators were selected for subsequent analyses. Their correlation was then checked between the green indicators NDVI and SAVI and water MNDWI (Table 5). According to the author, these indices should not correlate with MNDWI and should have a negative correlation to NDVI or SAVI.

Table 5. Correlation between selected development indicators and NDVI, SAVI and MNDWI indicators

	MNDWI	NDVI	SAVI
NDBI	0,6065	-0,5228	-0,6551
EBBI	0,6678	-0,5551	-0,7378
IBI	0,5813	-0,5012	-0,6345
MBUI	0,6730	-0,6460	-0,7206

The indicators listed in Table 4 should be useful in terms of delimiting built-up areas. Some of them take into account aquatic areas (as opposed to indicators for which the values for aquatic areas are similar to those for built-up areas) such as IBI others seem more appropriate for delimitation due to green areas. However, it is not possible to refer to Table 1 and the delimitation of these areas according to the literature, due to the fact that the values usually in the calculated indicators are too low. The problem of value ranges relating to the delimitation of built-up areas in the example of Upper Silesian cities should be studied in the future. In this work, it is not resolved whether this is related to the selected scene or perhaps other factors cause such low values, for example, an error in calculation.

The MBUI index was chosen for further analysis because of its usefulness in delimiting both built-up areas and green and water areas. It is the indicator that most comprehensively addresses the diversity of urbanised city areas. The next step of the work was the selection of scenes for statistical analyses for 3 editions of the UA: 2006, 2012 and 2018. Statistical calculation of the selected indicator based on the area classes used in the Urban Atlas service.

Since it was not possible to obtain scenes from the periods in which each UA was released, i.e. 2006, 2012 and 2018, scenes as close as possible to these periods were selected for analysis. Scenes from Landsat 7 dated 2002.06.05, Landsat 8 dated 2015.07.03 and 2019.08.31 were selected for calculating the MBUI and statistics for this indicator in the individual divisions of the three different UA releases. First, the MBUI indicator for the city of Gliwice was calculated based on the mentioned scenes. Next, the MBUI statistics were calculated for the different classes of areas used in the Urban Atlas. Next, the basic statistics of the MBUI index in the area classes of each UA edition are summarised. The minimum, maximum, mean, range and standard deviation values were tabulated. The tabular summaries are shown in Table 6.

Table 6. Summary of basic statistics of MBUI indicators as of August 31, 2019, July 3, 2015, and June 5, 2002 based on 3 editions of the Urban Atlas of 2018, 2012, and 2006, respectively, for the city of Gliwice

Types of surfaces according to Urban Atlas	UA 2018			UA 2012			UA 2006		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Continuous urban fabric (sealing level S.L. > 80%)	-0.54	0.24	-0.21	-0.436	0.163	-0.111	-0.44	0.5	0.02
Discontinuous dense urban fabric (S.L.: 50% - 80%)	-0.7	0.17	-0.27	-0.412	0.137	-0.159	-0.41	0.34	-0.05
Discontinuous medium-density urban fabric (S.L.: 30% - 50%)	-0.57	0.00	-0.33	-0.416	-0.014	-0.209	-0.4	0.21	-0.13
Discontinuous low-density urban fabric (S.L.: 10% - 30%)	-0.47	0.19	-0.26	-0.322	0.034	-0.139	-0.31	-0.27	-0.29
Discontinuous very low-density urban fabric (S.L. : < 10%)	-0.74	0.11	-0.25	-0.366	0.084	-0.154	-	-	-
Isolated structures	-0.59	0.03	-0.32	-0.394	0.041	-0.22	-0.45	0.08	-0.18
Industrial, commercial, public, military and private units	-0.66	0.38	-0.19	-0.455	0.313	-0.11	-0.6	0.59	0.00
Fast transit roads and associated land	-0.57	0.06	-0.24	-0.365	0.056	-0.076	-0.61	0.2	-0.25

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Other roads and associated land	-0.8	0.15	-0.26	-0.451	0.122	-0.154	-0.48	0.37	-0.06
Railways and associated land	-0.7	0.09	-0.29	-0.422	0.066	-0.185	-0.35	0.58	-0.04
Port areas	-0.72	0.15	-0.16	-0.321	0.092	-0.065	-0.33	0.26	0.02
Mineral extraction and dump sites	-0.58	0.23	-0.18	-0.428	0.139	-0.12	-0.47	0.37	-0.02
Construction sites	-0.65	0.11	-0.2	-0.314	0.029	-0.177	-0.66	0.25	-0.24
Currently unused land	-0.6	0.13	-0.28	-0.434	0.125	-0.188	-0.34	0.19	-0.12
Green urban areas	-0.84	0.17	-0.4	-0.487	0.202	-0.254	-0.45	0.29	-0.19
Sports and leisure facilities	-0.72	0.17	-0.34	-0.443	0.302	-0.236	-0.39	0.48	-0.13
Farmland, semi-natural areas, and wetlands – UA 2006 only	-	-	-	-	-	-	-0.68	0.39	-0.27
Arable land (annual crops) – UA 2012, 2018	-0.84	0.26	-0.43	-0.585	0.138	-0.266	-	-	-
Pastures	-0.84	0.17	-0.4	-0.56	0.119	-0.263	-	-	-
Forests	-0.86	0.14	-0.49	-0.455	0.117	-0.339	-0.49	0.2	-0.28
Herbaceous vegetation associations (natural grassland, moors)	-0.6	0.09	-0.35	-	-	-	-	-	-
Wetlands	-0.58	0.13	-0.24	-	-	-	-	-	-
Water	-0.89	0.05	-0.49	-0.442	0.04	-0.202	-0.49	0.34	-0.23

4. Conclusions

- The analysis carried out has increased knowledge of the various proposals for development delimitation indicators over a dozen years. There have been many modifications of the index for automatic development mapping (NDBI) since 2003, when it was first proposed. The reason for the modifications is that development areas have a variety of surfaces, such as asphalt, concrete, and roofs, which can reflect light in a similar way to bare ground. For example, both asphalt and some types of ground can reflect radiation in the near-infrared bands in a similar way, making it difficult to distinguish them in Landsat 8 satellite images.
- Although new indicators are emerging to eliminate errors in the delimitation of development, especially in the incorrect interpretation of bare land in favour of built-up areas, there are still no good solutions. These modifications originated in Asian countries, exemplified by highly urbanized cities, although some similarities were preserved, such as the presence of open areas, especially areas of bare ground or the character of built-up areas.
- For the NDBI index, areas of water bodies and exposed soils have the same values as built-up areas, which generates errors in delimitation. Of the selected indices, the most useful (besides the basic one, i.e., are widely used in development delimitation calculations) NDBI seems to be EBBI, MBUI, or IBI. Every index can mapping built-up and bare land areas using a single calculation. The Modified Built-Up Index (MBUI) integrates the water index MNDWI and built-up index BUI. The Enhanced Built-Up and Bareness Index (EBBI) algorithm, utilizing near-infrared (NIR), short-wave infrared (SWIR), and thermal-infrared (TIR) channels, achieves a high accuracy level compared to other indices. Index-based built-up index (IBI) algorithm uses three indices: soil adjusted vegetation index (SAVI), the modified normalized difference water index (MNDWI) and the normalized difference built-up index (NDBI). IBI is an index that distinguishes three urban components of vegetation, water and built-up land. The EBBI, MBUI, and IBI indicators have been proposed to remove these errors, which is mostly the case.
- The EBBI, MBUI and IBI indicators are relevant to the delimitation of built-up areas. Some of them take into account water areas, as opposed to indicators for which the values for water

areas are similar to those for built-up areas. The IBI is such an indicator. Others, on the other hand, seem more appropriate for delimitation due to green areas like MBUI or EBBI. The MBUI is the most widely applicable, as it takes into account green and water areas in the delimitation in addition to urbanised areas and exposed soils. Its application is therefore the most comprehensive and adapted to the diverse fabric of urban areas.

- Work on adjusting the index to the development delimitation of the Upper Silesian Conurbation areas should continue.

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