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Evolution of Built Surfaces Based on Copernicus High Resolution Layers. The Case of Growth Poles-Based Metropolitan Areas, Romania

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ABSTRACT

The evolution of built areas is a widely debated subject mostly because their high dynamics and expansion can be related to the economic development. Technically, the availability of European datasets that include the built areas extracted from satellite imagery is an advantage that could be used for further research. The study aims to analyse the spatial and temporal dynamics of the built areas in six metropolitan areas of Romania, in the period 2006-2018. Functional areas were delimited and the new cover of built areas was calculated for each administrative unit. The Imperviousness Classified Change datasets for the periods 2006-2009, 2009-2012, 2012-2015 and 2015-2018 were downloaded in raster format from Copernicus Land Monitoring Service website. The new surfaces, added from one period to another, were outlined in cartographic representations and Google Earth was used for validation. The results showed that, for the entire reference period, the largest increase values of the newly built area were registered in the metropolitan areas of Cluj, followed by Braşov and Timişoara, whilst lower increase values were recorded for Constanţa, Craiova and Iaşi. Also, by analysing the extension of the built areas, we were able to illustrate some spatial development directions within each of the metropolitan areas. The major differences can be explained by the economic development of the examined areas, which included the expansion of both residential and transport infrastructure. Moreover, the pace of development was more intense in the case of the administrative units located nearby the urban centre as opposed to those situated at a considerable distance. This conclusion emphasises the importance of proximity within the metropolitan area studies.

1. INTRODUCTION

Globally, urbanization is a process that has increasingly drawn attention of researchers and decision-makers, considering both the socioeconomic effects and the impact on the natural environment. The extension of built areas implies the replacement of natural areas and it can also create the premises for floods, landslides, increased pollution or urban heat islands (Arnold Jr. and Gibbons, 1996; Benedek, 2006; Yuan and Bauer, 2007; Scalenghe and Marsan, 2009; Artmann et al., 2019; Salvati and Lamonica, 2020; Morabito et al., 2021; Haidu and Ivan, 2016; Petrişor, 2017). Impervious areas are defined as *"any material that prevents the infiltration of water into soil"* (Arnold Jr. and Gibbons, 1996, p. 244). These surfaces are often *"associated with transportation (streets, highways, parking lots and sidewalks) and building rooftops"* (Yuan and Bauer, 2007, p. 378).

Based on data acquired by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS), Elvidge et al. (2007) created a map representing the world distribution of the impervious surface area (ISA), relative to population, at a resolution of 1 km. The states with the largest built areas were China, USA and India, with over 80,000 km² of ISA. European states such as Italy, Germany, UK, or France had less than 10,000 km², while Romania was ranked 39, with approx. 2100 km² of ISA (Elvidge et al., 2007). Kuang (2019) updated this database, using satellite scenes to extract impervious spaces and calculated the percentage of built areas in each state.

In the international literature, various methods and databases were employed in the study of built areas. Some researchers have analysed the spatio-temporal evolution of built space at different scales (state, city or metropolitan areas), using satellite imagery for various periods (Madhavan et al., 2001; Bauer et al., 2002; Esch et al., 2009; Meng-Fan et al., 2015; Kaspersen et al., 2015; Kuang, 2012; Sexton et al., 2013; Ivan and Benedek, 2017; Benedek and Ivan, 2018; Kawakubo et al., 2019; Flores and Gaudiano, 2020). Other authors have used databases on impervious surfaces especially created for the national level to examine the evolution of built areas (Xian and Homer, 2009; Nagel and Yuan, 2016; Wickham et al., 2020).

Imperviousness High Resolution Layers (HRL) time series, created by the European Environment Agency (EEA) represents a useful database, widely used by scholars. Gangkofner et al. (2010) described the methodology applied for the creation of imperviousness datasets from 2006 and their updated version from 2009. Also, Lefebvre et al. (2016) derived a methodology for update by using satellite scenes Sentinel 2 for Prague (Czech Republic) and Rennes (France). Lehner et al. (2017) compared the results of the unsupervised classification on Sentinel 1 scenes with HRL and the European Settlement Map 2016 and highlighted some improvements, namely the easier distinction between green areas and built spaces, and better defined building boundaries. The Degree of Imperviousness from HRL database was used by Hennig et al. (2015) to measure urban sprawl in Europe, both at national and regional level. Sannier et al. (2016) tested the accuracy of the Imperviousness database by various methods and concluded that it meets the standards (errors do not exceed 10-15% in omission and, especially, commission errors). Sarmento et al. (2015) assessed the accuracy of the 2012 data on the Degree of Imperviousness for Portugal, using statistical methods. The results show a good accuracy of the data, with an absolute average of 12% errors. There is, however, an overestimation of the degree of imperviousness value. Rosina et al. (2017) used Imperviousness Layer as supplementary data to spatially report the population of Austria and Slovenia. Karydas and Panagos (2018) used the database to calculate certain parameters that were subsequently integrated into a model that depicts soil erosion.

Li et al. (2018) developed a model to calculate heat island intensity in Berlin based on the relationship between Land Surface Temperature and Impervious Surface Areas, the latter being taken from the Copernicus database for 2012. Gilabert et al. (2016), Oliveira et al. (2020) used Imperviousness Degree to determine Local Climate Zones in various metropolitan areas in Europe. Alvioli (2020) used the database to delimit cities in Italy.

Salvati and Lamonica (2020) used Imperviousness High Resolution Layers for 2006–2009, 2009–2012 and 2012–2015 intervals to map urban sprawl in the metropolitan area of Athens. The authors considered only the areas represented by New Cover and Increased IMD from the Imperviousness Classified Change set, arguing that these two categories define an urban densification of 'brownfield development' type. This is represented either by the reuse of previously built sealed areas, or by the extension of some spaces built in a neighbourhood (Salvati and Lamonica, 2020, p. 4).

Also, some studies (Schmidt et al., 2015; Slaev et al., 2018; Sandu, 2016; Kovacs et al., 2019; Ivancsics and Kovacs, 2021; Różycka-Czas et al., 2021) focus on urban sprawl and the extension of built areas in Central and Eastern Europe states, arguing that the specific political regime has influenced the legislation and patterns of urban development.

Cole et al. (2018) used Corine Land Cover data series from Copernicus to highlight the changes that occurred between 2000-2006 and 2006-2012 in the United Kingdom. The results show that, until 2012, numerous changes occurred, both in terms of the size of the landfills and the use of land.

In Romania, there is a growing interest in the study of metropolitan areas - created in 2001, as part of the Europeanization of Romanian spatial planning (Benedek, 2013) - based on different considerations: their formation at a specific moment (Rusu et al., 2012), the analysis of demography, housing, economy, and governance (Popescu, 2011; Benedek and Cristea, 2014; Bădiţă et al., 2015; Nagy and Benedek, 2018; Drăgan et al., 2019), and their performance to achieve the Sustainable Development Goals (Nagy at al., 2018; Ivan et al., 2020a; Ivan et al., 2020b; Benedek et al., 2021). There are studies on the evolution of built areas in different metropolitan areas, using mainly Landsat or Sentinel satellite images (Ivan, 2015; Ianoş et al., 2016; Holobâcă, Ivan and Alexe, 2019; Bîrsănuc et al., 2019; Dolean et al., 2020). Others used Corine Land Cover database to examine built spaces (Grigorescu et al., 2012a; Grigorescu et al., 2012b) or even information provided by the local authorities (Carriere et al., 2018).

Urban sprawl in Romania has also been investigated by Gavrilidis et al. (2019); Grădinaru et al. (2020) and Grigorescu et al. (2021). This shows that the evolution of the built areas is a current topic that has been the focus of the research community.

In this study, the evolution of the new cover surfaces extracted from Imperviousness High Resolution Layers (HRL) time series is presented. The selected areas for analysis are represented by six metropolitan areas (MAs) organized around the major regional urban centres (growth poles) in Romania. Bucharest Metropolitan Area was excluded from the analysis because it is not designated among growth poles according to the Romanian Government's Decision no. 1149 from 2008 (Romanian Government, 2008). Moreover, its size cannot be compared to the areas under study. Much more, the selected metropolitan areas are investigated separately to observe their dynamics without being the shadow of the capital. It is their development that should counterbalance the large influence of the capital and aim towards reducing the regional inequalities (Benedek et al., 2022). The aim of the study is to observe how the built areas evolved during four reference periods (2006-2009, 2009-2012, 2012-2015, 2015-2018) both at the metropolitan level, but also at the local level of every MA and further explain the reasons for the significant differences between them, considering the development context. Presumably, there is a significant variation in the dynamics of the built areas of the MAs, explained by the disparities in their economic development. Another objective is to examine the relation between population and the growth of built areas and establish if there is any correlation between them. Also, the study aims to contribute to the growing body of literature on metropolitan areas by performing a comparative analysis on the evolution of their built areas. The study is organized in three sections: data, methods, and the description of the study area; results, discussion, and conclusions.

2. DATA, METHODS AND STUDY AREA

2.1. Data and methods

Free data were downloaded from Copernicus Land Monitoring Service Pan-European Collection of High Resolution Layers (HRL) Imperviousness Classified Change series for four intervals (2006-2009, 2009-2012, 2012-2015 and 2015-2018) (Table 1).

Table 1. Characteristics of the spatial data used.

Dataset	Period	Format	Spatial resolution (m)	Attribute	Coordinate reference system	Data of publication	Source
Imperviousness Classified Change	2006-2009	raster GeoTiff	20 m	New Cover	EPSG:3035 (ETRS89, LAEA)	26.04.2018	European Environment Agency (EEA), 2018a
Imperviousness Classified Change	2009-2012	raster GeoTiff	20 m	New Cover	EPSG:3035 (ETRS89, LAEA)	30.04.2018	European Environment Agency (EEA), 2018b
Imperviousness Classified Change	2012-2015	raster GeoTiff	20 m	New Cover	EPSG:3035 (ETRS89, LAEA)	30.04.2018	European Environment Agency (EEA), 2018c
Imperviousness Classified Change	2015-2018	raster GeoTiff	20 m	New Cover	EPSG:3035 (ETRS89, LAEA)	28.08.2020	European Environment Agency (EEA), 2020d

These data have a raster format with 20 meters resolution and they are available for the entire European territory in ETRS 1989 coordinate system. They were used to extract the built areas of the selected metropolitan areas for four intervals, which were set according to their availability in Copernicus database. Although reference periods have overlapping limits, we considered them suitable for use because they provide specific information, as further explained: the first interval, 2006-2009, contains the built-up areas that were developed during the three years, and the number of hectares for this interval represents the extra built-up surface added until 2009, considering 2006 as a reference year. For the next interval (2009-2012), the new cover is extracted for 2012 taking as reference the built-up areas recorded in 2009, as the difference between the two years. The same explanation is valid for the rest of the intervals.

Copernicus dataset includes built areas derived from the application of NDVI index on high-resolution satellite images (Langanke, 2018). They consist of areas occupied by buildings, road transport infrastructure, rail (airports, ports, parking lots), industrial areas, farms, solar parks. Within parks, cemeteries and recreational spaces, a distinction was made between spaces occupied by vegetation and areas designated for specific purposes (sports fields, running tracks) (Langanke, 2018, p. 7).

The database used in this study is the Copernicus change product, classified into six categories: unchanged no sealing, new cover, loss of cover, unchanged sealed, increased sealing and decreased sealing (Salvati and Lamonica, 2020). "Unchanged no sealing" shows pervious surfaces that did not change in the study period; "new cover" shows surfaces that were pervious at the beginning of the period, but became impervious; "loss of cover" is the class that was sealed, but became pervious; "increased sealing" shows surfaces that had a lower degree of imperviousness at the beginning of the interval, but this degree increased until the end (e.g. green spaces were converted into built areas) and "decreased sealing" is the term used to show some built surfaces that were replaced by natural cover until the last year of the interval (Salvati and Lamonica, 2020).

Only the evolution of new cover land was analysed for each period because the aim was to assess the extent of the built surfaces that were constructed during each of the four reference periods. The increased sealing class was not considered due to insignificant values and the lack of values for all territorial administrative units (TAUs) involved; only some of them registered it (especially the county capital cities). These surfaces were measured in hectares.

The first step was to convert the data in the national coordinate system, Stereographic 1970, using ArcMap 10.6. All MAs (except for Iaşi) included more than two raster scenes; therefore, before further operations, they had to be grouped to cover the entire metropolitan area. Next, the number of new cover pixels for each TAU was retrieved using Extract by mask tool from Spatial Analyst Tools (ArcMap software). Separately, the new impervious surfaces were calculated in hectares for each administrative unit, using the size of MAs for a better highlight of comparison. For spatial validation, Google Earth imagery was used. The high resolution and the image archive allowed for the distinction of the functions of the built space (residential, commercial, industrial or transport).

For the entire interval (2006-2018), the growth rate of built areas was calculated and represented graphically (fig. 2). The dynamics were expressed in relative values and they show to what extent each metropolitan area developed from 2006 to 2018. Similarly, the population growth rate was calculated based on data provided by the National Institute of Statistics.

2.2. Study area

The study area consists of the six largest metropolitan areas in Romania: Cluj, Constanţa, Iaşi, Timişoara, Braşov and Craiova (Fig. 1).

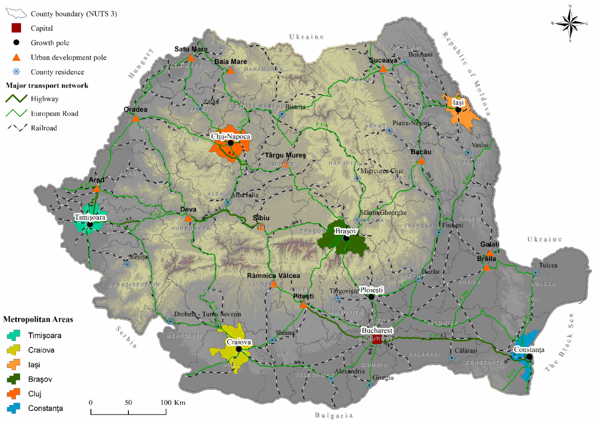


Fig. 1. The localization of metropolitan areas in the national context.

The cores of these areas are represented by the six largest cities of Romania, not only in terms of total population but also functionally: they are regional urban centres that polarize a larger region, which were promoted as national growth poles. The component TAUs of each MA were delimited according to various studies (Rusu et al., 2012; Grigorescu, 2010; Ionescu-Heroiu et al., 2019; Kriss et al., 2021).

Table 2. General features of the metropolitan areas.

Metropolitan area	Surface (km^2)	Population (2018)	Cities	Towns	Communes	% urban TAUs	% rural TAUs	Total TAUs
Braşov	1969.52	488 862	2	4	15	31.8	68.2	22
Cluj	1740.7	436 016	0	0	19	5	95	20
Constanţa	1115.62	491 148	0	5	10	37.5	62.5	16
Craiova	1822.57	409 581	0	2	26	10.3	89.7	29
Iaşi	1238.64	522 613	0	0	20	4.8	95.2	21
Timişoara	1173.23	428 126	0	0	15	6.3	93.8	16

Source: data processed based on data provided by the National Institute of Statistics (NIS).

Relative to their surface, the largest MA is Braşov, followed by Craiova and Cluj. On the other hand, Iaşi MA was the most populated area in 2018, mostly due to recent migration flows from the Republic of Moldova. Overall, Craiova MA has the largest number of TAUs (29), while for the rest of MAs the number of TAUs ranges from 16 (Constanţa and Timişoara MAs) to 22 (Braşov MA) (Table 2).

3. RESULTS

3.1. The evolution of built areas in the metropolitan areas

Except for Craiova, all MAs recorded positive growth of population for the period 2006-2018. The highest value (approx. 20%) was recorded by Iaşi, followed by Cluj (13%) and Timişoara (nearly 10%). In terms of built areas, Iaşi still remains on the first position, with approx. 35% more built space in 2018 than in 2006, followed by Braşov and Cluj with over 30%. Although with a decrease in population number, Craiova MA still maintained a high value of growth of built areas, while Constanţa registered the lowest value for the same period (approx. 15%).

However, the evolution of the built areas in the MAs seems to be independent of the evolution of population (Fig. 2).

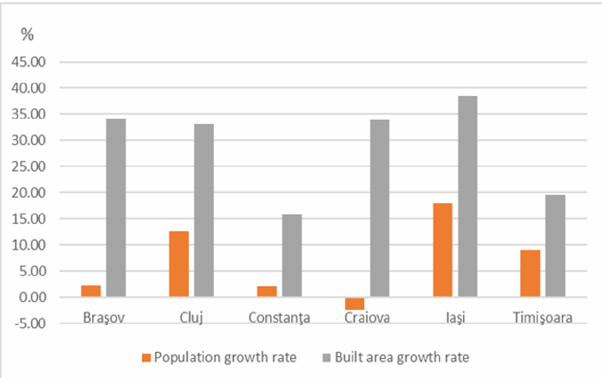


Fig. 2. Population and built area growth rates at metropolitan level, between 2006 and 2018 (%) *(source: data processed based on data provided by the National Institute of Statistics (NIS) and Copernicus).*

After the extraction and analysis of the newly built space, a differentiated dynamics of the new cover extension can be observed within the six MAs. For the entire period (2006-2018), the regional urban centres of the economic core regions showed the highest growth rate: Cluj (over 19 km² of new cover), Braşov (over 16 km²) and Timişoara (approx. 14 km²), followed by the urban centres of the less dynamic regions: Iaşi, Constanţa, and Craiova (Fig. 3).

When analysed for each of the four periods, the growth is differentiated at the metropolitan level (Fig. 4). Between 2006 and 2009, the most extended built areas were registered in Cluj MA (aprox. 1200 ha), followed by Braşov, Iaşi and Timişoara MAs. For the following period (2009-2012), Braşov had the highest growth (over 600 ha), Timişoara MA almost reached the same limit, whereas the rest of MAs recorded a modest growth (under 150 ha). Between 2012 and 2015, Craiova MA counted almost 600 ha in new cover, being followed by MAs of Constanţa and Iaşi, which exceeded 400 ha, whilst the lowest value is recorded by Cluj MA (145 ha). For the 2015-2018 period, Cluj MA returns on the first position of the top, with over 400 ha of new land cover. Braşov and Constanţa almost reached 400 ha, Iaşi and Timişoara MAs surpassed 200 ha, whereas Craiova remained below this threshold (almost 120 ha). We assume that this changing dynamics of the built areas is accompanied by significant transportation infrastructure development, as well as investments in the retailing and industrial sectors.

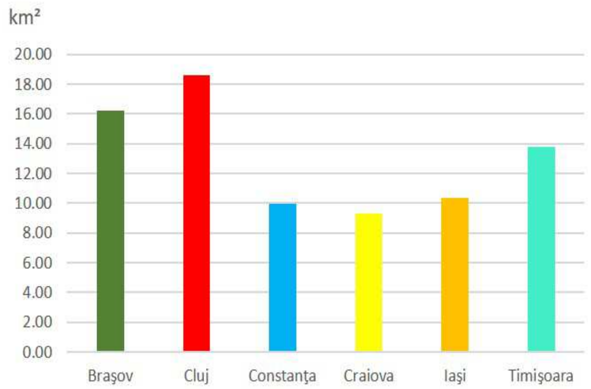


Fig. 3. Newly built areas constructed during the entire reference period (2006 – 2018), at metropolitan level (km²) *(source: data processed after Copernicus database).*

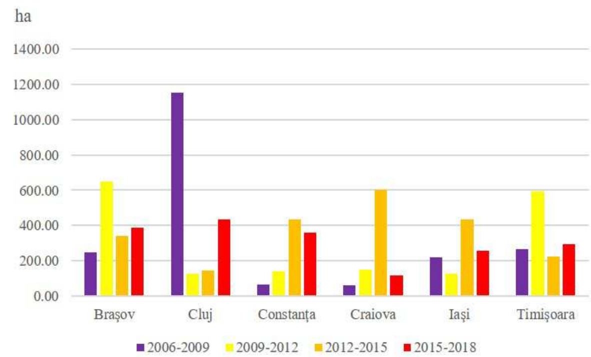


Fig. 4. Newly built areas at metropolitan level, comparatively for all reference periods (ha) *(source: data processed after Copernicus database).*

3.2. The evolution of built area at TAU level

When analysed at the local level, the dynamics of built space shows dissimilarities within metropolitan areas. In the case of Cluj Metropolitan Area (Fig. 5a.), in the period 2006-2009, when the highest value of newly built area was registered (62% of the total new cover spaces), Cluj-Napoca and Floreşti (the largest commune of Romania, with cca. 50 000 inhabitants) recorded the largest increases, of approx. 250 ha, followed by

Apahida (approx. 180 ha) and Săvădisla (approx. 150 ha), the rest of the TAUs having increases below 100 ha. The evaluation of Google Earth images made us conclude that the increases can be explained not only by the evolution of the housing market, but also by the development of large infrastructure projects, such as the highway section of A3 Gilău-Turda, or storage facilities, shopping centres and industrial buildings. In the period 2009-2012, the lowest increases of the newly built surfaces were registered, mainly due to the economic crisis, which strongly affected the construction sector.

The city of Cluj-Napoca registered approx. 60 ha of newly built space, while the rest of the TAUs recorded less than 15 ha, mostly represented by extensions of the residential areas, which continued to grow based on private funding, despite the economic crisis. In the period 2012-2015, due to a strong economic recovery, only Cluj-Napoca recorded a significant increase of almost 100 ha, through the development of the airport infrastructure, the rest of the communes registering insignificant increases. Between 2015 and 2018, Cluj-Napoca expanded its built space by approx. 130 ha, especially through real estate developments.

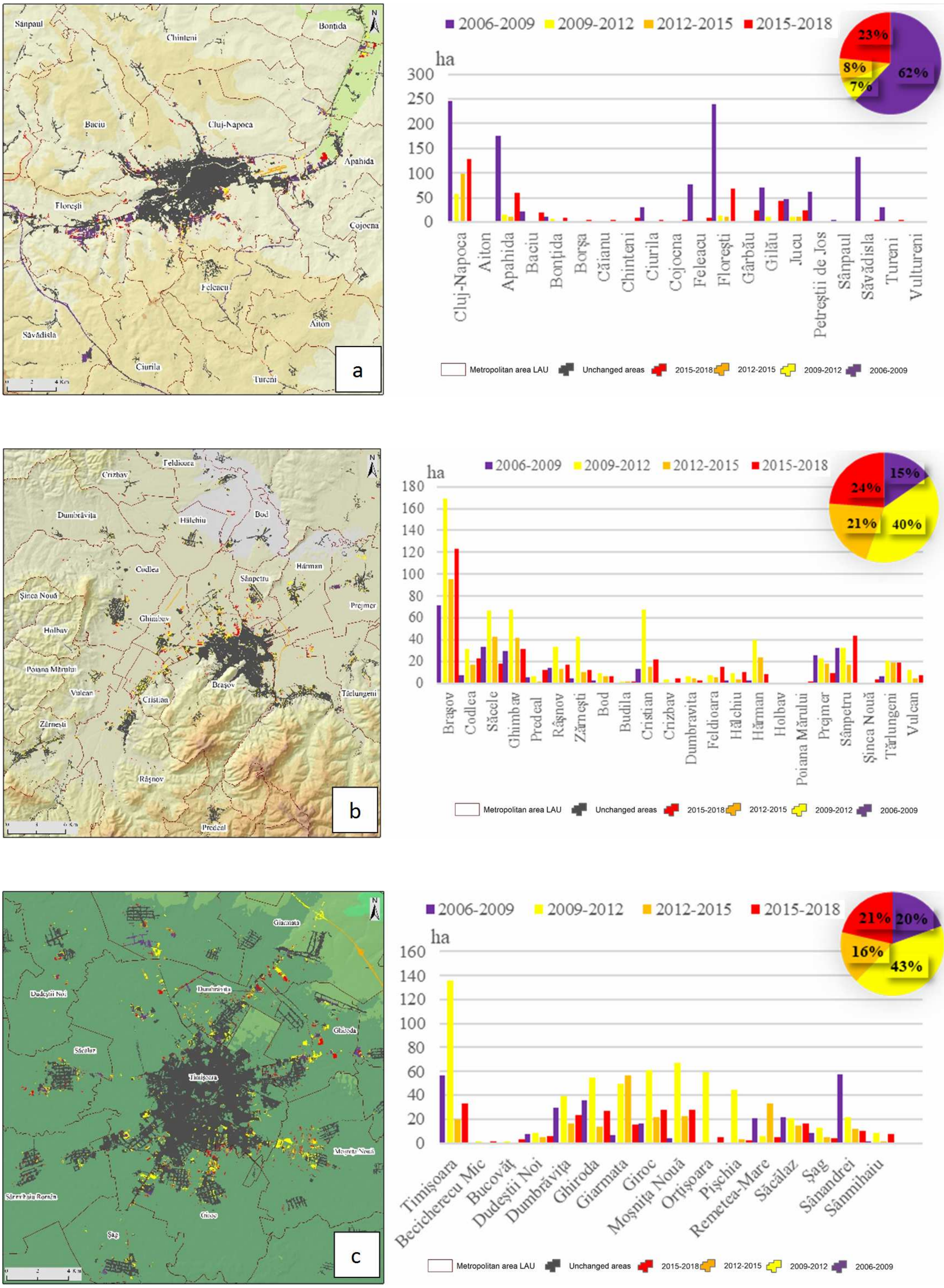
Braşov Metropolitan Area (Fig. 5b) recorded the lowest increases in built spaces between 2006 and 2009. However, regardless of the negative effects of the economic crisis, the largest built surface of the entire analysed period was registered during 2009-2012, as a mixture of residential spaces and industrial parks. During the next period 2012-2015, Braşov city had increases of approx. 95 ha, followed by Săcele and Ghimbav (where the airport runway was built), which are the only ones that exceeded 40 ha. During this period, the eastern section of Braşov belt was also built. In the last analysed period, 2015-2018, the built area in Braşov city recorded increases of approx. 124 ha, Sânpetru commune expanded its residential space by approx. 44 ha, while the rest of the TAUs had insignificant changes.

Timişoara Metropolitan Area (Fig. 5c.) did not record significant increases during the period 2006-2009, which is similar to Braşov MA. The largest built area was registered in Sânandrei commune (approx. 58 ha), followed by Timişoara municipality (approx. 57 ha). For the period 2009-2012, the largest increases are noticeable in the case of Timişoara (approx. 136 ha), by extending residential areas. In the period 2012-2015, Giarmata commune had the highest growth (approx. 57 ha), followed by Remetea Mare (approx. 33 ha) due to the construction of a new sector of the A1 highway. Timişoara city did not exceed 25 ha of built residential areas. In the last analysed period, 2015-2018, only Timişoara exceeded 45 ha of newly built space.

In the case of Iaşi Metropolitan Area (fig. 5d.), in the period 2006-2009, the municipality registered the highest growth (approx. 120 ha), mainly of residential areas in the south, and of commercial and industrial in the west. Significant extensions were recorded only in the communes of Miroslava and Bârnova (approx. 23 ha and 27 ha), not exceeding 12 ha in the rest of the metropolitan area. In the period 2009-2012, the lowest values of the newly built space were registered, as an effect of the economic crisis. Iaşi had only approx. 47 ha, followed by Bârnova (approx. 27 ha) and Miroslava (approx. 23 ha), and the rest of the communes did not exceed 11 ha. In the period 2012-2015, the largest increases was recorded. Miroslava commune was ranked first, with approximately 130 ha newly built space, followed by Iaşi (approx. 92 ha). In the last analysed period, 2015-2018, Iaşi and Miroslava had similar increases, of approximately 60 ha each, reflecting the dynamic development of some suburban communes.

Craiova Metropolitan Area (fig. 5e.) registered the lowest increase of the built area in the period 2006-2009, when, apart from Craiova municipality (approx. 21 ha) and Cârcea commune (approx. 19 ha), no other TAU exceeded 9 ha. In the period 2009-2012, Craiova reached approx. 48 ha of newly built space. The highest values of the newly built surfaces were registered in the period 2012-2015: approx. 163 ha in Craiova, 143 ha in Malu Mare, 91 ha in Cârcea, 51 ha in Podari. In the period 2015-2018, Craiova slowed down its development, with approx. 22 ha. Generally, the TAUs from Craiova MA showed low dynamics of the built space, a fact that can be linked to the low dynamics of the economic development.

In the case of Constanţa Metropolitan Area (fig. 5f.), the period 2006-2009 brought the lowest values of the newly built space. Constanţa had an increase of approx. 42 ha, while the only ones that exceeded 5 ha were Eforie, Ovidiu and Lumina. In the next period (2009-2012), Constanţa had an increase of approx. 2 ha compared to the first period (approx. 44 ha), but we found three TAUs with increases of over 10 ha: Mihail Kogălniceanu (industrial area in the south-east - approx. 37 ha), Lumina (residential area - approx. 18 ha), Murfatlar (industrial area on DN3) and Ovidiu (approx. 11 ha). In the period 2012-2015, the highest increase of built space was registered, due to the construction of the road connection on the A2 highway between Cernavodă and Constanţa and the A4 motorway. Constanţa registered about 106 ha of newly built areas, but was overtaken by Cumpăna commune, with approx. 110 ha, added by building road ramps. The rest of the TAUs where the highway was built also had the largest increases of all the analysed periods: Murfatlar, Valu lui Traian, Ovidiu, Agigea. In the period 2015-2018, Constanţa and Năvodari recorded about 50 ha of newly built land, especially in tourist areas. The residential area was also developed in Agigea (approx. 26 ha).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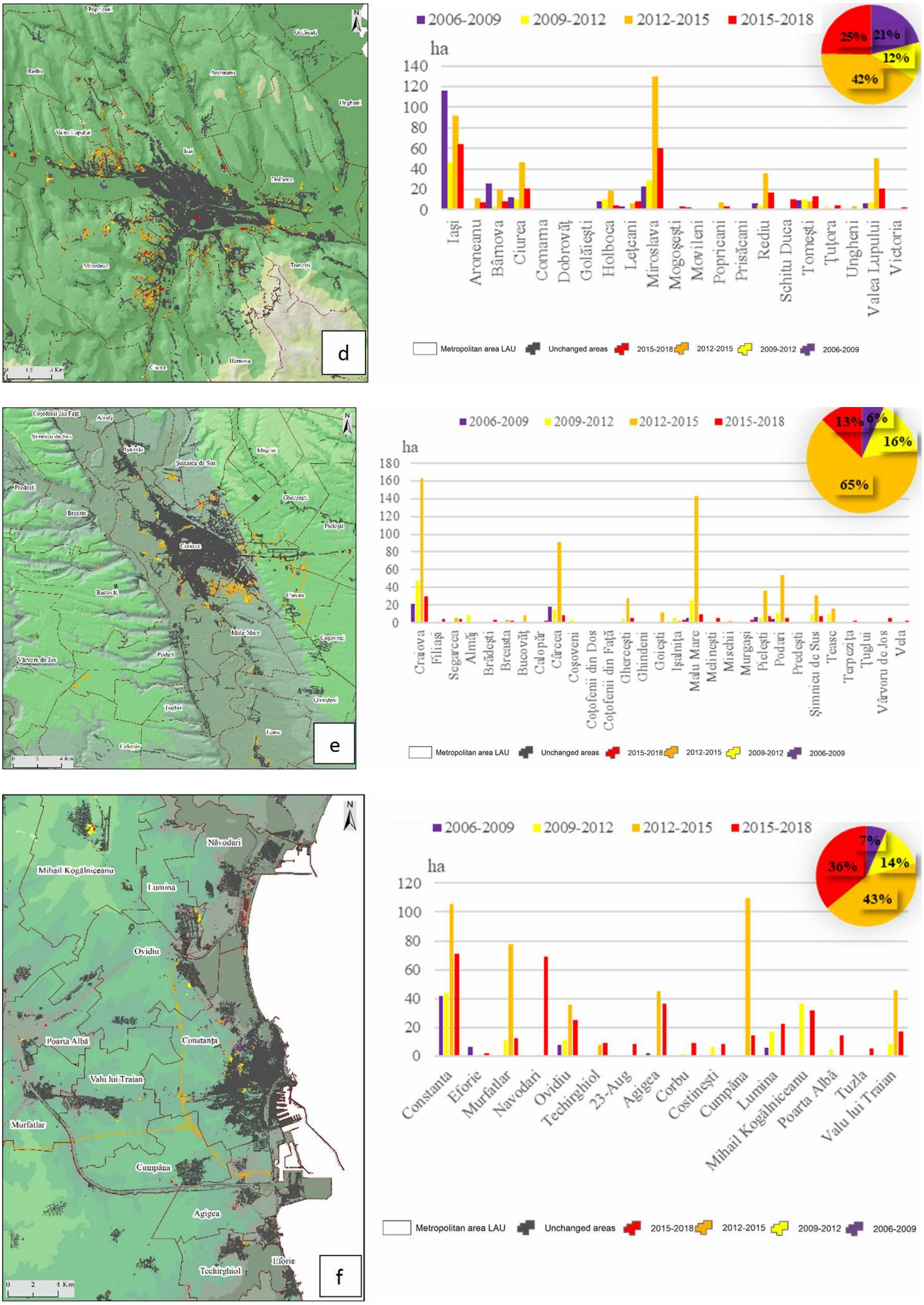

Fig. 5. Metropolitan areas and the new cover extent of built surfaces, at TAU level: a. Cluj MA; b. Braşov MA; c. Timişoara MA. d. Iaşi MA; e. Craiova MA; f. Constanţa MA *(source: data processed after Copernicus database).*

3.3. Comparative analysis of built areas at metropolitan level

The spatial distribution of the new cover areas for each period shows the evolution of the built areas in every TAU (Fig. 6). The surfaces were ranked in five classes, depending on the lowest and highest value. For the first two periods (2006-2009 and 2009-2012), the classes vary between 5 and 130 ha, while for the intervals 2012-2015 and 2015-2018 values between 6 and 80 ha are assigned. Between 2006 and 2009, Cluj MA was the only one that almost reached 250 ha of newly built land, while in the other MAs, the major cities reached 130 ha (Iaşi, Timişoara, Braşov). The main cities of Craiova and Constanţa MAs are in the third category, recording less than 50 ha of newly built space. The lowest values are found in the majority TAUs of Craiova, Constanţa and Iaşi MAs (approx. 20 ha).

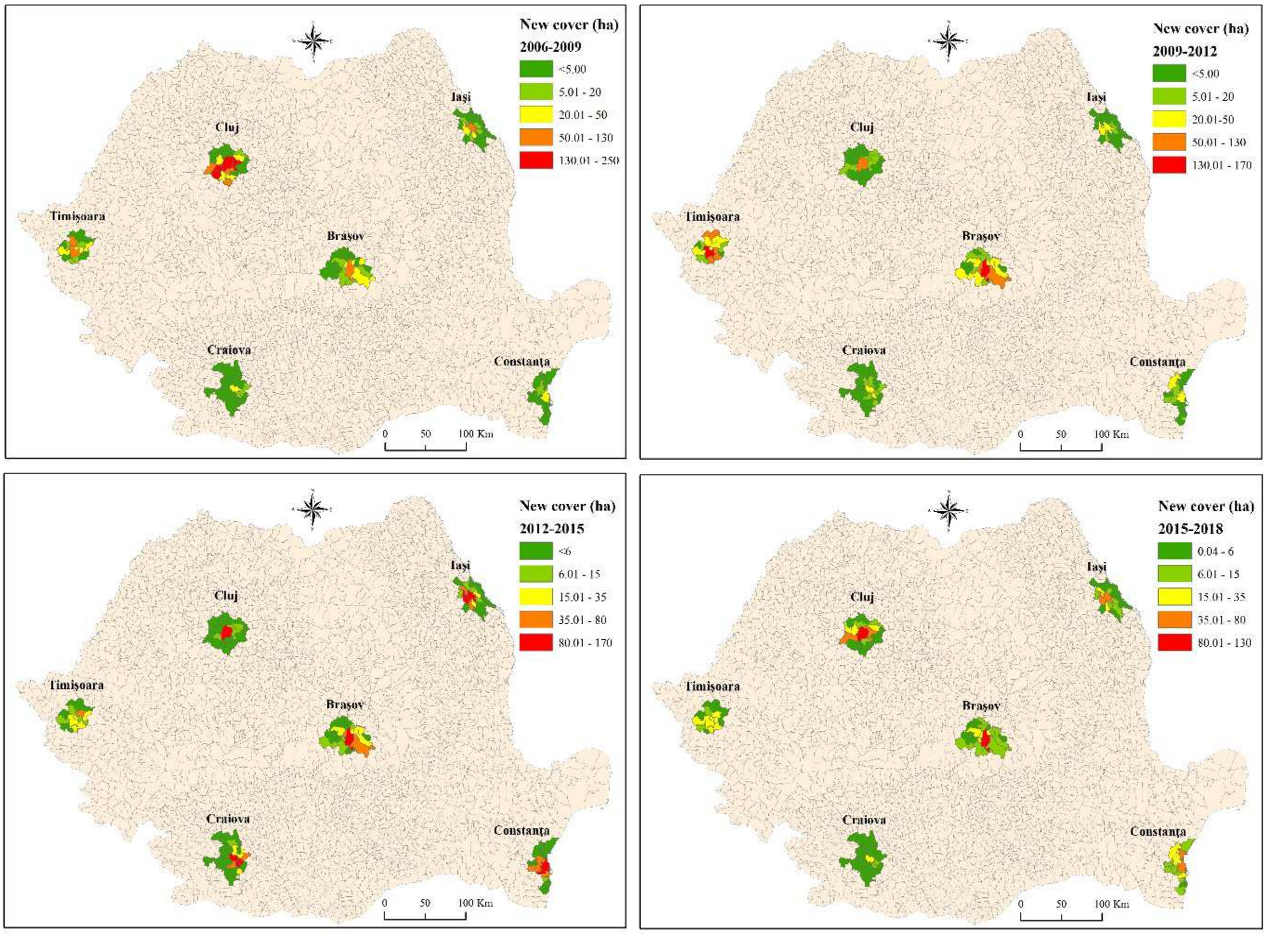

Fig. 6. New cover extent at local administrative level f *(source: data processed after Copernicus database).*

In the next period (2009-2012), Cluj MA is found in the second category of extension (under 100 ha). Timişoara and Braşov are the cities with the largest growth (up to 170 ha). In Iaşi MA, only the main city and Miroslava commune are rated in the third category (between 25 and 50 ha), the same being valid for Craiova and Malu Mare, as well as for Constanţa and Mihail Kogălniceanu. The 'greenest' MAs are Cluj, Iaşi and Craiova.

Between 2012 and 2015, many TAUs recorded the highest built area extension values, up to 170 ha: Cluj-Napoca, Iaşi, Miroslava, Braşov, Craiova, Malu Mare, Cârcea, Constanţa and Cumpăna. These TAUs are surrounded by other communes with newly built spaces ranging from 35 to 80 ha. The third class includes Timişoara and Braşov MAs, where residential areas (in the south and east of Timişoara MA) and roads and airport infrastructure (in Braşov MA) were recoded. The lowest values are held by Cluj MA, where we found more communes ranked in the last class (under 6 ha of newly built area), while for the rest of MAs this category was recorded by the administrative units located at the outskirts.

In the last reference period (2015-2018), the growth is mainly visible in Cluj-Napoca, Apahida and Floreşti, which recorded up to 130 ha of new cover. In Iaşi MA, besides the main city, Miroslava commune is in the same class. Constanţa and Năvodari are the only TAUs included also in this category, along Timişoara and Braşov. In the second class is Craiova city, being surrounded by other TAUs with the same value. This time, Craiova MA is the greenest, with less than 6 ha of newly built land. Iaşi and Cluj MAs also have many TAUs included in the last class.

4. DISCUSSION

The first major finding of this study is the Earth Observation-based high resolution evaluation of spatial differentiation in the extension of built space in the largest regional urban agglomerations of Romania. The extension of both built areas and new cover areas shows a similar spatial pattern. The MAs of Cluj, Braşov and Timişoara have the highest intensity of new cover areas extension, a situation explained by their higher economic dynamics compared to the second group of MAs (Iași, Constanţa and Craiova), this finding being in line with the results obtained by Grădinaru et al. (2020). However, the novelty of this study lies in the surprising fact that the financial crisis from 2007-2008 had little impact on the new cover extension. This fact is noticeable from the longitudinal analysis, according to which the extension of built space had similar intensity in the large urban agglomerations in the period 2009-2012.

The second novelty is the time delay observed in the dynamics of the extension process during certain periods for certain MAs. While 62% of the extension of Cluj MA was registered in the first reference period (2006-2009), the highest extension values for Brașov and Timişoara MAs were recorded in the period 2009-2012, and for the rest of the MAs in 2012-2015 (the record value of 65% being recorded by Craiova MA). This time delay may be in relation with the diffusion and character of the economic development process in less developed countries.

A third major finding of our paper is that the spatial extension of built areas is independent from the population dynamics, a conclusion in line with the findings of Sandu (2016), Carriere et al. (2018) or Grigorescu et al. (2021). The built area growth rate is not related to the population growth rate of the MAs. Accordingly, residential areas expanded in all MAs irrespective of their demographic evolution. This urban sprawl is generated mainly by the suburbanization process of population and economy, which, in turn, is fuelled by new attitudes towards housing, new urban development policies and the lack of affordable housing opportunities for young people in the core urban areas of the MAs (Slaev et al., 2018; Vesalon and Creţan, 2019; Benedek et al., 2022). Noteworthy is that, in certain MAs, the extension of industrial/ commercial areas and the development of new road infrastructure (highways) were also space consuming, adding higher values to the extension of built areas. It is the mainly the case of Constanţa MA, followed by Brașov and Timişoara MAs. Similar situations were found in other Central and Eastern European countries, where a new wave of low-wage jobs attracted industrialization, which further required a higher-quality road infrastructure. Thus, economic development is playing an important role in the land use change (Schmidt et al., 2015; Kovacs et al., 2019; Różycka-Czas et al., 2021; Ivancsics and Kovacs, 2021). Also, the airports runaways constructed in Cluj and Braşov MAs contributed to the urban development, their economic implications being emphasized by Creţan et al. (2009).

One of the shortages of our analysis is that the method employed does not allow an evaluation of the housing situation for socially deprived groups such as the Roma community. These groups are also of interest for the differentiated spatial extension of built areas, considering their marginalizing position both in social and spatial terms (Creţan and Turnock, 2008).

This study contributes not only to a timely mapping of the expansion of built spaces in the urban regional centres of Romania, but it has the potential to be developed and used to determine the suitability of certain areas for planning urban green spaces, as in the case of the city of Ploieşti (Gavrilidis et al., 2019). This objective should be a high priority for spatial planning considering that rapid urban sprawl in the analysed areas is largely affecting areas with high potential to be used as urban green spaces in the future.

5. CONCLUSIONS

The evolution of the built areas investigated in the present study has revealed some considerations on metropolitan areas and on urban development. Overall, for the entire reference period (2006-2018), Cluj MA registered the highest growth (over 19 km² of newly built land), followed by Braşov, (16 km²), Timişoara (approx. 14 km²), Iaşi and Constanţa (approx. 10 km²). The lowest increase of the newly built space was recorded by Craiova (9 km²).

Certain extension patterns of the built areas can be highlighted, which show the spatial direction of development and also bring out the marginalized TAUs, from this perspective. As a general rule, it was observed that the extension of built surfaces was more significant in the case of the local administrative units located in the immediate vicinity of the growth poles, as opposed to those located at considerable distances or even at the borders of the MAs, as in the case of Iaşi, where the increases were insignificant. Thus, in the case of Cluj MA, the development is visible mostly on the west-east axis. In Iaşi, the growth was concentrated more towards the west than the east, and Craiova MA extended towards south and east. The other metropolitan areas did not necessarily show a particular spatial pattern for the growth. The built areas expanded in different local administrative units in each analysed period.

The results were in accordance with the findings of other studies, which come as a confirmation of their validity. The evolution of the built areas is mostly influenced by the economic, political and social context, but major unfavourable events (i.e., the economic crisis) do not seem to considerably affect the building construction, as they continue to develop independently, depending on the evolution of the market and the private funds.

Results also show that there is no correlation between population dynamics and the growth of built areas, this finding being also consistent with previous studies.

Much more, the use of high-resolution database should be emphasized. Copernicus dataset proved to be a valuable source of data for the faster calculation of built areas than processing satellite imagery. The resolution of 20 m and the extent of the metropolitan areas were the premises that increased the relevance of the data used.

The paper contributes to the research in the field of metropolitan areas and the evolution of the built space and it can be used for identifying specific development patterns in relation to a target function of the built space. Moreover, the decision-makers could adopt new legislative measures to control and coordinate the construction activity and make sure it complies with the principles of sustainable development.

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REFERENCES

Alvioli M. (2020), Comparative study of delineation of urban areas using imperviousness products and open data. In Alvioli M., Marchesini I., Melelli L., Guth P. (eds.), Proceedings of the Geomorphometry 2020 Conference, 1-4. DOI:10.30437/GEOMORPHOMETRY2020_1

Arnold Jr. C. L., Gibbons C. J. (1996), Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association, 62(2), 243-258. DOI: https://doi.org/10.1080/01944369608975688

Artmann M., Inostroza L., Fan P. (2019), Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? Ecological Indicators, 96, 3-9. DOI: https://doi.org/10.1016/j.ecolind.2018.10.059

Bauer M. E., Heinert N. J., Doyle J. K., Yuan F. (2002), Impervious surface mapping and change monitoring using Landsat remote sensing. In IEEE International Geoscience and Remote Sensing Symposium (Vol. 4, pp. 2334-2336). IEEE. DOI: 10.1109/IGARSS.2002.1026536

Bădiţă A., Mazilu M., Popescu L. (2015), Challenges for human capital and sustainable development of rural areas. A case study on Craiova metropolitan area, Romania. Carpathian Journal of Earth and Environmental Sciences, 10(3), 101-112. ISBN: 1842-4090. URL: https://www.researchgate.net/publication/285220753_Challenges_for_human_capital_and_sustainable_development_of_rural_areas_A_case_study_on_Craiova_metropolitan_area_Romania

Benedek J. (2006), Urban policy and urbanisation in the transition Romania, Romanian Review of Regional Studies 1, 51 - 64. URL: https://www.researchgate.net/publication/49614847_Urban_Policy_and_Urbanisation_in_the_Transition_Romania

Benedek J. (2013), The Spatial Planning System in Romania. Romanian Review of Regional Studies, 9(2), 23-30. URL: https://www.researchgate.net/publication/306153384_The_spatial_planning_system_in_Romania

Benedek J., Cristea M. (2014), Growth Pole Development and 'Metropolization' in Post-Socialist Romania. Studia UBB Geographia, 59(2), 125-38. URL: https://www.researchgate.net/publication/314622091_GROWTH_POLE_DEVELOPMENT_AND_%27METROPOLIZATION%27_IN_POST-SOCIALIST_ROMANIA

Benedek J., Ivan K. (2018), Remote sensing based assessment of variation of spatial disparities. Geographia Technica, 13(1), 1-9. DOI: https://doi.org/10.21163/GT_2018.131.01

Benedek J., Ivan K., Török I., Temerdek A., Holobâcă I. -H. (2021), Indicator-based assessment of local and regional progress toward the Sustainable Development Goals (SDGs): An integrated approach from Romania. Sustainable Development, 1-16. DOI: https://doi.org/10.1002/sd.2180

Benedek J., Ursu C. -D., Varvari Ș. (2022), Growth pole policy's induced development and spatial inequalities in the metropolitan areas of Romania – a critical assessment. Tér és társadalom (Space and Society), 36 (2). DOI: https://doi.org/10.17649/TET.36.2.3435.

Bîrsănuc E. M., Man T. C., Petrea D. (2019), What Does Unsustainable Urban Sprawl Bring? Spatial Patterns Analysis of Built Environment in Cluj Metropolitan Area. Journal of Settlements and Spatial Planning, 10(2), 121-130. DOI: https://doi.org/10.24193/JSSP.2019.2.05

Carrière J. P., Filimon L., Guitel S., Savourey C., Irincu E. (2018), Urban Sprawl within the Metropolitan Area of Oradea. disP-The Planning Review, 54(3), 36-51. DOI: https://doi.org/10.1080/02513625.2018.1525211

Cole B., Smith G., Balzter H. (2018), Acceleration and fragmentation of CORINE land cover changes in the United Kingdom from 2006–2012 detected by Copernicus IMAGE2012 satellite data. International Journal of Applied Earth Observation and Geoinformation, 73, 107-122. DOI: https://doi.org/10.1016/j.jag.2018.06.003

Congedo L., Sallustio L., Munafò M., Ottaviano M., Tonti D., Marchetti M. (2016), Copernicus high-resolution layers for land cover classification in Italy. Journal of Maps, 12(5), 1195-1205. DOI: https://doi.org/10.1080/17445647.2016.1145151

Creţan R., Turnock D. (2008), Romania's Roma Population: From Marginality to Social Integration. Scottish Geographical Journal, 124(4), 274-299, PII 906893287. DOI: 10.1080/14702540802596608.

Creţan R., Turnock D., Wassing M. (2009), Romania's Airlines and Airports during Transition with Particular Reference to the West Region. Mitteilungen der Osterreichischen Geografische Geselshaft, 1-2, 241-276. DOI: 10.1553/moegg151s241

Dębowska A., Hościło A., Gruziel M., Napiórkowska M. (2014), High Resolution Impervious and tree cover layers as an additional source of data on land cover status in Poland. In 14th International Multidisciplinary Scientific GeoConference SGEM 2014, 651-658. DOI: https://doi.org/10.5593/SGEM2014/B23/S11.083

Dolean B. E., Bilaşco Ş., Petrea D., Moldovan C., Vescan I., Roşca S., Fodorean I. (2020), Evaluation of the Built-Up Area Dynamics in the First Ring of Cluj-Napoca Metropolitan Area, Romania by Semi-Automatic GIS Analysis of Landsat Satellite Images. Applied Sciences, 10(21), 7722, 1-20. DOI: https://doi.org/10.3390/app10217722

Drăgan M., Mureşan A., Benedek J. (2019), Mountain wood-pastures and forest cover loss in Romania. Journal of Land Use Science, 14(4-6), 397-409. DOI:10.1080/1747423X.2020.1719224

Elvidge C. D., Tuttle B. T., Sutton P. C., Baugh K. E., Howard A. T., Milesi C., Bhaduri B., Nemani R. (2007), Global distribution and density of constructed impervious surfaces. Sensors, 7(9), 1962-1979. DOI: https://doi.org/10.3390/s7091962

Esch T., Klein D., Himmler V., Keil M., Mehl H., Dech S. (2009), Modeling of impervious surface in Germany using Landsat images and topographic vector data. In 2009 IEEE International Geoscience and Remote Sensing Symposium (Vol. 3, pp. III-881). DOI: https://doi.org/10.1109/IGARSS.2009.5417910

European Environment Agency (EEA) (2018a), High Resolution Layer: Imperviousness Classified Change (IMCC) 2006 – 2009. URL: https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/change-maps/2006-2009/classified-change. Accessed on 21.01.2022.

European Environment Agency (EEA) (2018b), High Resolution Layer: Imperviousness Classified Change (IMCC) 2009 – 2012. URL: https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/change-maps/2009-2012/classified-change. Accessed on 21.01.2022.

European Environment Agency (EEA) (2018c), High Resolution Layer: Imperviousness Classified Change (IMCC) 2012 – 2015. URL: https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/change-maps/2012-2015/classified-change. Accessed on 21.01.2022.

European Environment Agency (EEA) (2020d), High Resolution Layer: Imperviousness Classified Change (IMCC) 2015 – 2018. URL: https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/change-maps/2015-2018/imperviousness-classified-change-2015-2018. Accessed on 21.01.2022.

Flores A. P., Gaudiano M. E. (2020), Fragmented or Compact: The Case of Periurban Municipalities in the Northwest of the Metropolitan Area of Buenos Aires. In 2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS), 369-374. DOI: https://doi.org/10.1109/LAGIRS48042.2020.9165639

Gangkofner U., Weichselbaum J., Kuntz S., Brodsky L., Larsson K., De Pasquale V. (2010), Update of the European high-resolution layer of built-up areas and soil sealing 2006 with Image2009 data. In 30th EARSeL Symposium, 185-192. URL: https://www.researchgate.net/publication/233397872_Update_of_the_European_High-resolution_Layer_of_Built-up_Areas_and_Soil_Sealing_2006_with_Image2009_Data

Gavrilidis A. A., Niţă M. R., Onose D. A., Badiu D. L., Năstase I. I. (2019), Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure. Ecological Indicators, 96, 67-78, Part 2. DOI10.1016/j.ecolind.2017.10.054

Grădinaru S. R., Fan P., Iojă C. I., Niţă M. R., Suditu B., Hersperger A. M. (2020), Impact of national policies on patterns of built-up development: an assessment over three decades. Land Use Policy, 94, 104510. DOI: https://doi.org/10.1016/j.landusepol.2020.104510

Gilabert J., Tardà A., Llasat M. C., Corbera J. (2016), Assessment of local climate zones over metropolitan area of Barcelona and added value of Urban Atlas, Corine Land Cover and Copernicus layers under INSPIRE specifications. Urban Climate, 17, 116-134. DOI:10.13140/RG.2.2.22495.25764

Grigorescu I. (2010), Modificările mediului în Aria Metropolitană a Municipiului Bucureşti (Environmental changes in the Metropolitan Area of Bucharest). Editura Academiei Române, Bucureşti. [Book in Romanian]. ISBN 978-973-27-2006-6

Grigorescu I., Mitrică B., Mocanu I., Ticană N. (2012a), Urban sprawl and residential development in the Romanian Metropolitan Areas. Romanian Journal of Geography, 56(1), 43-59. URL: https://www.researchgate.net/publication/280244881_URBAN_SPRAWL_AND_RESIDENTIAL_DEVELOPMENT_IN_THE_ROMANIAN_METROPOLITAN_AREAS

Grigorescu I., Mitrică B., Kucsicsa G., Popovici E. A., Dumitraşcu M., Cuculici R. (2012b), Post-

Communist Land Use changes related to urban sprawl in the Romanian Metropolitan Areas. Human Geographies--Journal of Studies & Research in Human Geography, 6(1), 35-46. DOI: https://doi.org/10.5719/hgeo.2012.61.35

Grigorescu I., Kucsicsa G., Popovici E. A., Mitrică B., Mocanu I., Dumitraşcu M. (2021), Modelling land use/cover change to assess future urban sprawl in Romania. Geocarto International, 36(7), 721-739. DOI: 10.1080/10106049.2019.1624981

Haidu I., Ivan K. (2016), The assessment of the impact induced by the increase of impervious areas on surface runoff. Case study the city of Cluj-Napoca, Romania. Carpathian Journal of Earth and Environmental Sciences, 11(2), 331-337. URL: https://www.researchgate.net/publication/301285712_The_Assessment_Of_The_Impact_Induced_By_The_Increase_Of_Impervious_Areas_On_Surface_Runoff_Case_Study_The_City_Of_Cluj-Napoca_Romania

Hennig E. I., Schwick C., Soukup T., Orlitová E., Kienast F., Jaeger J. A. (2015), Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy. Land use policy, 49, 483-498. DOI: https://doi.org/10.1016/j.landusepol.2015.08.001

Holobâcă I. H., Ivan K., Alexe M. (2019), Extracting built-up areas from Sentinel-1 imagery using land-cover classification and texture analysis. International Journal of Remote Sensing, 40(20), 8054-8069. DOI: https://doi.org/10.1080/01431161.2019.1608391

Ianoş I., Sîrodoev I., Pascariu G., Henebry G. (2016), Divergent patterns of built-up urban space growth following post-socialist changes. Urban Studies, 53(15), 3172-3188. DOI: https://doi.org/10.1177/0042098015608568

Ionescu-Heroiu M., Cristea M., China A.-M., Butacu B.-C., Dolean B. E., Vinţan A. D., Frant O., Mihăilescu G. M., Moldovan S. C., Sfârlea E. V., Irimia I. -A. (2019), Romania Catching-Up Regions: Metropolitan Romania, Washington, D.C.: World Bank Group. URL: http://documents.worldbank.org/curated/en/255131580296079611/Romania-Catching-Up-Regions-Metropolitan-Romania. Accessed on 1.02.2022.

Ivan K. (2015), The spatio-temporal analysis of impervious surfaces in Cluj-Napoca, Romania. Geographia Technica, 10(2), 50-58. URL: https://www.researchgate.net/publication/285220627_The_spatio-temporal_analysis_of_impervious_surfaces_in_Cluj-Napoca_Romania

Ivan K., Benedek J. (2017), The assessment relationship between land surface temperature (LST) and built-up area in urban agglomerations. Case study: Cluj-Napoca, Romania. Geographia Technica. 12:1, 64-74. DOI: https://doi.org/10.21163/GT_2017.121.07

Ivan K., Holobâcă I. H., Benedek J., Török I. (2020a), Potential of Night time lights to measure regional inequality. Remote Sensing, 12:1, 33. DOI:10.3390/rs12010033

Ivan K., Holobâcă I. H., Benedek J., Török I. (2020b), VIIRS Nighttime Light Data for Income Estimation at Local Level. Remote Sensing, 12:18, 2950. DOI: 10.3390/rs12182950

Ivancsics V., Kovacs K. F. (2021), Analyses of new artificial surfaces in the catchment area of 12 Hungarian middle-sized towns between 1990 and 2018. Land Use Policy, 109, 105644. DOI: 10.1016/j.landusepol.2021.105644

Karydas C. G., Panagos P. (2018), The G2 erosion model: An algorithm for month-time step assessments. Environmental research, 161, 256-267. DOI: https://doi.org/10.1016/j.envres.2017.11.010

Kaspersen P. S., Fensholt R., Drews M. (2015), Using Landsat vegetation indices to estimate impervious surface fractions for European cities. Remote Sensing, 7(6), 8224-8249. DOI: https://doi.org/10.3390/rs70608224

Kawakubo F., Morato R., Martins M., Mataveli G., Nepomuceno P., Martines M. (2019), Quantification and Analysis of Impervious Surface Area in the Metropolitan Region of São Paulo, Brazil. Remote Sensing, 11(8), 944. DOI: https://doi.org/10.3390/rs11080944

Kovacs Z., Farkas Z. J., Egedy T., Kondor A. C., Szabo B., Lennert J., Baka D., Kohan B. (2019), Urban sprawl and land conversion in post-socialist cities: The case of metropolitan Budapest. Cities, 92, 71-81, DOI: 10.1016/j.cities.2019.03.018

Kriss P., Ivanov I., Taralunga N., Racoviceanu S.-C., Stadler R.-L., Ghintuiala D.-L., Ionescu-Heroiu M., Silimela Y.-T., Vinţan A. D., Moldoveanu G. A., Sfârlea E. V. (2021), Romania Catching-Up Regions: Interjurisdictional Cooperation Models, Washington, D.C.: World Bank Group. URL: http://documents.worldbank.org/curated/en/338051580282390068/Romania-Catching-Up-Regions-Interjurisdictional-Cooperation-Models. Accessed on 15.02.2022.

Kuang W. (2012), Evaluating impervious surface growth and its impacts on water environment in Beijing-Tianjin-Tangshan Metropolitan Area. Journal of Geographical Sciences, 22(3), 535-547. DOI: https://doi.org/10.1007/s11442-012-0945-y

Kuang W. (2019), Mapping global impervious surface area and green space within urban environments. Science China Earth Sciences, 62(10), 1591-1606. DOI: https://doi.org/10.1007/s11430-018-9342-3

Kuc G., Chormański J. (2019), Sentinel-2 imagery for mapping and monitoring imperviousness in urban areas. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42(1/W2), 43-47. DOI: https://doi.org/10.5194/isprs-archives-XLII-1-W2-43-2019

Langanke T. (2018), Copernicus land monitoring service – High Resolution Layer Imperviousness: Product Specifications Document. European Environment Agency, Land Copernicus [online], URL: https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015. Accessed on 15.02.2022.

Lefebvre A., Sannier C., Corpetti T. (2016), Monitoring urban areas with Sentinel-2A data: Application to the update of the Copernicus high resolution layer imperviousness degree. Remote Sensing, 8(7), 606-627. DOI: https://doi.org/10.3390/rs8070606

Lehner A., Naeimi V., Steinnocher K. (2017), Sentinel-1 for urban areas-comparison between automatically derived settlement layers from Sentinel-1 data and Copernicus high resolution information layers. In International Conference on Geographical Information Systems Theory, Applications and Management (Vol. 2, pp. 43-49), SCITEPRESS. DOI: 10.5220/0006320800430049

Li H., Zhou Y., Li X., Meng L., Wang X., Wu S., Sodoudi S. (2018), A new method to quantify surface urban heat island intensity. Science of the Total Environment, 624, 262-272. DOI: https://doi.org/10.1016/j.scitotenv.2017.11.360

Madhavan B. B., Kubo S., Kurisaki N., Sivakumar T. V. L. N. (2001), Appraising the anatomy and spatial growth of the Bangkok Metropolitan area using a vegetation-impervious-soil model through remote sensing. International Journal of Remote Sensing, 22(5), 789-806. DOI: https://doi.org/10.1080/01431160051060200

Meng-Fan W., Bo Y., Fei-Fei H., Liu-Wen L. (2015), Analyses on spatio-temporal patterns of impervious surface coverage in Changsha metropolitan area. In 2015 23rd International Conference on Geoinformatics (pp. 1-6), IEEE. DOI: https://doi.org/10.1109/GEOINFORMATICS.2015.7378669

Ministry of Regional Development and Public Administration (MRDPA) (2008), Government Decision No. 1149 for the Designation of National Growth Poles, URL: https://legislatie.just.ro/Public/DetaliiDocumentAfis/98393. Accessed on 12.02.2022.

Morabito M., Crisci A., Guerri G., Messeri A., Congedo L., Munafò M. (2021), Surface urban heat islands in Italian metropolitan cities: Tree cover and impervious surface influences. Science of the Total Environment, 751, 142334, 1-19. DOI: https://doi.org/10.1016/j.scitotenv.2020.142334

Nagel P., Yuan F. (2016), High-resolution land cover and impervious surface classifications in the twin cities metropolitan area with NAIP imagery. Photogrammetric Engineering & Remote Sensing, 82(1), 63-71. DOI: https://doi.org/10.14358/PERS.83.1.63

Nagy J., Benedek J. (2018), Towards a balanced metropolitan governance: combating the "back-door" status of peripheral rural areas. Transylvanian Review, 27(1), 3-20. URL: https://www.researchgate.net/publication/325876571_Towards_a_Balanced_Metropolitan_Governance_Combating_the_Back-door_Status_of_Peripheral_Rural_Areas

Nagy J., Benedek J., Ivan K. (2018), Measuring Sustainable Development Goals at local level. A case of a metropolitan area in Romania, Sustainability, 10:11, 3962. DOI: https://doi.org/10.3390/su10113962

Oliveira A., Lopes A., Niza S. (2020), Local climate zones in five southern European cities: An improved GIS-based classification method based on Copernicus data. Urban Climate, 33, 100631, 1-25. DOI: https://doi.org/10.1016/j.uclim.2020.100631

Petrişor A. I. (2017), Long term urbanization within and around the large cities in developing countries: a Romanian perspective on the main transitional dynamics. Algerian Journal of Engineering, Architecture and Urbanism, 1(1), 14-19. URL: https://www.aneau.org/ajeau/Art/v1n1a02.pdf

Popescu C. (2011), The demographic component in the development of metropolis. A case study: Iaşi. Transylvanian Review of Administrative Sciences, 7(33), 255-276. URL: https://rtsa.ro/tras/index.php/tras/article/viewFile/294/287

Rózycka-Czas R., Czesak B., Staszel A. (2021), Which Polish Cities Sprawl the Most. Land, 10(12). DOI: 10.3390/land10121291

Romanian Government (2008), Decision no. 1149/2008 regarding the amendment and completion of Government Decision no. 998/2008 for the designation of national growth poles in which priority investments are made from programs with community and national financing. The Official Monitor, Romania. URL: https://lege5.ro/Gratuit/geyteobuha/hotararea-nr-1149-2008-privind-modificarea-si-completarea-hotararii-guvernului-nr-998-2008-pentru-desemnarea-polilor-nationali-de-crestere-in-care-se-realizeaza-cu-prioritate-investitii-din-programele?pid=38271056#p-38271056. Accessed on 20.01.2022.

Rosina K., Hurbánek P., Cebecauer M. (2017), Using OpenStreetMap to improve population grids in Europe. Cartography and Geographic Information Science, 44(2), 139-151. DOI: 10.1080/15230406.2016.1192487

Rusu R., Moldovan C., Petrea D. (2012), Premises for shaping Metropolitan Areas in Romania. Romanian Review of Regional Studies, 8(2), 99-108. URL: https://rrrs.reviste.ubbcluj.ro/site/arhive/Artpdf/v8n22012/RRRS802201210.pdf

Salvati L., Lamonica G. R. (2020), Containing urban expansion: Densification vs greenfield development, socio-demographic transformations and the economic crisis in a Southern European City, 2006–2015. Ecological Indicators, 110, 105923, 1-13. DOI: https://doi.org/10.1016/j.ecolind.2019.105923

Sandu A. (2016), Mapping the Spatial Patterns of the Urban Sprawl in Central and Eastern Europe. What Particularities for the Post-Socialist City? SGEM, Informatics, Geoinformatics and Remote Sensing Conference Proceedings, SGEM 2016, VOL III, International Multidisciplinary Scientific GeoConference-SGEM, 319-326. DOI: 10.5593/SGEM2016/B23/S11.041

Sannier C., Gallego J., Dahmer J., Smith G., Dufourmont H., Pennec A. (2016), Validation of Copernicus high resolution layer on imperviousness degree for 2006, 2009 and 2012, in: Proceedings of the International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, Montpellier, France, 5–8. DOI: 10.1481/icasVII.2016.g42b

Sarmento P., Marcelino F., Monteiro G., Schmedtmann J., Caetano M. (2015), Accuracy assessment of Copernicus program 2012 High-Resolution Layers for Continental Portugal. Technical report, DGT, 1-36 [online], URL: http://mapas.dgterritorio.pt/atom-dgt/pdf-cous/TemasGrandeResolucaoEspacial/report-HRL-2012-PT-accuracy-assessment.pdf. Accessed on 11.03.2022.

Scalenghe R., Marsan F. A. (2009), The anthropogenic sealing of soils in urban areas. Landscape and urban planning, 90(1-2), 1-10. DOI: https://doi.org/10.1016/j.landurbplan.2008.10.011

Schmidt S., Fina S., Siedentop S. (2015), Post-socialist Sprawl: A Cross-Country Comparison. European Planning Studies, 23(7), 1357-1380. DOI: 10.1080/09654313.2014.933178

Sexton J. O., Song X. P., Huang C., Channan S., Baker M. E., Townshend J. R. (2013), Urban growth of the Washington, DC–Baltimore, MD metropolitan region from 1984 to 2010 by annual, Landsat-based estimates of impervious cover. Remote Sensing of Environment, 129, 42-53. DOI: https://doi.org/10.1016/j.rse.2012.10.025

Slaev A. D., Nedovic-Budic Z., Krunic N., Petric J., Daskalova D. (2018), Suburbanization and sprawl in post-socialist Belgrade and Sofia. European Planning Studies, 26(7), 1389-1412. DOI: 10.1080/09654313.2018.1465530

Vesalon L., Crețan R. (2019), “Little Vienna” or “European Avant-Garde City”? Branding Narratives in a Romanian City. Journal of Urban and Regional Analysis, 11(1), 19 – 34. DOI: 10.37043/JURA.2019.11.1.2

Wickham J., Stehman S. V., Neale A. C., Mehaffey M. (2020), Accuracy assessment of NLCD 2011 percent impervious cover for selected USA metropolitan areas. International Journal of Applied Earth Observation and Geoinformation, 84, 101955, 1-9. DOI: https://doi.org/10.1016/j.jag.2019.101955

Xian G., Homer C. (2009), Monitoring urban land cover change by updating the national land cover database impervious surface products. In 2009 Joint Urban Remote Sensing Event (pp. 1-5), IEEE. DOI: 10.1109/URS.2009.5137597

Yuan F., Bauer M. E. (2007), Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sensing of Environment, 106(3), 375-386. DOI: https://doi.org/10.1016/j.rse.2006.09.003