

## ANALYSIS OF BUCHAREST URBAN DEVELOPMENT BASED ON MULTITEMPORAL SATELLITE-DERIVED DATASETS AND STATISTICAL DATA

A.M. Lazar<sup>1,3</sup>, I.F. Dana Negula<sup>2,3</sup>, C. Moise<sup>2,3,\*</sup>, F. Dediu<sup>1,3</sup>, C.E. Mihalache<sup>2,3</sup>, A. Badea<sup>1,3</sup>

<sup>1</sup> Romanian Space Agency, 010362 Bucharest, Romania (andi.lazar, florina.dediu, alexandru.badea)@rosa.ro

<sup>2</sup> Department of Mathematics, Physics and Land Measurements, Faculty of Land Reclamation and Environment Engineering, University of Agronomic Sciences and Veterinary Medicine of Bucharest, 011464 Bucharest, Romania (iulia.dana, cristina.mihalache)@fifim.ro

<sup>3</sup> Romanian Society of Photogrammetry and Remote Sensing, 020396 Bucharest, Romania (chair.srft@srft.ro)

\*Corresponding author: cristian.moise@fifim.ro

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### ABSTRACT:

Almost worldwide, urban expansion has been increasing at a rapid pace in the last decades. Although metropolitan areas strongly contribute to economic growth, they are also usually characterized by uncoordinated urban development that consequently causes overburdened infrastructure and higher air pollution. Bucharest (the capital of Romania) and the surrounding Ilfov County underwent a significant expansion during different growth stages, roughly tripling their population since 1930.

The present study analyzes the evolution of the urban spatial expansion of Bucharest and Ilfov between 1985 and 2015, using the World Settlement Footprint Evolution dataset created by the German Aerospace Center. The research integrates data provided by the National Institute of Statistics in relation to the resident population, population density, the average monthly net income and the gross domestic product. The results reveal that Bucharest - Ilfov development region had an impressive expansion during the investigated time interval in comparison with the other Romanian regions. In 30 years, the built-up area corresponding to Bucharest and the Ilfov County doubled, 2007 being the most prolific for the development of new built-up areas. In what concerns Bucharest city, the most noteworthy urban expansion occurred in District 1. Several urban growth hotspots were also identified and analyzed in detail (e.g., North of the capital).

### 1. INTRODUCTION

According to the latest United Nations' reports regarding the Sustainable Development Goals, presently more than half of the world's population lives in urban settlements and it is predicted that the numbers will reach 60% by 2030 and 70% by 2050 (United Nations, 2020), (United Nations, 2021). Although the urban areas represent only 3% of the planet's land surface, they are major energy consumers and carbon emitters, as stated in the above-mentioned reports.

Urban expansion can be accurately monitored from space. Satellite remote sensing provides unparalleled data for the mapping, complex characterization and long-term observation of the urban settlements (Moeller, 2005), (Al-Bilbisi, 2019).

The identification of built-up areas can be performed based on radar or optical (multispectral) satellite imagery or by integrating both types of data. Semenzato et al. (2020) proved the benefits of using synthetic aperture radar (SAR) data (in this case, Sentinel-1) for urban footprint detection by exploiting the interferometric coherence. Schneider (2012) monitored urban expansion based on multi-seasonal Landsat imagery. Berila and Isuf (2021) also proved the suitability of the multitemporal Landsat data for the determination of urban growth during large time intervals. For the mapping of the urban expansion, Forget et al. (2021) proposed an approach that integrates multi-sensor satellite imagery such as Landsat, Envisat, ERS and Sentinel-1 as well as the OpenStreetMap (OSM) geospatial dataset. Also, through the combination of multispectral optical and SAR data, Zitzlsberger et al. (2021) introduced a method that enables fully automated continuous urban monitoring. Likewise, by the joint exploitation of Sentinel-1 and Sentinel-2 data, Petrushevsky et

al. (2022) proposed a methodology for the fast and effective generation of urban land cover maps.

Nowadays, the information derived from satellite imagery also supports the early detection and assessment of risks and vulnerabilities as well as climate change impacts on urban areas and may contribute to the development of efficient planning strategies for sustainable and resilient urban establishments (Chrysoulakis and Mitraka, 2018), (Ennouri et al., 2021).

Furthermore, urban development can be monitored using satellite -derived datasets that display the status corresponding to different years and the changes that took place during these times. Examples include Corine Land Cover (CLC), Urban Atlas (UA) and the Imperviousness dataset provided by the Copernicus Land Monitoring Service (CLMS, 2022). In a study that aimed to identify and quantify the urbanization processes, Cieślak et al. (2020) concluded that the CLC datasets can be successfully used for urban sprawl monitoring. Besides CLC, Aksoy et al. (2022) used UA to detect and compare the changes in the artificial and non-artificial surfaces. A detailed study that encompassed CLC, UA and the Imperviousness layer investigated the expansion of the urban areas and demonstrated the usefulness of these Copernicus databases for an enhanced urban sprawl monitoring (Dražković, 2021). Mc Cutchan et al. (2020) proposed a new approach for urban growth prediction that embodies the Copernicus Imperviousness change layer as ground truth data.

Nowadays, Bucharest is considered the largest post-socialist city in the EU, while Ilfov is the most dynamic county, predominantly urban, within the region. The first decade after the fall of communism was marked by modest territorial transformations. But starting with 2000, an ongoing process of

unplanned built-up area expansion into the predominantly agricultural landscape of Ilfov County started (Stoica et al., 2021). Using Landsat data, the study investigated the evolution of the Ilfov between 2000 and 2018. The results showed that the county underwent major territorial rearrangements that led to a heterogeneous landscape especially in terms of built-up density. Also, based on Landsat imagery, Aldea and Petrescu (2014) studied Bucharest's urban growth within a decade. Costăchioiu et al. (2014) also used long-term satellite image time series for the analysis and assessment of Bucharest and Ilfov growth within a time span of more than 25 years. The research pointed out that a steady increase of the urban surface was observed since 1999. Based on multitemporal Landsat data and Copernicus land cover datasets, Mihai et al. (2015) demonstrated that Bucharest had an accelerated growth between 2003 and 2010. Nistor et al. (2021) mapped the urban landscape changes of Bucharest that occurred in a time frame of more than 50 years, using CORONA, SPOT and Sentinel imagery. The study proved that the extension of Bucharest's outskirts for the development of new residential areas is a distinctive feature for Eastern European cities.

## 2. STUDY AREA

### 2.1 Geographic location

The city of Bucharest is located in the southern central part of Romania, in the middle of the Romanian Plain, 64 km North of the Danube River, 250 km West of the Black Sea and 100 km South of the Carpathians, at the intersection of parallel 44°26' North latitude with the meridian of 26°06' eastern longitude. It has an area of 228 km<sup>2</sup> which represents approximately 0.8% of Romania's total surface. Within the city the altitudes decrease from the northwest to the southeast, the maximum altitude being 96.3 m and the minimum, 57 m with an average altitude of 79 m. Bucharest's relief is mainly represented by the Bucharest Plain and is crossed by two main rivers, Dâmbovița and Colentina (Comănescu et al., 2017). In order to obtain a harmonic politics of territorial development compared to those in the European Union (EU) and financial support for the territorial profile development, Romania created 8 development regions (Surd et al., 2011), which are classified by the EU as Nomenclature of Territorial Units for Statistics (NUTS) 2 level regions. The Bucharest - Ilfov region is one of the 8 development regions emerged as the result of a PHARE project from 1997 and it encompasses the national capital, Bucharest, as well as the surrounding Ilfov County. The other 7 development regions are: North-West, Center, North-East, South-East, South-Muntenia, South-West Oltenia, and West. For a better understanding of the Bucharest - Ilfov development region evolution in Romania, the analysis is made in comparison with the rest of the other 7 development regions of Romania.

### 2.2 Evolution of the urban development

Bucharest is the capital of Romania and documentary evidence points to the existence of the town as early as 1459 (Turnock, 1990). Bucharest and the surrounding Ilfov County have been experiencing significant growth during the last decades. Under the communist regime, Bucharest had undergone particularly radical changes in line with Ceausescu's personal ambitions (1974-1989). During this period of time, the development of apartment blocks occurred in the suburbs, partly on greenfield land and partly in areas with rural-type cottages. At the same time, the rearrangement of the old central area took

place. Under the leadership of Ceausescu, many grand projects were built: The House of the Parliament (also known as People's House), a new east-west boulevard flanked by apartment buildings, the channeling of Dâmbovița River with an underground sewerage/flood water conduit, two large lakes (Dudești and Lacul Morii), and the metro system. The transformation of Bucharest was linked with the development of the Danube-Black Sea Canal (Nae and Turnock, 2011). An interesting phenomenon happened outside Bucharest because a ring of communes has developed around the city even since the interwar period (Nicolae, 2002). The evolution of this urban agglomeration was strongly controlled during the communist era (1945–1989) by the extensive industrialization and urban policy (Cercleux, 2009). The industrialization policy encouraged the development of huge industrial sites in the outskirts of Bucharest, generating an incomplete urbanization centered on industrial activities (Ianoș and Jones, 2019). These industrial sites employed around 500,000 workers of which about one fifth were commuters (Ianoș, 1994). During this period, Bucharest was declared to be "a closed city". Law No. 66/1971 prevented people from other parts of Romania from residing in Bucharest. This measure forced the population from other parts of the country to settle in neighboring villages around Bucharest and increased the daily and weekly commuting rates within an area of around 100 km from the city (Ianoș and Jones, 2019). Despite these restrictions, during the period 1977–1992, the population of Bucharest increased by 14% (Ianoș, 2016). In 1989, the revolution brought an end to the grandiose communist projects and a crisis ensued over the construction of new homes. Priority was given to maintaining the industrial establishments while reducing the workforce. After almost a decade of stagnation and inactivity, the renewed economic growth, political stability, and the prospect of European Union accession created an economic boom. During this period of time new shopping malls and hotels were built, along with substantial housing projects, and office buildings. The changes within the city also had impacts upon the industrial zones, where privatization occurred. After 2000, the growing pressure on inner-city land led to relocation outside the city (Nae and Turnock, 2011).

## 3. DATA AND METHODOLOGY

### 3.1 Remote Sensing Dataset

The present study concentrates on the identification and assessment of the urban growth patterns in the Bucharest - Ilfov development region based on the World Settlement Footprint (WSF) Evolution dataset that contains the development of the built-up area within a time span of 30 years (between 1985 and 2015). The dataset has a higher spatial resolution of 30 m in comparison to the available relevant datasets also derived from satellite imagery (e.g., Urban Atlas and Corine Land Cover with 100 m spatial resolution). The WSF Evolution dataset produced by the Earth Observation Center (EOC) of the German Aerospace Center (DLR). The dataset was derived from a series of multitemporal Landsat-5/7 imagery (Marconcini et al., 2021). Although it presents a comparable content, the Imperviousness High Resolution Layer was not integrated into the research due to the different time coverage of the datasets (i.e. Imperviousness corresponds to the 2006 - 2018 period) and the slightly different geometric resolutions (i.e. Imperviousness has 10 m for the new products and 20 m for the previous ones) that could hinder the correct interpretation of the comparative results.

### 3.2 Statistical data

The study was substantiated with data provided by the National Institute of Statistics (NIS) concerning the 8 development regions. Depending upon their availability, the following time series were extracted: the resident population (1997-2015), population density (1997-2015), average monthly net income (2008-2015) and the gross domestic product (GDP) (2000-2015) (National Institute of Statistics, 2022). These statistical data are relevant for the characterization of urban settlements, being indicators of urban development.

### 3.3 Methodology

Firstly, proceeding from the WSF Evolution dataset, the overall development of Bucharest and Ilfov between 1985 and 2015 was examined. The analysis was enriched with statistical data in relation to the major development regions. Emphasis was placed on geospatial and statistical data correlation and interpretation. Next, the study area was divided into equal slices corresponding to cardinal and ordinal directions. The analysis focused on identifying the areas with the most significant land changes and urban development. Finally, a detailed examination of the most dynamic urban areas was performed. In our study, the built-up area includes all artificial surfaces, such as residential apartment buildings or houses, commercial and industrial facilities, areas used for transport and communications, technical infrastructure, etc. Hence, the built-up area refers to the built-up environment.

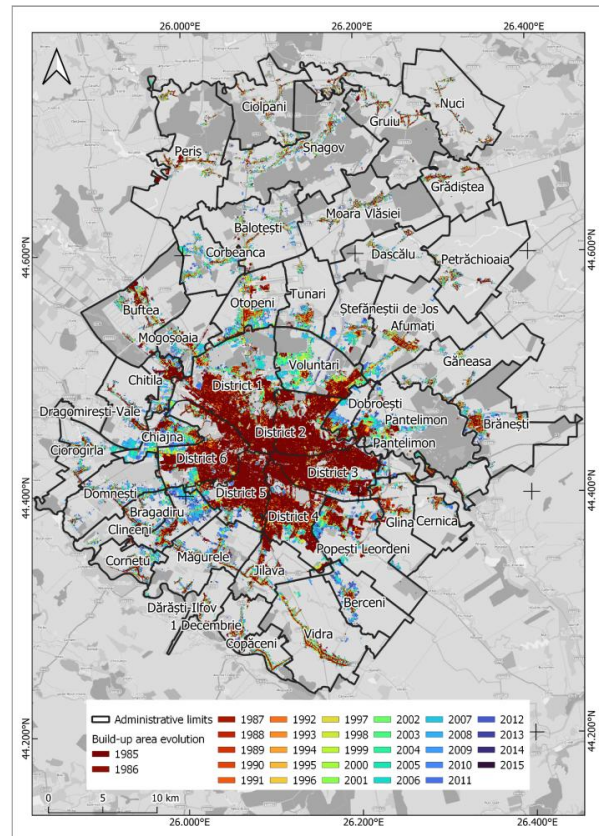
## 4. RESULTS AND DISCUSSION

### 4.1 Overview of Bucharest and Ilfov urban expansion

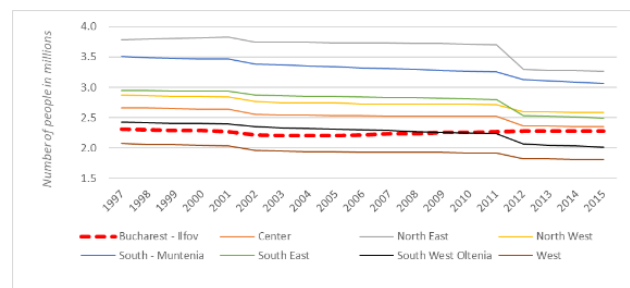
For this study it was used a macro-micro approach, starting with the NUTS 3 level analysis for a better understanding of the growth of the Bucharest-Ilfov development region, then it was analyzed Bucharest city urban growth by districts, and lastly, for a better view of the urban growth in Bucharest-Ilfov development region from a geographical point of view, an analysis based on cardinal points was made.

The Bucharest-Ilfov development region presented in Figure 1 had a spectacular extension within the study period (1985 - 2015). In 2013, Ilfov County was cataloged by Eurostat as the third NUTS 3 region by the increase in population density (Eurostat, 2013). This is largely due to the accentuated economic growth of the Bucharest - Ilfov development region compared to the other regions of Romania (Figures 2-5). Consequently, the economic growth led to a strong migration of people from all regions of the country to Bucharest - Ilfov in the search of better living and work conditions, and higher incomes. The resident population graph (Figure 2) shows a slight increase for Bucharest - Ilfov development region while for the other development regions of Romania, the graph indicates a decline of population. This is in contrast to the migratory trends registered in Romania after the 1989 revolution, a period in which over 3 million Romanians migrated to other countries.

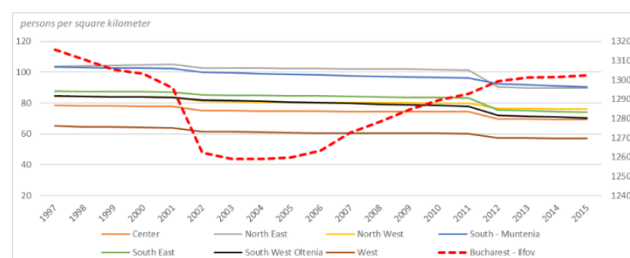
The population density graph (Figure 3) shows a much different pattern of changes between the Bucharest - Ilfov development region which had a big drop in population density between 2002 and 2006, while the other development regions of Romania indicate a steady moderate decrease.



**Figure 1.** Overall urban expansion of Bucharest and Ilfov County between 1985 and 2015 (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

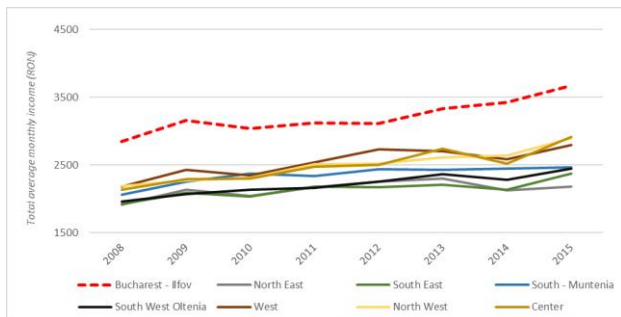


**Figure 2.** Evolution of resident population within the 8 development regions between 1997-2015 (data source: NIS 2022)



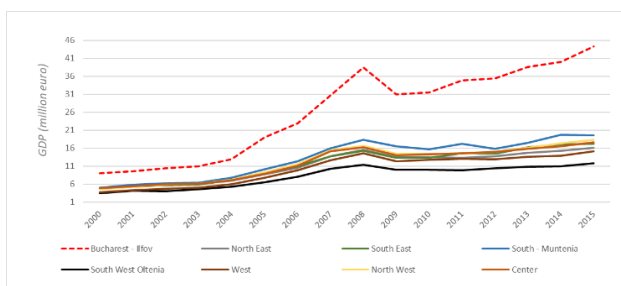
**Figure 3.** Evolution of population density within the 8 development regions between 1997 and 2015. Values on the right of the graph correspond to Bucharest - Ilfov and the ones on the left concern the other development regions (data source: NIS 2022)

The average monthly income graph (Figure 4) illustrates an increasing trend for the Bucharest - Ilfov development region, showing that in 2015 it exceeded the threshold of 3500 RON (approximately 708 euros by the 2021 exchange rate) while for the other development regions, the average monthly income is under this threshold for the entire analyzed period of time.



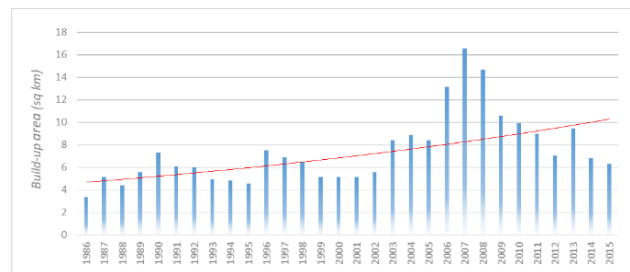
**Figure 4.** Evolution of average monthly net income within the 8 development regions between 2008 and 2015 (data source: NIS 2022)

The GDP graph (Figure 5) illustrates a pronounced increasing pattern with a substantial spike in 2008. Starting with 2009, under the effect of the financial crisis, the economic growth has slowed down, but started to recover in the following years. Bucharest - Ilfov has a clear, overwhelming evolution in comparison with the other regions. The main differences between the development regions are given by the value of GDP. While the GDP for Bucharest - Ilfov development region exceeded the threshold of 41 million euro, the other regions also recorded an upward trend but, even though the values were below 21 million euro.



**Figure 5.** Evolution of gross domestic product within the 8 development regions between 2000 and 2015 (data source: NIS 2022)

The substantial development of Bucharest-Ilfov was built upon the infrastructure already existing in the country's capital. The strong relocation impulse was justified by the existence in Bucharest of the most important institutions, but also of a superior infrastructure compared to the rest of the country. From an industrial point of view, the economic growth led to the creation of a large number of warehouses and supermarkets in the immediate vicinity of Bucharest, being built mainly on land that was used for agriculture in the past. These types of constructions have an important contribution in increasing the built-up area (Figure 6). Another factor that led to the increase of the built-up area in Ilfov County was the lack of space for horizontal development in Bucharest as well as the desire of the population to move from an apartment building to a house in the city outskirts.



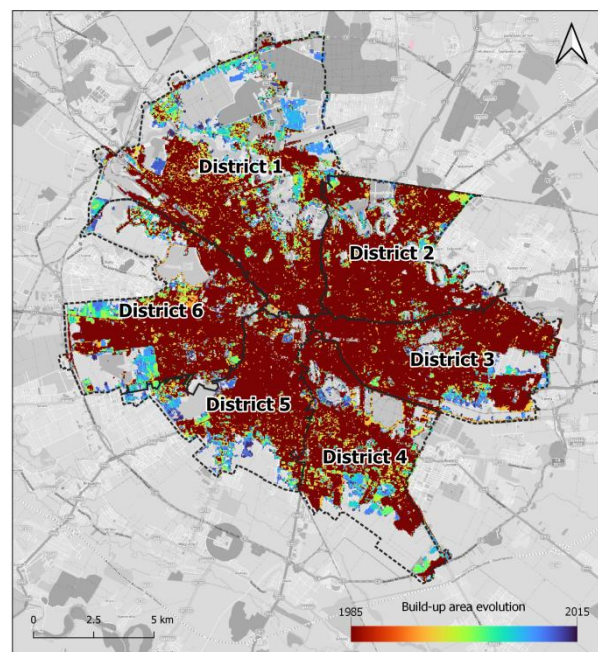
**Figure 6.** Evolution of the new built-up area in Bucharest-Ilfov between 1985 and 2015 (data extracted from the WSF Evolution dataset created by DLR)

The data regarding the extension of the built-up area in the Bucharest - Ilfov region presented in Figure 6 show a significant increase within the period 2006 - 2008 that was characterized by an accentuated economic growth at global level. In the coming years, the expansion slowdown is explained by the economic recession that affected the region as a result of the global economic crisis that occurred from December 2007 to June 2009.

Summarizing the numerical information extracted from the WSF Evolution dataset, it was possible to determine that the built-up area in the Bucharest - Ilfov region has more than doubled, from 182.9 km<sup>2</sup> in 1985 to 405.6 km<sup>2</sup> in 2015.

#### 4.2 Bucharest's expansion by districts and geographic orientation

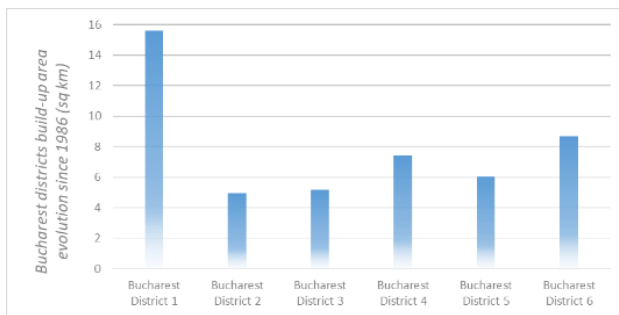
Bucharest is composed of 6 administrative districts, each of them having a different expansion rate within the investigated time span (Figure 7). District 1 of Bucharest is the largest district by area with a total surface of 59.37 km<sup>2</sup> according to the Territorial Administrative Units geospatial dataset provided by the National Agency of Cadastre and Land Registration.



**Figure 7.** Bucharest's urban expansion by districts between 1985 and 2015 (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

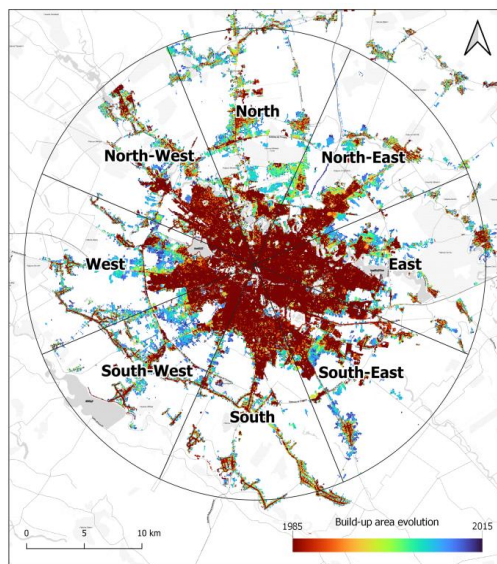
District 1 contains the most exclusive and affluent neighborhoods in Bucharest, such as: Primăverii (home of a large number of embassies), Dorobanți, Floreasca, Aviatorilor, etc. The district is crossed by the National Road no1 and is close to the Henri Coanda International Airport. In addition, it hosts the Aurel Vlaicu International Airport. These facilities, together with the large unbuilt areas located on the territory of the district, contributed to the largest growth of the built - up area within the limits of Bucharest after 1990.

In 2015, in the case of District 1, the analyzed data (Figure 8) revealed an increase of 15.6 km<sup>2</sup> of the built-up area compared to the reference year 1986. The proximity of the newly developed residential projects to the Băneasa forest, which represents an increasingly popular recreation area, make District 1 one of the most desired areas for living in Bucharest. A significant extension of the built-up area can also be observed in Districts 4 and 6, both having large available unbuilt areas but lacking a socio-geographical position similar to District 1. These districts are composed of residential neighborhoods for the middle class.



**Figure 8.** Bucharest’s built-up area evolution by districts between 1986 and 2015 (data extracted from the WSF Evolution dataset created by DLR)

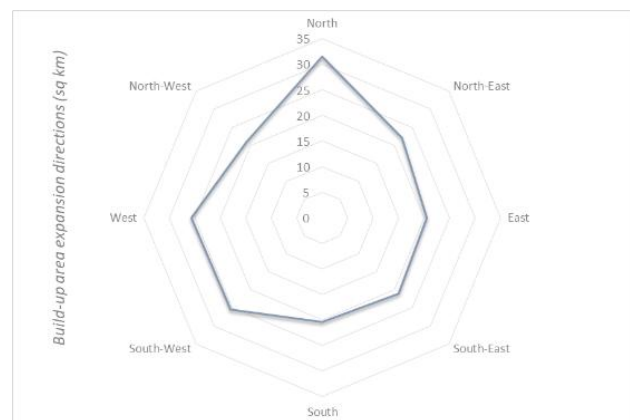
For an in-depth analysis of Bucharest's extension towards Ilfov County, an investigation regarding the urban development in relation to the cardinal and ordinal directions was performed (Figure 9).



**Figure 9.** Urban expansion of Bucharest between 1985 and 2015 by cardinal and ordinal directions (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

At present, localities such as Voluntari in the North, Chiajna in the West and Popești Leordeni in the South-East are integrated into the continuous fabric of Bucharest’s built-up area. The geospatial analysis was created by firstly generating a centroid using the official boundary of Bucharest City. Using the centroid, a buffer with a radius of 20 km was generated, reaching the eastern and western limits of Ilfov County. The buffer was divided into 8 cardinal and ordinal directions (North, North-East, East, South-East, etc.) and the resulting polygon was intersected with the input data regarding the urban expansion as depicted in Figure 10.

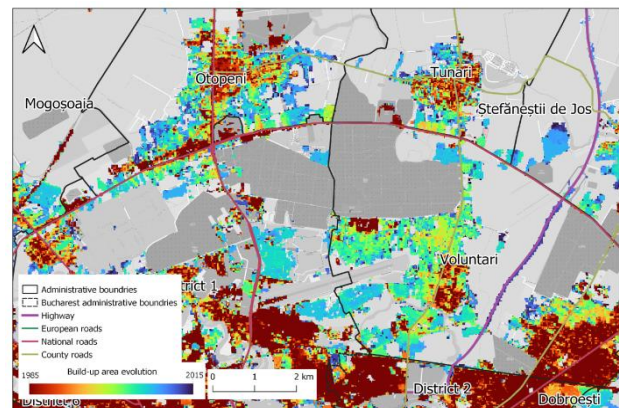
The graph shows a significant increase towards the northern cardinal point, including the localities Voluntari, Tunari and Otopeni. Also, the population of villages and towns located West of Bucharest has a tradition of working in the construction industry being the predominant labor force utilized in the development of Bucharest, especially during the communist era.



**Figure 10.** Urban expansion of Bucharest between 1985 and 2015 by cardinal and ordinal directions. The graph illustrates the geospatial analysis within a 20 km radius buffer (data extracted from the WSF Evolution dataset created by DLR)

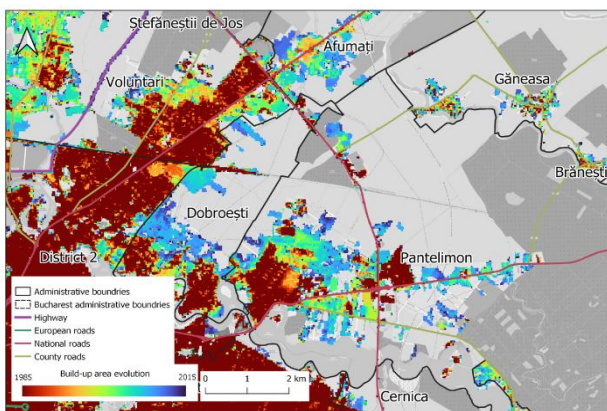
### 4.3 Detailed view of Bucharest’s expansion hotspots

The detailed analysis of the North area (Figure 11) reveals that the largest expansion took place in recent years. This may have happened due to the road infrastructure works carried out in that area, especially the construction of the A3 Motorway that connects the capital with the city of Ploiești. These new road infrastructure projects also led to the construction of new logistics warehouses and industrial halls.



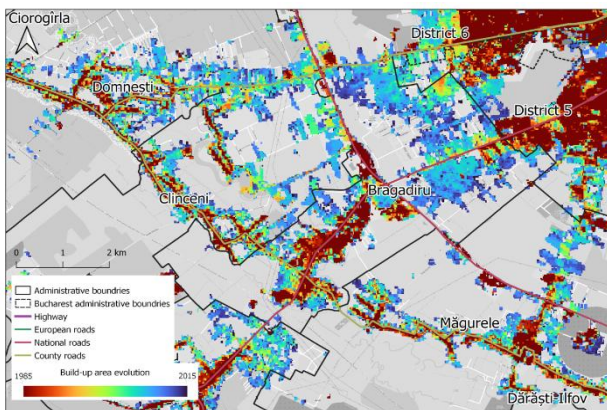
**Figure 11.** Urban expansion of Bucharest between 1985 and 2015 - North (data source: WSF Evolution, DLR, CC-BY 4.0, base map: © OpenStreetMap contributors)

In the eastern part of the city (Figure 12), the development pattern of the built-up area shows that it expanded constantly over the years and new settlements were built along the road network.



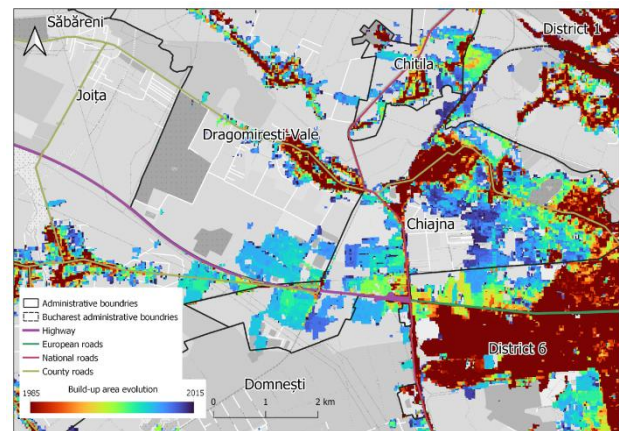
**Figure 12.** Urban expansion of Bucharest between 1985 and 2015 - East (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

The southern part of Bucharest (Figure 13) went through a major expansion in recent years. This area managed to attract numerous private real estate investments as well as public investments, such as: modernization of access roads, modernization of parking lots and construction of new recreation areas. Most residential complexes are located in this part of the city.



**Figure 13.** Urban expansion of Bucharest between 1985 and 2015 - South (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

The main driver of development in the western part of the city (Figure 14) is the A1 Motorway that connects Bucharest to Pitești, one of Romania's major cities, home of the main Dacia Plant. Also, the western part of Bucharest is the main area of interest for companies looking to set up industrial and logistics parks, due to the direct access to the Ring Road and the large areas of available land.



**Figure 14.** Urban expansion of Bucharest between 1985 and 2015 - West (data source: WSF Evolution, DLR, CC-BY 4.0; base map: © OpenStreetMap contributors)

## 5. CONCLUSIONS

The present study aimed at assessing the urban growth of Bucharest and the surrounding Ilfov County within a time span of 30 years, using a satellite-derived dataset, namely the WSF Evolution created by DLR, and statistical data provided by NIS. Urban expansion within the Bucharest - Ilfov development region was clearly identified and assessed using the WSF Evolution dataset together with the relevant statistical data provided by NIS. The statistical data supported the results obtained from the WSF Evolution analysis regarding the expansion of the built-up areas in Bucharest as well as of the nearby settlements around it.

A large discrepancy between the economic and demographic evolution of the Bucharest - Ilfov region in comparison with the other development regions of Romania can be observed. The gross domestic product of the region favors a positive migratory flow leading to an increase in the number of inhabitants and implicitly in the areas occupied by residential areas, commercial facilities and office spaces. Within the investigated period, the most significant built-up area growth occurred between 2006 and 2008. For example, in 2007 the Bucharest - Ilfov development region had an expansion of the built-up area by almost 17 km<sup>2</sup>. Concerning Bucharest alone, District 1 had an impressive growth of the built-up area within the 30 years of analysis. Compared to 1986, District 1 (located in the North of Bucharest) increased its built-up area by approximately 16 km<sup>2</sup>. The results of the study proved that WSF Evolution is a very effective source of information for urban expansion monitoring due to the accurate data it provides regarding the built-up areas. Moreover, the dataset enables the consistent assessment of urban growth over a large time period, offering an unprecedented detailed perspective on world settlement evolution. Overall, the spatial resolution of the WSF Evolution dataset showed good performances concerning the delineation of the built-up areas. Although the small-sized artificial structures could not be detected given the geometric resolution of the dataset, WSF Evolution showed its excellence in identifying the unequivocal areas of urban development and by providing a valid overview of the annual growth rate. Hence, although the spatial resolution of the WSF Evolution dataset is not very high, the availability of annual data corresponding to a long period of observation allows the elaboration of exhaustive studies, including modeling and prediction of urban expansion. Lastly, WSF Evolution dataset represents a reliable data source for urban growth monitoring, that is an important component of sustainable urban planning and disaster risk reduction.

## 6. ACKNOWLEDGEMENTS

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