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Remote Sensing-Based Analysis of Urban Landscape Change in the City of Bucharest, Romania

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Abstract: The paper investigates the urban landscape changes for the last 50 years in Bucharest, the capital city of Romania. Bucharest shows a complex structural transformation driven by the socialist urban policy, followed by an intensive real-estate market development. Our analysis is based on a diachronic set of high-resolution satellite imagery: declassified CORONA KH-4B from 1968, SPOT-1 from 1989, and multisensor stacked layers from Sentinel-1 SAR together with Sentinel-2MSI from 2018. Three different datasets of land cover/use are extracted for the reference years. Each dataset reveals its own urban structure pattern. The first one illustrates a radiography of the city in the second part of the 20th century, where rural patterns meet the modern ones, while the second one reveals the frame of a city in a full process of transformation with multiple constructions sites, based on the socialist model. The third one presents an image of a cosmopolitan city during an expansion process, with a high degree of landscape heterogeneity. All the datasets are included in a built-up change analysis in order to map and assess the spatial transformations of the city pattern over 5 decades. In order to quantify and map the changes, the Built-up Change Index (BCI) is introduced. The results highlight a particular situation linked to the policy development visions for each decade, with major changes of about 50% for different built-up classes. The GIS analysis illustrates two major landscape transformations: from the old semirural structures with houses surrounded by gardens from 1968, to a compact pattern with large districts of blocks of flats in 1989, and a contemporary city defined by an uncontrolled urban sprawl process in 2018.

Keywords: urban policies; land cover/land use; built-up area change; Corona imagery; SPOT; Sentinel data

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1. Introduction

Urban landscape change analysis is a necessary approach for the Eastern European cities [1,2], being related to quality of life [3] and socio-ecologic configuration [4,5]. The landscape change analysis plays a key role in understanding the present-day pattern of the city, useful for decision-making, urban planning [6,7], and urban modelling [8,9]. Land cover and land use features are the first issue in urban remote sensing analyses [10] and in the study of city evolution and configuration, while the thematic classification of higher spatial resolution satellite data for the urban area is essential in mapping process for practical uses [11].

Bucharest is the largest urban area of Romania and the sixth biggest European Union capital city with more than 2.1 million inhabitants [12]. The transformation of Bucharest urban structures was massive, as the socialist urban policies from the second half of the 20th century were followed by the real-estate market-driven policies during the last 20–25 years [13–15]. The city of Bucharest represents an example of intensive and complex urban landscape change [16]. It shows the effect of a remarkable demographic and industrial growth between 1950–1989, followed by an uncertain transition period between 1990 and 2001 and finally by a real-estate and private investment boom after [17–20]. During the socialist times, one of the urban policies was implemented around the “working class” people, which materialized with the construction of blocks of flats and factories. People were concentrated in districts of blocks of flats [21]. This process resulted in a new urban pattern with a compact city featured by small parks, narrow streets, and a lack of open spaces and parking places [15]. Moreover, a particularity for Bucharest was the clear delineation of the built-up area by the ring road beyond which dominated the agricultural land [22].

Similar to other former socialist cities, Bucharest followed the same development trajectory in its transition from socialism to democracy [23]. The collapse of communism and the transition to new real-estate market rules was abrupt and led to the development of new and uncontrolled process like urban sprawl or peri-urbanization [24]. Urban sprawl is defined as the unplanned extension of the city by a mix of low density built-up spaces into the surrounding agricultural area [25]. In particular, Eastern European countries are susceptible to urban sprawl. The main consequences of this process are the inefficient use of land resources [26] and the decrease of life quality [27].

Thus, the large temporal frame of about 5 decades was marked by major changes of the political system, followed by a total transformation of the urban planning policies in the context of the transition from the centralized economy to the present-day market driven economy. This process can be modelled with the help of remote sensing data.

The declassified data archive hosted by the USGS Earth Explorer portal [28] is used in many contributions focused on land cover changes and urban structures analysis. Previous contributions mostly combined image interpretation of CORONA KH-4B images with thematic classification of the multispectral Landsat imagery [29–34]. Some authors integrated KH-4B data with 2–3 m spatial resolution with Very High Resolution (VHR) imagery in urban area change detection approaches, applied in different regional studies from Kazakhstan [35], Hungary [36], China [37], or Iraq [38].

The latest developments of the Earth Observation (EO) tools in Europe, after the initialization of the European Space Agency (ESA) and Copernicus Programme [39–41], opened up new opportunities for urban landscape change research. The launch of Sentinel-1 Synthetic Aperture Radar (S1 SAR) and Sentinel-2 Multispectral Images (S2 MSI) satellites with enhanced resolutions offer new possibilities for LCLU (land cover land use) change detection analysis, using the synergy of the imagery data in order to explore in detail selected areas [42–44].

Different authors focused on medium to high resolution satellite data for urban land cover/land use change mapping, but the main limit was the archive data of multispectral images starting from the early 1970s, although intensive transformation of urban structure started earlier, during the 1960s. In this respect, mainly large urban regions or big cities were modelled in terms of LCLU dynamics.

Topaloğlu et al. [45] developed a case study focused on LCLU changes in Istanbul, Turkey based on the integration of Sentinel-2 MSI with Landsat 8 OLI imagery. The thematic classification process applied on Sentinel-2 imagery was assessed using pixel-based approaches [46] or OBIA techniques [47]. Ghanea et al. [48] and Lefebvre et al. [49] focused on urban area LCLU classification.

Due to the improved spatial resolution, SPOT images were used worldwide for urban mapping [50] urban sprawl monitoring [51], change detection analysis [52], and classification of urban land use [53].

Sentinel-1 delivers adequate information for discriminating the features on the ground thanks to the C-band Synthetic Aperture Radar (C-SAR), useful for land cover classification [54–56] and mainly for urban footprint delineation [57,58]. There are some studies using the multisensor approach by developing a synergy of S2 MSI and S1 SAR images for urban feature extraction [59–62] or crop classification [63–66].

The city of Bucharest was the subject of some studies regarding remote sensing change detection. Most of them are based on Landsat data for land abandonment mapping in the urban sprawl area [67], for the identification of the change pattern of built-up area [68] and for land cover change detection [69]. Sandric et al. [70] compared CORONA KH 7 and Ikonos imagery for mapping and describing urban structural changes in some critical areas. Noaje and Sion [71] integrated CORONA and VHR imagery to retrieve a qualitative analysis of urban landscape change for a sample area in the city. Most of these studies are based on image classification followed by change detection analysis and only indicate the area of change for a few land cover classes. They lack the quantification of classes involved [72].

The aim of this study is to understand and reveal urban dynamics in the capital-city of Bucharest, like super-compaction and artificiality with increase of built-up category. Moreover, qualitative data about urban sprawl and suburbanization can be extracted, as the information is stored in archived earth observation images.

The approach proposes a case study of Bucharest urban landscape change over the last 5 decades, with an emphasis on built-up land cover classes. The basement of the starting point of the study consists of three datasets from different reference years: CORONA KH-4B declassified imagery from 1968, SPOT-1 multispectral and panchromatic imagery from 1989, and a stacked dataset containing Sentinel-1A SAR together with Sentinel-2A MSI images from 2018. The study focuses on the key LCLU classes for the urban landscape change analysis, extracted from diachronic imagery by using complementary approaches: (1) a digital photogrammetric processing of declassified data CORONA KH-4B, followed by (2) visual interpretation and features digitization for 1968 and 1989 years and (3) a digital processing and automatic thematic classification of Sentinel-1 SAR and Sentinel-2 MSI multisensor stacked data for multiple land cover features mapping. Finally, the resulted datasets were integrated into a metric and statistical analysis. Three detailed case studies illustrate the major changes that occurred in Bucharest.

2. Materials and Methods

The city of Bucharest is situated in the south-eastern part of the country, in the Romanian Plain, at 55–97 m above sea level (a.s.l.) (Figure 1), developed along Dâmbovița River floodplain and terrace fields.

The analysis is performed within the official limits of the administrative unit, divided into six sectors, covering 228 km^2. Bucharest has a population density of 8,200 inhabitants per km^2 and a building density of about 500 units / km^2 [12]. The urban configuration is radial and concentric at first sight [73], but it is more complex as an effect of the multi-coredevelopment within each sector. Along with the population increase during the communist time, the city faced the necessity of constructing new living spaces.

The current study proposes a methodology for the integration of historical imagery dataset with recent EO images. Therefore, this approach is based on three datasets taken from different spaceborne sensors presented in Table 1.

The workflow follows four levels corresponding to the main stages of data processing and analysis (Figure 2). The first part is related to the identification of the available Data Input for the analysis: CORONA KH-4B, SPOT-1, Sentinel-2A MSI, and Sentinel-1A SAR C band satellite imagery. The second level corresponds to data processing, including a complete digital photogrammetric processing approach for CORONA images [74] and data correction and enhancement for multispectral and radar images, using ENVI and SNAP softwares. The third level refers to the preliminary results of corrected data. The fourth level corresponds to GIS data processing for LCLU feature delineation, based on image interpretation techniques on CORONA 4B and SPOT 1 images and semi-automatic classification of Sentinel-1 and Sentinel-2 decorrelated data stack. The final step refers to the integration of all datasets generated from previous steps, resized on the official limits of the municipality of Bucharest.

The photogrammetric processing of the historical CORONA KH-4 B images from 1968 started from two digitized film frames, available on Earth Explorer geoportal [28]. The non-metric camera model was set according to the technical parameters, while the exterior orientation was based on 31 Ground Control Points (GCP) collected on available orthophotos at 1:5,000 scale [75] and Digital Elevation Model (DEM) based on 1:25,000 Military Topographic Maps [76]. The final bundle-adjustment of Aerial Triangulation (AT) subset was accomplished by using Brown model, integrated in MATCH-AT Trimble and endorsing an accuracy of less than 0.5 meters [77]. The 16-parameter model describes five trapezoidal distortions in X and Y, three corrections for lens eccentricity, and three for radial distortion [78,79]. The resulted orthophotomosaic with 2 m spatial resolution was the support of photointerpretation of the LCLU classes for the single-date mapping from 1968. A manual feature extraction was preferred due to the limited spectral resolution and because the scanned film frame grain size strongly reduces the quality of the automatic image segmentation accuracy.

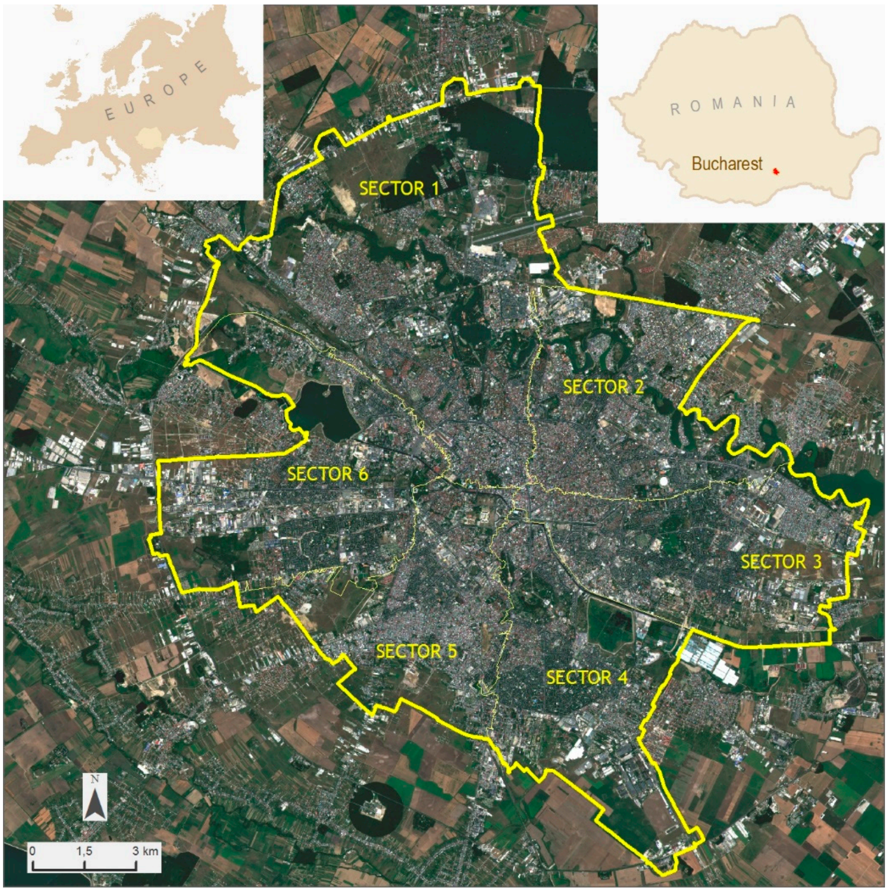

Figure 1. Location map and overview of the city of Bucharest. Basemap: Natural colour composite of Sentinel-2 MSI from 14 August 2018 (ESA Copernicus).

Table 1. Remote sensing imagery used in the urban landscape change analysis of Bucharest City.

Datasets	Date	Data Source	Spatial Resolution	Spectral Resolution	Processing Level
CORONA KH-4B	5 May 1968	DECLASS 1 from USGS Earth Explorer	2 m	Panchromatic image	Scanned film frames
SPOT 1	8 July 1989	CNES	10 m	Panchromatic image	Level 2A
			20 m	Multispectral Image, 3 bands	
Sentinel-1A SAR	17 August 2018	Copernicus ESA Sentinel Scientific Hub	10 m	C-band	IW-SLC, dual polarisation VV-VH
Sentinel-2A MSI	14 August 2018	Copernicus ESA Sentinel Scientific Hub	10 m, 20 m	Multispectral 13 bands	L1C processing level

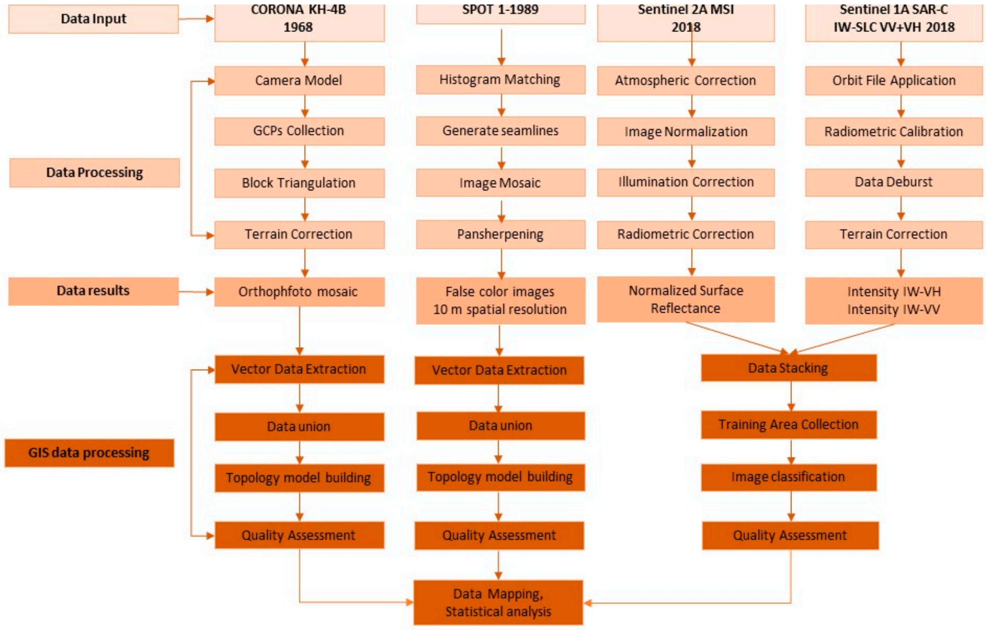

Figure 2. Flow chart of data processing for urban landscape change analysis.

Satellite image processing focused on the preparation of SPOT-1, Sentinel-1, and Sentinel-2 imagery for data extraction.

SPOT-1 images were freely delivered for scientific use by CNES ISIS (Centre National D'Etudes Spatiales, Initiative for Space Innovative Standard) [80]. Images processed at level 2A came in two scenes panchromatic at 10 m spatial resolution and multispectral with Near Infrared, Red, and Green bands at 20 m spatial resolution. In order to generate a continuous coverage, both scenes were mosaicked for panchromatic and multispectral data. To ensure the resolution for multispectral image, we produced a Gram–Schmidt pansharpened combination [81]. As a result, the false color image at 10 m spatial resolution was the subject of visual interpretation for LCLU feature extraction.

The Sentinel-1 or S1 radar imagery was radiometrically calibrated in order to generate the backscatter intensity component image [82]. This followed a general workflow dealing with radar images processing [83], including the identification of radar data with the orbit and the terrain features (Figure 2). After the application of the Range-Doppler Terrain Correction followed by a speckle filtering, the backscatter image of the VV-VH polarization components was prepared for co-registering with the optical imagery S2 MSI at L2A processing level in terms of surface reflectance, at 10 m spatial resolution [84].

The image classification process based on the recent satellite Sentinel-1 and Sentinel-2 images from 2018 was performed after building a hybrid and highly decorrelated image stack dataset [63]. Training reference data for eight LCLU classes generated on the image dataset was analysed using the separability tool [85]. This explains the limited number of classes that can be extracted due to the similar spectral signature of some of the classes. For an increased accuracy of the classification, Support Vector Machine (SVM) algorithm with a radial basis function was used for the LCLU classes delineation [86,87].

Urban landscape change analysis and mapping used a GIS application for the harmonization of the three datasets to the built-up area coverage. For statistic approach and metric analysis, we introduced the Built-up Change Index (BCI) as a percentage difference of built-up area quantified for a reference surface of 1 hectare (1).

$$BCI(\%) = \frac{Built-up\ change}{Reference\ surface} \times \frac{1}{100} \quad (1)$$

The analysis was performed in detail for three complementary case studies from the city of Bucharest, which illustrate the direction and magnitude of changes in each key area.

3. Results

The first results of this analysis are represented by the LCLU maps for the three reference periods: 1968, 1989, and 2018. The thematic classification of the S1-S2 layer was statistically compared with a set of random sample points representing ground truth data through an error matrix. The assessment of S1-S2 classification raster returned a high overall accuracy of 96% with a kappa coefficient of 0.942 for built-up area, which validates the result for the integration in the urban landscape analysis. These new products offer support for conducting spatial and statistical analysis for changes that occurred in the urban landscape.

The thematic map representing the past date LCLU (Figure 3) has a legend of 24 classes where the built-up area is the most detailed one, composed of nine different sub-classes, with a clear separation based on functional criteria. The map from 1968 shows an accurate radiography of a city at the beginning of a demographic explosion, with large parts covered by districts of houses with gardens, surrounded by large agricultural plots and forest patches. This past landscape preserves large semi-rural districts with houses and gardens to the border of the built-up area, and an emerging block of flat districts built on empty grounds, near intensive and systematic industrial areas developments [88,89].

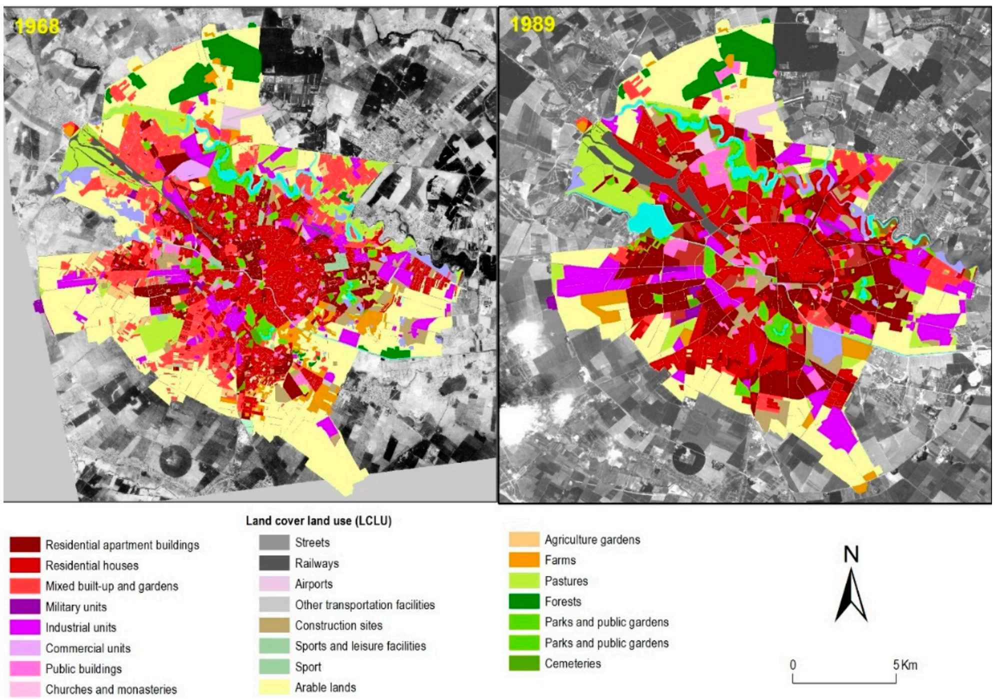

Figure 3. LCLU maps of the City of Bucharest from 1968, with CORONA KH-4B orthophoto in background (**left**) and from 1989 with SPOT 1 panchromatic in background (**right**).

LCLU map from 1989 reveals the image of a compact city with clearly delineated neighbourhoods of blocks of flats, most dominant in the western and eastern parts. The presence of small houses surrounded by gardens was rare in 1989. Moreover, large industrial areas appeared at the border of the city. The arable land at the outskirts decreased in the southern part. Also, there are many construction sites in the city center. Major hydrological works appeared, such as the construction of Morii Lake and Dîmbovița river regulation.

The most recent LCLU map (Figure 4), from 2018, highlights the residential areas of the block of flat districts or residential apartment buildings that surround the entire historical core and modern time development belts, partly replacing the former residential house with garden districts.

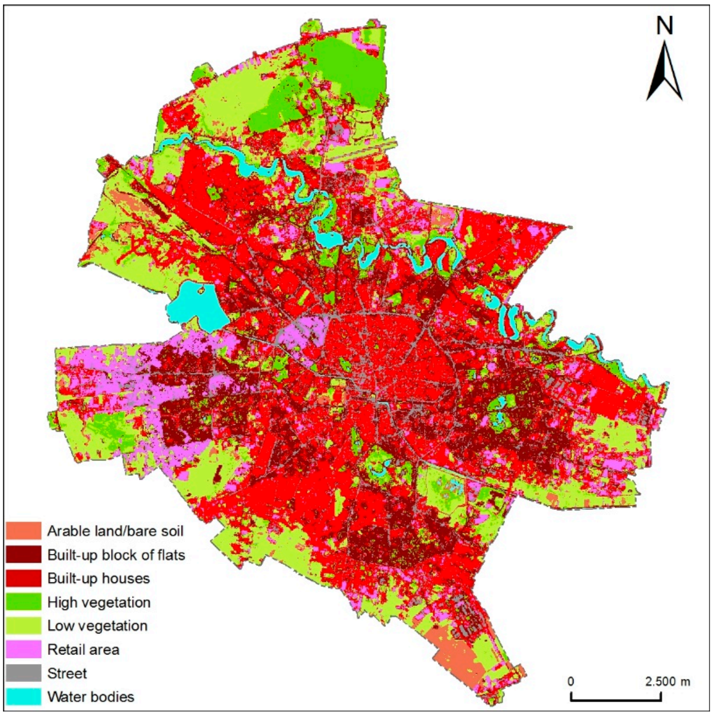

Figure 4. LCLU map of the City of Bucharest in 2018, based on Sentinel-1 and Sentinel-2 data.

Overall, the recent LCLU map is the image of a compact city, with a regressive dynamic of green areas and empty grounds, with brownfields in the process of transformation after the real-estate boom of 2002–2008 [17]. A second set of results is represented by the maps showing the BCI for each time interval: 1968–1989 and 1989–2018 (Figure 5). This index is introduced in order to quantify the city's fragmentation for each time period, with a focus on built-up classes. It offers a visual support for understanding the urban sprawl process, which occurred mostly at the periphery.

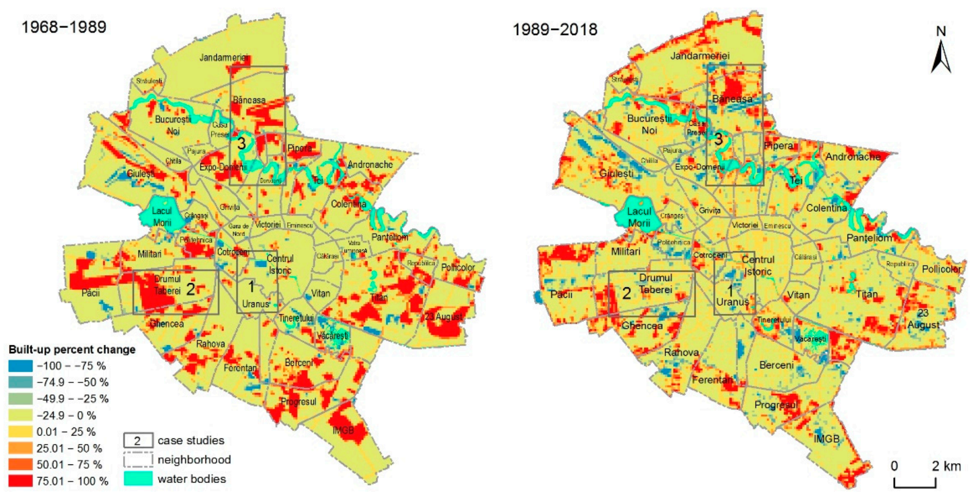

Figure 5. Maps of the built-up area change 1968–1989 and 1989–2018 in the City of Bucharest.

The period 1968–1989 illustrates the large-scale development of blocks of flats and factories replacing the house districts, marked by an increase of BCI index between +75 and +100%. The increase of built-up areas is the direct consequence of population growth from 1.36 million in 1966 up to 2.06 million in 1992 [12]. Population density almost doubled from 5900 inhabitants/km^2 in 1966 to 9052 inhabitants/km^2 in 1992.

On the other side, the map also reveals decreases of built-up area as a trend of a sustainable policy of urban development. The Palace of Parliament, also known as The House of the People, was constructed after 1984 and it is composed of a very large building and large open spaces around it [17]. It replaced two districts of houses with gardens—Uranus and partly Izvor [90] with a negative BCI of −75% to −100%.

The BCI map for the period 1989–2018 (Figure 5) highlights the conversion from arable land and gardens into large commercial or retail areas. Moreover, the map spatially explains the continuity of urban growth through the sprawl process, featuring the transition stage to the market-driven economy but mainly the real-estate development after 2001 [91]. This is related to the highest built-up area development rates between +75% and +100%. Here, the arable land or gardens and the large brownfields were replaced by large commercial or retail areas, after they were abandoned due to a high rate of bankruptcy at the beginning of 1990s [92].

On the other hand, a decrease of built-up area of −50% is reported in the eastern part of the city: This is the place of the declared protected area of Văcărești Nature Reserve of 190 hectares [93]. Similar trends are observed along the lakes of Colentina River, a special protection area of patrimony. Giulești district, in the north-western part, is another example of brownfields that were located in less attractive places for real-estate development due to the large railway transportation infrastructure in a railway junction area, degraded and partly dismantled after 1989 (marshalling yards, locomotive depots, rolling stock maintenance and other specific facilities).

The transformation of the urban structures is presented from a quantitative perspective in Figures 6 and 7a,b, showing the intensity of changes.

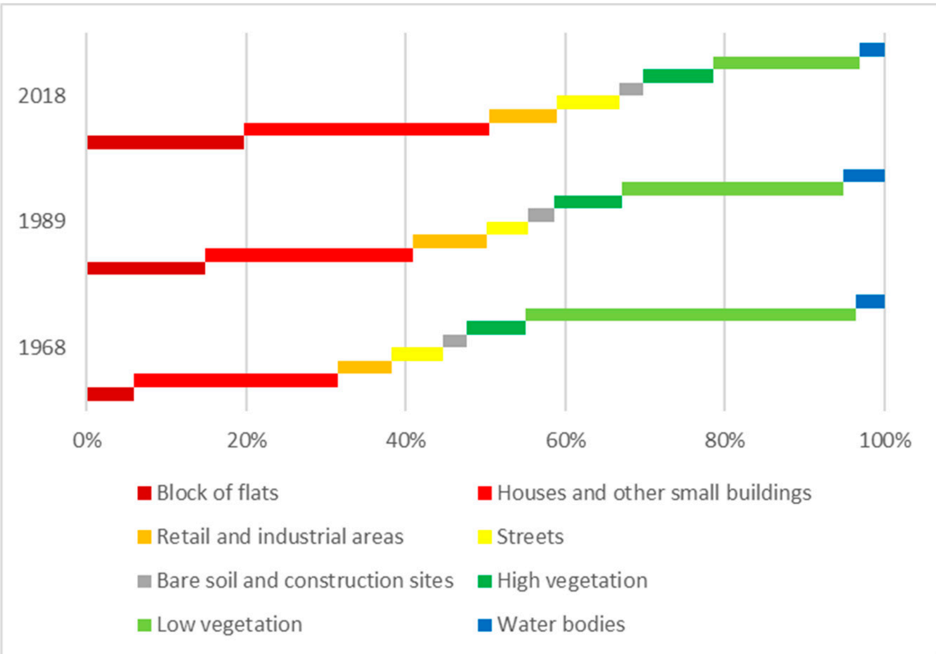

Figure 6. The percentage of LCLU classes in the city of Bucharest for each reference year.

The change diagrams focus on the key urban LCLU classes, selected after simplification of the first datasets (1968 and 1989). These were in fact the classes used for supervised classification training on the recent image stack (2018). Table 2 contains a description of these classes according to the ground truth data and providing an argument of their selection. For example, it is easy to notice the replacement of the green zones by built-up areas, in the context of the economic development of Bucharest and the demographic increase, while industrial areas combine with retail areas for the 1989 and 2018 datasets in terms of spectral signatures.

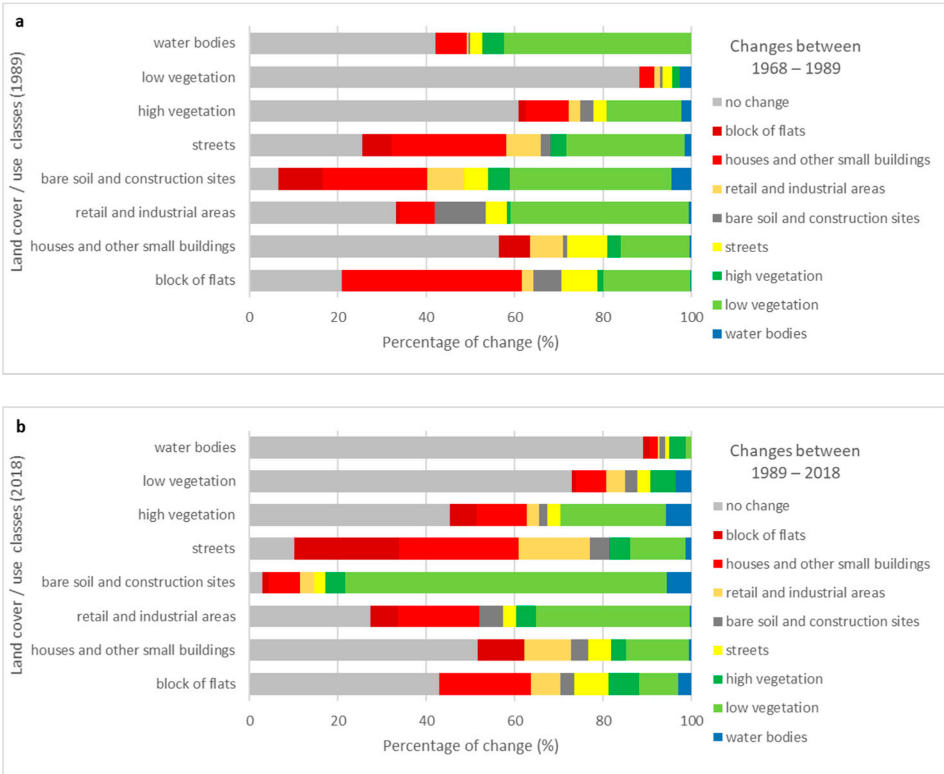

Figure 7. Statistical approach representing the percentages: (**a**) of the 1968 LCLU features to the composition of the 1989 LCLU classes; (**b**) of the 1989 LCLU features to the composition of 2018 LULC classes.

Table 2. Urban LCLU key classes description for the city of Bucharest.

Class Name	Description	Observations
Block of flats	Compact areas with blocks of flats of 4–12 floors in big ensembles (1960s and 1970c) and linear block of flats pattern along boulevards (mainly 1980s).	Building grouped with very narrow green areas, parking places, and playgrounds around with a typical pattern of planned areas.
Houses and other small buildings	Houses and gardens with one to two floor surrounded by gardens, in different patterns, from non-organized to rectangular.	Usually small surface building, with gardens, remained from the traditional urban fabric (compact in the centre and more disperse to the periphery)—specific to the old urban landscape before the communist era.
Retail and industrial areas	Industrial building with big surfaces of halls and production facilities. Commercial or retail areas with large buildings surrounded by parking places.	Difficult to separate industrial and commercial facilities with semi-automatic image supervised classification. Interpretation was the only solution to extract them from 1968 and 1989 images. Also includes the Băneasa international airport area and transportation facilities along railways.
Streets	Street network including the entire paved/asphalt covered streets and boulevard/avenues of the city.	In the 1968 image, the interpretation of these features made it possible to extract paved and non-paved streets. Semi-automatic approaches focus mainly on paved/ asphalt covered street areas (polygons).

Table 2. *Cont.*

Class Name	Description	Observations
Bare soil and construction sites	Barren land on the place of former demolished houses and industrial facilities, around railways and motorways as well as on the place of some former agricultural land/gardens at the periphery.	Still remained around the Palace of Parliament (downtown) for a long time after 1984, largely extended on industrial areas before the conversion of land use to residential and commercial.
High vegetation	Forested grounds to the city periphery (ex. Băneasa, northern from airport) on large parks with compact configuration and linear patterns along alleys.	Typical forested grounds from the regional forested landscape and adapted to the urban parks landscape in different periods.
Low vegetation	Pastures and other grass-covered areas, together with some agricultural land at the periphery.	It corresponds to parks and natural reserves and also to open air stadium and sport facilities, as well as to some of the largest gardens around recently built leisure facilities around residential villa ensembles (after 2001).
Water bodies	Lakes and rivers in built-up areas	Anthropogenic lakes along Colentina and Dâmbovița rivers and the hydrotechnical works along Dâmbovița River floodplain.

According to the description provided, it was essential to limit the number of key classes in order to facilitate the production of more relevant results and to map the change in a simple and accurate cartographic formula. Different uncertainties in class separation and description were taken into account but they were investigated when evaluating and interpreting the results.

4. Discussion

Our study brings an added value that refers to the increased number of classes used for the thematic classification. Also, the analysis covers a larger temporal frame of 5 decades compared to other similar studies that were conducted for Bucharest [94–96].

The approach started from the four satellite images collection featured by a variable spatial resolution of 2 meters, 10 meters and 20 meters. First of all, the resolution of the multispectral SPOT image was resampled based on panchromatic band at 10 meters in a pansharpening product, and also the 20-meter Sentinel-2 bands were resampled at 10 m. The target was also to use a similar mapping unit size when extracting the LCLU classes with a minimum mapping unit of 1 ha, for each reference year: 1968, 1989 and 2018. We used a semantic generalization by joining of land use classes that refer to the same land cover class, in order to integrate the different number of classes extracted for this diachronic dataset.

Multi-date satellite imagery synergy is a reality built on a complex methodology for data calibration and geographical information production. A combination of photogrammetric and digital image processing workflows opened an opportunity to generate three LCLU data coverages for the Bucharest urban area.

Two aspects are essential in this context. First, spatial and spectral resolution differences between the images did not allow a unique approach for time series data production. It is the reason why we combined the visual interpretation of 1968 and 1989 images with the thematic classification of a decorrelated image stack, where multispectral and radar signatures helped the mapping process of the key LCLU classes. The second aspect is the topological models building and their evaluation. In this context, the RMSE computation for the 1968 orthoimage mosaic was done and a map of errors distribution was interpreted before the interpretation of the dataset for LCLU layer production.

In order to assess the accuracy of 2018 image stack classification, the results were compared with the ground truth data systematically extracted from the 0.5 m resolution color orthophotos (ANCPI—National Agency for Cadastre and Land Registration, 2012) using a special confusion matrix (Table 3). An independent set of 346 polygons was produced and equally distributed to the evaluated LCLU classes. The overall accuracy of 94% and the kappa coefficient of 0.92 indicate a very good result in classification. The confusion matrix indicates the accuracy per each class and the same low results can be noticed for street-related class and for the retail area class, imposed by the almost similar spectral response with other classes.

Table 3. Classification confusion matrix for 2018 S1-S2 image stack.

	Ground Truth (%)							
Class	**Arable Land**	**Water Bodies**	**High Vegetation**	**Low Vegetation**	**Streets**	**Built-Up Houses**	**Built-Up Block of Flats**	**Retail Area**
Arable land	99.98	0.00	0.00	0.00	0.00	0.07	0.00	0.15
Water bodies	0.00	99.78	0.00	0.00	0.48	0.00	0.58	0.00
High vegetation	0.00	0.00	99.75	0.46	0.00	0.00	0.00	0.00
Low vegetation	0.00	0.00	0.01	99.48	0.00	0.08	0.00	0.00
Street	0.00	0.06	0.00	0.00	66.59	2.44	12.79	10.97
Built-up house	0.01	0.00	0.00	0.00	11.06	95.36	3.17	36.95
Built-up block of flats	0.00	0.16	0.25	0.03	21.75	1.65	82.35	0.03
Retail area	0.00	0.00	0.00	0.00	0.12	0.40	0.00	51.59
Total	100	100	100	100	100	100	100	100
Overall accuracy: 94.0686%								
Kappa coefficient: 0.9255								

A noticeable aspect that resulted from the comparison between 1968 and 1989 thematic datasets is the disappearance of the high fragmentation of gardening plots around the built-up area, especially in the eastern and southern parts. The problem of land use classes still occurred for the year 1968. It is true that it is not a semi-urban, semi-rural or semi-wild area. This is reflected by the classes introduced. We use the term “mixed class” in order to define a particular pattern featured by small houses surrounded by vegetable gardens, vineyards, and orchards, where people develop a survival-like small agriculture, which is a feature of Balkan cities. It is not a “class like category”, because this was a spatial projection of a traditional way of life, adapted to local conditions that survived over the centuries and was systematically destroyed during the communism period by house and farm demolition, replaced by block ensembles/industrial plants and later by the real-estate market pressures (an intensive one after the year 2001, when ownership recovery was helped by a new special legislation).

Other important changes are related to hydrotechnical works, in order to protect and control water level during floods [96], such as the channelization of Dâmbovița River and the building of Morii Lake reservoir in the western part of the city.

Among the mapped classes, the *built-up class* was selected to highlight the relevant urban changes. City development policies introduced new zonation of the functional areas. For example, in 1968, the limits of commercial and retail areas were not clearly defined, while residential areas were not combined with other structures like houses and gardens or industrial districts [97].

For an adequate understanding of the urban structural changes in the city of Bucharest, it is necessary to explore some complementary case studies to reveal specific transformations. Three selected areas are presented in the context of built-up area change rate levels, together with a comparative survey of urban configuration in 1968, 1989, and 2018. From this point of view, the selection focuses on:

1. The Palace of Parliament area, downtown of Bucharest, with a dramatic replacement of an entire urban area by an extremely large building that was supposed to be the emblem of the communist regime in Romania.

2. Drumul Taberei neighbourhood, in the western part of the city, where rural-like structures were replaced by a totally new district with blocks of flats and industrial en-

terprises, and later by new developments related to the market-driven economy and real-estate investments.

3. Băneasa area, where arable land and orchards were replaced by office parks, logistics, and retail areas.

These case studies were selected because of their complementary characteristics. They summarise the most common key aspects that Bucharest faced in the last decades: (i) city reshape for the Parliament House area, and (ii) massive conversion from garden houses into blocks of flats in Drumul Taberei district, (iii) urban sprawl and sub-urbanisation in Băneasa district.

The Palace of Parliament area (Figure 8) is probably the most spectacular urban landscape change not only in Romania, but in Central Eastern Europe, well-known in literature as the "Vanished Bucharest" [98]. Here, a rate of BCI between 50 and 100% is visible along the axis, which splits the historical centre into two parts. It also illustrates the total replacement of the old traditional urban structures, composed of small houses and gardens, together with a dense and complex street network, which resulted from the unplanned development before the 19th century (Figure 8a,b), with socialist-style public building of the Palace of Parliament and the blocks of flats along Dâmbovița River (Figure 8c) and some green areas [15,99].

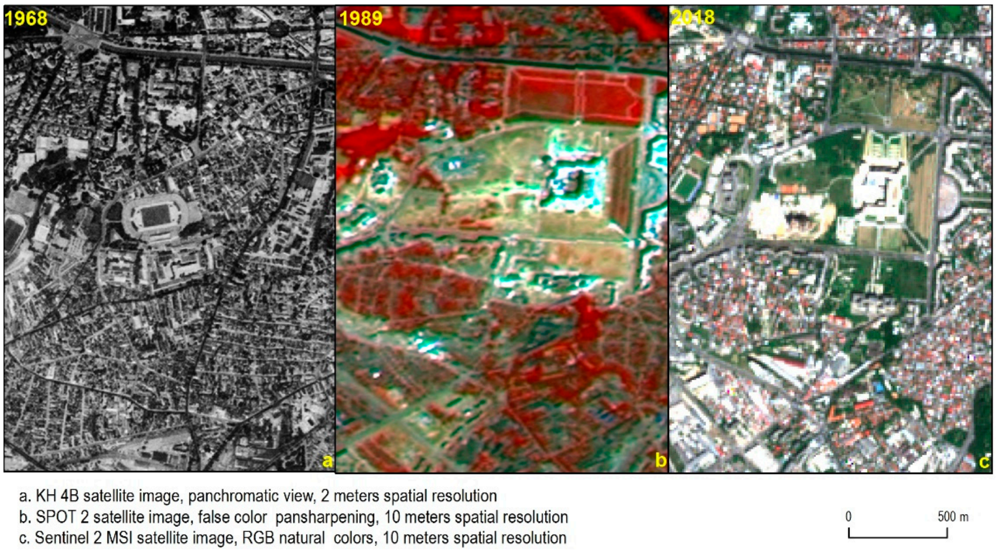

Figure 8. The Palace of Parliament area in the downtown of the city of Bucharest. Percent rates of the LCLU change (1968–2016) and qualitative features.

According to the urban planners' documentations [100], a total surface of 580 hectares was affected by demolition works after 1984, although the projects started after the earthquake of 4 March 1977. The qualitative change of these structure can be explained by the rising from the ground of urban identity elements: 1 monastery, 10 churches, 5 moved churches to new sites, 1 stadium, and 1 inn, while the new block-of-flats type building along the avenue hide other remained historical monuments of an outstanding value [101]. This case study is an example for erasing the city's legacy and the forced introduction of a totalitarian urban policy, which is contrary to the adequate urban LCLU features [98]. The area still has a real problem related to urban re-integration, although the palace is now part of the administrative buildings ensemble, as it is the house of the Romanian Parliament [18,102]. In the vicinity of the Palace of Parliament, there is the emerging building of the new Romanian Orthodox Church cathedral (started 2010), which is to be finished in the coming years.

Drumul Taberei district area is a typical urban landscape change that occurred in the city of Bucharest at the end of 1960s and the beginning of 1970s. It is an example of totally new urban structures superposed on former rural structures, as the town's built-up area was for a long time in a close relationship with the neighbouring agricultural area. This finding is also confirmed by other studies [95] and is related to the unplanned development until the 19th century in the context of an unfortified urban centre. Figure 9 highlights the total replacement of houses and farms with gardens, orchards, and vineyards, which resulted from an unplanned configuration (Figure 9a), with structures of a particular physiognomy, after the relaxation of the urban policies of the 50s and the increasing respect to the new urban regulations emphasized by Athens Charter [103]. This urban district with block-of-flats and green areas, with service spaces and other, was projected as a new township for 100,000 inhabitants in the context of demographic increase and intensive industrialization. However, nowadays, it hosts about 400,000 people (Figure 9b). In the last 10 years, new urban structures with the same physiognomy appeared here even if the real-estate market value decreased (Figure 9c), as a result of emerging superficial investments and lack of modernization of urban transport.

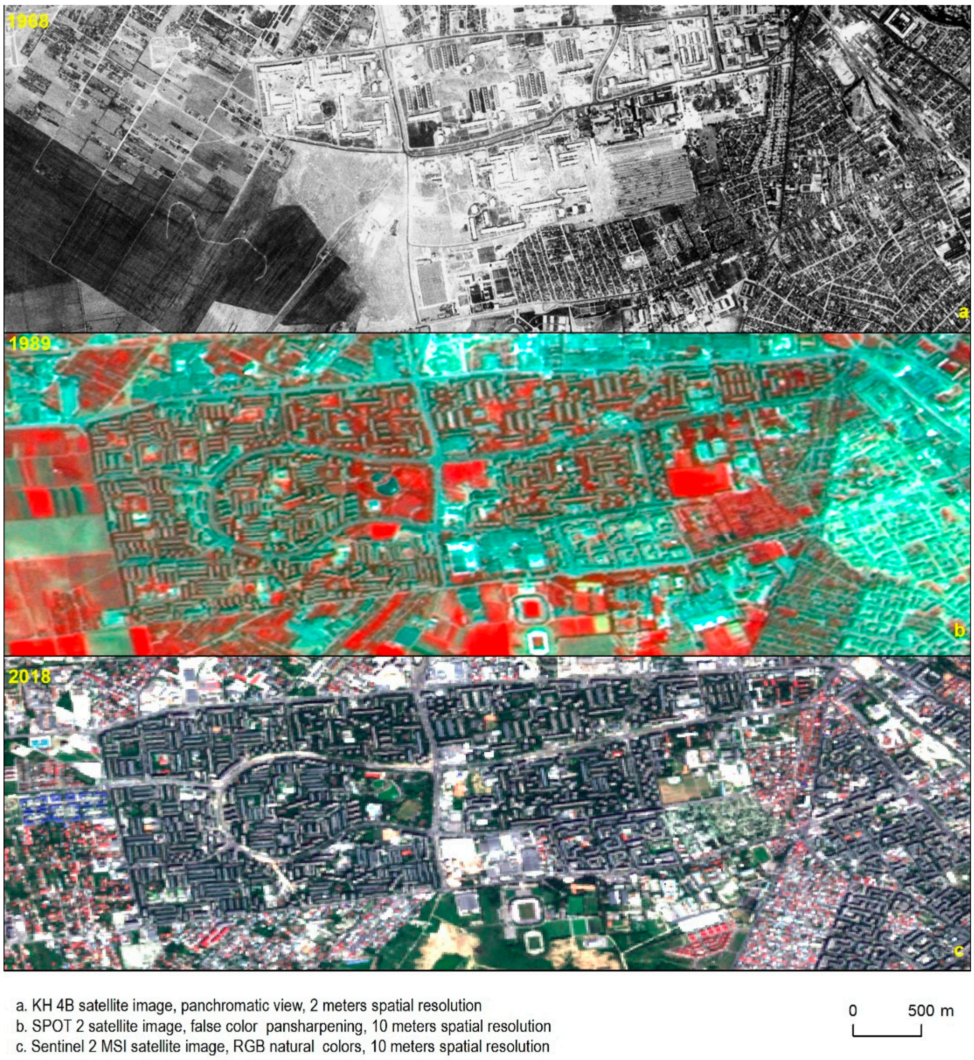

Figure 9. Drumul Taberei district to the western edge of built-up area, an example of rural structures and agricultural land, replaced by a totally new urban district.

Băneasa area (Figure 10), in the northern part of the city, is a typical example of urban structures in the globalization trend. Here, the urban sprawl process can be easily noticed and driven by economic-market rules and lack of planning regulation. This situation is common in the majority of the former socialist countries [14]. This area also integrates the

Aurel Vlaicu International Airport, which has been operating since 1920s and nowadays is enclosed in the built-up area. Besides the airport, this area is crossed by the main national and European highway connecting Bucharest to Ploiești and Brașov. This main route is used daily by residents who commute between Bucharest and Ploiesti and by people who travel during the weekend. At the same time, it represents the main road access to the main international airport of Romania at Otopeni (Henri Coandă). It is the reason for a lot of infrastructure investments for road traffic improvement during the last two decades. Therefore, this area is characterized by a spectacular urban sprawl and development, mainly after the 1990s and more intensively after 2001 [104]. The urban land ownership recovery starting from 1995, as well as the release of the latest Bucharest Urban Master Plan, contributed to the current landscape as it is today: complex built-up area and Băneasa forest zone. This area is the largest complex urban development in Romania after 1990, where 221 hectares were covered by a combination of business parks and residential districts with villas, green areas, and a large commercial space. This represents an increase of the urban landscape change rate between +75 and +100%, around Băneasa airport (Figure 10c).

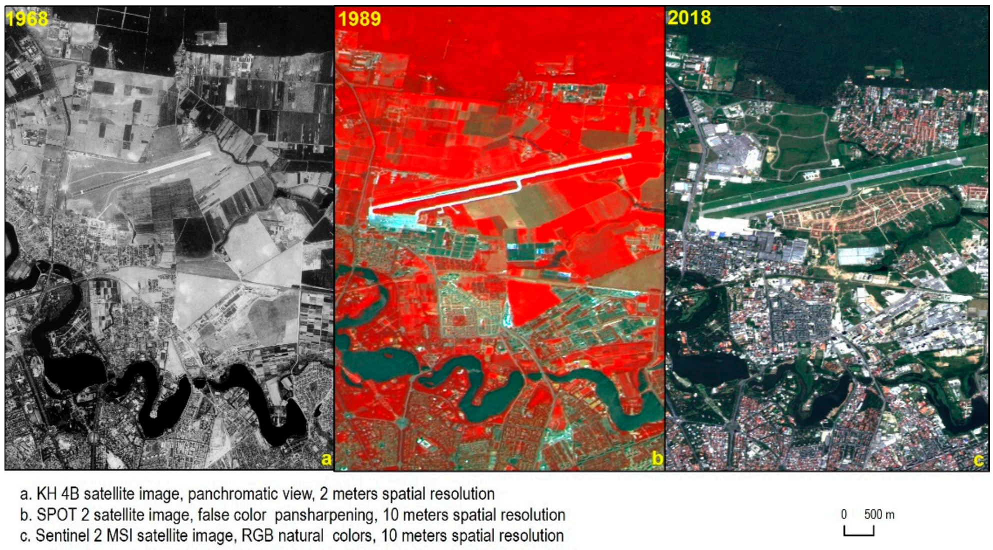

Figure 10. LCLU change in Băneasa zone, with increasing rate to the north of the Băneasa International Airport.

Bański [105], found that the greatest loss of agricultural lands took place in the periphery of large urban area, and we can confirm this situation for Bucharest city. Grigorescu et al. [106] underline the conversion of arable land to urban, industrial, and commercial uses after 1990, especially around the capital cities such as Bucharest.

These three case studies confirm the complex pattern of the urban landscape change in Bucharest. This is an illustration of the incoherent urban development policy of a city and the chaotic transition from a communist regime to a capitalist market driven economy. The planning strategies occurred after 1831 legislation were based on radial and concentric configuration of the built-up area within the city. However, the systematic planning was possible only after the first master plans from 1921 and 1935, which tried to draw the main street network and to differentiate between the urban structures and the development areas [107,108]. This normal historical evolution was interrupted by the socialist urban planning after 1948, where private planning strategies were oriented towards the demographic and the industrial growth of the town between 1950 and 1980, followed by a severe transformation of the city center and the loss of local identity between 1980 and 1989 [92]. New financial opportunities were exploited as soon as the ownership regime changed after the 1990s. These changes are visible especially after 2000 when a new

Master Plan was released and investments increased for expansion of built-up area based on conversion of brownfields.

5. Conclusions

Mapping the urban landscape changes with a span of about 50 years was accomplished using the synergy between CORONA, Spot and Sentinel remote sensing imagery. The declassified dataset from 1968 allowed the manual extraction of the former structure of the urban landscape, same as for the reference year 1989. The multisensor approach based on the recent radar and optical Sentinel images enabled the semi-automatic production of the urban land cover features. The data is integrated and harmonized, thus obtaining a very accurate result for a city with a complex and heterogeneous urban pattern.

The main progress element of the analysis is the detailed GIS mapping and the statistical quantification of the key urban structures change for the reference 5-decade period, which is a step forward from the existing approaches. Its dynamics draw a projection of the urban landscape transformation and urban system dynamics with all the background systemic connection, from land to social life and economy. The urban imprint is actually a key feature strictly connected to the LCLU data layers.

The metric analysis using BCI index quantifies the changes that occurred in a synthetic way. The analysis emphasizes the urban sprawl of Bucharest within the conversion of the agricultural lands to built-up areas. The systematic replacement of the traditional land use pattern composed by small houses and agriculture gardens with the new block of flats met the necessities of the growing population. However, the uncontrolled real-estate developments have many social effects including life quality in the city of Bucharest. New problems were generated, such as low living comfort, lack of green space, lack of parking spaces, and deficiency of the urban and transport infrastructures. The landscape change is also related to the replacement of historical districts with socialist buildings. This evolution led to the fragmentation of the historical area and the decreasing of the architectural patrimony density.

Bucharest, unlike other Eastern European capital cities, had a transformation based on the destruction of a lot of semi-rural zones but especially on urban areas with historical architecture of a real cultural value, in order to free the land for the construction of new government buildings that correspond to the ideology of communist propaganda (after 1984). This is also reflected in the city evolution of the post-communist period that failed to integrate these ensembles in a typical urban structure. We believe that not only the shape, but especially the model of spatial distribution by extending to the periphery of the new ensembles, is a distinctive feature for Eastern European cities.

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