# URBAN GROWTH PATTERNS FOR BUCHAREST, ROMANIA: ANALYSIS OF LANDSAT IMAGERY

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## ABSTRACT

Is there any spatial pattern for Bucharest urban growth that occurred during the last 25 years, after the end of Cold War? This question is answered by the results obtained through the Landsat data analysis performed in order to detect the changes produced in land use in the last 25 years for the city of Bucharest and its surroundings. The analysis is based on the four major land use classes that are generated by means of a processing methodology proposed in this paper.

## INTRODUCTION

Is there any spatial pattern for Bucharest urban growth that occurred after the end of Cold War? To answer this question it is necessary to characterize the situation that it is observed *per se* as the manifestation of the urban growth as a phenomenon for the city of Bucharest. Are there specific patterns of urban expansion like sprawl? Is it expansion or growth? These types of patterns are what we are looking for in our remotely sensed image analysis. Our research has the World Bank study *The Dynamics of Global Urban Expansion* (1) as a starting point as it examines satellite images and produces a land use classification as a way to measure urban expansion. The respective study included 120 cities all over the world but does not contain any major city from Romania so we wanted to extend this kind of research over the city of Bucharest with a somewhat similar algorithm as the World Bank's one. At the same time, we considered that our work should be easily applicable for any other city in Romania or elsewhere in the world. Consequently, our approach consisted in using multi-temporal satellite open data, where the term "open data" is defined as "a piece of data or content is open if anyone is free to use, reuse, and redistribute it; subject only, at most, to the requirement to attribute and/or share-alike" (2). Actually, we used Landsat data only, but in the (near) future other satellite data will be available as open data, such as ESA's Sentinel satellite data.

## METHODS

In order to determine the manifestation of the urban growth as a phenomenon it is necessary to characterize the situation that it is observed *per se*, what it is and what it is not. Thus the urban expansion phenomenon is a particular kind of observed situation and there is a notable difference between urban expansion, urban growth or urban sprawl. The difference between urban growth, urban expansion and urban sprawl is best described by (3) in considering urban growth to be a sum of increase in developed land, manifesting itself in different forms, one of these forms being urban expansion, whereas urban sprawl is expressed as „an undesirable type of urban growth" or the opposite of compactness „urban sprawl has been understood as a specific pattern of urban expansion" (4). In order to determine the growth pattern for Bucharest through remote sensing, we need to analyze which are the characteristics that can be "seen" by the satellite. The character of urban growth is to have a spatial dimension, a temporal dimension and a speed related dimension (the rate of urbanization over time) much similar to the character of sprawl identified by (5) as a "condition characterizing an urban area, or part of it, at a particular time" but also as a "process of development by looking at changes in patterns of land use over time"; or by (6) as the extension „along the fringes of metropolitan areas with incredible speed". These dimensions are important for us as they can be measured through the technique of remote sensing, through the time-series imagery that documents the changes over time. The spatial manifestation of the growth/expansion

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phenomenon emphasizes the pattern of land use and refers to the arrangement or spatial distribution of the built environment for socio-economic activities (4). Based on the three dimensions identified for urban growth, we can identify the patterns that determine urban expansion and its specificity with remote sensing and image processing technique. There are three main categories of urban growth (Figure1) that were identified by (7): the infill pattern, the expansion pattern and the outlying patterns (the isolated, linear and clustered patterns of growth).

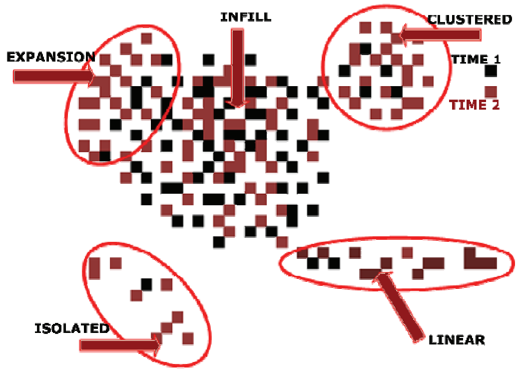
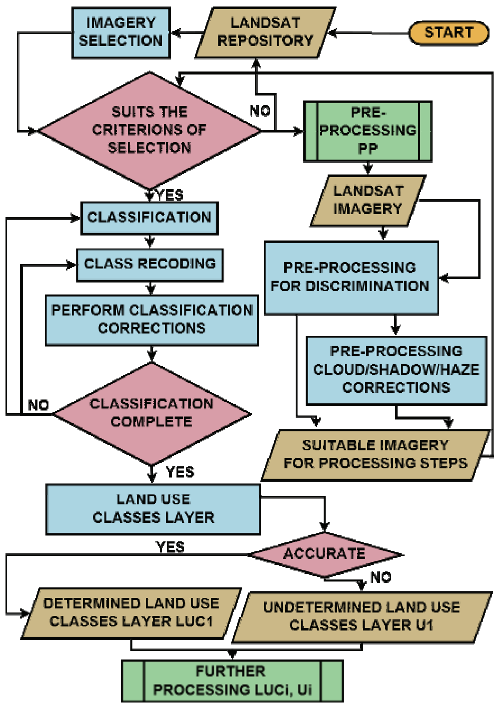



*Figure 1: Urban growth patterns (adaptation of the schematic diagramme in (3)).*

Starting from the World Bank study (1) we devised our methodology (Figures 2 and 3) to generally encompass many possibilities to perform different pre-processing, processing and post-processing tasks like haze correction, water and vegetation discrimination based on NDWI (8) and NDVI (9) in order to obtain an accurate land use classification and to have an easily applicable methodology available at our national level. In the case that besides the radiometric corrections there is also needed a cloud and shadow detection, this could be performed like in our case by analyzing the spectral profiles and masking the pixels with the reflectance values observed for clouds and respectively for shadow.



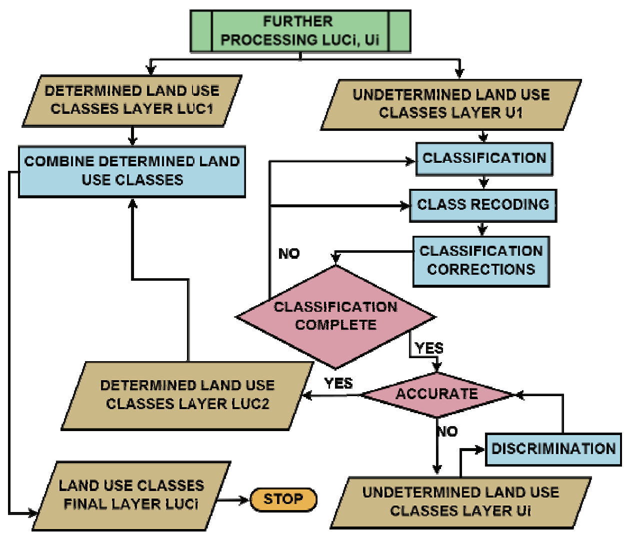




*Figure 2: Methodology flowchart: first iteration.* *Figure3: Methodology flowchart: next iterations.*

The land use classes for three time periods, a decade apart, were obtained automatically using the ISODATA algorithm for unsupervised classification to divide each image into 40 spectrally separable classes. These classes were combined and then recoded into the following pre-defined classes: water, built-up, vegetation, soil and undetermined (Figure 2). The undetermined class, recoded where the land use/land cover was not determined satisfactory, was afterwards introduced into a new iteration and classified until it produced adequate classes only in the water, built-up, vegetation and soil category. The automatic classification suffered such iterations (Figure 3) and was followed by the human analyst interpretation to detect misclassifications by direct comparison with the source image and correction by on-screen editing of the vector classes which increased classification accuracies both thematic and spatial. Although „the manual process of digitizing is the most accurate technique" (10) of extracting the built-up class, it is best to be minimized due to the fact that it is time-consuming and thereafter costly. The way to minimize this human intervention is to iterate as many times as needed the classification steps LUCi and Ui, presented in Figure 3 above, in order to increase the classification accuracy.

## RESULTS

The study area was selected using a framing rectangle to include about a 30 km radius from the city centre containing the farthermost side of the Bucharest-Ilfov development region. This area of interest was chosen because the economic activity of this region is "dominated by the capital due to the active population working within the economic units that function here" (11). We used in this study Landsat imagery that suited as much as possible the following criterions: a) no clouds in the study area, only haze if a clear image is unavailable; b) seasonally suited imagery that makes the identification of built-up areas easier, meaning less vegetation present and c) imagery correlated with the census periods for future continuations in analysis with the statistical information included.

The imagery chosen for the 1993 land use/land cover classification was a mosaic of two Landsat 5 images from April 23 and October 16; these required some pre-processing steps and consequently cloud and shadow detection was performed by masking the pixels with the reflectance value in the GREEN band ρGREEN greater than 0.18 for clouds and respectively the ρNIR value in the NIR band lesser than 0.1 for shadow. For the other two, a decade apart, time periods a March 26th 2003 Landsat 7 image and an April 30th 2013 Landsat 8 image was used. Unlike the 1993 set, they only needed radiometric corrections. These pre-processed images, corresponding to the chosen three time periods, were then classified according to the methodology in Figures 2 and 3. Table 1 presents the different accuracy obtained for the 1993 classification after one and three iterations respectively. The 2003 and 2013 images were processed in only one iteration (Table 1).

*Table 1: Classification accuracy for the land use classes obtained from the Landsat imagery*

| | **1993 Classes Iteration 1** | | | | **1993 Classes Iteration 3** | | | |
|---|---|---|---|---|---|---|---|---|
| | Prod. Acc. (%) | User Acc. (%) | Prod. Acc. (Pixels) | User Acc. (Pixels) | Prod. Acc. (%) | User Acc. (%) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
| **Water** | 99.64 | 100.00 | 829/832 | 829/829 | 99.64 | 100.00 | 829/832 | 829/829 |
| **Vegetation** | 85.78 | 84.49 | 790/921 | 790/935 | 85.78 | 87.39 | 790/921 | 790/904 |
| **Soil** | 74.14 | 85.53 | 473/638 | 473/553 | 89.35 | 88.63 | 998/1117 | 998/1126 |
| **BuiltUp** | 86.80 | 79.35 | 684/788 | 684/862 | 86.93 | 86.11 | 998/1148 | 998/1159 |
| | 2003 Classes Iteration 1 | | | | 2013 Classes Iteration 1 | | | |
| | Prod. Acc. (%) | User Acc. (%) | Prod. Acc. (Pixels) | User Acc. (Pixels) | Prod. Acc. (%) | User Acc. (%) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
| **Water** | 97.16 | 100.00 | 1678/1727 | 1678/1678 | 89.67 | 99.71 | 3073/3427 | 3073/3082 |
| **Vegetation** | 98.84 | 90.96 | 1449/1466 | 1449/1593 | 99.76 | 87.53 | 3284/3292 | 3284/3752 |
| **Soil** | 86.16 | 90.68 | 1488/1727 | 1488/1641 | 70.24 | 93.48 | 3439/4896 | 3439/3679 |
| **BuiltUp** | 91.17 | 90.73 | 1508/1654 | 1508/1662 | 94.42 | 71.94 | 3331/3528 | 3331/4630 |

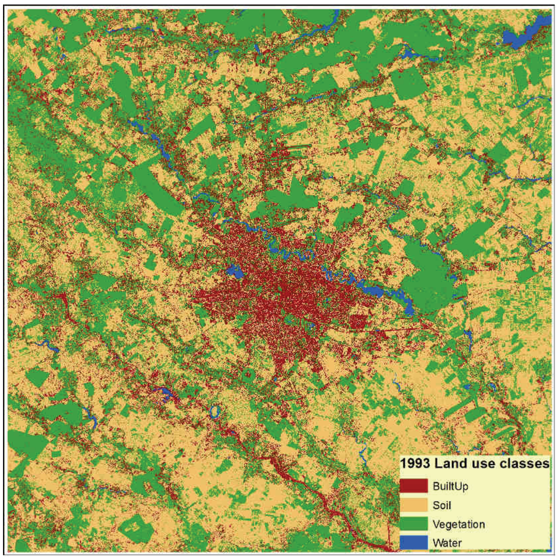



*Figure 4: Built-up environment in 1993.*

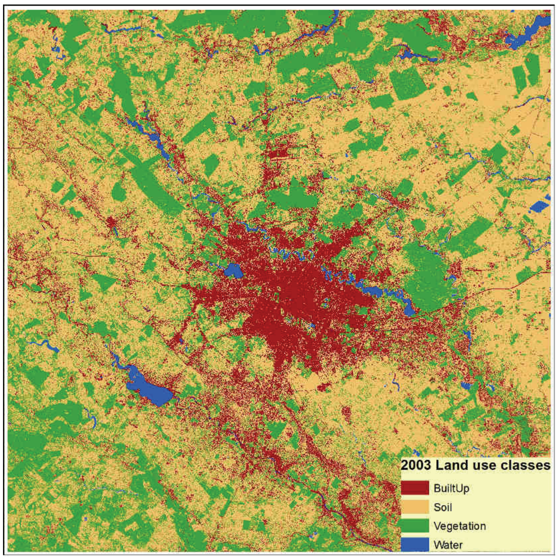



*Figure 5: Built-up environment in 2003.*

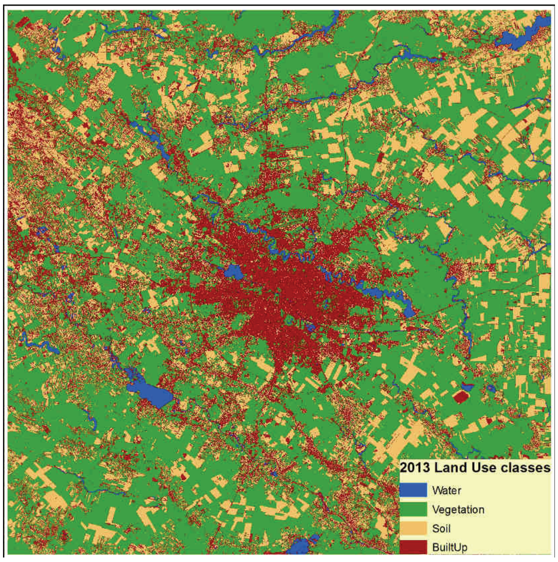



*Figure 6: Built-up environment in 2013.*

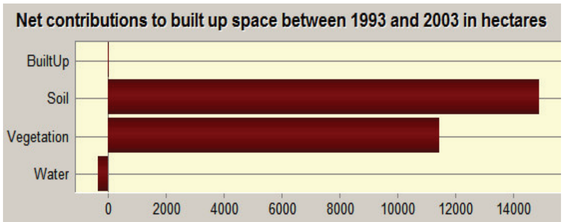



*Figure 7: Built-up areas between 1993 and 2003.*

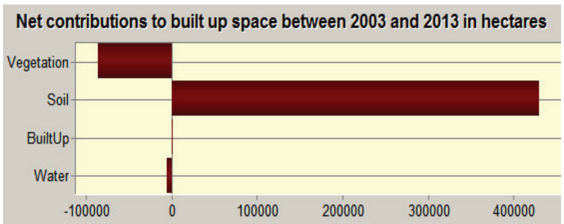



*Figure 8: Built-up areas between 2003 and 2013.*

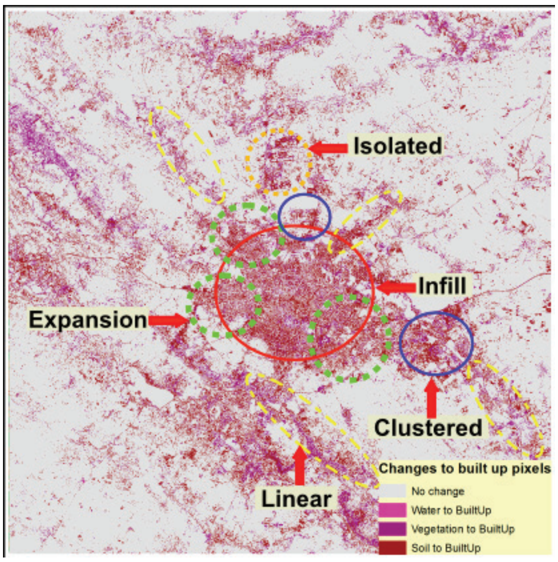



*Figure 9: Patterns of urban growth between 1993 and 2003.*

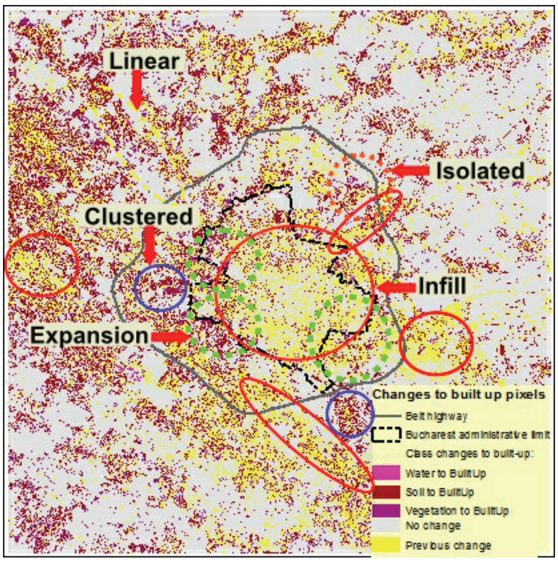



*Figure 10: Patterns of urban growth between 2003 and 2013.*

The 1993, 2003 and 2013 classifications are presented in Figures 4-6 and they illustrate the urban changes that have occurred. Both spatially and temporally they are self-evident in offering insights to understand the urban growth patterns. We used the pixels from the built-up class to measure these spatial urban patterns and to obtain an image of the extent to which the city and its area of influence has grown. Certain groups of pixels in the built-up class were identified that resemble the spatial patterns described in Figure 1 and were marked. The result of the change detection process between 1993 and 2003 (Figure 9) presents the transformations of the water, vegetation and soil classes in 1993 into built-up class in 2003, distributing the unchanged pixels into a no change global class containing soil, vegetation or water pixels that remained unchanged. The change detection between 2003 and 2013 distinguishes the same transformations taking into account when establishing patterns of urban growth the change resulted between 1993 and 2003. Consequently in the last two decades we found, as expected for the infill pattern, the contiguous clusters of built-up pixels inside the city boundary.

For the expansion pattern clusters of somewhat more dispersed pixels were found at the city boundary and beyond it. For the outlying patterns we found specific linear, isolated and clustered groups of pixels. It is concluded that the initially stated objective to find the patterns of growth for the city of Bucharest is met as we identified that in the last 21 years all the urban growth pattern types are equally present with no dominant growth pattern being exhibited. The total measured transformation in built-up space is about 76000 ha in the last 21 years. As can be seen in Figures 7 and 8 the built-up space advanced with about 26000 ha in 10 years in the first decade followed by a 40000 ha in 10 years over the next decade. These measurements show an increase in the rate of growth in the last 10 years and this accelerated rhythm corresponds to a 53.84% growth rate over the last decade. This rate can be correlated to the annual percentage growth rate of the gross domestic product (GDP) at market prices based on constant local currency over the same decade which is 76.99% as it results from the World Bank statistical data (12). Because in relatively “high income countries, rates of urban land expansion are slower and increasingly related to GDP growth”, as stated by (12), and since in Europe population growth contributes less to urban growth than GDP and even though there might be “a variety of factors difficult to observe comprehensively at the global level” it is still possible to make the observation that the rate of urban growth is relatively slow in Bucharest, at least in the past ten years.

## CONCLUSIONS

The socio-economic change that affected Bucharest (the 6th largest capital in the European Union) and its surroundings in only two decades from the end of the Cold War is captured by our research and proves that the developed methodology, compatible with the World Bank study (1), can be successfully applied. The classification process previously presented performs well generally (1) in extracting land cover information. The most common sources of errors were in the spectrally similar classes of build-up environment and soil. These errors were eliminated by further iterations and by final manual on screen removal. The large spectral variation of urban spaces determined the classification methods to be developed further and the improvement of their accuracy to become a scientific goal (10,13). The methodology presented shows that this goal is also met by the results obtained in our study.

Based on this remotely sensed kind of “tracking changes” in the urban extent, there is a large range of correlations to be made with demographic or environmental information to better understand the causes and the effects of urban expansion and growth. The “big picture” is in the end one of the best ways to study the urban growth because it is “often incremental, change may be overlooked in the short term, but the visual illustration of this growth can be quite dynamic over several decades“ (14).

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