THE DYNAMICS OF A CITY. OVER 40 YEARS OF CHANGE IN BUCHAREST AND ITS DETECTION IN MULTITEMPORAL SATELLITE IMAGERY.

Mihaela Aldea[1]; Florian Petrescu[1], Eberhard Parlow[2] and Cristina Iacoboaea[1]

1. Technical University of Civil Engineering, Department of Urban Engineering and Regional Development, Bucharest, Romania; imihaela@utcb.ro; florianp@utcb.ro; cristinai@utcb.ro
2. University of Basel, Institute of Meteorology, Climatology and Remote Sensing (MCR Lab), Department of Environmental Sciences, Basel, Switzerland; eberhard.parlow@unibas.ch

ABSTRACT

Bucharest is the Romanian capital city, a city with a special dynamics over time, peculiar in many ways. It went through some important periods of changes, starting with the 40's, extending over two quite significant economical periods that influenced its urban growth. The years when the decision that large masses of people, over 11 million, to be moved into high density, newly built-up urban spaces, came into effect, coincided with the years of the first recorded Landsat images that are available today. Taking this opportunity, we studied the correlation between the dynamics of the Bucharest city and the land use/land change patterns identified from satellite imagery during various stages: the mentioned years of dramatic change; the following period of transition and the opening to the rest of the world economic order; the years following the entrance in the European Union, a period of investments and growth (economic and in construction) and the ultimately downturns at the end of the last decade. Our study will contribute actively, with the case of our capital city, in assessing the degree of reliability of the information obtained from analysing the patterns of land use/land cover from remotely sensed imagery as it addresses the variability of interpretation based on chronological documentation.

INTRODUCTION

The objective of this paper is to evaluate the degree of reliability of the information obtained from analysing the patterns of Land Use/Land Cover from remotely sensed imagery and its assessment through interpretation based on chronological and statistical records. Following its history, we studied the possibility to produce correlations between the written literature describing the dynamics of the Bucharest city and of the changes detected through the generation and analysis of the Land Use/Land Cover features identified from satellite imagery during various stages of development.

The post-WWII Romaina and Bucharest as its capital city, evolved during three very important political periods: the period between 1947-1989 under a communist regime, the period between 1989-2007 following a revolution which started the democratisation process and the period from 2007 to present marked by our acceptance in the European Union and our adherence to the body of laws and economic principles of the other western societies

For Bucharest as a city, its urban form have been transformed, sometimes radically, by these periods. Until the 70's and in the previous years, Bucharest have been transformed, and followed a so called modernisation model which inserted iconic, representative buildings of the era and the eastern regimes (1), scattered across the whole city. Thus, at the beginning of the 70's some imposing structures were already built, along with the necessary infrastructure. Such a structure, a replica of the "Lomonosov" Moscow State University, is the "Spark House" now called the "House of Free Press", a structural complex – a four sided assembly with a large interior courtyard plus another two side buildings, one of the tallest building in the city since 1956, when it's construction was completed and served as the main publishing centre of press and other publications. In 1952, the Council of Ministers issued a resolution that “set out the main elements that were to be pursued in most of the systematization plans to follow” regarding the “reconstruction of the city of Bucharest” (2). The main restrictions that were imposed limited the city’s boundary and limited the maximum number of residents to 1.7 million (2).

Thus, at the end of the 60’s, the new “model of urban development”, was fully implemented in the form of “economically self-sufficient residential districts” (2) which were erected for the labourers who were brought in to work in the newly built-up factories and they were mainly relocated from rural areas or were evicted from the demolished suburbs. The industrial buildings also erected in this period were located at the peripheries of the city. They were all constructed in the outskirts of Bucharest on empty land or in populated suburbs, along roads with access to the city. The spatial form of this districts consisted in 6 story blocks of flats flanked by 8-story high density residential buildings along the main arteries, peripheral districts developed in all directions: N (Floreasca), N-V (Bucurestii Noi), E (Vatra Luminoasa, Titan) close to two factories (23 August and Republica), V (Drumul Taberei) and S (Berceni). In the already populated suburbs like S-V (Militari, Ghencea, Giulesti) or E (Balta Alba) individual houses on entire streets were evicted by this high raise blocks of flats (P+6 – P+10 actually) sweeping along the main boulevards. At the beginning of 1970, there were a series of symbolical buildings built-up in a vision closer to the western world: the Intercontinental Hotel, the Television and the Otopeni airport, plus the French type of residential blocks situated in the rear contributing to more and more compact residential districts.

There were a series of laws and decrees that operationalized the vision of rural and urban planning in Romania: Resolution 2448/1952 maintained the city of Bucharest artificially limited in growth: both its perimeter and in its number of inhabitants conducting to an extreme compact form. Law 58/1974 of rural and urban planning of localities which introduced a plan for the configuration of the cities and villages, the compactness of the urban areas based on the limitations on their development and major reductions in built-up space in rural areas and relocations. Starting with 1975 the traces of this last piece of legislation were remarkable in the transformations in brought upon the city, as it resulted in a severe compact form for the cities in Romania, almost total replacement of the older types of buildings with standard types of blocks and was close enough to the relocation of the entire rural population in urbanised areas, in medium density condominiums.

Two major natural hazards – severe inundations in 1975 affecting a large area of the country and a powerful earthquake in 1977 affecting mostly old buildings served as the triggering mechanism in the excesses in the implementation of the law. In order to have constructions corresponding to the newly produced technical standards in structural engineering following this 1977 earthquake, the preferred option was that of demolition and reconstruction. This is the case of the central and historical area of Bucharest, where the demolitions were started in 1984, the year from which they start being visible from above: the disappearance of the entire Uranus district. Following this period, big, mega buildings were erected, in a grouped manner, they are easily identifiable due to their size, in more recent higher resolution Landsat imagery.

In the period of transition, following the year of 1989, Romania was confronted with an economical decline and its capital city followed this trend. Most of the industrial buildings and factories stopped their activity in the aftermath of the political change. Some of them were replaced by big commercial buildings, or by residential investments. Many of them simply remained in degradation. Starting with the year 2000, as the economic situation continued to improve, an important number of economic activities moved outside the city, along the belt road of the city. Starting with 2007, modern, high raise office buildings and grouped high raise residential developments started to explode inside and around the city.

METHODS OF IMAGE PROCESSING AND ANALISYS OF REMOTELY SENSED DATA

Image acquisition

The first Landsat adequate image available containing the Bucharest city in the Landsat Level 1 data products archive was a Landsat MSS satellite image, dating from 13 September 1976, with four bands available and a 60 meter spatial resolution resampled by the USGS production system from the original pixel size of 79 x 57 meters. Because the evictions and demolitions in the historical core of the city in order to construct the "Civic Centre" were started in 1984 and they continued until the end of the regime in 1989, the representative image was selected from Landsat TM, recorded on 09 August 1989, from the year that seems to reflect this entire stage in the city's evolution.

For the next period, following the year of 1989, the images were selected based on the growing trends estimated from the statistical information regarding the erected residential constructions, statistics which are shown in figure 1.

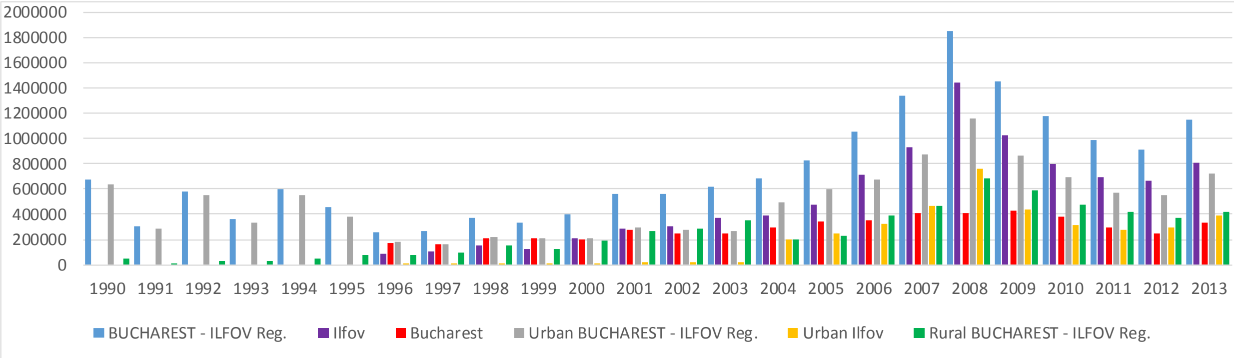

Figure 1: Residential constructions footprint in sq m between 1991 - 2013

Since 1990 until 2002, the statistical records are showing that residential built-up footprint in Bucharest grew at a medium low variable rate of 219000 m2 per year. The best suited imagery selected was the 26 March 2003 Landsat ETM+ imagery, a year that covers best what happened in this decade of slow growth and is close enough to the census period from 2002. The same criteria is applied for the next period, for which was selected a Landsat OLI image recorded in 26 April 2014, a date that can reveal all the accelerated growth which started in 2004 and produced many changes at the city level and in its vicinity.

Land Use/ Land Cover classes production/generation

Pre-processing consisted in the usual radiometric corrections since the images were selected from multitemporal cloud free satellite data. Due to the differences in sensors, spectral bands and resolution, the best classifier that would extend over such a variety seems to be the Decision-tree which allows "a selectivity of techniques" and is "an efficient mode of separating observations into classes or for predicting the best response to a given situation" (3) as the human intervention process of interpretation appears to be the most accurate technique (4) of extracting the built-up class,

These features were identified based on the Landsat sensors corresponding to their respective bands plus vegetation indices NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index) and SAVI (Soil Adjusted Vegetation Index). (5) The SAVI is more suitable for areas with the plant cover as low as 15% such as dense urban areas, unlike the NDVI which emphases areas with more than 30% vegetation (6). SAVI is calculated using the equation (7), where l is the correction factor taking values of 0.5 for an intermediate vegetation density or 1 for a very low vegetation density. Also, the Normalized Difference Water Index (NDWI) (8) was proposed to help in discriminating open water features. Their equations are presented next:

$$SAVI = [(NIR-Red)(1+L)]/(NIR+Red+L)$$

NDVI = (NIR-Red)/(NIR+Red)

NDWI = (Green - NIR)/(Green + NIR)

The NDWI is not suitable anymore for open water and built-up land background because the built-up area has close values. The Normalized Difference Built-up Land Index of (9) based on the fact that built-up lands that have higher reflectance in MIR wavelength range than in NIR wavelength range, even if this is not always true. All this indexes could all be used in the modified form: MNDVI, MNDWI etc using the MIR band instead of NIR.

NDBI = (MIR – NIR)/(MIR + NIR)

One of the frequent methods of image fusion applicability involves the fusion of the Panchromatic and Multispectral images form Landsat ETM+ and OLI to take advantage of the 15 m spatial resolution of the panchromatic band. In consequence, for the 2003 and 2014 images, such an image fusion technique was performed. The main goal of this step was to obtain an image that retains the spectral characteristics of the multi-spectral Landsat image and improves the spatial resolution based on the higher panchromatic Landsat image. In recent literature (10), (11) and (12), it was pointed out that among the usual fusion techniques, the best impact on the classification accuracy was achieved by techniques such as the more popular PCA, whereas the more traditional ones such as the HSV technique has not performed satisfactory. Moreover, the PCA is useful for change detection and multitemporal analysis (13).

In order to perform discrimination on large discrete groups of pixels, an image segmentation process was employed. During this step the image is divided into spectral homogenous regions of discrete groups of pixels suited for various land-use/land-cover mapping. The optimum thresholds and population were determined by visual assessment of the segmentation results (14).

RESULTS

The resulted patterns of growth exhibited by Bucharest city in the last 40 years, were identified to be either intensification (15) as the new constructions were erected on the open space or by redevelopment and eviction, “increasing density and spatially characterised by the infill pattern” (15) or greenfield development as new constructions appeared on previous non-urban space on the outskirts of the city.

The 1976 image presents a city with a star-like form, both the railway and the belt road are identifiable were digitized in order to be compared to the situation in later years. The belt road was also identified in a 1946 guide as a fortification road finished in 1895. The city was actually contained inside this belt road by the 1935 Master Plan and successive legislation especially until 1989 and the area between the city border and the belt road was considered suburb. Both airports are visible and were classified per se. The Imperv_HiBuilt class shows the newly constructed districts in the N-E, E, S-E, W, S-W and S. At first they were built relatively less dense, as spatial form at least, although the blocks were 6 to 10 storeys they were built sparsely enough to allow open space as identified in the LowBuiltUp class. Soil or higher built up LULC contain components representing building sites still underway. We can identify “Spark House” complex as a large developed area. Two lakes existing today, the „Ciurel Lake” and “Mihailesti Lake” were not harnessed yet, being identified only in later year’s classifications. According to the statistical data, the Bucharest population in 1976 was of about 1.8 million inhabitants, almost doubling the population of 1948, of about 1 million inhabitants. The old town core can be identified as HiBuiltUp class, meaning that this excess population was commuted into the newly districts mentioned before.

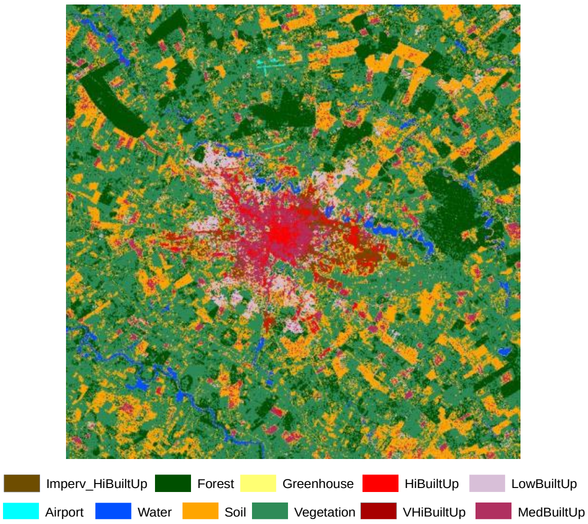

Figure 2 1976 LULC resulted features

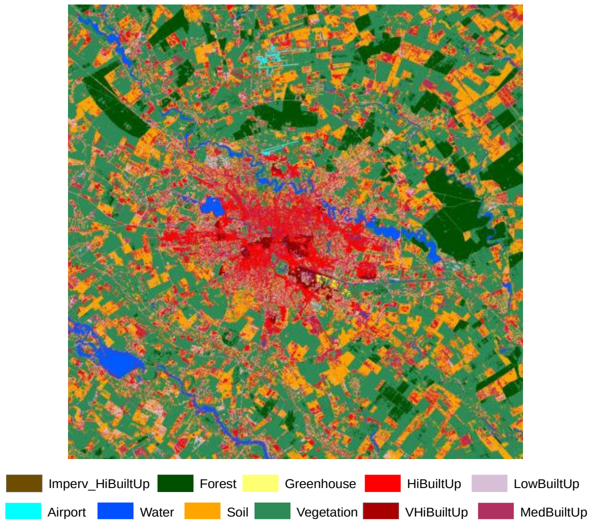

Figure 31976 LULC resulted features

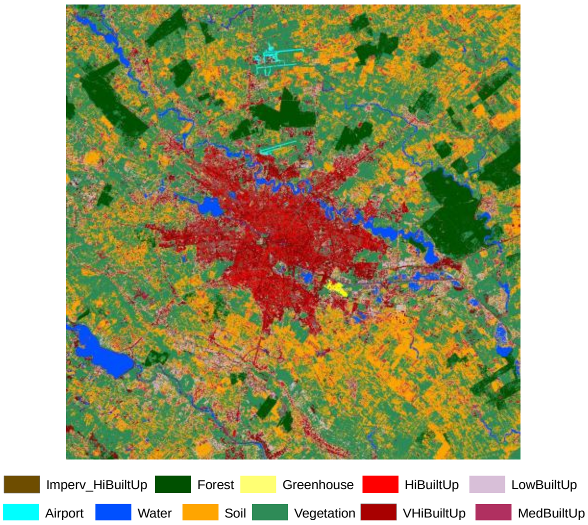

Figure 4 1976 LULC resulted features

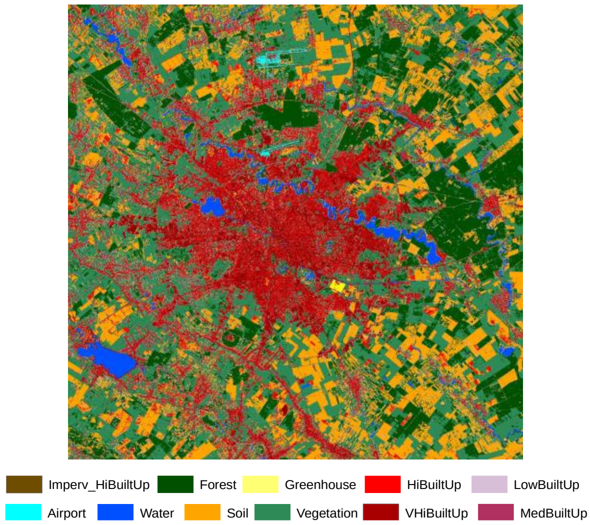

Figure 5 1976 LULC resulted features

According to the Bucharest-Ilfov Strategy for 2014-2020, the official area of the city is 283 km2 and it's built-up area is about 70%. That means that the 219000 m2 rate of the official inner city residential growth is about 0.13%, a rate at which the doubling time expected for the inner built-up area to double its size is more than 500 years. Starting with the year of 2003, the medium rate of the inner city residential growth was close to 0.2%, a rate at which the inner built-up area would need 350 years to double its size. The most unfavourable scenario based on statistical data available, is to consider the useful areas of all the erected buildings equal to the footprint areas. Then the annual built-up space would be of 1341000 m2 and a growth rate of 0.8% with the possibility that the size of the built-up city to grow double in about 86 years. There is an important aspect that needs to be observed – that the population related residential dwellings contribute less to the growth pressure over the developable space. Thus, in the same unfavourable scenario, the residential built-up space would grow at about 0.5% rate, doubling the total built-up area in more than 140 years.

CONCLUSIONS

The analysis revealed the development of the city in the same way as it has been recorded in written documents and shows that satellite imagery can be used to document historical evolution of a city, in relation with other chronological records. The evolution of the city's development revealed by our results, even using distinct sensors and resolutions, proved to be in direct relationship with the historical reality of the city's development and growth. Regarding the last two decades of urban development of Bucharest, we found that the infill pattern of the "contiguous clusters of built-up pixels inside the city boundary" and the expansion pattern of "clusters of somewhat more dispersed pixels at the city boundary and beyond it" (16) were the predominant changes until in urban form until 2003.

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