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THE MAIN CHARACTERISTICS OF THE URBAN CLIMATE IN RELATION TO THE BUILT SPACE EVOLUTION IN BUCHAREST, ROMANIA

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Abstract: The urban climate is a specific type of topoclimate characteristic to big cities, like Bucharest, which is formed due to the horizontal and vertical expansion of the space, the nature of the materials used for constructions, the pollution, and other side effects of the socio-economic activities. The main objective of this study is the analysis of the variability of four main meteorological elements (air temperature, atmospheric precipitation, relative air humidity, duration of sunshine) in Bucharest and its neighboring area, in relation to the built space evolution. In the last decades, Bucharest has been experiencing an exceptional development, materialized both by territorial expansion, as well as structural-functional and architectural-urbanistic transformations. The fact that the population of the city is increasing, correlated with the expansion of the built space area, suggests the intensity of the *urban sprawl* phenomena. This has numerous side effects, among which is the creation of a specific topoclimate, different from the one in the periphery. As an example, the results of the meteorological analysis showed that the air temperature is higher inside the city, at the Filaret station, with 0.1ºC, than at the periphery (Baneasa station) and the periurban area (Afumati station).

1. Introduction

This study analyzes the correlation between the *urban sprawl* phenomena, the existence of an urban topoclimate, and the variability of four main meteorological parameters: air temperature, sunshine hours, relative humidity and atmospheric precipitation. The higher the intensity of the urban development, the larger the differences between the values recorded at meteorological stations are (Waffle et.

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al., 2016), which has direct consequences on the meteorological parameters (especially in the central area, where the air temperature and the sunshine hours are higher, while the relative humidity is lower) (Ionac and Grigore, 2013; Tiscovschi and Diaconu, 2004).

As a result, understanding the influence of the urban climate in built areas and reducing its effects over the meteorological parameters characteristics and, indirectly, over the population (especially the vulnerable categories represented by old people and cardio-respiratory patients) and the socio-economic activities is a necessity for a sustainable long-term development (Dumitrescu, 2007).

As many other major cities, Bucharest has experienced numerous problems, like air and water pollution, traffic jams, illegal and chaotic buildings, due to uncontrolled growth. The faster the urban growth, the more difficult it is for the authorities to cope with all those side effects. The soil, plants and open water sources are replaced by hard surfaces like concrete, asphalt, or slate. The most dramatic changes, however, occurred in the periphery, where the agricultural fields and forests have been converted into residential and industrial areas, made of concrete and glass (Ianos et all, 2017). This led to the creation of a very different landscape, with different characteristics from the original stateof all system's components, which has an enormous impact on the meteorological parameters (Pacala et. al., 2001).

It is known that Bucharest is the most important city in Romania and that here exists an urban topoclimate that has a significant impact on the economy and social life of the area (Dumitrescu and Cheval, 2015). The urban topoclimate of the capital depends on the size of the city, the geometrical configuration of buildings and the anthropic activities (Ciulache and Ionac, 2007). There are many intervals characterized by higher temperature values in the central areas during the warm season, that pose a higher health risk for old and sick people (especially the ones with cardio-respiratory diseases) (Dumitrescu, 2007).

2. Methodology

Bucharest is the capital and the largest city of Romania and it is located in the southern part of the country, in Vlăsiei Plain, which is part of the Romanian Plain. The first building here appeared in the 1370-1380 period and it represented a 160 m^2 tower that marked an intersection of commercial roads. Since then the city grew both from quantitative (population, built space surface) and qualitative (functional optimization of space, functional restructuring, decentralization, periurbanization, gentrification etc.) points of view (Mihai et all, 2015).

The climate has unique characteristics in this area, which are highlighted by the comparative analysis of meteorological data from three stations (Fig. 1) located in the center (Filaret) and the periphery (Baneasa) of the city, as well as in the exterior of its metropolitan area (Afumati).

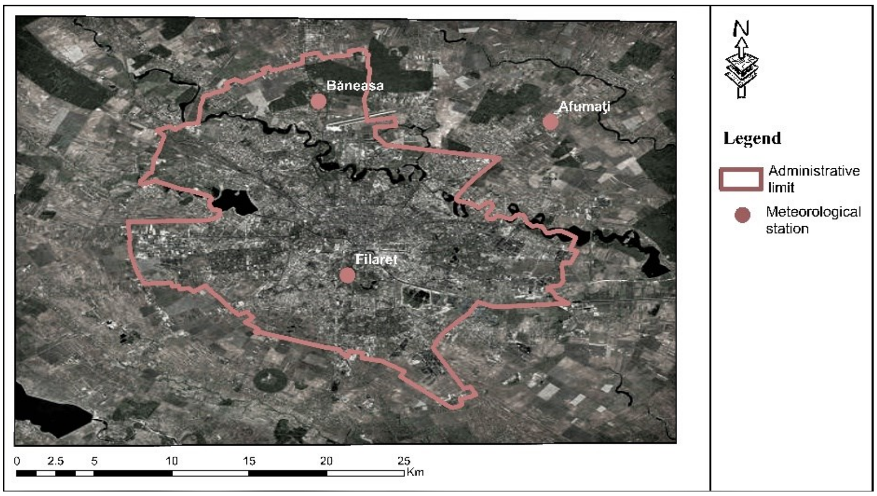

Fig. 1. Localization of Filaret, Baneasa and Afumati meteorological stations
Source: Google Maps; Edited in QGis

The study had three main objectives, namely the analysis of historical and vertical evolution of built space in Bucharest and its metropolitan area in the 1956-2016 period; the highlighting of monthly and average climatic characteristics of Bucharest and its surrounding area for the main meteorological parameters (air temperature, sunshine hours, relative humidity, and atmospheric precipitations) for the 1961-2013 period; as well as the correlation between the meteorological elements and the built space evolution of Bucharest, with emphasis on the climatic differences between the city and its surrounding areas.

In order to realize this study, besides the biographical research, meteorological data from Filaret, Baneasa and Afumati stations for the period 1961-2013 from NMA Archive, as well as General Urbanistic Plans from 1956 and 1970, satellite images available through Google Earth Pro, and statistical indicators from National Institute of Statistics were used in order to apply different statistical methods and to create representative graphic and cartographic representations using Microsoft Office and open source GIS programs.

3. Results and discussions

After processing the data from National Meteorological Administration, Bucharest City Council, National Institute of Statistics and the satellitary images, a series of graphic and cartographic representations resulted. Those highlight the urban expansion of the city and its periphery, as well as the variability of the meteorological elements (air temperature, sunshine duration, relative humidity, and atmospheric precipitation). By correlating the results of the spatial dynamics of Bucharest analysis with its climatic variability the creation of a specific topoclimate can be observed.

3.1. The spatial evolution of bucharest

Bucharest had an increase of built space from only 15 ha in the 14-15 centuries, to 5.593 ha in 1910, 14.991 ha in 1950, 16.914 ha in 2002, and 19.123 ha in 2016. The total growth (of 2.209 ha in the last 14 years, with an annual rate of 221 ha) is specific for an extensive and uncontrolled *urban sprawl* (Knox and Finch, 2010; Petrișor, 2012). This development of built space, correlated with a decreasing population, highlights the intensity of the phenomena. The area that according to legislation can be built also increased from 79.6% of Administrative Territorial Unit (ATU) to 98% (since 2000) (Mihai et all, 2015).

A specific characteristic for the *urban sprawl* phenomena in Bucharest is the intensive and extensive growth in the communist period, when most of the area of the ATU was covered built-space expansion programs. After 1989, and especially in the 21st century, the growth was concentrated mainly around the city, in its close proximity (Ianoș, 2004) (Fig. 2).

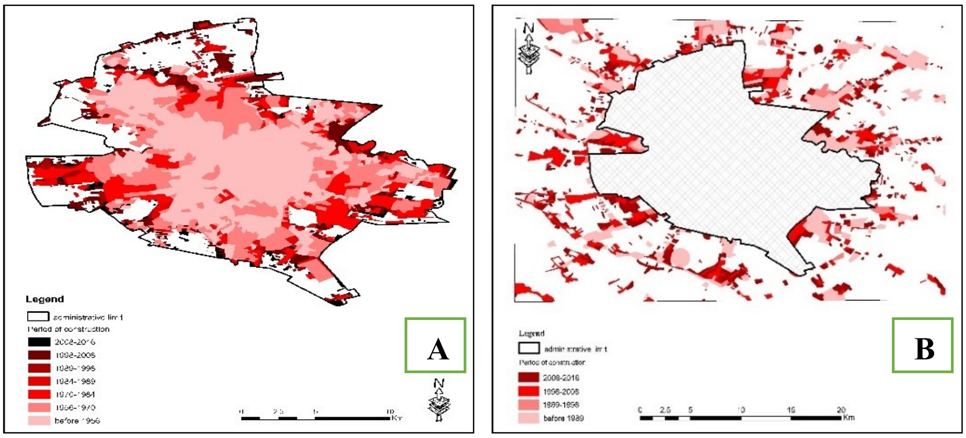

Fig. 2. The evolution of built space in Bucharest in 1956-2016 period inside Bucharest (A) and in its periphery (B). Source: 1956 and 1970 PUG, Google Earth Pro; Edited in QGis

This phenomena has different causes. Before 1989 the legislation was not permissive regarding the horizontal evolution of the built space and migration to big cities was strictly controlled (Ianos et all, 2017). Everything related to the growth of the city was decided by the communist authorities and it was mainly based on big architectural projects concentrated in the central part of Bucharest (mainly residential and administrative buildings) and near its ring road (mainly industrial buildings).

Since 1990, those restrictive laws were abrogated and people could easily move to the capital in order to take advantage of the larger number of jobs and other professional opportunities. However, due to the high prices of land in the city center and the rapid development of transports and communications, as well as the increase in the number of personal vehicles, people were determined and motivated to move in the periphery, in its satellite-cities (Otopeni, Voluntari, Pantelimon, Magurele, Bragadiru, Bolintin, Chitila and so on). This process, known as periurbanization, is stronger nowadays than the urbanization, and it represents the main source of spatial growth of the Romanian capital (Candea et all, 2011).

However, the maximum growth of Bucharest was reached in the communist period, when, besides the creation of the extensive industrial platforms, the number of apartment buildings largely increased. If, in the 1945-1964 period, 80.641 flats were built, this number increased to 446.100 from 1965 to 1984. New neighborhoods like Titan – Balta Alba (90.000 flats), Drumul Taberei (63.000 flats), Berceni (70.000 flats), and Militari (40.000 flats) were built entirely under communist administration and largely extended in the 21st century (Ioja et all, 2014, Patroescu et all, 2012) (Fig. 3). This process of extensive urban growth takes place nowadays mainly in the satellite-cities of the capital, but at a much smaller scale and with a higher degree of chaotic growth (compared with the controlled extensive growth of the city before 1989).

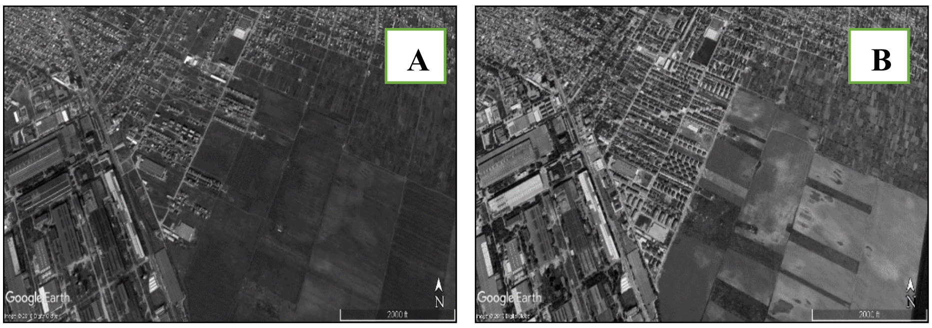

Fig.3. Evolution of Berceni neighborhood from March 24, 2011 (A) to May 3, 2017 (B). Source: Google Earth Pro

At the same time as the city extended horizontally, the average height of buildings increased too. This growth can be seen by analyzing the number of flats/building in the 1990-2016 period, which grew from below 2.6 flats/building to over 3.1 flats/building (Fig. 4).

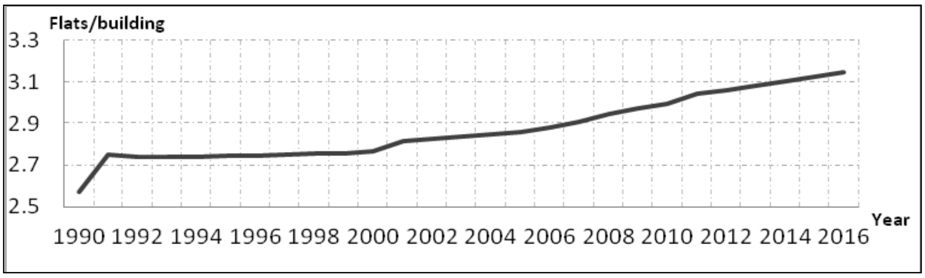

Fig. 4. The evolution of flats/building in Bucharest in the 1990-2016 period
Source: edited using National Institute for Statistics data

3.2. The main characteristics of the urban climate in bucharest

It is very important to understand the relation between urban growth and the main meteorological elements. By analyzing the characteristics of the urban climate and the variability of the meteorological parameters, a clear difference between the central and the surrounding areas of the city can be made.

3.2.1. Air temperature. The first parameter taken into consideration is the average monthly and yearly air temperature at all three meteorological stations. The minimum values of air temperature for the whole year are registered in January, with frequent values below 0ºC, and the lowest value recorded at Filaret and Afumati stations (-2ºC).

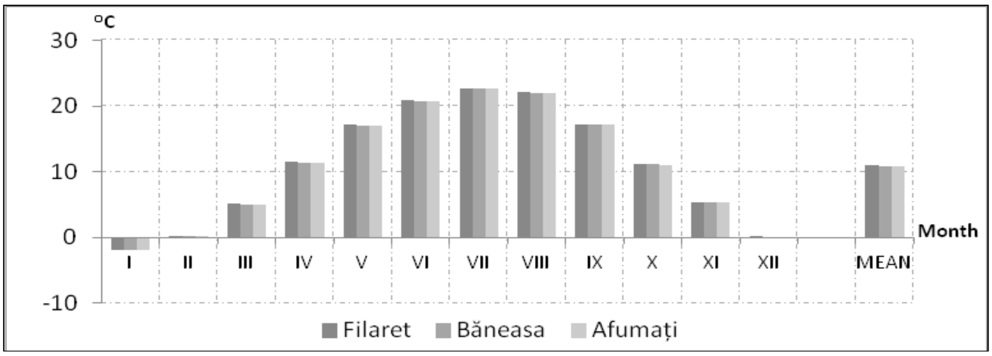

Fig. 5. Average monthly and yearly mean values of air temperature at Filaret, Baneasa and Afumati meterorological stations the period 1961-2013. Source: data processed, NMA 2018

Regarding the average multianual yearly mean values, for the 1961-2013 period, the values are relatively equal, with only 0.1ºC higher inside the city (10.9ºC at Baneasa and Filaret) compared to the value registered at Afumati station (10.8ºC) (Fig. 5).

The maximum monthly difference between the three stations is registered in April and August, when values with de 0,2ºC higher are reached at Filaret compared with Afumati.

3.2.2. Sunshine hours. The second meteorological element analyzed, sunshine hours, is directly influenced by the days' length and the transparency of the air layers (Bogdan, 2017). Those layers are more polluted in the central area of the Bucharest, while in the periphery there is a higher frequency of fog (due to the large active surface covered by vegetation and water bodies), both elements having a great impact on sunshine hours.

The information taken from Fig. 6-A reveals that, in July, the maximum values are 299.7 hours at Filaret, 294.8 hours at Baneasa and 294.6 hours at Afumati. The minumum values from December are 65 hours at Afumati, 65.4 hours at Filaret and 65.6 hours at Baneasa. This leads to an average multiannual yearly difference of 5.1 hours between central part and periphery.

The highest difference between the central area of Bucharest and the surrounding area is of 5.1 hours and it is reached in July, with the higher value, of 299.7 hours, recorded at Filaret.

Yearly, the maximum values are registered at Filaret (2163.4 hours), and the minimum at Afumati, with 2141.7 hours. This means a difference of 21.7 hours (Fig. 6-B).

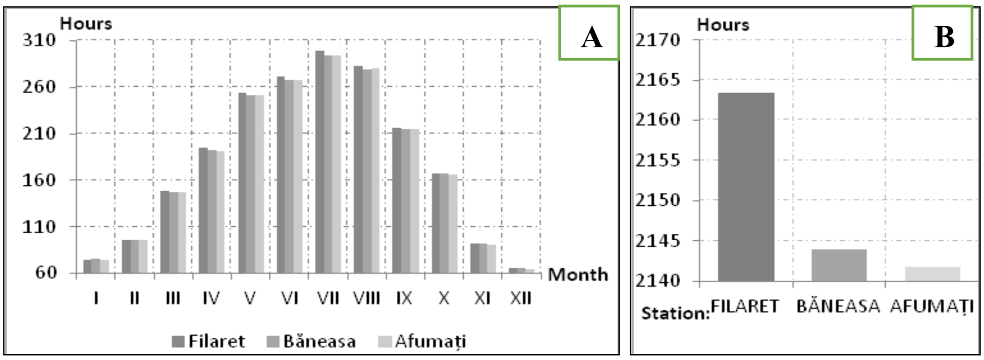

Fig. 6. Average monthly (A) and yearly mean (B) values of sunshine hours at Filaret, Baneasa and Afumati meteorological stations for the period 1961-2013. Source: data processed, NMA 2018

In conclusion, there are more sunshine hours in the central part of the city (Filaret) than outside it (Afumati). This is a consequence of the reduced air humidity, which determines a low nebulosity.

3.2.3. Relative humidity. The relative humidity is the next main meteorological element analyzed, and it is very representative for highlighting the urban topoclimate's different characteristics. In the warm season, it is lower in central part because of the materials from which constructions are made (concrete, asphalt, glass) and the lower evapotranspiration values. In contrast, it is higher in the cold season due to air pollution, that leads to urban fogg formation.

The relative humidity registers a maximum value in December, with 88.4% at Filaret, and lower values at Baneasa and Afumati, of 87.8%. The higher values recorded in winter in the city centre are determined by the large number of condensation nuclei, which are a consequence of the intense car traffic and pollution (Constantin et all, 2017) and determine the occurrence of the urban fog phenomena. The minimum value is recorded in August, with the lowest value, of 66.9%, at Filaret, due to the lack of evapotranspirant surfaces (Fig. 7).

The maximum difference between the centre and periphery is 0.6%, with the highest values recorded at Filaret (88.4%) in December.

Yearly, we notice the maximum value at Filaret (76.6%), and the minimum value at Baneasa and Afumati (76.5%), the difference between the three meteorological stations is of just 0.1%.

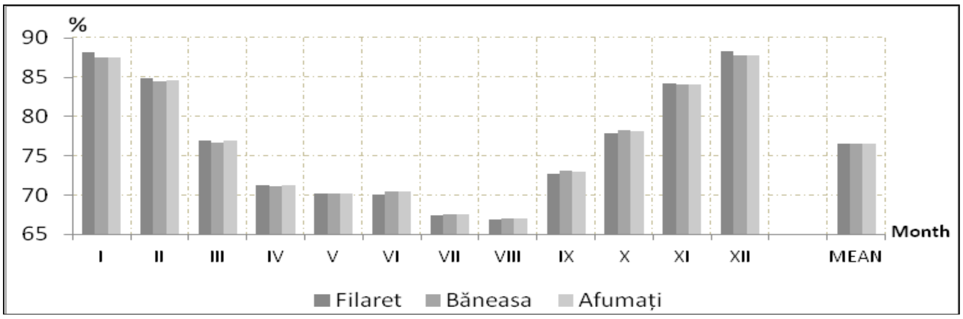

Fig. 7. Average monthly and yearly mean values of relative humidity at Filaret, Baneasa and Afumati meteorological stations for the period 1961-2013. Source: data processed, NMA 2018

3.2.4. Atmospheric precipitation. The last meteorological element taken into consideration in this study is the atmospheric precipitation. The importance of this parameter is very high, especially in the urban hydrology and rainfall water management.

The maximum monthly value is recorded in June, with values of 75.8 mm at Baneasa, 75.2 mm at Afumati and 72.9 mm at Filaret. The minimum values are reached in January, with 36.4 mm at Afumati, 37 mm at Baneasa, and with 37.5 mm at Filaret (Fig. 8-A).

The maximum difference between the stations is recorded in July, when at Afumati the quantity of precipitation is with 2.6 mm higher than at Filaret.

Yearly, the maximum values are registered at Afumati, with 589.3 mm, and the minimum values at Baneasa, with 586.1 mm (Fig. 8-B). The differences are more relevant during summer, when convective clouds are formed, which are often accompanied by showers, thunder and lightning phenomena and hail. Due to the large precipitation quantities, urban floods can occur as a consequence of the uncontrolled urban growth, which is faster than the sewing network expansion or overburden it and exeed its capacity.

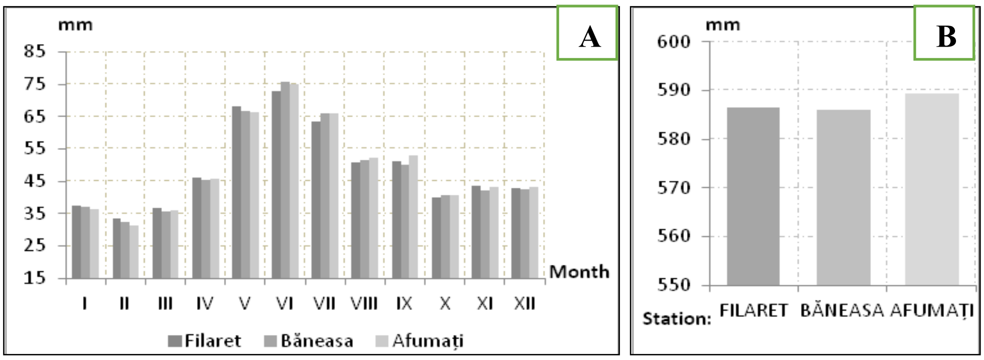

Fig. 8. Average monthly (A) and yearly mean (B) values of atmospheric precipitations at Filaret, Baneasa and Afumati meteorological stations for the period 1961-2013

Source: data processed, NMA 2018

Conclusions

Bucharest had a strong horizontal and vertical evolution of built space from 1956 to 2016. In the communist period, the growth was concentrated mainly inside the Administrative Territorial Unit, while in the 21st century it was focused on periurban development. The height regime changed, by constructing taller buildings and replacing the ones with a low rooftop height with taller apartment or office blocks and sky-scrappers.

This resulted in the creation of a different topoclimate, which is reflected through the analysis of the meteorological parameters: air temperature, average sunshine hours, relative humidity, and atmospheric precipitation.

The air temperature is higher inside the city, at the Filaret station, with 0.1ºC, than at the periphery (Baneasa station) and the periurban area (Afumati station). The highest difference is recorded in August (0.2ºC).

Average sunshine hours are higher inside the city than at the periphery, with the largest difference registered in January, of 0.8 hours (74.6 hours at Filaret, 75.4 hours at Baneasa).

The relative humidity is lower in summer and higher in winter inside the city compared to the periphery and the suburbs. Thus, in July, it reaches values of 70.1% at Filaret and 70.4% at Baneasa and Afumati, while in December higher values are recorded: of 88.4% at Filaret and of 87.8% at Baneasa and Afumati.

The built space influences the atmospheric precipitation especially in winter, when the values recorded in February at Filaret station (33.3 mm) are higher than at Baneasa (32.4 mm) and Afumati (31.3 mm). In summer (August), the atmospheric precipitation is lower at Filaret (50.8 mm) compared to Baneasa (51.6 mm) and Afumati (52.2 mm).

All things considered, the results of the analysis of the four meteorological parameters reveals the differences between the city and its surroundings, which are determined by the urban built-space expansion. The specific topoclimate which is formed has numerous side effects on human health and all socio-economic activities. Understanding its main characteristics is very important in order to know how to manage these effects, to mitigate their negative consequences and to successfully plan sustainable cities.

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