THE INFLUENCES OF LAND USE ON THE URBAN HEAT ISLAND IN BUCHAREST

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ABSTRACT. The Influences of Land Use on the Urban Heat Island in Bucharest. The aim of the paper is to investigate the contribution of different land use types on the intensification/reduction of the Urban Heat Island (UHI) in the four seasons. The study was carried out in the Bucharest metropolitan area, the capital of Romania. To analyze the land use impact on the UHI, the following stages were performed: i) it was made a land use classification in three major classes (water, green areas and built-up-areas), which in their turn were divided into other categories (water bodies, parks, forests, industrial-commercial area, low density residential area, high density residential area); ii) the Landsat satellite images were selected, from which land surface temperature was derived; iii) a basic statistical analysis was performed based on which was determined the relationship between the land use type and land surface temperature. The study results shows that the industrial-commercial areas and the high density residential areas correspond to the highest values of the land surface temperatures, thus contributing to the intensification of the UHI phenomenon, regardless of the season, while the water bodies and the forests have the lowest values of the land surface temperatures, also regardless of the season.

Keywords: UHI, Remote Sensing, Landsat, land cover, surface temperature

1. INTRODUCTION

Currently over half of the world's population lives in urban areas and the urbanization trend is increasing (DESA, 2002; Zhou et al., 2011). Excessive urbanization changes the coverage type of the Earth's surface, changing at the same time the energy balance, water balance in nature and affect the air movement (Oke, 1987), resulting in a warmer climate in the city compared with the surrounding rural areas, known as urban heat island (UHI). This phenomenon has an influence both on the comfort and health (Zhao et al., 2014), but changes other factors such as biodiversity (Li and Norfoda, 2016), air quality (Grimm et al., 2008) and consumption energy (Lowe, 2016).

UHI intensity depends on a variety of factors, including the size of the city, population density (Oke, 1973), building materials, urban traffic density and the shape and structure of buildings. It also depends heavily on weather conditions and

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wind speed, and therefore the maximum heat island intensity is obtained from measurements carried out under a clear sky and no wind (Oke, 1982).

Lately the UHI phenomenon has become increasingly studied for the Bucharest area, because like most large cities, has some higher temperatures compared to those in suburban and rural areas (Tumanov et al. 1999; Cheval et al., 2009; Cheval et al., 2015). This is mainly due to large areas of concrete and asphalt in urban areas, small areas of green spaces and water bodies and anthropogenic heat derived from road traffic and industrial areas.

In general, studies on the UHI phenomenon are made in two ways: i) by measuring air temperature at the standard height of 2 m using sensors mounted on cars (moving on transects) and measurements at meteorological stations located within the city or ii) land surface temperature (LST) obtained from remote sensing data. Unlike in situ measurements providing data with higher temporal frequency but with low spatial distribution, satellite data allow the UHI monitoring on a large scale, with better spatial coverage, allowing detection of urban areas where the phenomenon is more pronounced.

Since there are a small number of weather stations that can analyze the air temperature values, the study area is very large and there are no resources for in situ measurements, to achieve this research was selected the usage of satellite data.

2. SATELLITE DATA USED

The range of Landsat products that are generated is about 2 weeks. Depending on the satellites and their sensors on board, the periods containing data thus different: Landsat TM 4-5 from 1982 to 2011, Landsat 7 ETM (2003, there was a malfunction in the satellite sensor so that images have errors areas uncovered every scene) and Landsat 8 OLI 2013-present.

To study the thermal differentiations in the metropolitan area of Bucharest, there were used Landsat 8 images. They are more useful in achieving the proposed because they have a good spatial resolution of 30 m (compare to the 1 km MODIS, moderate resolution imaging spectroradiometer).

Temperature values used for the present study were drawn from 21 scenes, April 2013 - August 2016. Each scene represents the values of when the satellite has completed a flight over the study area, all images being made around 9:00 UTC of each day.

There were selected for analysis the images with no cloud coverage, or with cloud cover below 10%. The images were downloaded from the Glovis portal belonging to USGS (United States Geological Survey) and were processed to eliminate the errors (exaggerated values, or areas covered with clouds). The Landsat data does not contain values of air temperature, but the TIRS (Thermal Infrared Sensor) data that must be converted to at-satellite brightness temperature, however using this data can make correlations and analyzes on the evolution and variability of temperature and even can be highlight the "urban heat island" phenomenon.

3. ANALYSIS METHODOLOGY

In order to highlight the influence of land use on high temperatures and the Bucharest's heat island, the study area was divided into land use categories. These temperatures were correlated with the data obtained from the satellite.

Land use classification. The study area was divided into the following categories: water bodies, urban green spaces (parks), forest, industrial-commercial areas, continuous urban area and rural area (discontinuous urban). The result of this classification is represented graphically in Figure 1.

Classification of areas was inspired by "Urban Atlas" series data from the website of the European Environment Agency (EEA), data made by French company SIRS (Systèmes d'Information Space à Référence) within GMES/ Copernicus land monitoring services program.

Since both high-density areas and low density areas belonged to the same category (urban area), they were divided into two categories: areas with high density urban areas (blocks) and low density urban areas (houses) that were added and belonging to rural areas. The reason is the similarity between the urban house areas and rural/ suburban, the initial classification (urban-continuous and discontinuous urban areas =) being suitable rather to the Western European urban areas.

Processing of the satellite data. The Landsat data does not contain values of surface temperature, just TIRS (Thermal Infrared Sensor) data stored as DN (decimal numbers). To obtain temperature values it's necessary to use certain algorithms, so that the pixel values of satellite images (DN) will be converted to Kelvin and further to Celsius.

The formula that convert DN to TOA (Top Of Atmosphere) spectral radiance:

$L_\lambda = ML*Q_{cal} + AL$

where: L_λ = TOA spectral radiance; ML = Band-specific multiplicative rescaling factor; AL = Band-specific additive rescaling factor; Q_{cal} = Quantized and calibrated standard product pixel values.

The formula that convert brightness temperature from spectral radiance:

$TB=K2/[\ln(K1/ L_\lambda)+1]$

where: TB = at-satellite brightness temperature, in Kelvin degrees; L_λ = TOA spectral radiance (Watts/(m^2 *sr * μm)); K1, K2 = Band-specific thermal conversion constant (L10, L11) (source: http://landsat.usgs.gov/).

The formula that convert brightness temperature to land surface temperature (Weng, et al. 2004):

$T=TB/[1+(\lambda*TB/c2)*\ln(e)]$

where: λ = wavelength of emitted radiance; $c2=h*c/s=1.4388*10^{-2}$m K

h = Planck's constant = $6.626*10^{-34}$ J s; s = Boltzmann constant = $1.38*10^{-23}$J/K; c = velocity of light = $2.998*10^{8}$ m/s; e = emissivity, where emissivity was estimated using NDVI from Table 1 (Liu and Zhang, 2011).

Table 1. ***Estimation of emissivity using NDVI***

NDVI	Land surface emissivity (e)
NDVI < −0.185	0.995
−0.185 ≤ NDVI < 0.157	0.97
0.157 ≤ NDVI ≤ 0.727	1.0094 + 0.047 ln (NDVI)
NDVI > 0.727	0.99

Where NDVI (normalized difference vegetation index) is:
NDVI = (NIR - R) / (NIR + R); NIR= band5; R = band4.

4. RESULTS AND DISCUSSIONS

The study regarding the relationship between land use and higher temperatures values in Bucharest area was performed over a space of 30 x 30 km, which falls as central agglomeration. The land use categories used in the study occupies 533 km^2 from the total analyzed area of 900 km^2.

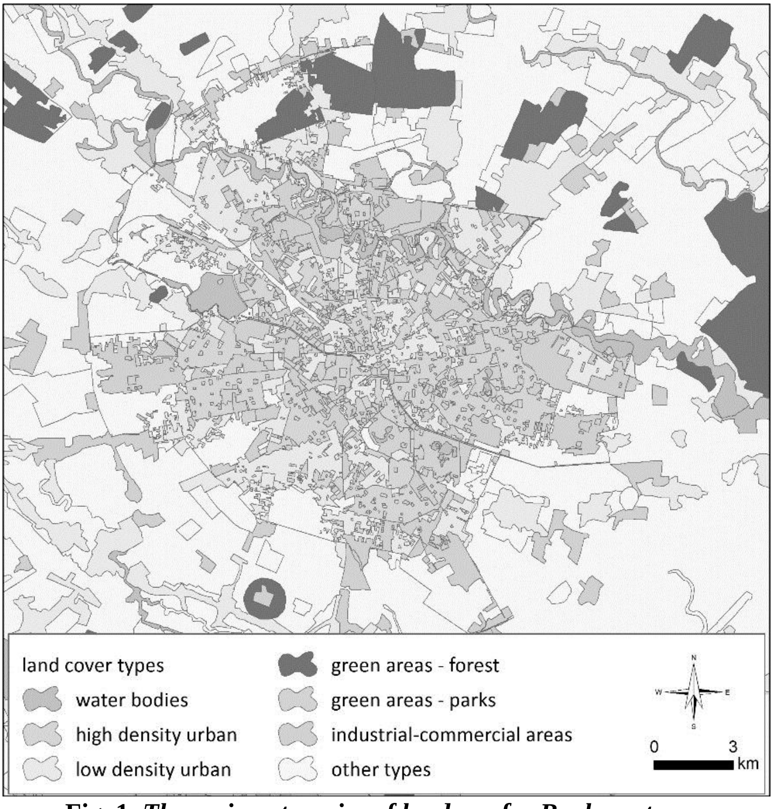

Fig. 1. ***The main categories of land use for Bucharest area***

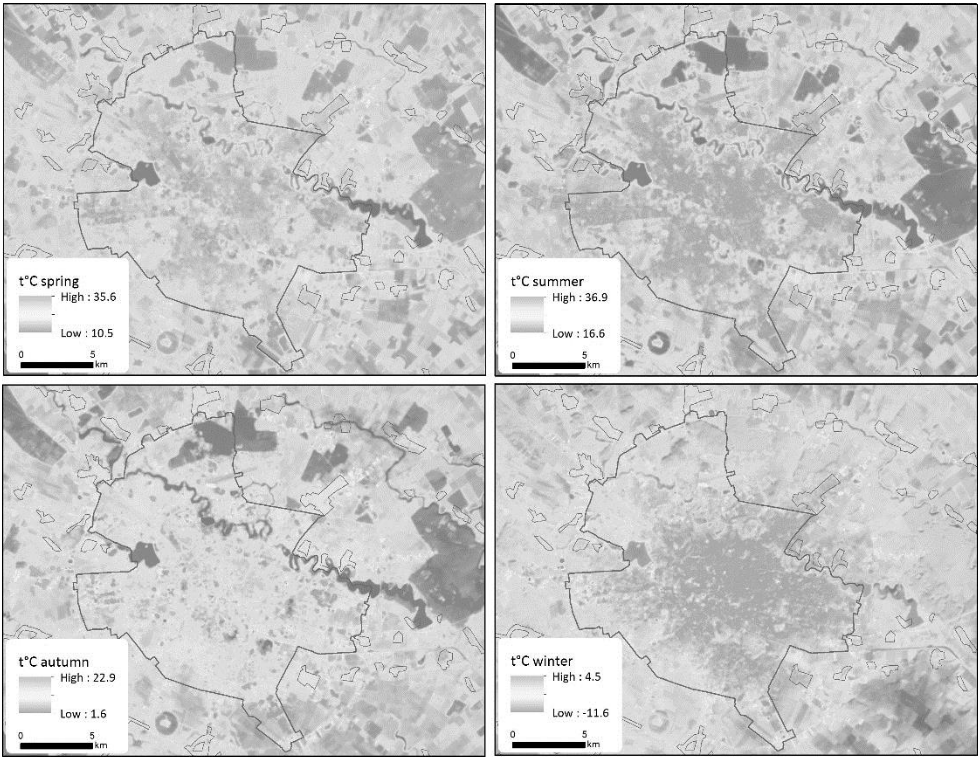

Fig. 2. ***The land surface temperature for the 4 seasons***

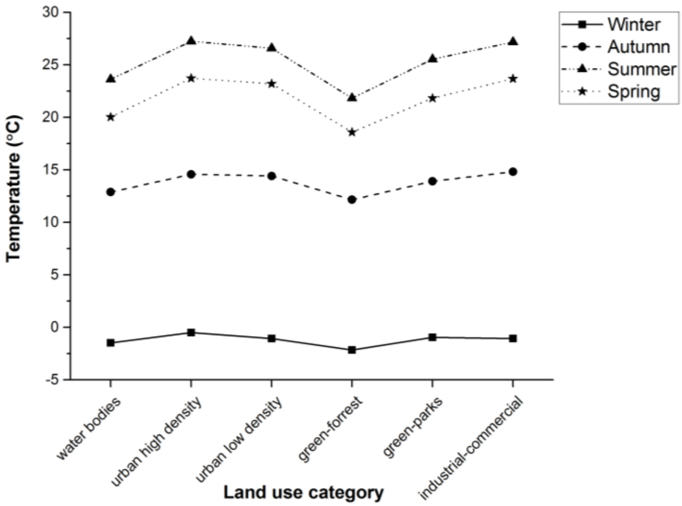

Fig. 3. ***The land surface temperature for the 4 seasons***

It is noted that in all seasons, green areas and water bodies have the lowest values of surface temperature than the rest of types from the studied area, because under the incidence of solar radiation, the water warms more slowly than the rest of the land, and for the areas with green spaces consisting of large and dense trees the radiation is reflected in a higher proportion than in the other types of land. In addition, the trees offer shade and thus generates lower temperatures. Compared to built-up areas (residential and industrial), which have the highest temperature values at surface, green spaces and water bodies act as "islands of coolness". The latter represent areas with very low values of temperature relative to surrounding areas, and having the role of controlling the "urban heat island" phenomenon.

The main areas with high temperatures values recorded at ground level are industrial areas and densely residential buildings. Industrial platforms have the disadvantage of generating heat due to large surfaces occupied and materials they are made (especially concrete).

Regardless of season the highest values recorded at ground level are in built-up areas such as residential areas and industrial-commercial. (Figure 3), all 3 categories with close values (for summer the highest values belong to industrial-commercial areas = + 27.2 °C while the lowest values are for the areas are covered with forests = + 21.8 °C). Instead for the cold season, the highest values belong to urban areas with high density (only -0.5 °C compared to forest areas = -2.1 °C or to the industrial areas = -1.1 °C) one explanation is that the homes are heated during winter.

5. CONCLUSIONS

Satellite data can be successfully used for the analysis and monitoring of the "urban heat island" phenomenon. Even with some shortcomings (can be influenced by water vapor in the atmosphere, soil moisture, air temperature, wind effects, diversity of materials in a scene, topographic irregularities and especially clouds coverage), they offer the advantage of allowing study of large areas at a good spatial resolution and can be generated according to the desired product.

The study showed that the commercial and industrial areas are correlated with high temperatures values in the area of Bucharest. Also, an obvious influence on high temperatures, they have the residential areas with high density of buildings, which have a large area expansion. From the classification of land use it was observed that green spaces occupy a very small percentage of the city area. The study carried out on Bucharest highlights that the green areas and water bodies correlates with the lowest temperatures from the analyzed area, therefore we can affirm that they serve the role to combat the "urban heat island" phenomenon and it would be necessary to extend the areas occupied by them.

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