THE ASSESSMENT RELATIONSHIP BETWEEN LAND SURFACE TEMPERATURE (LST) AND BUILT-UP AREA IN URBAN AGGLOMERATION. CASE STUDY: CLUJ-NAPOCA, ROMANIA

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ABSTRACT:

The built-up area in many large cities has shown a continuous growth during the last decades. In the present study we aimed to evaluate the connection between Land Surface Temperature and built-up areas within the urban areas, based on statistical correlation. Experiments were performed in the surrounding area of Cluj-Napoca – one of the most dynamic urban agglomerations of Romania – in order to determine LST and built-up areas during the period 2007-2015. Detection of changes in land cover and in Land Surface Temperature was possible using Landsat satellite imagery. The extraction of the built-up area was achieved by using the Maximum Likelihood classification method, and for estimation of Land Surface Temperature (LST) we have used the single channel algorithm. Investigations of the degree of dependence between LST and built-up area revealed a direct statistical relationship between the two analyzed variables. Results have shown that areas with LST higher than 35°C generally coincide with large hypermarkets and industrial areas of the city. Satellite imagery proved to be an important source of data in detecting changes in surface of the urban area and in estimating temperature from the land surface during the reference period.

Key-words: *Land Surface Temperature, Built-up area, Pearson correlation, Cluj-Napoca (Romania).*

1. INTRODUCTION

In most big cities built-up surfaces have increased continuously in recent decades. Since 1989, following the change of political regime in Central and Eastern Europe, a general tendency of spatial dispersion could be observed in population and economy (suburbanization). This tendency was felt in the city of Cluj-Napoca as well, where the functional structure of the city went through considerable changes: after the intense period of socialist industrialization, the residential and commercial areas dramatically expanded in a short period of time. As a consequence, over the past two and a half decades we have witnessed a dramatic change in land use within the city and its adjacent suburban areas. These changes in land cover are manifested by Land Surface Temperature increase. The main objective of this study is to evaluate the connection between built-up areas and surface temperature within an urban agglomeration.

Built-up areas in Cluj-Napoca have grown significantly lately. Currently 95% of the housing stock in Cluj-Napoca is privately owned, compared to the 25% in 1989. This means that a considerable housing market has been developed which defines the dynamics of the residential zones. The radical change in the ownership structure influenced the

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dominant models of land use. During the transition period the real estate prices and rents increased and differentiated according to the physical conditions of the housing stock, the quality of the services and the social standing and prestige of the neighborhoods. However, the real estate development in Cluj-Napoca couldn't keep the pace with the increasing intensity of in-migration, fuelled by the strong development of the local economy. As a consequence, three suburban settlements (Floreşti, Baciu, Apahida) of Cluj-Napoca became attractive for housing and registered an important increase in population and built-up area (Benedek et al, 2013). In turn, the suburbanization of the population and the concentration of the workplaces in Cluj-Napoca have increased commuting to work, which has led to intensifying emissions and traffic jams (Benedek et al, 2016).

On the basis of these changes regarding land cover, in the present study, we aimed to evaluate the connection between the built-up areas and surface temperature in Cluj-Napoca municipality, in the period 2007-2015. Similar studies to measure the relationship between built-up areas and LST were carried out by Afrakhteh et al (2016). For detecting land cover type for the reference period we have used satellite imagery of medium resolution (Landsat TM/OLI). Satellite images were the basis for identification of built-up areas and LST during the reference period, for the studied urban areas.

Land Surface Temperature (LST) estimations using Landsat data in an urban area were made by Walawender et al (2014), who determined hot and cold points of the Land Surface Temperature for the city Krakow in Poland. Majumdara & Biswasb (2016) analyzed spatio-temporal changes of LST and delineated thermal provinces in the urban agglomeration of Calcutta (India) during 2001-2013. Besides Landsat data, LST can be also estimated using MODIS or ASTER satellite data. LST estimation based on MODIS data were made by Ma et al (2016) for studying the effect of the urban heat island in Shanghai, China. Another research made by Yang et al (2016) estimated LST using combined MODIS and ASTER datasets.

In Romania LST estimations in an urban area were made by Imbroane et al (2014), based on Landsat satellite images, for the city Cluj-Napoca, and by Herbel et al (2016), who have been detecting atmospheric urban heat islands. Likewise, in regards to detecting atmospheric urban heat islands based on Modis satellite images we can mention Apostol et al, (2012) for the municipality of Iasi and Cheval & Dumitrescu (2009, 2015) for Bucharest.

The present study whishes to analyze the connection between the increase of built-up areas and Land Surface Temperature (LST) within an agglomerated urban area. This research is among the few studies carried out worldwide and the first one in Romania which demonstrates that increasing built-up area directly lead to increasing Land Surface Temperature in an urban area.

2. STUDY AREA AND DATA

In the present study we have chosen the city of Cluj-Napoca as our study area, with a population of 321 687 people (INS, 2016), the second largest city and one of the major urban centers from economic point of view in Romania.

In order to capture the spatial dynamics of the vicinity of the municipality of Cluj-Napoca, we analyzed, in the present study, an area covered within a radius of 10 km from center of the city (**Fig. 1**).

In the present study we used both remote sensing and meteorological data. The data obtained by remote sensing was used in the extraction of the built-up area and to identify areas with elevated Land Surface Temperature values. The meteorological data was used in the calculation of Land Surface Temperature (LST).

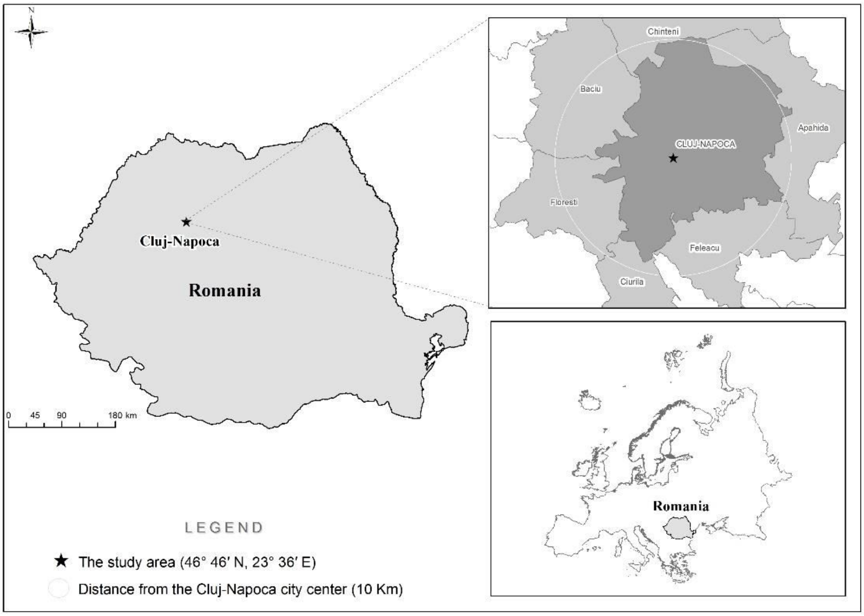

Fig. 1. Location of the study area *(Source: authors).*

The estimation of LST and of built-up areas in one of the most dynamic urban agglomerations in Romania was possible by using Landsat satellite images, of medium resolution (30m). These were carefully chosen, with no clouds or fog within the perimeter of the study area, for our reference period (**Table 1**). Landsat satellite images were used in the calculations due to their large archive which allowed to select images captured in the same month for each individual year. We chose August as the month of the analysis because it had the most satisfactory images available for each year included in the study.

Table 1.

Characteristics of Landsat satellite images used within the present study.

Landsat scene	Date	Scene center scan time (UTC)	Sun azimuth (°)	Sun elevation (°)
Landsat 5 TM	Aug 2, 2007	9:08:12	142.5	55.6
Landsat 5 TM	Aug 23, 2009	9:04:08	146.7	49.7
Landsat 5 TM	Aug 22, 2011	8:57:42	144.4	51
Landsat 8 OLI_TIRS	Aug 14, 2014	9:08:59	146.1	54.4
Landsat 8 OLI_TIRS	Aug 8, 2015	9:14:20	146.3	54.8

(Source: authors)

For Land Surface Temperature determination a series of meteorological data were necessary (temperature, pressure and humidity), data corresponding to the schedule in which the satellite images were captured. Meteorological data was obtained from the INFOCLIMATE database (InfoClimat, 2016), for Cluj-Napoca meteorological station.

3. METHODOLOGY

3.1.Land Surface Temperature (LST)

The basis of Land Surface Temperature (LST) estimation within the present study was a single channel algorithm. LST was estimated based on Landsat satellite images, as follows:

- *Sensor spectral radiance* (L_S) *determination*

Conversion of DN values to absolute radiance assumed converting pixel values (Digital Number – DN) of the thermal band of Landsat images (B6 for Landsat 5 and B10 for Landsat 8) in sensor spectral radiance (L_S) based on the formula (Walawender et al, 2012; Kumar & Shekhar, 2015):

$$L_S = gain * DN + bias \tag{1}$$

Where, for Landsat 5 gain conversion coefficients were used = 0.055376, bias = 1.18, and for Landsat 8 gain = 0.0003342, bias = 0.1 (Walawender et al, 2012).

- *Sensor Brightness temperature (T_S) determination*

For sensor spectral radiance (Ls) transformation into sensor brightness temperature (Ts) Planck's Law was applied invertedly and calibration constants for Landsat 5 K1 = 607.76, K2 = 1260.56, ln = 11.457, and for Landsat 8 K1 = 774.89, K2 = 1321.08, ln = 10.904, based on the formula (Walawender et al, 2012; Kumar & Shekhar, 2015):

$$T_S = \frac{K_2}{\ln\left(\frac{K_1}{L_S} + 1\right)} \tag{2}$$

- *Land Surface Emissivity (LSE) determination*

This was calculated on the basis of the NDVI index. For Landsat 5 this was determined by using bands B3 (Red) and B4 (NIR), and for Landsat 8, bands B4 (Red) and B5 (NIR).

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \tag{3}$$

Subsequently NDVI values were transformed in Land Surface Emissivity (LSE), by using the emissivity values: 0.96 for soil, 0.99 for vegetation, and 0.995 for water. (Walawender et al, 2012).

- *Land Surface Temperature* (LST) was estimated by using previously resulted entry data: Sensor spectral radiance (L_S), Sensor brightness temperature (T_S) and Land Surface Emissivity (LSE), respectively atmospheric parameters: atmospheric transmissivity, up-welling atmospheric radiance and down-welling atmospheric radiance. These parameters were determined with the help of a tool named *Atmospheric Correction Parameter Calculator (ACPC)* (Barsi et al, 2003).

Land Surface Temperature (LST) was estimated based on the formula (Walawender et al, 2012):

$$LST = \gamma\left[\frac{1}{\varepsilon}\left(\psi_1 L_S + \psi_2\right) + \psi_3\right] + \delta \quad (4)$$

where, ε - Land Surface Emissivity (LSE)

L_S - sensor spectral radiance

ψ_1, ψ_2, ψ_3 - represent atmospheric functions calculated on the basis of the three atmospheric parameters (atmospheric transmissivity, up-welling atmospheric radiance and down-welling atmospheric radiance) (**Table 2**).

Table 2.

Atmospheric parameters.

Year	Atmospheric transmissivity	Up-welling atmospheric radiance	Down-welling atmospheric radiance
2007	0.82	1.32	2.17
2009	0.61	2.79	4.37
2011	0.67	2.48	3.92
2014	0.66	2.93	4.64
2015	0.87	1.05	1.9

(Source: authors)

γ and δ are dependent parameters estimated based on the formula (Walawender et al, 2012):

$$\gamma = \left\{\frac{c_2 L_s}{T_s^2}\left[\frac{\lambda^4 L_S}{c_1} + \frac{1}{\lambda}\right]\right\}^{-1} \quad (5)$$

$$\delta = -\gamma \times L_S + T_S \quad (6)$$

where, c_2 and c_1 represent Planck's constant radiation c_1 (1.19104 10^8 W µm^{-4} m^{-2} sr^{-1}) and c_2 (1.4387710^4 µm K), and γ represents the wavelength of the thermal band (Walawender et al, 2012).

Land Surface Temperature estimation (LST) based on Landsat satellite imagery was achieved by the use of the tool developed by Walawender et al (2012), named Landsat TRS toolbox within the program ArcGIS 10.2.

3.2. Built-up area

The expansion of the built-up areas in the urban zones lead to increased impervious surfaces, decreasing areas with green spaces and reducing the volume of the drained water.

We extracted built-up areas to investigate the consequences induced by the growth of these areas on Land Surface Temperature change.

In the present study all built-up areas were extracted based on Landsat satellite images. Before applying a method for the extraction of built-up areas, Landsat satellite images have undergone calibrations in the program ENVI 5.1. Thus, DN values (Digital Number) were converted in TOA (Top of Atmosphere) reflectance, and then in surface reflectance using Dark Object Subtraction (DOS), in order to obtain accurate image from atmospheric perspective (Ivan, 2015).

The converted images in surface reflectance (DOS) were subject to a supervised classification. Images were classified using the Maximum Likelihood classification method (Brigante & Radicioni, 2014) on the basis of five sample classes: built-up areas, vegetation, soil, water and forest. In the classification of the images bands 1-5 and 7 were used (Zhang et al, 2014) for Landsat 5 and bands 2-7 for Landsat 8 (Haidu & Ivan, 2016). The validation of the results was carried out based on 100 control points, using the Google Satellite archive imagery, and results of the validation revealed a good precision of the classification process, confirmed by the high accuracy values of over 90%.

3.3. Statistical correlation

The majority of the studies carried out over time on urban areas, were only focused on analyzing the spatial or temporal evolution of the built-up areas or only on Land Surface Temperature determination. In the present study we wanted to examine the relation between these two variables, the built-up area and Land Surface Temperature (LST), wanting to see if there is or no a direct connection between them. Researching the relation between these two variables was made possible by using statistical correlation.

Statistical correlation formed the basis of research for the connection between areas with different LST values and areas occupied by built-up areas. The determination of linear intensity between the two variables, LST and built-up areas was calculated based on the Pearson correlation coefficient (r) using the formula (Lee & Wong, 2001; Ivan et al, 2015):

$$r = \frac{\frac{\sum_{i=1}^{n} xiyi}{n} - \overline{X} \bullet \overline{Y}}{SxSy} \tag{7}$$

Where,

$\overline{X}$ and $\overline{Y}$ is the average of x and y

S_x and S_y is the standard deviation of x and y, calculated according to the formulas (Lee & Wong, 2001; Ivan et al, 2015):

$$Sx = \sqrt{\frac{\sum_{n=1}^{n} x^2}{n} - \overline{X}^2}, \quad Sy = \sqrt{\frac{\sum_{n=1}^{n} y^2}{n} - \overline{Y}^2} \tag{8}$$

4. RESULTS AND DISCUSSIONS

Built-up areas in the analyzed study area (Cluj-Napoca and its peripheral areas) have shown a remarkable growth in the southeastern part, more precisely in the locality of Floreşti, as well as in the eastern part, in the proximity of Cluj-Napoca airport, during the study period.

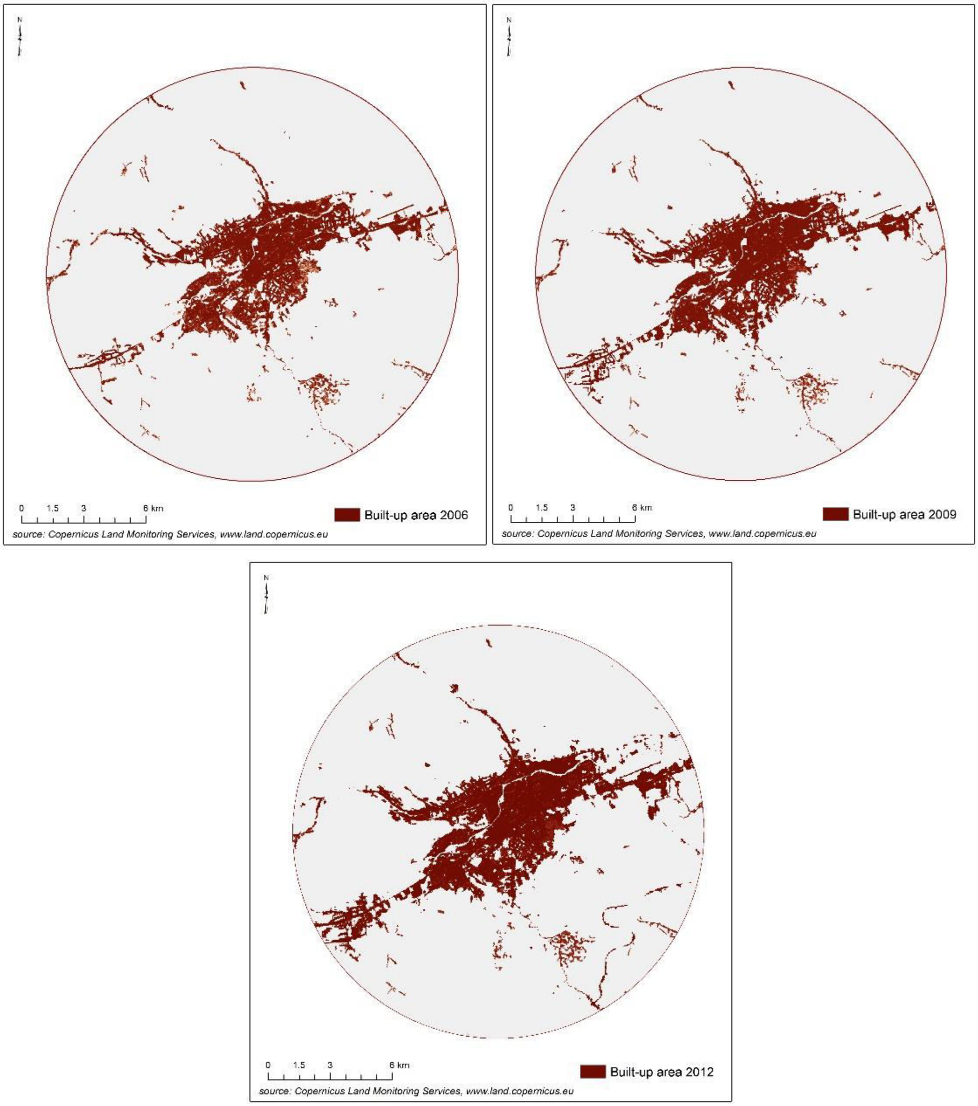

Fig. 2. Ilustration of built-up areas in 2006, 2009 and 2012 in the study area (*data: Copernicus Land Monitoring Services, 2016; source: authors).*

Built-up areas in Floreşti increased along with population growth and due to the lower prices in real estate compared to Cluj-Napoca. Concerning the area of the airport, the dynamics of the built-up areas is due to the growth of residential areas and due to the modernizations of the Cluj-Napoca airport. In the southern and northern parts of the city built-up areas presented a more moderate growth in the study period. In order to have an overview of the spatial dynamics of built-up areas from 2006 to 2012 in the analyzed study area, we used the Copernicus Land database (Copernicus Land Monitoring Services, 2016) in order to illustrate built-up areas from the years 2006, 2009 and 2012 (**Fig. 2**). **Fig. 2** shows a dynamics of the built-up areas in Floreşti locality and the proximity of the Cluj-Napoca airport in the period 2006-2012.

In order to analyze the relationship between the growth of built-up areas and the growth of land surface (LST), we established three categories of temperatures: higher 35°C, 38°C and 40°C (**Fig.3**). These temperatures were extracted from raster data, obtained after the calculation of LST.

The research of the relationship between the areas occupied by LST > 35°C, LST > 38°C, LST > 40°C and built-up areas for each of the analyzed years 2007, 2009, 2011, 2014 and 2015, was carried out based on statistical correlation. Results have revealed a Pearson correlation coefficient of over 0.80 for each temperature category in part (**Table. 3**).

Table 3 shows a decrease in the Pearson correlation coefficient from 0.87 to 0.84, along with the increase of temperature at surface level. This drop is due to the decrease of surfaces along with the increase of temperature. Areas occupied by LST > 35°C are more extensive in the study area as those of LST > 40°C.

Table 3.

Pearson correlation between areas with different LST values and built-up areas.

Pearson value between:	Area with LST > 35°C	Area with LST > 38°C	Area with LST > 40°C
Built-up area	0.87	0.85	0.84

(Source: authors)

For an overall picture, in **Fig. 3.** we illustrated the areas which showed LST > 35°C, LST > 38°C and LST > 40°C in all reference years.

It is obvious that areas with temperatures higher than 35°C in all years of the study period generally correspond to large commercial areas such as Polus Center (commercial center), Metro and Cora hypermarkets in the southwestern part of the city. In the northwestern part of the city areas with LST > 35°C are within the Western Industrial Zone and Lidl store, Dedeman store, Liberty Technology Park and nearby industrial areas in the north. In the northwestern and eastern parts these areas are mainly the industrial zones, and hypermarkets such as Kaufland, Lidl, Selgros, Transilvania Logistic Park, respectively Sanex. An area of LST > 35°C can be found in the center of the city as well.

Areas of LST > 38°C are a little more reduced in size. We can find such an area in the southwestern part of the city, in the neighborhoods' of Polus Center (commercial center) and of Cora hypermarket, in the northern part near Dedeman store, Liberty Technology Park and nearby industrial areas, while in the east of the city near the Transilvania Logistic Park, and Sanex.

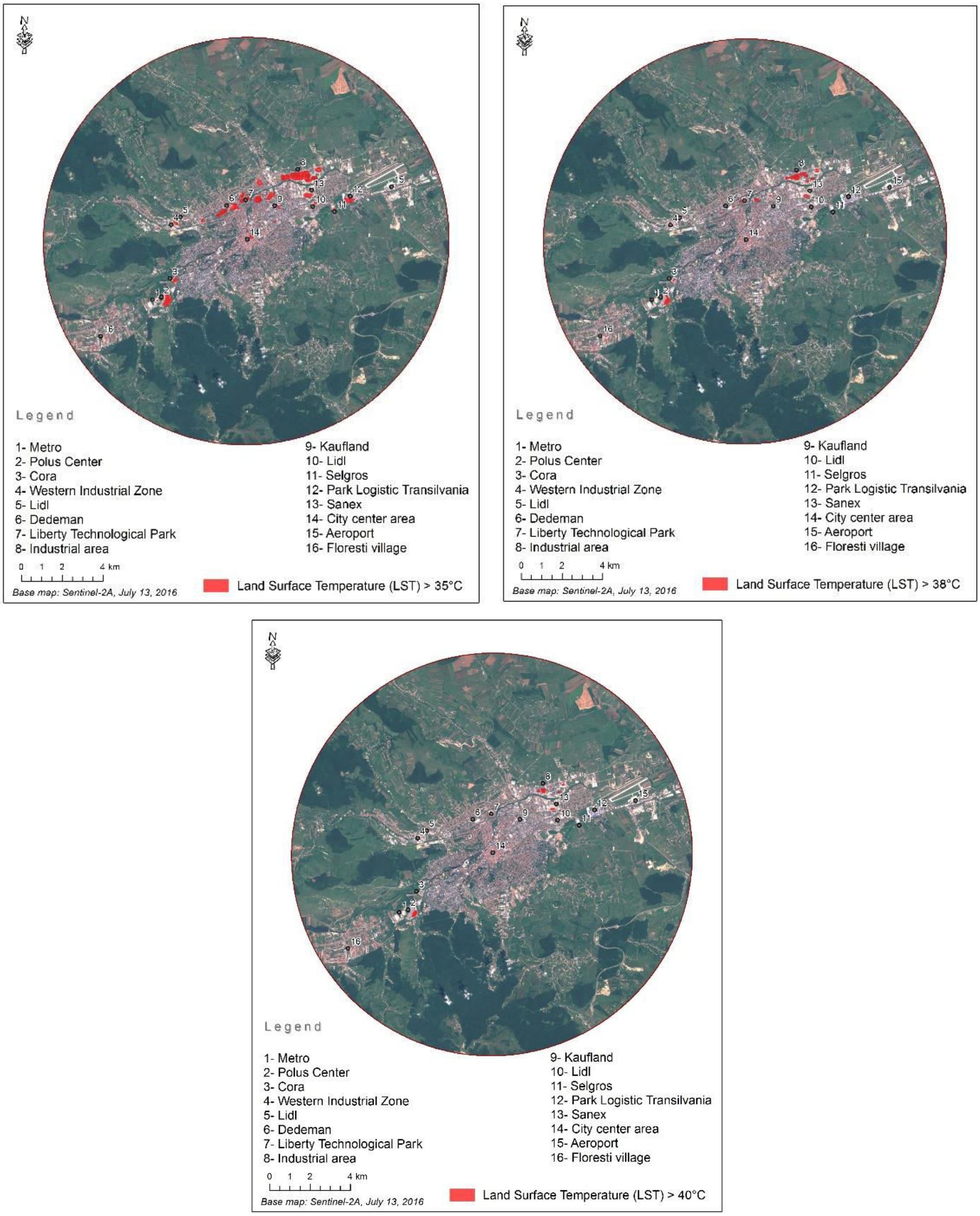

Fig. 3. The areas with LST > 35°C, LST > 38°C and LST > 40°C in the period between 2007- 2015 *(Source: authors).*

As to areas with LST > 40°C these are even more reduced in size and can be found only in the neighborhoods of the Polus Commercial Center and of the industrial areas in the northeastern part of the municipality Cluj-Napoca.

It can be observed that the most extensive areas with LST > 35°C, LST > 38°C and LST > 40°C are located in the northeastern part of the city, these results being in line with the direct observations made by Herbel et al (2016) who have shown that the hottest places are located in the eastern half of Cluj-Napoca municipality.

5. CONCLUSIONS

Landsat satellite imagery proved to be an important source in extracting built-up areas and in estimating Land Surface Temperature (LST) within urban areas. During the reference period of 2007-2015 built-up areas have shown a remarkable growth in the locality Floresti, located in the western part of the study area and in the vicinity of Cluj-Napoca airport, in the eastern part. During the analyzed study period areas with LST > 35 °C broadly coincided with large commercial areas of Cluj-Napoca (Polus Center) and with the industrial areas located in the northeastern parts of the city. The research of the statistical relationship between built-up areas and different values of the LST have shown a direct statistical relation between the two variables, with a Pearson correlation coefficient of over 0.80 for all the years of the reference period. These results prove the fact that, one of the predisposing factors of Land Surface Temperature growth is the concentration of commercial and industrial activities in Cluj-Napoca municipality.

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