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Study of urban heat islands through first-order models. Case study - Galati and Braila counties area

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Abstract
The urban heat island is the phenomenon by which cities become suggestively hotter due to the absorption and holding of heat by built issues. The study of urban heat islands is a present subject in Romania as well. In this paper, we present a procedure for noticing climate change using extreme values of air temperature by using first order model. The modeling urban heat islands (UHI) was achieved by using ArcGIS tools. In the case of this paper, we conducted a data collection covering the period 2017-2024, regarding the temperature in 8 monitoring stations of National Air Quality Network (.calitateaer.ro): Gl-2, GL-3, GL-4, BR-2, BR-3, BR-4, GL-5 and BR-5. The used algorithm includes: multivariate analysis - based on the ANOVA method, clustering - to group the stations according to thermal behavior. Using spatial interpolation procedures based on methods such as IDW or Kriging to create thermal maps, we managed to obtain a zonal classification.

Keywords: Heat islands, UHI index, statistical analysis, GIS

1. INTRODUCTION

Expansion of urban cities implies a very multilayered action on the climate, both through the appearance of artificial issues and through changes in energy flows at ground level [1]. The study of urban heat islands is a current topic in the world and particularly in Romania [2], especially in the context of climate change. Strictly speaking, urban heat islands (UHI) represent urban areas where the temperature is meaningfully higher than in neighboring rural areas, due to build shells (concrete, asphalt, etc.), lack of vegetation and human activities [3].

2. EXPERIMENTAL

In general, in the literature, two methods have been developed to assess the intensity of UHI [4]. First, UHI can be counted by cross-sectional measurements across the city, considering the temperature values in the center of city being compared with those in adjacent rural areas [1-4]. Second, UHI can be quantified by remote sensing. In this paper we used the first approach strategy.

As it is known, the temperature in urban areas can be higher than in rural areas in any season, but the most significant impact happens in the summer season, when urban heating (UHI) amplifies the natural warming of the atmosphere, leading to serious consequences for the lives of the urban population. This paper presents a study on heat islands in the south-eastern area of Romania [5] considering two adjacent counties: Galati County and Braila County. We considered two time intervals 01.05.2017 - 30.10.2017 and 01.05.2024 - 30.10.2024, respectively, with a measurement resolution of 1 hour. In practice, temperatures were collected from the National Network, considering exactly 4370 records for each data set. The marked station (Gl-3* and BR-3*) are urban monitoring gauging points used to compare urban temperature values.

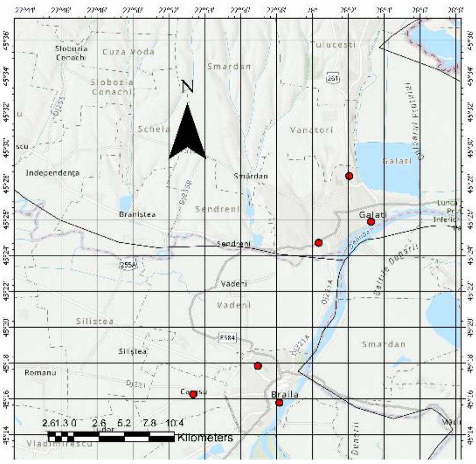

Table 1- The monitoring stations list

Coordinates of monitoring stations.

name	**Longitude**	**Latitude**
BR-2	27.96951	45.26314
BR-3*	27.88921	45.27087
BR-4	27.94946	45.29733
GL-2	28.05474	45.43154
GL-3*	28.03441	45.47416
GL-4	28.00597	45.41187
GL-5	27.43959	45.81826

Fig. 1. The study area and the monitoring station.

3. RESULTS AND DISCUSSION

The monitoring stations are described in Table 1 and the position map in Fig.1. In Figure 2 and 3 are presented de diurnal variations for the 8 monitoring stations.

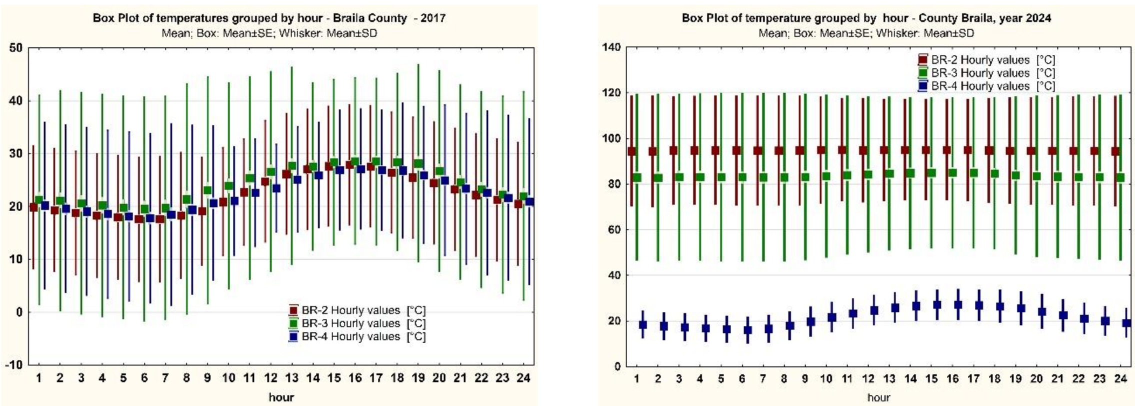

Fig. 2. Boxplot of diurnal variations Braila County stations: (a) year 2017 (a) year 2024.

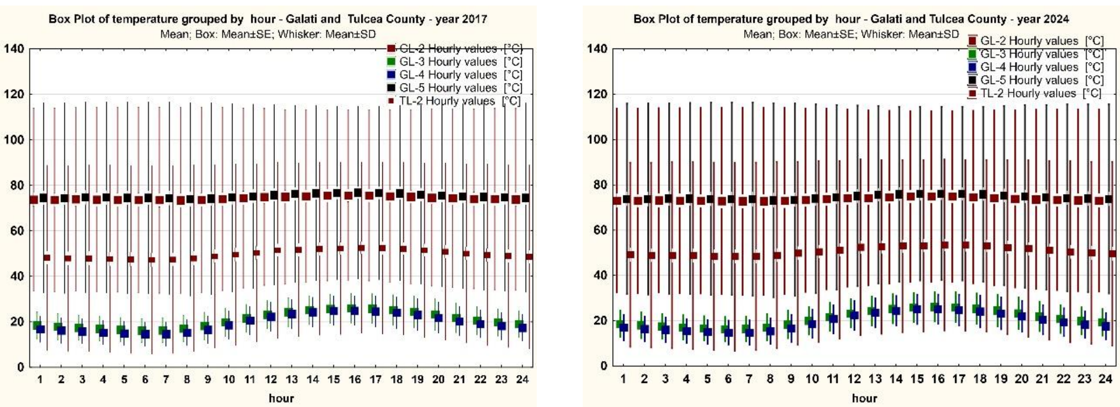

Fig. 3. Boxplot of diurnal variations Galati County stations: (a) year 2017 (a) year 2024.

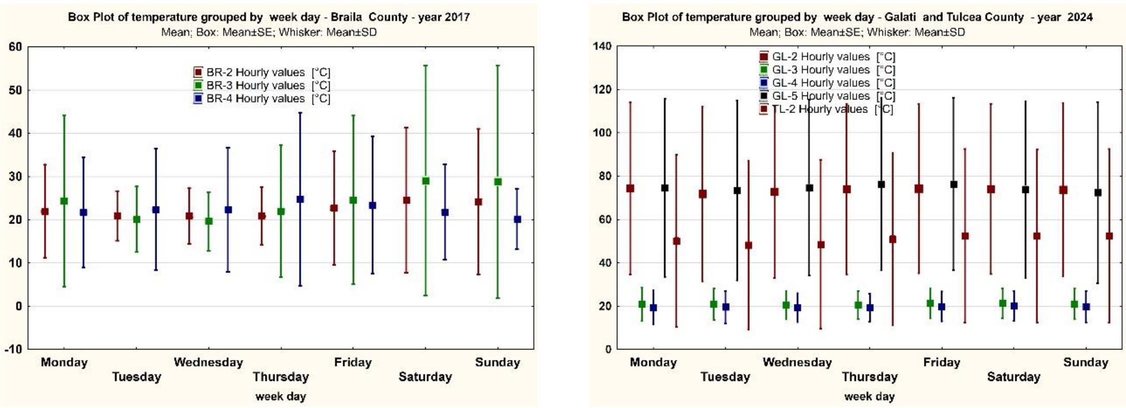

Fig. 4. Boxplot of week days variations Braila County stations: (a) year 2017 (a) year 2024.

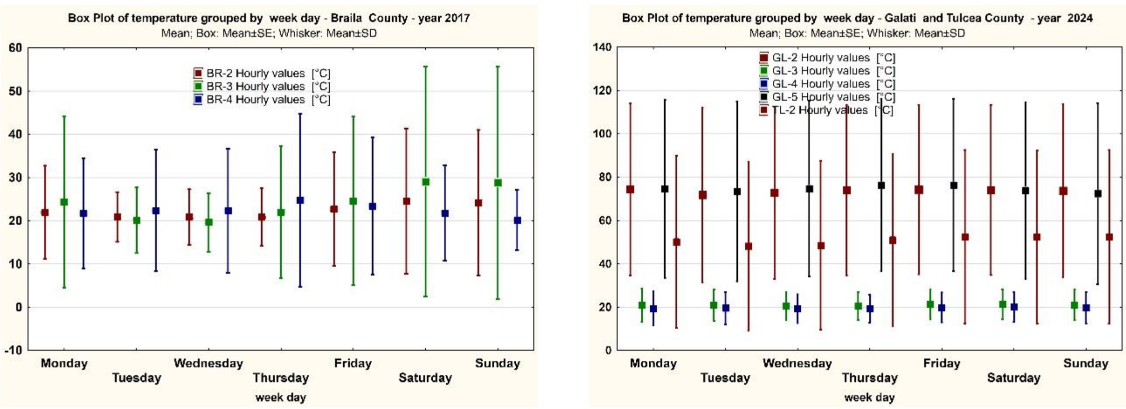

Fig. 5. Boxplot of week days variations Braila County stations: (a) year 2017 (a) year 2024.

In Figure 2 and Figure 3 for the diurnal temperature variations in the monitoring stations, are presented significant variations mainly for the GL-3 and BR-3 reference monitoring points. The variations for these monitoring points are, in all cases, significant, and the ANOVA analysis showed confidence levels of $p<0.01$. In Figure 4 and Figure 5 are Boxplot representations for the week days' temperature variations in the considered monitoring stations. The variations are in all cases significant, the ANOVA analysis shows confidence levels $p<0.01$ especially for BR-2, BR-3, BR-4 and GL-3 stations.

In the second part, a numerical approach was considered. We used a first-order model to evaluate the urban heat island index [4-5] -UHII using the definition relation as [1]:

$$UHII_{thsh}(DH) = \{UHII'_{thsh} - \delta_{thsh}\} \times CF_p \times\times CF_{tp} \qquad (1)$$

Or, equivalent, by using relation (2):

$$UHII = \sum_{h=1}^{H(JJA)} \left[\mathrm{T}_{u,k,h} - \min\left(\mathrm{T}_{u,k,h}, \mathrm{T}_{nu,k,h}\right)\right] \qquad (2)$$

where $T_{u,k,h}$ is the urban temperature at time-step h, $T_{nu,k,h}$ is the nonurban temperature at time-step h, H is the number of time-steps, and k is the location index (census tract) [2]. The calculation yields a cumulative UHII (in degree-hours) over designated periods [3-5].

Figures 5 and 6 present the distributions of the average temperature obtained from the considered database records. The interpolation used method ArcGIS procedure - Inverse Distance Weighted (IDW) interpolation - technique often used in the literature [2, 4, 5].

From the literature, it is known that the Inverse distance weighted (IDW) interpolation is a spatial analysis technique that estimates unknown values based on the assumption that closer known points are more similar than farther ones [1]. It calculates a value for an unknown location [3] by taking a weighted average of nearby known points, where the weights are inversely proportional to the distance from the unknown point, often raised to a power [4].

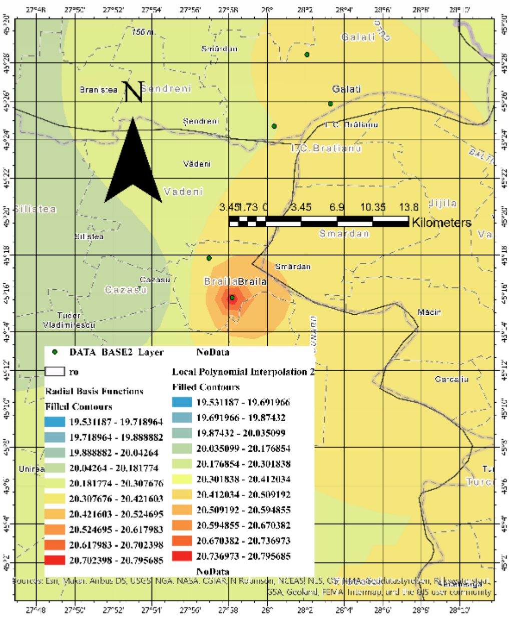

Fig. 5. temperature distribution – year 2017.

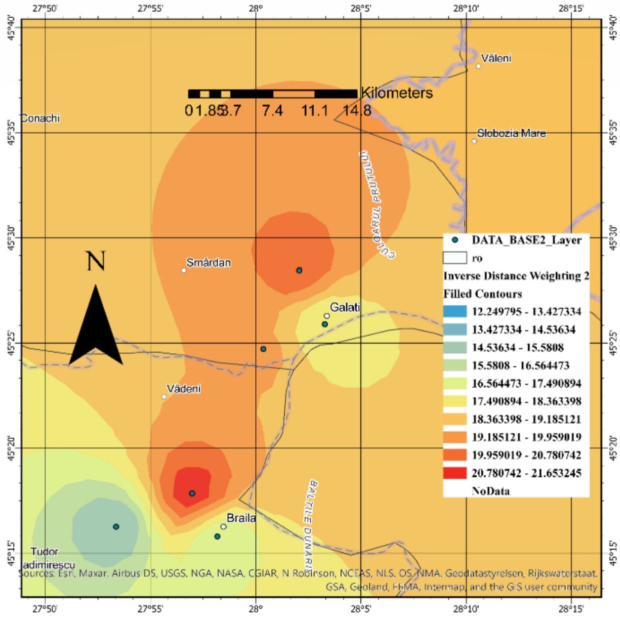

Fig. 6. temperature distribution – year 2024.

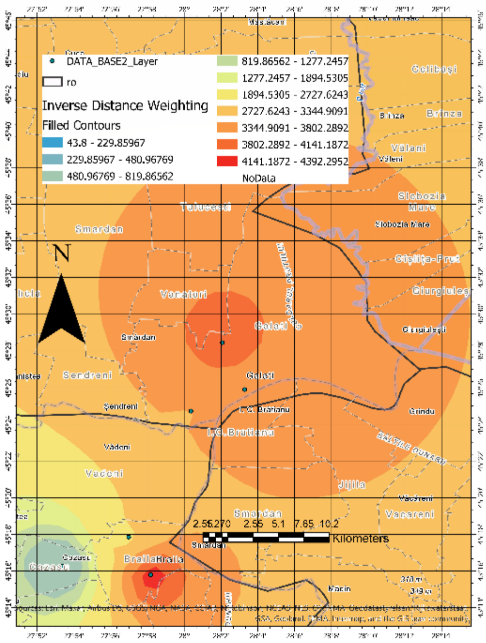

Fig. 7. UHII distribution – year 2017

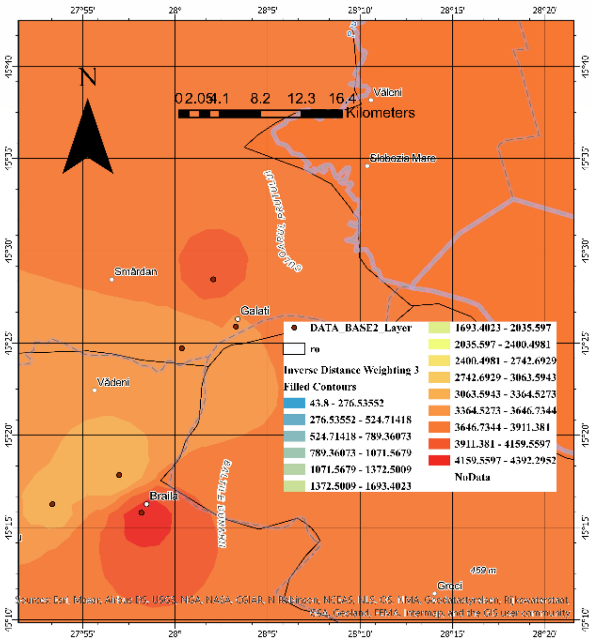

Fig. 8. UHII distribution – year 2024

By comparing the two maps for UHII, a significant difference could be recognized, with significantly increased values in the period May - October 2024 compared to the corresponding period in 2017 (Fig. 7 and Fig. 8).

It could be easily observed that, if in 2017, in the central area of Galati city, the UHII index had a maximum value of over 3300. In 2024, in the central areas of Galati and Braila city, the UHII index exceeded the value of 3600. This represents an increase in the urban thermal stress factor, as can be easily observed.

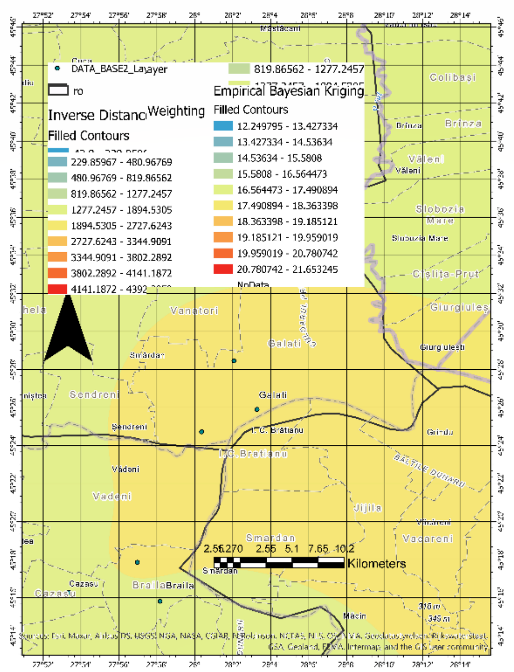

Fig. 9. Bayesian interpolation method for UHII distribution – year 2017

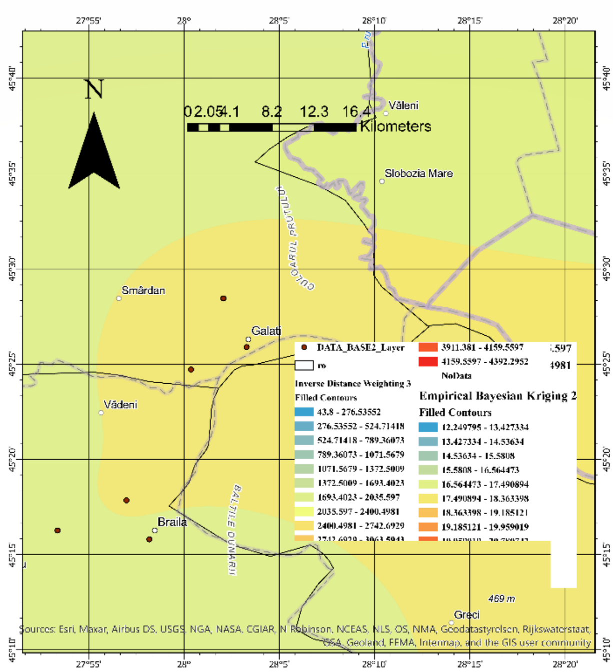

Fig. 10. Bayesian interpolation method for UHII distribution – year 2024

Figures 9 and 10 present the distributions of the average UHII using the Bayesian interpolation method considering the ArcGIS analyst related tool [2].

4. CONCLUSIONS

The modelling presented in this study was for the only purpose of characterizing the UHII under existing conditions and counting the UHII accordingly (Level – 1 characterization). As such, the UHI offered in this report simply is a characterization of the UHII in several urban areas. By measuring, modeling and assessing UHII in specific cities can provide appreciated data sets for further studies. In the presented methods, these could be considered important aspects, besides supervisory urban planning and design policies. In the assessments that can be carried out, cities that do not respect the appropriate urban structure (such as places with extremely tall buildings, close together) can be identified.

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