Impacts of Some Surface Parameters on Urban Heat Island Development

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Abstract

Effects of two important surface parameters (distance from the center of the settlement and extent of evaporating surfaces) on development of urban heat island (UHI) are examined in the present paper. The study area is the town of Beregszász (Transcarpathia, Ukraine) with a population of 26 000. Mobile temperature measurements were carried to out in order to gain information on the characteristics of the UHI in ten day intervals in two one year long campaigns in 2005 and 2008. The main purpose was to determine the urban thermal excess in the different parts of a relatively small town, and to elaborate an empirical model equation of the development of UHI in the different parts of the town affected by horizontal surface conditions.

Keywords: Urban heat island, non-evaporating surfaces, empirical model

1. Introduction

Spatial and temporal characteristics of the urban heat island (UHI) are well known on the base of the numerous studies in that field in the last decades [3,6,7,8]. Attempts of researchers are focused on the examination of the impacts of forming factors of the UHI today. Consequently, in the present paper attempts have been taken to trace the role of surface parameters played in the development of the UHI. Statistical model equations have been elaborated for estimation of the spatial pattern of the mean maximal UHI intensities in a small town. From the numerous factors urban surface geometry and ratio of non-evaporating surfaces have been taken into consideration here for the summer-, winter seasons and the whole year. The study area was Beregszasz, a small town with 26 000 inhabitants in Transcarpathia, Ukraine.

2. Methods

2.1 Temperature datasets

Mobile measurements were carried out to gain abundant information on spatial differences in UHI intensities. Since spatial pattern of the UHI is determined by build-up structure of settlements the measurement route had to involve every typical build-up units of the town, abandoned areas at the borders of the town and roads that climb the heights along the Eastern edge of the town. This way, there were 42 measurement sites established. 36 mobile measurements were carried out in 2005 and 2008.

2.2 Determination of surface parameters

From the numerous parameters of UHI development two factors have been chosen for the examinations:

- ratio of non-evaporating surfaces within the build-up area of the town and in its environment
- distance from the geometric center of the settlement.

Ratio of evaporating surfaces have been estimated on the base of satellite images. Accordingly, ratio of non-evaporating surfaces have been determined visually using real color high definition satellite images of Google Earth available on the Web. For this purpose a grid network of squares of 15.4×15.4 meters was established on the images with the measurement sites in their centers. It was judged visually if measurement sites were located on evaporating or non-evaporating surfaces.

An important question was to find what size of spatial units of the environment of individual measurement sites has the strongest impact on UHI intensities. Four different variants were tested statistically:

- ✓ 9 grids represent a 0.21 ha of surface unit of the environment of the measurement sites;
- ✓ 25 grids represent a 0.59 ha of surface unit of the environment of the measurement sites;
- ✓ 49 grids represent a 1.2 ha of surface unit of the environment of the measurement sites;
- ✓ 81 grids represent a 1.9 ha of surface unit of the environment of the measurement sites.

Correlation coefficients between the ratio of evaporating surfaces and mean UHI intensities in the measurement sites have been calculated. Significant correlations have been found in each case. Strongest correlations have been found in the third case, therefore the 1.2 ha surface unit of the environment of the measurement sites has the strongest impact on mean UHI intensities (LÁSZLÓ E., 2008).

Ratio of evaporating and non-evaporating surfaces within the settlement and in its environment has been determined in the next step for 109485 points using the 15.4×15.4 m grid network by kriging method. 1.2 ha surface units in the environment of the measurement sites were taken into consideration in the data analyses. Distance of the measurement sites from the geometric center of the settlement was determined on the base of the grid network.

2.3 The statistical model

Beyond basic statistics (calculating averages and correlation coefficients) attempts have been made to elaborate an empirical model for forecasting the intensities of the UHI. The method of multivariable linear regression was used for this purpose, what is widely used for such kind of analyses. The next equation was gained:

$$Y = a + b_1 X_1 + b_2 X_2 + ... + b_n X_n ,$$

where Y is the dependent variable, a is a constant, X_i is independent variable number i, b_i is the partial regression coefficient of independent variable number i, i = 1, 2, …, n, n is the number of independent variables taken into consideration. Fitting of the multiple regression equation was performed using the method of least squares. Calculations were carried out using SPSS software pack.

Kolmogorov–Smirnov tests [3] have proved that distribution of dependent and independent variables involved in the model is not different significantly from normal distribution what is a condition of correlation and regression calculations.

3. Results

3.1 Multivariable model development

In this phase a qualitative analyses of the relationships between static urban surface parameters and mean maximal UHI intensities was performed. Features of the complex non-evaporating urban surfaces have a dominant impact on the spatial pattern of UHI. The main aim was to elaborate a general model for estimation of spatial pattern of mean maximal UHI intensities on the base of datasets of Beregszasz.

Elements of the multivariable model:

– UHI intensities as dependent variables (t, °C)

- Ratio of non-evaporating surfaces as an independent variable (NES, %)

- Distance from the center as an independent variable (D, m)

Using the multivariable regression method in SPSS the following model equation was gained for the spatial pattern of annual mean maximal UHI intensities (**Δtannual**):

$$\Delta T_{annual} = 1.642 - 0.00026 \times D + 054 \times NES$$

Values of Δt_{annual} were between 0.4-2.3°C with higher values in the inner parts of the settlement in the studied period. The two independent variables in the model equation has been proved to responsible for the development of the UHI to a ratio of over 76% (r^2 = 0.76154). The role of partial correlation coefficient D is more emphasized (r=0.766), since its value was higher than that of the other parameter (NES r=0.447). On this base, D parameter has more important role in the development of the UHI.

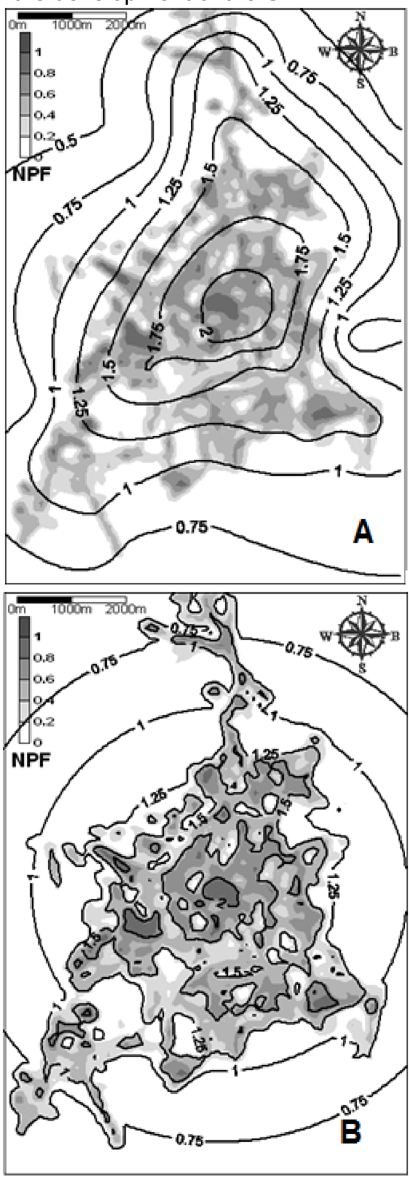

Figure 1 Spatial structure of non-evaporating surfaces, the measured (a) and the estimated (b) mean max UHI intensities (difference between isotherms is 0.25°C)

Spatial structure of parameter Δt_{annual} has been created using the equation for Beregszasz on the base of the values of the predictor calculated for the 109485 measurement sites in the next step. On this base, values of mean maximal UHI intensities were calculated and visualized with isotherms on the NES ratio maps (Figure 1). There is a strong relationship between the spatial pattern of isotherms of the estimated Δt_{annual} NES values, while correlation between 2D spatial distribution of measured Δt_{annual} values and Nes values is a bit weaker (Figure 2). UHI intensity isotherms are parallel with NES values where NES ratio is over 40%. Therefore, artificial surfaces have a determinant effect on spatial differences of Δt within the settlement than in its rural environment.

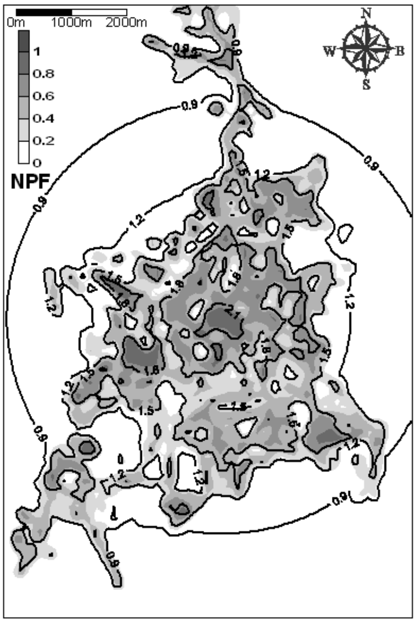

Figure 2. Ratio of non-evaporating surfaces and spatial structure of estimated mean max UHI intensities in the vegetation periods (difference between isotherms is 0.3°C)

Empirical forecasting model equations were elaborated for the summer (from16 April to 15 October) and the winter periods (from 16 October to 15 April) their details are presented in Table 1.

Table 1. Multivariable linear regression equations of UHI intensities and surface parameters; and partial correlation coefficients of the parameters of the equation for the settlement of Beregszasz. Notations: Δt/S is the mean maximal UHI intensities in the summer season, Δt/W is the mean maximal UHI intensities in the winter season, R2 is the multiple determination coefficient.

	Multivariable linear regression equation	R^2	**Partial correlation coefficients**	
			T	**NPF**
Δt/ S	=1,652-0.00027x D+0.709xNES	0.650	-0,665	0,513
Δt/ W	=1.679-0.000273x D+0.319xNES	0.732	-0,737	0,309

Values of Δt fluctuated between 0.5 and 2.3°C in the summer and between 0.4 and 2.2°C in the winter periods, so differences are insignificant in the empirical model of UHI intensities for the two periods. On the base of *R2* values it can be claimed that UHI intensities are more strongly determined by the two surface parameters in the winter season than in the summer (table 1, Δt/S and Δt/W). Differences of partial correlation coefficients suggest a relatively stronger impact in the case of parameter D in the winter period.

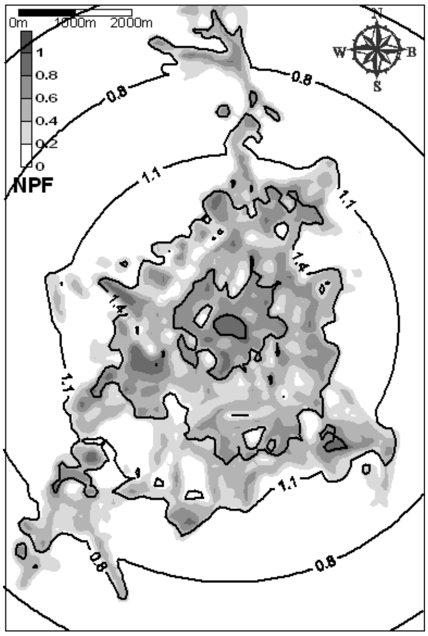

Figure 3. Ratio of non-evaporating surfaces and spatial structure of estimated mean max UHI intensities in the non- vegetation periods (difference between isotherms is 0.3°C)

Relationship between ratio of non-evaporating surfaces and UHI intensities is stronger in the summer season than in the winter (Table 1), since in the summer non-evaporating surfaces can accumulate large amount of heat as it is indicated in the maps (Figure 2 and 3).

4. Conclusions

In the present paper simple methods are presented for qualitative analyses of horizontal surface parameters of settlements. General model equations have been elaborated for the estimation of spatial structure of UHI in our studied settlement.

On the base of our results it can be stated that the multivariable linear regression model elaborated using the ratio of non-evaporating surfaces and distance from the geometric center of the settlement represents well the spatial pattern of UHI intensities in Beregszasz.

The most important conclusions can be drawn from our results are the following:

- UHI intensities are more strongly determined by the two surface parameters (D and NES) in the winter season than in the summer.
- Relationship between ratio of non-evaporating surfaces and UHI intensities is stronger in the summer season than in the winter.
- The two independent variables (D and NES) in the model equation has been proved to be responsible for the development of the UHI to a ratio of over 76%. Partial correlation coefficient D has stronger effect.

6. Acknowledgements
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