TOPOGRAPHY AND VEGETATION COVER INFLUENCE ON URBAN HEAT ISLAND OF ZARAGOZA (SPAIN)

S.M. Vicente Serrano, J.M. Cuadrat Prats, Miguel A. Saz Sánchez
Departamento de Geografía y Ordenación del Territorio. Universidad de Zaragoza. 50009, Zaragoza, Spain.
vicens@posta.unizar.es

Abstract

This work analyses the relationships between the spatial patterns of urban heat island and the distribution of topography and vegetation cover in Zaragoza (Northeast of Spain). Two independent variables were considered: Elevation, which was obtained from a Digital Elevation Model (DEM), and Normalized Difference Vegetation Index (NDVI), mapped from a Landsat ETM+ image. Different spatial analysis were applied using GIS. The results indicate a high spatial correlation between the general spatial patterns of urban heat island and elevation ($r = -0.57$), and temperature patterns and NDVI ($r = -0.60$), both statistically significant ($p < 0.01$). The percentage of thermal spatial variance explained by vegetation cover and elevation is very high (54 %), and although the prediction of temperature values is poor in some areas using these independent variables, the results of this work indicate that the physical and environmental attributes within the city can not be neglected in the explanation of the UHI in Zaragoza.

Key words: Urban Heat Island, NDVI, Elevation, Zaragoza, Spain.

1. INTRODUCTION

Urban heat island (UHI) is a general characteristic of medium and large urban areas (Arnfield, 2003). This phenomenon is explained by human modifications, such as changes in land use, changes of vegetation cover and the inclusion of building materials (Bretz et al. 1998). The changes affect the surface-atmosphere fluxes and cause the changing of climate, which is shown usually in a temperature increment of the city (Goward, 1981). The human activity also affect in the process of creation of UHI due to traffic and artificial fonts of heat (Swaid, 1993). However, although the UHI is mainly caused by human factors, its spatial patterns can be influenced by the spatial distribution of physical and environmental factors within the city. Relief configuration (Beral-Guyonnet, 1997) or localisation of vegetation (Dimoudi and Nikolopoulou, 2003; Upmanis et al. 1998) can determine the distribution of air temperature within the city. Low elevation areas and topographical depressions condition make possible the creation of mass of warm air. Moreover, the vegetation can determine the magnitude and intensity of the radiant fluxes surface-atmosphere, affecting the air relative humidity and temperature.

For this reason, it is very important to determine the influence of the factors that affect the magnitude, intensity and distribution of the UHI, because the knowledge of the role of each factor can be useful for urban management and contaminant dispersion control. However, in the analysis we must not only consider human factors in the UHI explanation (traffic, urban density or building materials); the topography of the city and the distribution of green areas can have a relevant importance in the explanation of temperature distribution within the city, and knowing the influence of these factors would help in the determination of the most favourable areas for urban growth. For this reason, in this work we analyse the influence of relief and green cover on the spatial distribution of temperatures in a medium size city of the Mediterranean region (Zaragoza, NE of Spain), where the UHI is a frequent phenomenon (Saz et al. 2003).

2. METHODOLOGY

A precise description of the study area is shown in Cuadrat et al. (1993). The analysis method and the mapping techniques used to determine the general UHI patterns in Zaragoza are explained in detail in Cuadrat et al. (2002) and in Saz et al. (2003). The general spatial distribution of temperatures and the shape of the UHI in Zaragoza can be consulted in Saz et al. (2003), in which the mean temperature map of Zaragoza was obtained in spatial standardised values at a grid cell size of 30 meters. In this work the temperature and UHI distribution were considered as dependent variables in a model in which elevation and green cover values were integrated as explanatory variables.

Topography and vegetation cover were created using GIS and remote sensing. The elevation was obtained from a Digital Elevation Model (DEM), using a digital cartography of z interpolated contour lines (1:25000) using the ISOMDE module of MiraMon GIS. The result was a grid with cell size of 30 m, coinciding with the map of temperature and with the spatial resolution of the satellite image used. The vegetation cover distribution map was carried out using a Landsat-ETM+ image from March of 2000. The image was geometrically (Palà and Pons, 1995) and radiometrically corrected (Pons and Solé, 1994). The Normalized Difference vegetation Index (NDVI)
was computed from the reflectance data (Tucker, 1979). The NDVI is a measure of photosynthetic activity, which is directly related to cover and total vegetation biomass (Carlson and Ripley, 1997). This radiometric index has been used by Gallo et al. (1993), Gallo and Owen (1999), among others to assess the effect of vegetation cover on UHI. The NDVI allows identify a detailed distribution of the vegetation. For generalising the spatial patterns of vegetation distribution within the city, and diminishing the spatial heterogeneity we applied a low pass filter (21 x 21 pixels) to the original NDVI image.

Figure 1 shows the spatial distribution of elevation and NDVI within the city. Elevation ranges between 190 and 280 m. The most depressed area is located in the left bank of the Ebro River. The elevation increases at north, but mainly at south, where the high terraces of Ebro River have the highest elevations. The elevation range is scarce (90 m), but the most significant characteristic is that topography forms a depressed bottom, which coincides with the historical centre of the city and with the left bank of the river. The spatial distribution of vegetation cover shows clear spatial patterns. The urban centre (right bank) and some industrial areas of the left bank appear as areas of low vegetation cover whereas the peripheral margins (mainly in the northern and southern areas), concentrate the highest vegetation cover densities, due to the presence of irrigated lands (in the north) and parks (in the south).

![Figure 1: Spatial distribution of elevation and filtered NDVI (low pass filter of 21 x 21 pixels) in Zaragoza city.](image)

The spatial distribution of UHI was compared with the distribution of elevation and NDVI by means of regression analysis. The objective is to identify the spatial variability of temperature explained by both factors. Finally, we analysed the spatial distribution of model residuals to determine the areas in which the temperature prediction is more accurate.

3. RESULTS

3.1. Relationship among UHI patterns, elevation and vegetation cover distribution

Figure 2 shows the relationship between the spatial distribution of temperature and elevation and between temperature and NDVI patterns in the city. The relationship is strong in both cases. A high percentage of the spatial variation of temperature is explained by means of elevation and NDVI. Nevertheless, the relationship between temperature and the two independent variables is not linear. Between elevation and temperature patterns there is a potential relationship, with a strong fall in temperatures from 230 m, whereas the fall is less sharp until this elevation value. The relationship between NDVI and temperature is clearly potential. The fall in temperature values is strong for low values of NDVI, although it is less pronounced for high vegetation cover values.

3.2. Explanation of shape and intensity of UHI by means of elevation and vegetation cover distribution

Table 1 shows the results of the multiple regression analysis. The independent variables have been transformed according to the exponents indicated in figure 2. With the inclusion of one variable (elevation) in the explanatory
model the spatial variance of temperature is explained in a 35 %. Introducing the NDVI, the variance explained increases (54 %). The percentage of spatial variation of the UHI explained using this model is very significant, since we have only considered two environmental variables. In the model it has not been used other urban variables such as urban structure, population density, building materials or traffic density. As we have observed, for the explanation of the UHI conformation in Zaragoza, physical and environmental attributes can not be neglected.

![Figure 2](image)

**Figure 2**: Relationship between mean standardised temperature and elevation and between mean standardised temperature and NDVI

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R square</th>
<th>Adjusted R square</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>0.59</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>2**</td>
<td>0.73</td>
<td>0.54</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 1: Results of the stepwise multiple regression analysis. *Model 1, variable included: elevation. *Model 2, variables included: elevation and NDVI

The table 2 shows the coefficients of the model 2. The partial correlation between the independent variables and temperature has also shown. The correlation is negative in both cases and the weight of the two independent variables is similar. Nevertheless, the two variables are not redundant since they have passed a collinearity test (VIF < 10), and moreover the correlation between NDVI and elevation is low (r = 0.31).

<table>
<thead>
<tr>
<th></th>
<th>Non-standardised coefficient</th>
<th>Standardised coefficients (Beta)</th>
<th>P</th>
<th>Partial correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.7</td>
<td>-0.46</td>
<td>&lt;0.001</td>
<td>-0.54</td>
</tr>
<tr>
<td>(Elevation)$^3$</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NDVI)$^{0.5}$</td>
<td>-4.5</td>
<td>-0.45</td>
<td>&lt;0.01</td>
<td>-0.53</td>
</tr>
</tbody>
</table>

Table 2: Model 2 coefficients and partial correlation among spatial distribution of temperature in Zaragoza, elevation and NDVI.

The figure 3 shows the spatial distribution of residuals resulting of the regression analysis (observed thermal values – predicted thermal values). We can see that the spatial distribution of residuals indicates an overestimation of temperature in the west and north areas of the city using as predictive variables NDVI and elevation. Nevertheless, in the centre of the city, and in wide areas of the right bank of the Ebro River there is an underestimation of temperature. These areas coincide with spaces in which there is a high edification density. This result indicates that although the environmental variables considered in this study have an important influence in the shape and intensity of UHI, other urban structural variables can explain why in some areas mean temperature conditions are less influenced by elevation and vegetation cover.

4. CONCLUSIONS

We have analysed the influence of elevation and vegetation cover on UHI patterns in a medium size city of the Mediterranean area. The vegetation cover has a negative influence on temperature. In Zaragoza a negative exponential relationship exists between both variables with a strong correlation (-0.60). The result is similar to the results obtained by other authors that have also used the NDVI to quantify the vegetation cover within urban areas (Gallo and Owen, 1999). The relationship between elevation and temperature is also negative (r = -0.57),
confirming that the depressed areas accumulate hot air in urban areas and favor the persistence of warmer conditions.

The independent variables considered explain a high percentage of the spatial variability of the temperature distribution in the city (54%), in this way, the physical and environmental attributes within the city can not be neglected in the explanation of the UHI conformation in Zaragoza. Nevertheless, in some areas the estimation is very poor, coinciding with high built density areas in the centre of the city. For this reason in further analysis we must consider other urban variables (mainly related to human activity and edification) in the explanation of causes of urban heat island in Zaragoza for the creation of more accurate explanatory models.

ACKNOWLEDGEMENTS

This paper was supported by the following projects: “Caracterización espacio-temporal de las sequías en el valle medio del Ebro e identificación de sus impactos” (BSO2002-02743) financed by the CICYT, "Clima y calidad ambiental en la ciudad de Zaragoza" financed by the Zaragoza council, and the “Programa de grupos de investigación consolidados” financed by the Aragon Government.

References


