

Determination of Heat Islands from Landsat Tm Data: Relationship between Surface Temperature and Urbanization Factors in Istanbul

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Abstract - Structuring, which is increasing due to the growth and the inevitable in urbanization, is one of the most important factor of urban climate change. City centers grow warmer than outer regions and due to the factors' intensity, urban heat islands form in the city. The aim of this paper is to introduce relationship between BAC (Basement Area Coefficient) and FAC (Floor Area Coefficient) datas on pixel base with the temperature values gained by remote sensing methods. The study involves juristical boundaries - Anatolian and European side- of Istanbul city.

The preliminary work is applied with data taken from Istanbul Region Meteorology Directorate. According to the station points, when comparison of average summer temperatures between 1975-1999 and 2000-2008 are made, increase between 1-2 Degrees Celsius is determined.

In this study Landsat TM image which belongs to summer period is used. Single-channel algorithm is applied on thermal band (band 6) and land surface temperatures (LST) are determined. Building database¹ which consist of storey and area was utilized to calculate BAC and FAC values and their maps are generated. The last step was to join all the whole raster and vector data in GIS and to accommodate them to statistical interpretation.

When linear regression analyses are made on BAC and FAC data, their effect on surface temperature is 99% meaningful. According to this analysis, made for both Asian and European side, statistical results show that BAC has more effect on rising surface temperature than FAC.

Keywords: climate, urban, environment, GIS, land use

1. INTRODUCTION

The world is rapidly urbanizing. Cities now house slightly more than half of the world's population, and 70 percent of the global population will live in urban areas by 2050 (UN, 2007).

In recent years, the relationship between urban land use and environmental quality has an received is increased attention in both planning research and practice (Stone et al, 2001). In this relation urban climate loom large as one of the most important parameters and cities have important roles to play increasing the impacts of urban climate.

Built-up areas appear as uneven artificial terrains with building materials partly different from those of natural surfaces. In addition, anthropogenic processes release excess heat and pollution to the ambient air. Together they result in higher urban temperature compared to the relatively natural surroundings –

this is the so-called urban heat island (UHI), or urban heat archipelago if the spatial structure is multi-cellular (Unger, 2004).

Research in the recent past has unearthed a series of causal relationships between a wide range of urban factors and climate. These range from urban geometry to work-week patterns, from anthropogenic heat to thermal characteristics of urban surfaces, and from obstruction to wind flow to lack of vegetation. However, the widely prevalent view among urban climatologists is that at neighborhood and small scales urban geometry leads the list of possible causes for heat island phenomenon (Emmanuel, 2005).

The intra-urban distribution of the temperature excess is largely dependent on local surface characteristics, such as geometry: building heights (H), street (canyon) width or spaces between buildings (W) (Unger, 2004).

Surface measurements are also preferable for an analysis of land use and urban warming in that surface temperatures may be measured through remote sensing techniques. An advantage of this technique is that these methods facilitate the collection of a very large number of thermal observations (Stone, 2001; Oke, 1973). In this study nearly 2 million surface temperatures was used.

The urban geometry of a city is characterized by BAC (basement area coefficient), FAC (floor area coefficient) and canyon geometry.

This article presents findings from a case study on the intra-urban surface geometry (BAC, FAC) and surface temperature relationships in the metropolitan region of Istanbul, Turkey.

2. METHODOLOGY

2.1 Data

The TM data was used to perform the UHI detection because of their high spatial resolution, especially in thermal infrared band (Du et al., 2009).

June 28, 2007 - summer period- Landsat-5 TM image was used parallel to the aim of this study. It has seven spectral bands; six of them acquire earth reflectance and one of them acquires earth temperature. In visible and infrared regions, spatial resolution of Landsat TM images is 30 meters and in thermal region, it is 120 meters.

2.2 Study Area

Istanbul is a megacity, as well as being the cultural, economic, and financial centre of Turkey. The province covers 39 districts with an area of 5,343 km². It's located at 41.01°N, 28.97°E in North-west of Turkey. The Bosphorus is a 30 km straight which connects the Sea of Marmara to the Black Sea and it divides the

¹ Building database were obtained from municipality

city into two sides; European and Asian. As such, Istanbul is the unique bi-continental city in the world (figure 1).

Istanbul's population nearly quadrupled between 1980 and 2010 and last decade's population growth rate was 40 %. Now, with the development of urbanization, its population is nearly 12.8 million (TUİK, 2008). And this makes Istanbul the 5th largest crowded city in the world.

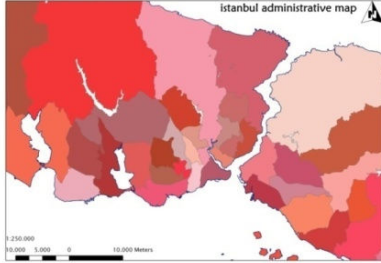


Figure 1. Study area

2.3 Analysis

2.3.1 Image Processing Studies

In satellite images, each pixel value is represented as digital numbers (DN) or brightness values changing for each sensor type. In calculation of Land Surface Temperature (LST) from Landsat thermal data, the digital number of (DN) image pixels needs to be converted into spectral radiance using the sensor calibration datas in order to obtain useful values. So, according to (Chander et al, 2009) equation (1), DN were converted to spectral radiances (L_λ).

$$L_\lambda = [(L_{\max\lambda} - L_{\min\lambda}) / (Q_{\text{cal max}} - Q_{\text{cal min}})] (Q_{\text{cal}} - Q_{\text{cal min}}) + L_{\min\lambda} \quad (1)$$

$$Q_{\text{cal max}} = 255 \quad Q_{\text{cal min}} = 0$$

$$L_\lambda = [(L_{\max\lambda} - L_{\min\lambda}) / 255] * Q_{\text{cal}} + L_{\min\lambda}$$

$$L_\lambda = G_{\text{rescale}} \times Q_{\text{cal}} + B_{\text{rescale}}$$

L_λ = Spectral radiance at the sensor's aperture [$W/(m^2 \text{ sr } \mu\text{m})$]
 Q_{cal} = Quantized calibrated pixel value [DN]
 $Q_{\text{cal min}}$ = Minimum quantized calibrated pixel value
 $Q_{\text{cal max}}$ = Maximum quantized calibrated pixel value
 $L_{\min\lambda}$ = Spectral at-sensor radiance that is scaled to $Q_{\text{cal min}}$ [$W/(m^2 \text{ sr } \mu\text{m})$]
 $L_{\max\lambda}$ = Spectral at-sensor radiance that is scaled to $Q_{\text{cal max}}$ [$W/(m^2 \text{ sr } \mu\text{m})$]
 G_{rescale} = Band-specific rescaling gain factor [$(W/(m^2 \text{ sr } \mu\text{m}) / \text{DN})$]
 B_{rescale} = Band-specific rescaling bias factor [$(W/(m^2 \text{ sr } \mu\text{m}) / \text{DN})$]

After proper corrections for calculating LST, normalized difference vegetation index (NDVI) and emissivity (ϵ) values which highlight the reflection properties of surface elements, must be calculated.

Emissivity is the embodiment of ability of object's sending out electromagnetic wave. It depends on not only object's composing but also object's surface state (such as surface roughness, etc.). In addition, it changes according to the measurement wave-length and the angles. It is very difficult to

survey emissivity in large scale accurately. It is usually calculated relatively based on hypotheses (Gong, 2005).

Van measured series of thermal infrared emissivity and NDVI values in natural surfaces and found logarithmic correlation between them (Van, 1993). According to Van's equation, ϵ values were calculated eq (3).

$$\text{NDVI} = (\text{Band4} - \text{Band3}) / (\text{Band4} + \text{Band3})$$

$$\epsilon = 1.0094 + 0.047 \text{Ln}(\text{NDVI}) \quad (3)$$

Then, according to the single channel algorithm eq. (4) which was used by Gong (2005), surface temperatures were calculated. However, at the time of satellite passing, atmospheric conditions were not known and therefore, mid-latitude aestival standards were used as given above.

$$L_{\lambda, \text{atm}\downarrow} = 1.68 \text{ Wm}^{-2} \mu \text{ m}^{-1} \text{Sr}^{-1}$$

$$L_{\lambda, \text{atm}\uparrow} = 1.74 \text{ Wm}^{-2} \mu \text{ m}^{-1} \text{Sr}^{-1}$$

$$\tau = 0.77$$

$$L_\lambda(T_S) = [(L_\lambda - L_{\lambda, \text{atm}\uparrow}) / (\tau \epsilon_\lambda)] - [(1 - \epsilon_\lambda) * L_{\lambda, \text{atm}\downarrow} / \epsilon_\lambda] \quad (4)$$

In the final stage of the processing, surface temperature (T_S) was calculated with the simplified formula (5).

$$T_S = 1260.56 / \text{Ln} [(607.76 / L_\lambda) + 1] \quad (5)$$

Then, the image was converted to a point data and 5000 points of obtained T_S image were used to get contour map of surface temperature of Istanbul which was shown in figure (2).

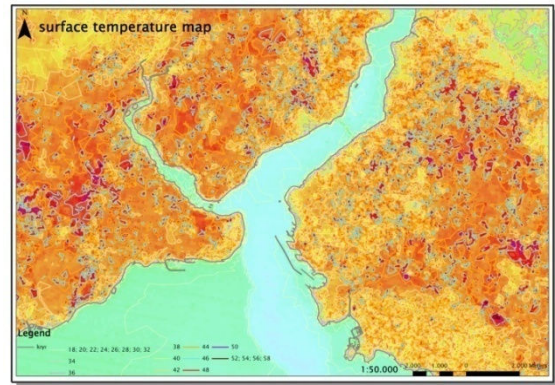


Figure 2. Istanbul surface temperature contour map

2.3.2 GIS Studies

In the pre-GIS studies era, the study area was divided to 150x150m. grid polygons. And then, each grid cell was encoded by grid_id.

At this step, building data of Istanbul province area for 2007, including the basement area and floor numbers, have been used. Then each grid cell was intersected with building data. If a building intersects with more than one cell, only the covered area is selected for calculation (figure 3).

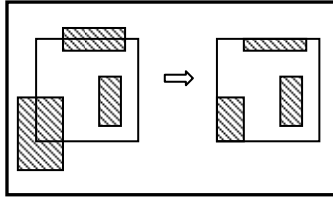


Figure 3. Used building areas

At first, each building's basement area and construction area (eq. 6) were calculated and their sum for each cell was added to the table.

$$\text{Construction Area} = \text{basement area} \times \text{number of floor} \quad (6)$$

basement area coefficient : BAC
 floor area coefficient : FAC

$$\text{BAC} = \frac{\sum \text{basement area}}{\text{grid area}} \quad (7)$$

$$\text{FAC} = \frac{\sum \text{construction area}}{\text{grid area}} \quad (8)$$

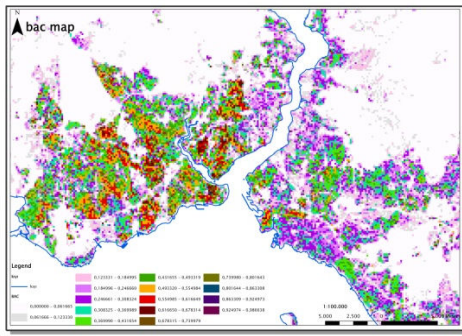


Figure 4. Istanbul basement area coefficients map

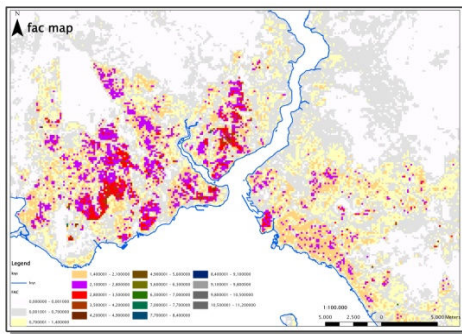


Figure 5. Istanbul construction area coefficients map

Then, the prepared surface temperature map was brought into consonance with the database. For this, each pixel of surface temperature image was converted to a point shape-file and consequently intersected with grid polygons which were used for calculating BAC and FAC values. Then average surface temperature values inside each grid cell, were calculated and added to the table as a new column. At the last stage, surface temperatures of each grid cell were combined with BAC and FAC values in a single table.

2.4 Results

Because of Istanbul province is located on two continentals which have different topographies and city geometries, the study was considered to be three models as whole of Istanbul, European side and Asian side.

As a result of regression analysis between BAC and FAC variables, the determinations of coefficients are given in Table A.

Table A. Model Summary

Model	R	R ²	Adj. R ²	Std. Error
Whole Istanbul	.217	.047	.047	2.92
European Side	.315	.099	.099	2.73
Asian Side	.189	.036	.036	3.00

a . Predictors: (Constant), bac, fac

Table B. Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	
	B	Std. Error	Beta			
Whole Istanbul						
	40.891	.005		8102.358	.000	
	bac	3.395	.037	.171	92.716	.000
	fac	.224	.008	.052	28.307	.000
European Side						
	40.124	.007		5973.123	.000	
	bac	2.863	.044	.155	64.453	.000
	fac	.705	.010	.174	72.435	.000
Asian Side						
	41.513	.007		5611.445	.000	
	bac	5.621	.060	.253	93.379	.000
	fac	-.403	.013	-.087	-32.087	.000

All three models' variable interactions were found to be significant at the 0.001 level, and the complete results of the regression analysis are detailed in Table B.

2.5 Discussion

Many factors affect the UHI; in this study we chose only two effective factors of urban geometry; BAC and FAC. But in this study canyon geometry, which is another important parameter of city geometry was not calculated in order to avoid improper

results. Because the database includes only road lane numbers but not the pavement width and garden width values.

Heat island effect is influenced by the following manmade factors or design variables that contribute to the physical properties in urban environment (Giridharan, 2004)

- Urban structure
- Size of the city (population, density of built-up area)
- Ratio of building height to distance with them
- Width of the streets
- Building materials
- Surface materials
- Sky-view factor.

Among all these factors, only two parameters were used; and so independent variables' definition rates of dependent variable (R^2) were too weak (0.047; 0.099; 0.036) as seen in Table A.

Istanbul is a high density city with temperate zone and a hilly topography. The urban gross density of Istanbul is around 250 persons per hectare. In some residential piece of Istanbul net density can be up to 2000 to 2500 persons per hectare.

It is known that a major negative factor to increase thermal load is building volume, whilst topography on the other hand green space are positive factors contributing to a reduced thermal load. A major negative factor to decrease air ventilation is ground coverage, whilst natural landscape and proximity to openness are the main positive factors contributing to increased air movement (Ng et al.; 2009). Moreover, the micro scale thermal conditions vary considerably in a city. Thermal conditions are dependent on buildings, surface conditions and open space obstacles causing climates from very hot to cool in the summer period.

All three models, BAC values were found to have a significant positive effect (3.395; 2.863; 5.621) on surface temperatures. On the other hand, FAC values effects have been changed either positive or negative effect (0.224; 0.705; -0.403) due to the model area.

When our analysis results were evaluated according to BAC and FAC maps; the surface temperature was affected positively by both BAC and FAC values in where high density at 3D and 2D (European side) is. On the other hand, it was seen that in Asian side, BAC values were increasing surface temperature but FAC values were decreasing it. The geometries of European side and Asian side are clearly different from each other as it is seen on BAC and FAC maps (figure 4, figure 5). In Asian side the settlement pattern is generally formed by separated buildings with changing storey from 2 to 20, on the contrary the pattern in European side is generally very compact.

Building density and floor area ratio have already been the key indicator while controlling and studying urban fabric. Building density refers to the ratio constituted by the sum of the built-up area in the project land area (Chen, 2009)

Therefore urban planners need detailed spatial and time dependent information of urban climate conditions. To understand urban climatic conditions more clearly, detailed information and studies are needed in Istanbul.

To examine the changes with enough precision in the scope of planning for the studies on urbanization and climate relations, land measurements should be sampled with much more station points (Kuşçu, 2010). Such studies are expensive and waste of

time and instead of this, using satellite images bring more advantage than the other methods.

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