World Applied Sciences Journal 20 (2): 319-326, 2012
ISSN 1818-4952
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DOI: 10.5829/idosi.wasj.2012.20.02.3661

Land Surface Temperature Assessment in Semi-Arid Residential Area of Tehran, Iran Using Landsat Imagery

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Abstract: Land cover change especially from green areas to urban areas may increase land surface temperature (LST). In this study, Landsat Enhanced Thematic Mapper Plus (ETM+) on 15 May 2000 (spring), 9 July 2000 (summer), 26 November 2000 (autumn) and 10 January 2001(winter) were utilized to study LST in Tehran, Iran. The accuracy of the LST analysis was evaluated using six year ground temperature data. The Non Linear Correlation Coefficient (NLCC) between normalized differences vegetation index (NDVI) and LST was found to be higher in the spring compared to the other seasons. The LST value in the west of the city was similar to the surrounding areas, but in north, east and south of the city were lower compared to the north, north east and east of the surrounding areas in all seasons. The gravel and sandy soil in the western part of the surrounding areas were warmer than the impervious surface area (ISA) in the city in summer. It was found that high urban density in semi arid climate with low vegetation in the surrounding areas does not increase the LST value in the city compared to its surrounding areas.

Key words: Urban · Gravel and sandy soil · Semi arid area · NDVI · Iran

INTRODUCTION

Normally, temperature in the center of urban locations is higher than its surrounding rural areas. This phenomenon is known as Urban Heat Island (UHI) [1]. Nieuwolt [2] conducted the first research on the UHI in Singapore. Changes in the biophysical attributes of the earth's surface in non-evaporating and impervious materials cause the solar energy to raise Land Surface Temperature (LST) [3]. The important parameters to control LST are means of partitioning latent heat fluxes and surface radiant temperature. Surface radiant temperature is a function of varying surface soil water content and vegetation cover [4]. Recently, LST obtained by satellite technologies has replaced thermometer networks to assess the UHI [5, 6]. National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) was the first sensor which was utilized to drive the LST for regional scale of urban temperature mapping [7, 8]. Moderate Resolution Imaging Spectroradiometer (MODIS) on board Aqua and Terra satellites is another sensor used for measuring this temperature [9-14]. Local studies of UHI need to use a sensor with a high resolution; therefore, the Thermal Inferred (TIR) data of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) with 120m and 60m spatial resolutions, respectively, were used [15-20]. [18] Showed the increase both of the extent and magnitude of UHI in Shanghai. Chen *et al.* [15] as well as Zhang *et al.* [20] reported slightly negative correlation between temperature and Normalized Difference Vegetation Index (NDVI). In this study, no effort is made

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to show the UHI based on land use and land covers change mentioned in previous studies. The objective of this research is using Landsat ETM + images to test the UHI in the city of Tehran, which has a semi arid climate. Thus, the two main objectives of the study are: (1) to determine the relationship between LST and NDVI and (2) to determine the LST variation in Tehran compared to its surrounding areas.

MATERIALS AND METHODS

Study Area: The study area consists of Tehran and its surrounding areas (Figure 1). Tehran is the largest city in Iran. As the capital of Iran and Tehran Province (Figure 1), it is faced with many socio-economic and environmental problems such as water and air pollutions. Ground temperature data at the same time of Landsat overpass Tehran between 11 am and 12 pm from four stations namely; Chitgar, Mehrabad Airport, Geo-Phisyc and Doshan Tape were analyzed (Figure 1).

The northern and eastern areas of Tehran are parts of Alborz Mountains, but its southern region is a part of Iran Plain [21]. The land form of the northern part of Tehran consists of rocks and mountains and the southern part mainly consists of red sandstones and conglomerates with red hilly land features [21] where Geo- Phisyc and Doshan Tape stations are located (Figure 1). The black color in the south east and east of the surrounding areas are coal bearing shale sandstone and andesitic indicated by rock in the legend of Figure 1c [22]. The stones have created a strip shape in the north east of the surrounding area (Figure 1c). Gravels, sand and silt are dominant towards the west, the city and its surrounding areas [23] where Mehrabad Airport and Chitgar stations are located (Figure 1c).

Data and Image Processing: The Landsat Enhanced Thematic Mapper Plus (ETM+) on 15 May 2000, 9 July 2000, 26 November 2000 and 10 January 2001 were utilized to obtain the LST in stud area. The Landsat images were rectified to the UTM projection system (datum WGS-84, zone 39N) and were geo-referenced based on the topographical map (1:25,000) from National Cartographic Center of Iran using 50 ground control points with RMSEs lower than 1 pixel. The nearest neighbor resampling algorithm was utilized to preserve the brightness values of the pixels [18]. The thermal bands (band 6) were filtered using self-adaptive method to remove the non-periodic noise that may affect the brightness temperature [15].

Retrieval LST from Landsat ETM +

The computation procedure for retrieval of LST from Landsat ETM+ by [6] was used in this study. Land surface temperature for Landsat ETM+ images was computed in two steps. In the first step, the Digital Number (DN) that is the value of pixel that depends to surface reflectance were converted to spectral radiance (Equation 3) [24]:

$$L_\lambda \frac{L_{\max} - L_{\min}}{(QCal_{\max} - QCal_{\min}) \times QCal} + L_{\min} \tag{3}$$

where: $L_ë$ = spectral radiance, maximize quantized calibrated pixel value in DN ($QCal_{max}$) =255, minimum quantized calibrated pixel value in DN ($QCal_{min}$) = 1, QC_{al} = DN, L_{max}, L_{min} = spectral radiance for band 6 at DN 255 and 1, respectively (watts/ m^2* ster *µm). In the second step, the spectral radiance of points were converted to black body temperature by using the following equation:

$$T = \frac{K_2}{\ln((\frac{K_1}{L_\lambda}) + 1)} \tag{4}$$

where: T is the effective at- satellite brightness temperature in Kelvin; K_1= first calibration constant (watts/m^2 * ster *µm) = 666.09, K_2 = second calibration constant in Kelvin =1282.7 and $L_ë$ = spectral radiance (watts/m^2 * ster *µm).

NDVI: Landsat images were categorized into three sections, namely: urban, surrounding areas with light vegetation and surrounding areas with higher elevation level and thick vegetation. In order to study the relationship between LST and vegetation NDVI was derived for the images as follows:

$$\text{NDVI}= R_{\text{NIR}}-R_{\text{RED}} / R_{\text{NIR}}+R_{\text{RED}} \tag{5}$$

Where: R_{NIR} and R_{RED} are the spectral reflectance in the red and near-infrared bands, respectably. The NDVI equation shows values between-1 and 1, where negative values indicate non-vegetated areas while positive values imply vegetated areas. NDVI values were classified into four categories (Table 1).

The supervised classification with minimum distance algorithm was utilized to classify the LST and NDVI values.

Table 1: NDVI classification range in the study area for all images

Vegetation Index	NDVI
Good	NDVI > 0.10
Moderate	0.01< NDVI ≤ 0.10
Weak	0.< NDVI ≤ 0.01
Non-Vegetation	NDVI ≤ 0

Ground Station Temperature Analysis: Six year temperature data from 2005 to 2010 in the city and its surrounding were used. Temperature data for each station was divided in four seasons (spring, summer, autumn and winter) in each year. In order to show the highest and lowest temperature mean the temperature data in the stations were averaged for each season. Finally, the LST derived using Landsat imagery and ground station temperature data was compared in order to obtain the more reliable LST variation in Tehran city and its surrounding areas.

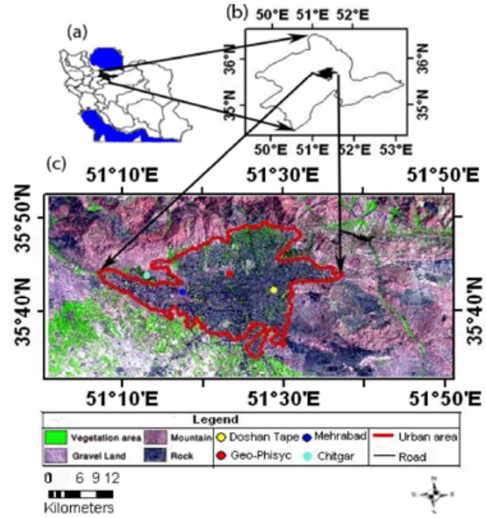

Fig. 1: (a) Iran, (b) Tehran Province and (c) Tehran city, four ground stations which assigned by different color and surrounding areas of city as of 9 August 2002

RESULTS AND DISCUSSION

Ndvi in Study Area: Tehran's rainy season is between November and May; snow falls between December and February [25]. The seasons in this city are classified as spring (March, May and June), summer (July, August and September), autumn (October, November and December) and winter (January, February and March). The highest temperature is approximately between 30°C and 40°C in the summer and the minimum temperature is in the winter when it dips to below the freezing point [25]. The Mediterranean low pressure system spreads over Tehran in spring and autumn, while the Siberian high pressure system extends over the region in winter and can cause cold temperatures over the study area [25]. The NDVI values and the LST variation in Tehran and its surrounding areas in spring, summer, autumn and winter were showed in Figure 2. The highest vegetation cover was obtained in the spring with moderate vegetation cover in the north, center and east of the city (Figure 2a). The vegetation cover in the city and north part of the surrounding area disappeared during the summer, while in the south and south east parts of the surrounding area it was still observable (Figure 2c). The north and east parts of surrounding area are of a natural vegetation cover; thus, an increase in air temperature dries them, but in the south and south east parts of surrounding areas have an agricultural vegetation cover that is regularly irrigated.

A moderate and low vegetation cover was observed in the north of the city and north east of its surrounding areas in autumn due to the autumn rains (Figure 2e). The growth of vegetation stopped with a decrease in the air temperature at end of the autumn. During winter, most of the vegetation cover disappeared (Figure 2g). The relationships between LST and NDVI in three categories were analyzed using non linear correlation coefficient (NLCC) with polynomial equation using 50 points for each category (Table 2) [26] in four seasons.

A low vegetation cover during the summer, autumn and winter may effect the NDVI value. As a result, the NLCC between LST and NDVI decreases to below-0.33 in all those seasons in the study area. Slightly negative correlations were noted for all categories. This result is consistent with the previous similar studies in Fuzhou and Guangdong of China were undertaken by [15, 20]. respectively. A lower correlation coefficient and a higher standard deviation were obtained in the light vegetation area (Table 2). Many areas of bare land are scattered throughout this area (Figure 2a). The lower correlation coefficient may be due to the different background of the soil which may affect the NDVI Values. Near-infrared reflectance from plant canopy, plant species, the reflectance of the same spectra from the soil and the atmospheric reflectance may affect the NDVI measurements [27]. As a result, the NDVI values were inaccurate and correlation coefficient decreases (Table 2). Thus decreased the NLCC between NDVI and LST to-0.20 and below-0.10 in the city and in the dense and light vegetation areas respectively in the summer, autumn and winter.

Table 2: Correlation coefficient between LST and NDVI on 15 May (spring), 9 July 2000 (summer), 26 November 2000 (autumn) and 10 January 2001(winter) 2000 in the study area

		NDVI				LST(°C)			
	Corr. Coef.	Min	Max	Mean	St. devi	Min	Max	Mean	St. devi
Spring									
City	-0.44	-0.10	-0.01	-0.03	0.02	34.83	43.99	36.41	1.62
Light vegetation	-0.01	0.01	0.13	0.07	0.03	23.59	34.83	29.31	2.55
Thick vegetation	-0.29	0.13	0.71	0.35	0.12	21.14	28.29	24.41	1.70
Summer									
City	-0.19	-0.07	-0.33	-0.26	0.06	35.42	45.76	37.78	1.37
Light vegetation	-0.10	0.01	0.09	0.052	0.02	31.32	37.82	34.51	3.59
Thick vegetation	-0.05	0.11	0.44	0.32	0.10	24.92	34.20	27.95	1.11
Autumn									
City	-0.20	-0.08	0.15	0.13	0.01	13.48	15.38	14.63	0.51
Light vegetation	-0.03	0.01	0.09	0.05	0.02	13.48	14.91	14.21	0.65
Thick vegetation	-0.06	0.12	0.32	0.22	0.05	12.02	14.43	13.34	0.34
Winter									
City	-0.18	-0.09	-0.82	-0.19	0.17	10.55	12.51	11.14	0.62
Light vegetation	-0.08	0.03	0.09	0.06	0.02	9.56	11.54	10.45	0.68
Thick vegetation	-0.10	0.11	0.36	0.23	0.08	9.56	11.05	9.91	0.49

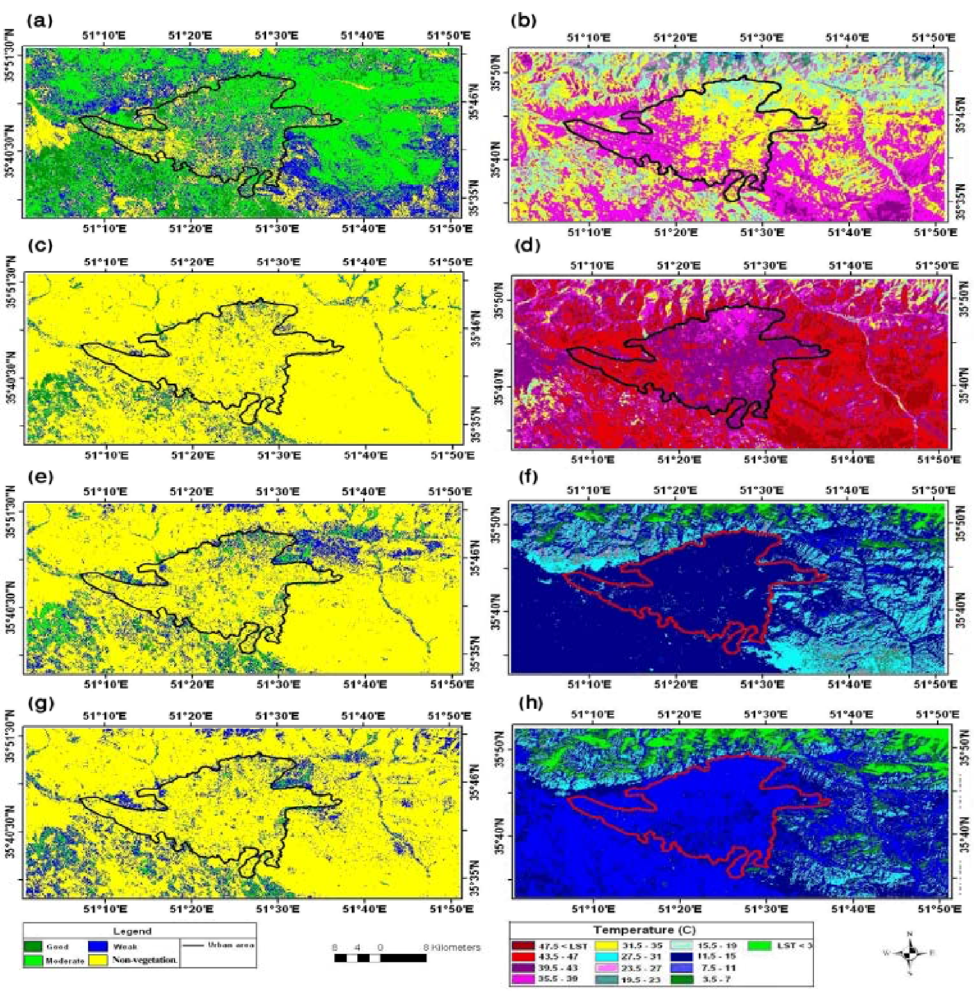

Fig. 2: NDVI and LST values during the four seasons in Tehran and its surrounding areas; (a), (c), (e) and (g) show the NDVI value and (b), (d), (f) and (h) shows the LST values in spring, summer, autumn and winter, respectively

Uhi in Study Area

Uhi Retrieval Using Remote Sensing: Tehran with 7.31 million inhabitants consists of about 10% of Iran's total population of 69.51 million [28]. More than one million people commute to Tehran daily from the surrounding residential areas [29]. The number of vehicles was reported to be about 2 million in 2000 [30]. By 2005, the number reached to about 2.5 million vehicles [28]. Air pollution in this area is aggravated by topographical location of Tehran. Tehran is surrounded by Alborz Mountains to the north and east which block the air movement in Tehran [29] (Figure 1c). Moreover, most of the industrial units are located in the west, south and southeast of the city and surrounding areas, where major winds blow to Tehran. These two conditions worsen the air pollution in Tehran [31]. In all seasons, the lowest temperatures were obtained in the northern part of surrounding area due to its higher elevation compared to the other parts (Figures 2b, 2d, 2f and 2h). These parts are covered by snow at the end of autumn and in winter. In the figures 2f and 2h, they are shown by green color. They can be also observed in the north west and north east of the surrounding area in the winter (Figure 3b). The higher LST values in surrounding areas of city compared in the city in the spring and summer are much clearer than those in the other seasons (Figures 2b and 2d). Similar LST values were observed for the west part of the city and the south west part of its surrounding areas. These values were higher compared to those of the northern and eastern parts of the city in the spring. The northern part of the city has been built on the south hillside of the Alborz Mountains which is at the higher elevation compared to the other areas; hence, the temperature is lower. There are also a lot of trees and parks in this area (Figure 1c) result in diverse LST value. The south west part of the city has a low vegetation cover with gravel soil (Figures 2a and 1c). Therefore, they can absorb more sunlight which in turn can result in higher LST values as compared to those of the north and east parts. During the summer, the LST variation in the surrounding areas and the city indicates the effects of natural vegetation cover on LST. In this season, as the natural vegetation cover dries out especially in the north and north east of the surrounding areas, they indicate higher LST values as compared to those in the spring (Figure 2c). However, normally a rise in the temperature in summer increased the LST in all parts of the study area (Figure 2c). In contrast to spring and summer, similar LST values were obtained in the autumn and winter in the city and its surrounding areas in the south and south west. Such similar values are due to drying of vegetation like trees and gardens in the center, south and north of the city. Ecept the snowy places in the autumn and winter, the LST values in the north, east and south east of the surrounding areas were higher compared to the city area in all seasons (Figures 2b, 2d, 2f and 2h).

The variation in LST value may be due to the black color of coal bearing shale sandstone and andesitic in the east, south east and some strip of them in the north west of its surrounding area (Figure 1). The relationship between LST and NDVI was also evaluated on 24 January 2000 to determine the result of winter season (Figure 3). LST values in the western part of the city and south and south western part of the surrounding areas were higher compared to those of the center, northern and western parts of the city (Figure 3b). Meanwhile, NDVI maps show a low and moderate vegetation cover in these areas (Figure 3a). This reveals that vegetation cover in winter season may increase the LST value.

UHI Determination Using Ground Station Data: Results of UHI retrieved using Landsat imagery were able to explain amounts of LST in four days in study area and maybe those days can not represent the distribution of temperature in seasons. In order to increase the reliability of the result, temperature data from the ground stations may be utilized. Therefore, the temperature at the time Landsat satellite overpass over Tehran in six year from 2005 to 2010 were averaged (Figure 4) [25]. With coincide the figure 1c and figures 2b, 2d and 3b it's be clear Mehrabad Airport and Doshan Tape stations have a temperature range similar to surrounding areas of city.

This finding is consistent with the LST images ranges in figures 2b, 2d and 3b. Although, the Doshan Tape temperature data in 2007, 2009 and 2010 is not available (Figures 4c, 4e and 4f) however the mean temperature of seasons in 2005, 2006 and 2008 were similar to Mehrabad Airport station (Figures 4a, 4b and 4d). Both stations are placed in the city but they were surrounded by bare lands. The highest temperature range in those areas is probably due to soil type where in the Mehrabad Airport is sandy gravel and in the Doshan Tape station is conglomerates with red soil. When the gravel and sand composition in the soil increase, the natural vegetation cover will decrease [32] (Figures 2a and 2c). Although soil type of Chitgar Park is similar with the Mehrabad Airport station, however, the temperature mean is lower (Figures 2a, 2c and 4). This is probably due to high density of trees and

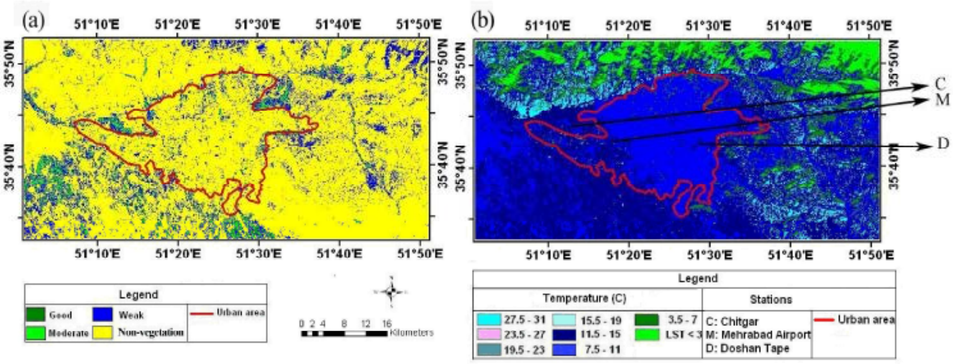

Fig. 3: NDVI and LST variation in the city of Tehran and its surrounding areas on 24 January 2000

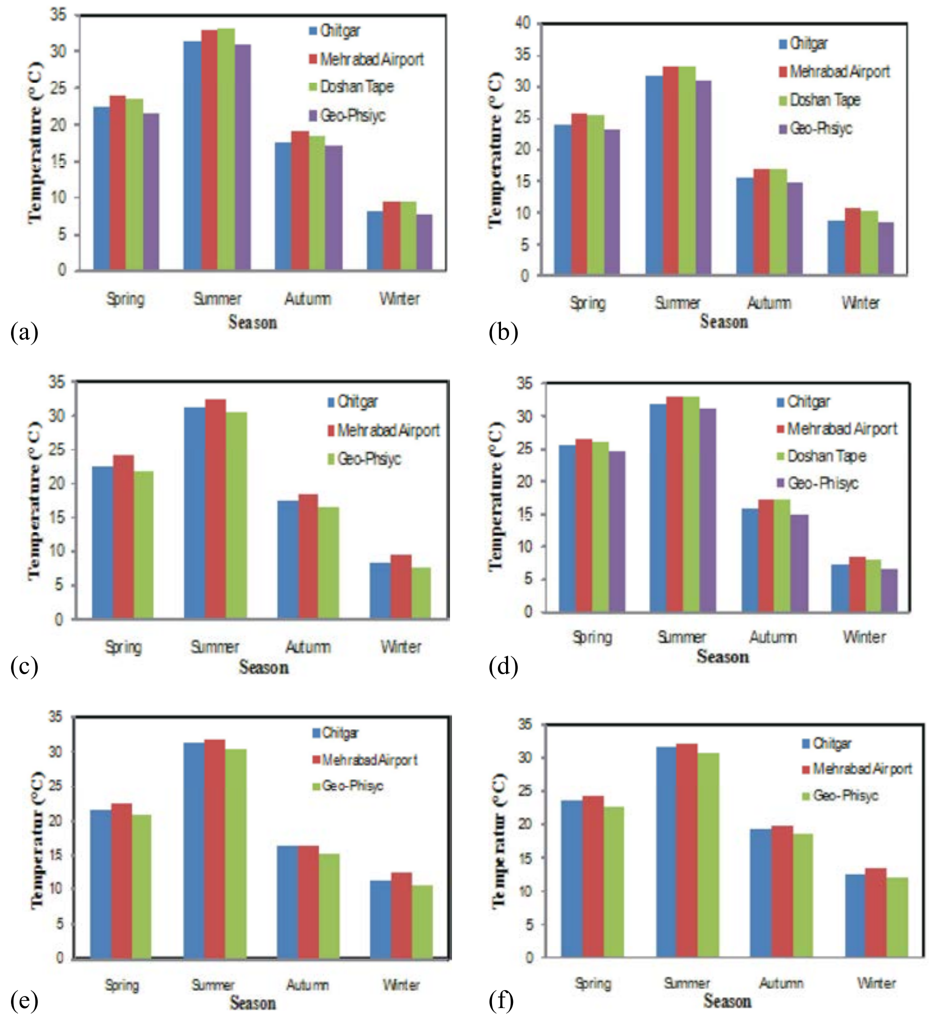

Fig. 4: (a), (b), (c), (d), (e) and (f) are seasonal means of temperature for 2005, 2006, 2007, 2008, 2009 and 2010 respectively in study area

vegetation cover which are regularly irrigated in the Chitgar Park. Temperature mine in Geo-Phisyc station where is located in ISA area in center of the city was obtained lower than other stations in figure 4 for all seasons which is coincided with the result of LST images (Figures 2b and 2d).

CONCLUSION

Tehran with its high population and human activity rate along with its topographical features must have a higher LST than its surrounding areas. This assumption was evaluated using Landsat ETM+ in spring, summer, autumn and winter. Six year temperature mean data from four ground stations were analyzed to examine the result LST retrieved by Landsat imagery. Results showed the NLCC value between LST and NDVI is affected by variations in vegetation cover density and different land use. Lower LST values were obtained in the city than its surrounding areas in the north, east and north east in all seasons. By the rise and fall of LST values in the summer and winter vegetation cover can balance the LST. The results of temperature data analysis at the ground stations were similar to the LST analysis by Landsat imagery. It can be concluded that the color and texture of soil in semi arid climate with weak vegetation can play an important role in determining the LST value and that the LST in the city area is not higher despite the high urban densities.

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