EVALUATION OF URBAN HEAT ISLAND IN ISTANBUL USING REMOTE SENSING TECHNIQUES

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ABSTRACT:

In this study, Urban Heat Island (UHI) in Istanbul has been studied using Landsat 5 TM satellite sensor data and long-term temperature data from meteorological stations within and around the city. The thermal remote sensing technique is used to study of urban climate in Istanbul for the first time. Thermal and other channels of the Landsat satellite images were used for three different years: 1987, 1997 and 2007. In addition, meteorological data which are temperature, precipitation, humidity, for the same period which are 25 September 1987, 18 July 1997 and 28 June 2007, were used. The images are classified according to the thermal channel. The temperature data and the coordinates of stations have been added to this classification. Two major centers for urban heat island is found in Istanbul. Our major finding is that expansion of urban areas in Istanbul lead growth in thermal radiation of land surface in highly dense areas. This is mainly due to unplanned and unorganized rapid urbanization in last two decades.

1. INTRODUCTION

Urbanization is the development of cities and suburban areas as a result of population growth. Approximately 47% of world's population are currently living in cities (Wu and Murray, 2003), and this number is expected to increase as more people are moving from countryside to cities, especially in the less developed countries where the fraction of the population that lives in cities (41% in 2005) is much less than that of the more developed countries (76% in 2005) (Population Reference Bureau, 2005).

Immigration to urban, because of education, working on a better job, entertainment & fashion, has cause using more impervious materials on the construction of the structures. Urbanization is also a land-use change that was made by humans. To understand the urbanization and its relation with climate, lots of researches have studied these topics. For example, Arnfield's study (2003) presents the progress in urban climatology during the two decades after 1980 and Voogt & Oke's study (2003) is a review of the use of thermal remote sensing in the study of urban climate.

Because of the residual structures and increasing population, vegetation areas are dissipated. When the vegetation is reduced, the natural cooling effect of shading and evapotranspiration decrease. Moreover, artificial land surface change induces narrow streets and tall buildings which are reduce air flow, and this is called "canyon effect".

All these effects cause temperature increase in the urban air and surface temperatures than the surrounding rural areas, and this is called Urban Heat Island (UHI) effect. The heat island is an example of unintentional climate modification when urbanization changes the characteristics of the Earth's surface and atmosphere (Voogt, 2004, Ezber et al., 2007). The urban heat island is best observed at clear and calm nights because radiative cooling differences are maximized between urban and surrounding rural areas (Voogt, 2002).

There are three types of heat islands: first canopy layer heat island (CLHI), second boundary layer heat island (BLHI), and the last one surface heat island (SHI) (Voogt, 2004). The first two refer to a warming of the urban atmosphere; the last refers to the relative warmth of urban surfaces. The first two refer to a warming of the urban atmosphere; the last refers to the relative warmth of urban surfaces (Voogt, 2004). The canopy layer heat island below the roof tops in the space between buildings (Mills, 2007). Above the urban canopy layer lies the urban boundary layer, which may be 1 kilometer (km) or more in thickness by day, shrinking to hundreds of meters or less at night. It is the BLHI that forms a dome of warmer air that extends downwind of the city. Wind often changes the dome to a plume shape (Voogt, 2004).

Living in urban areas has been increased rapidly in Turkey for last three decades. While the metropolitan population was 24% of the total Turkish population in 1945, it increased to 65% in 2000 (DIE, 2008, Kaya, 2005).

Population of Istanbul is 680,857 in 1927, 5,475,982 in 1985, 9,260,438 in 1997 and 12,5 million in 2007 (DIE, 2008, Basar, 2008). The aim of this study is to show the relationship between growth of urban heat island borders in Istanbul and increase in the city's population using remote sensing techniques.

Urban Heat Island in Istanbul has been previously studied by several researchers using long-term temperature data from meteorological stations within and around the city. In this work, we use the thermal remote sensing to study of urban climate in Istanbul from 1987 to 2007 for the first time. Thermal and other

channels of the Landsat satellite sensor images were used for 1987, 1997 and 2007 years. Density slice algorithm was used for classification of the image which is Landsat satellite's thermal channel. Little ranges were used for digital number. Moreover, classification of the urban, maximum likelihood method which is a supervised control system was used. More than 30 classes were chosen at the beginning of the study for the classification of the urbanization. Then, the number of the classes was decreased to 5 basic classes and these basic classes have been shown in different colors. In addition, meteorological data which are temperature, precipitation, humidity, for the same period which are 16 July 1987, 18 July 1997 and 28 June 2007, were used. The images that we have are classified for thermal channel; also the temperature knowledge and the coordinate knowledge of the stations have been added to this classification. Urban heat islands were created by the meteorological data and coordinate data for Istanbul. Different major centers for urban heat island are found in Istanbul. Our major finding is that expansion of urban areas in Istanbul lead growth in thermal radiation of land surface in highly dense areas. This is mainly due to unplanned and unorganized rapid urbanization.

2. STUDY AREA AND DATA

2.1 Study Area

The city of Istanbul, which is located at 41,01 ^{o}N, 28,58 ^{o}E in Asia and Europe, is the largest city of Turkey with a population of over 12,5 million (DIE, 2008). Istanbul's population was nearly doubled in 20 years between 1980 and 2000, the fastest growth period. For the period between 1990 and 2000, the population growth rate of Istanbul is 29,64% for urban parts and 81% for rural parts of the city. Total population growth rate is 33.1% for the same period. In near future its population is expected to reach 20 million by 2030 (Turkstat, 2008). The Bosphorus, a 30-km strait that connects the Black Sea with the Sea of Marmara, is considered to be the boundary between Europe and Asia, and the urban Istanbul is located on both sides of the southern half of the strait. The north of the city towards the Black Sea is mostly covered by protected forest patches, and the expansion of the city in that direction is mostly confined to along the Bosphorus. The most densely populated parts of the city lie in the south along the Sea of Marmara.

UHI in Istanbul has been previously studied by several researchers using long-term temperature data from meteorological stations within and around the city. In this work, we use the thermal remote sensing to study of urban climate in Istanbul from 1987 to 2007 for the first time. Thermal and other channels of the Landsat satellite sensor images were used for 1987, 1997 and 2007 years.
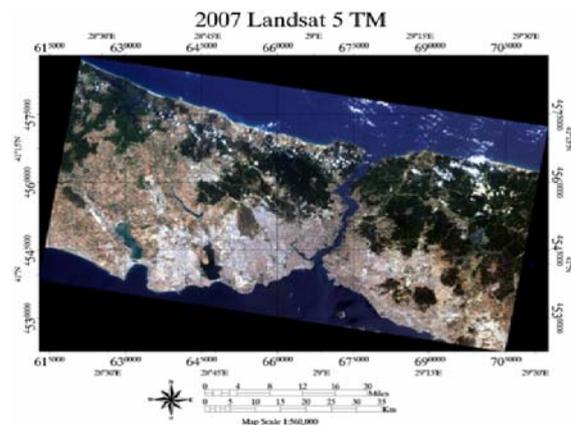

Figure 1. Study area, Istanbul 2007 (RGB : 321)

2.2 Landsat Data

Landsat Thematic Mapper satellite's images have the 120m spatial resolution of thermal infrared band, and the other bands have 30m spatial resolution. The dates of the images are;
25 September 1987
18 July 1997
28 June 2007

2.3 Meteorological Data

Temperature data which are belongs to 28 June, 2007, provided by meteorological stations in Istanbul, are used. There are 20 meteorological stations in Istanbul, some of them are belong to Turkish state meteorological service and some of them are automatic weather observation stations (AWOS) which are belong to the greater Istanbul Municipality. The automatic weather observation stations are started up in 2006 in Istanbul. The stations are Çatalca, Kumköy, Sarıyer-Kireçburnu, Göztepe, Şile, Bahçeköy, Florya, Kartal, Kandilli, İstanbul University, Şile, Kartal, Gebze, Samandıra stations, Atatürk and Sabiha Gökçen Airport stations, Çavuşbaşı, Ömerli, Büyükada, Olimpiyat, Aksaray, Terkos, AKOM, Çanta, Kamiloba, Hadımköy stations.

3. METHODOLOGY

3.1 Classification

3.1.1 Urban Classification
Firstly, 1, 2, 3, 4, 5 and the 7. bands of the Landsat 5 TM satellite are classified to show the urbanization in Istanbul for last 20 years. Maximum Likelihood classification method, which is a supervised method, is used. More than 30 classes were chosen at the beginning of the study for the classification of the urbanization. Then, the number of classes was decreased to 7 basic classes which are urban, road, agriculture, sea, lakes, forest, sand, and the eighth is cloud. These basic classes have been shown in different colors.

First image of the classification is shown in figure 2, and it belongs to 25 September, 1987. This classification has 8 classes which are urban area, agricultural area, forest, sea, lake, sand area, roads and clouds. Figure 3 belongs to 18 July, 1997 image's classification. There is no cloud in this classification, and it has 7 classes which are urban area, roads, forest, agricultural area, sea, lake and sand. Classification of the 28 June 2007 is shown in figure 4 as the third image of the classification. This classification besides cloud classification

includes urban area, agricultural area, forest, road, sea, lake and sand classifications.

There is 10 year difference between images. Classification of the images shows the progress of the urban area in 10 year period which is started in 1987 and finished in 2007. There is a big difference between 1997 and 2007 images to 1987 image when their urban area compared to each other.
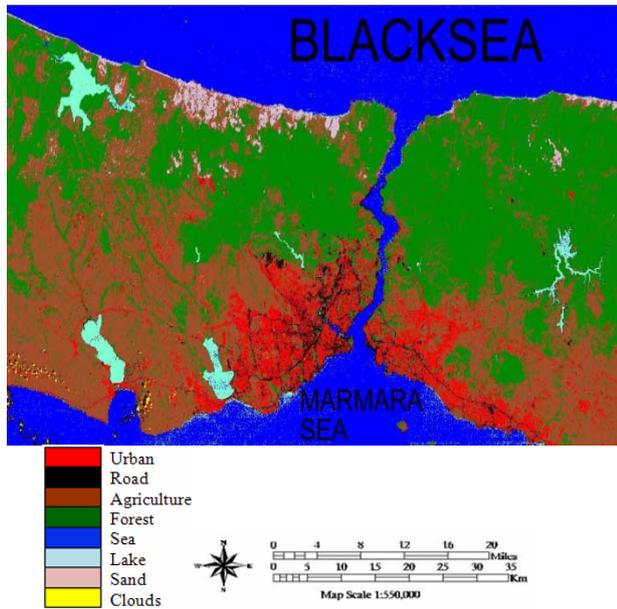
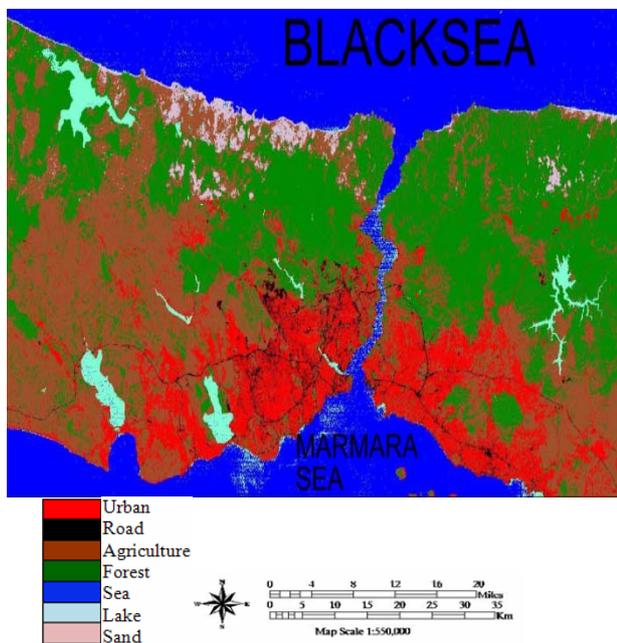Figure 2. Classification of the urbanization for Istanbul image in 1987.

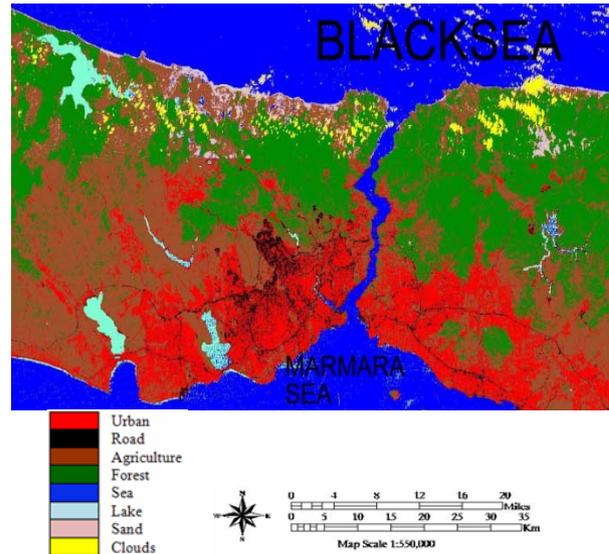Figure 3. Classification of the urbanization for Istanbul image in 1997.

Figure 4. Classification of the 1987 year urbanization for Istanbul image in 2007.

Increasing of the urban areas and dicreasing of the forest and field areas have shown in the classification of images (figure 2, 3, and 4) which are belong to 1987, 1997 and 2007. Moreover, numerical values of the urbanization change for 1987-2007 period, are displayed in Table 1.

	1987	1997	2007
Urban (km^2)	325,964	594,237	746,583
Roads (km^2)	90,794	101,855	132,874
Field (km^2)	1587,780	1543,586	1514,900
Forest (km^2)	1640,618	1388,679	1216,794
Lake (km^2)	123,661	138,291	122,517
Sea (km^2)	1409,151	1400,358	1312,194
Sand (km^2)	52,333	73,322	102,726
Cloud (km^2)	8,974		60,740

Table 1. Surface coverage of years 1987, 1997 and 2007.

As indicated in Table 1, the urban area and roads increase, in addition to forest is reduced in Istanbul between 1987 and 2007.

As indicated in the Table 2, the urban area difference is increased 275,332 km^2 between 1987 and 1997, 183,365 km^2 between 1997 and 2007, 458,699 km^2 between 1987 and 2007. Moreover, growth rate of the city between 1987 and 1997 is 65%, between 1997 and 2007 is 26%, between 1987 and 2007 is 109%. Istanbul's urban area is almost doubled in 2007 of its value in 1987.

	1987–1997	1997–2007	1987–2007
Urban area difference	275,332 km^2	183,365 km^2	458,699 km^2
Growth (%)	65%	26%	109%

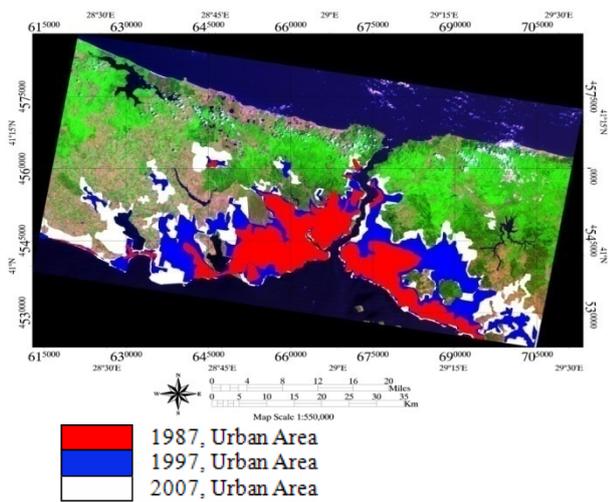Table 2. Urban area change from 1987 to 2007.

Figure 5. Urban boundaries.

Urban boundaries of Istanbul for every year are shown in Figure 5. The Figure shows urban areas expension. Red area presents the 1987 urban boundary, blue area symbolizes the 1997 urban boundary, and the white area represents the 2007 urban area.

3.1.2 Thermal Channel Classifications

If one wants to detect UHI with satellite images, satellite image's thermal band must be used. Landsat 5 TM satellites sensor's thermal band is used for classification of the images.

Density slice algorithm is used for classification of the image which is Landsat satellite's sensor's thermal channel.

When the satellite image has warm colors like red, orange or yellow after the classification, these colors present warm areas in the image. If the image has cool colors like blue or green, they represent the cold areas of surface.

UHI in Istanbul is shown in figure 6, figure 7 and figure 8 which is the classification of the thermal channel. The 2007 Istanbul image in figure 8 represents more definitively urban heat islands than other images.
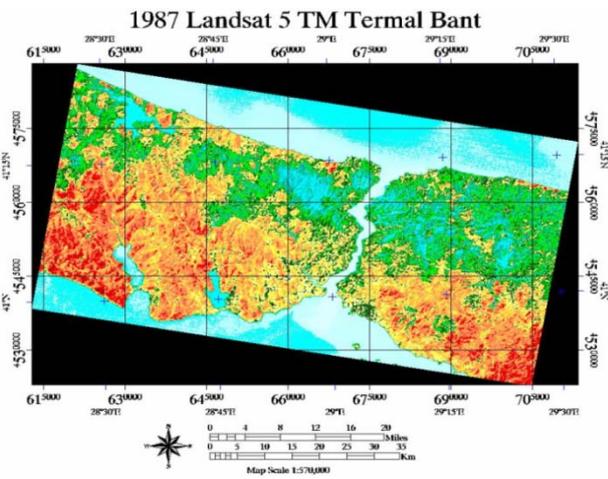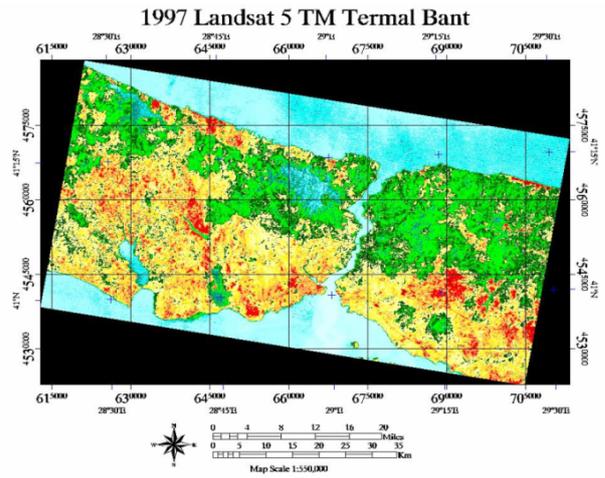

Figure 7. Thermal band classification of 1997 image.
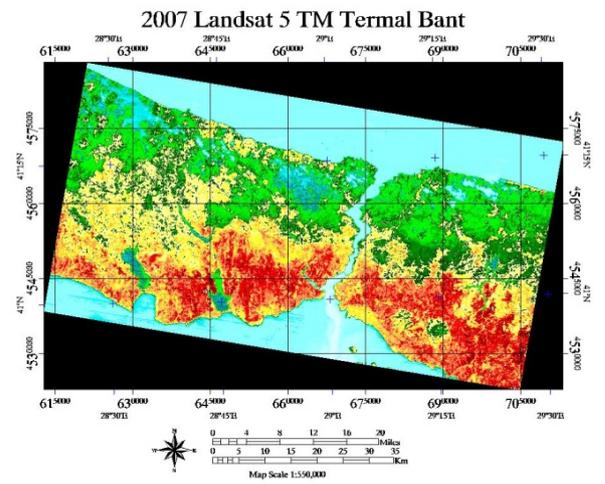

Figure 8. Thermal band classification of 2007 image

The boundary of the urban area is added to the thermal classification of Istanbul image in Figures 9, 10 and 11

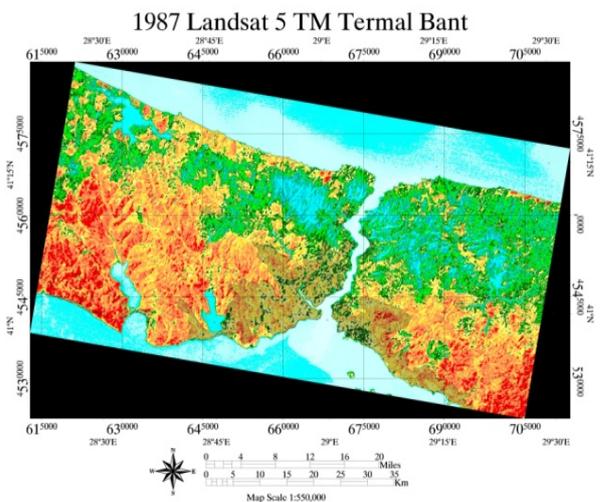Figure 6. Thermal band classification of 1987 image

Figure 9. Istanbul image's thermal band is classified and urban boundary is added for 1987.
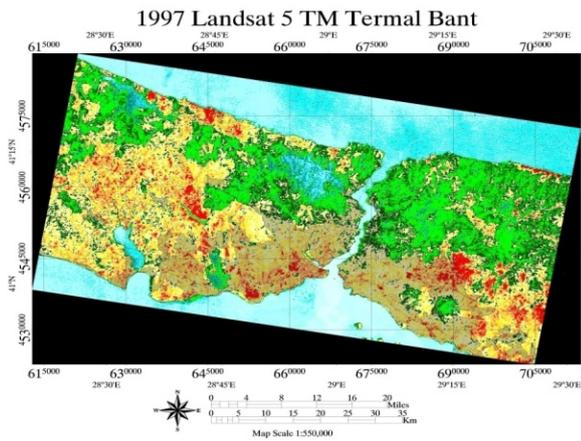
Figure 10. Istanbul image's thermal band is classified and urban boundary is added for 2007.
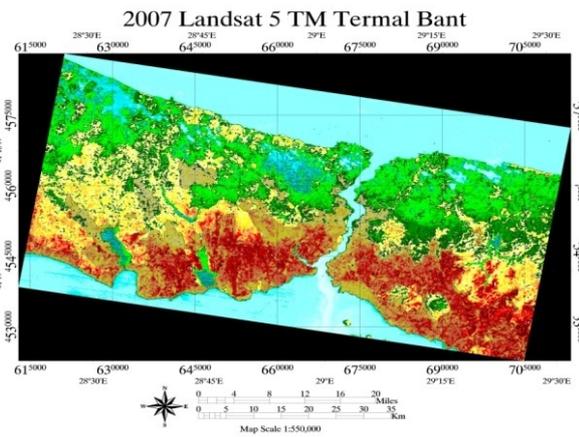

Figure 11. Istanbul image's thermal band is classified and urban boundary is added for 1997.

Radiance values and temperature data are shown in the Table 3
Radiance values of the thermal images, belong to 2007, are associated with temperature data provided by the meteorological stations.

METEOROLOGICAL STATIONS	UTM LATITUDE	UTM LONGTITUDE	TEMPERATURE (°C)	RADIANCE (Wm^{-2}sr^{-1})	DN
ÇATALCA	623078,4851	4556545,831	27	0,9577	153
GEBZE	704648,4851	4522855,831	33,1	1,093888	173
S. GÖKÇEN AIRPORT	694538,4851	4530145,831	33	1,090951	169
KANDİLLİ RASATHANESİ	673298,4851	4547935,831	34	1,091341	173
İSTANBUL UNIVERSITY	665738,4851	4542115,831	32,7	1,089045	175
ATATÜRK AIRPORT	652898,4851	4536745,831	32	1,083529	174
KUMKÖY	670808,4851	4568605,831	28,3	0,9677	146
KAMİLOBA	620468,4851	4545385,831	30,11	1,039404	166
HADIMKÖY	637298,4851	4545685,831	29,58	1,022857	163
GÖZTEPE	675338,4851	4537255,831	31,1	1,011825	161
KARTAL	678248,4851	4533625,831	32,8	1,04492	164
ÇAVUŞBAŞI	680618,4851	4550335,831	30,52	1,028373	164
ÖMERLİ	696278,4851	4541485,831	30,45	1,011825	161
BÜYÜKADA	676928,4851	4527565,831	31,16	1,032857	163
OLİMPİYAT	648428,4851	4551445,831	31,45	1,04492	164
AKSARAY	659738,4851	4544005,831	32,23	1,066982	167
TERKOS	639518,4851	4575535,831	27,94	0,951153	141
AKOM	664748,4851	4550275,831	30,78	1,022857	163
SAMANDIRA	686588,4851	4535635,831	32,1	1,055951	163
ŞİLE	711158,4851	4560415,831	28,9	0,978059	154

Table 3. Meteorological stations in Istanbul and their temperature data with radiance values.

The relationship between radiance and the temperature is given in the Figure 12. There is a linear relation between radiance values and temperature data in a good agreement.

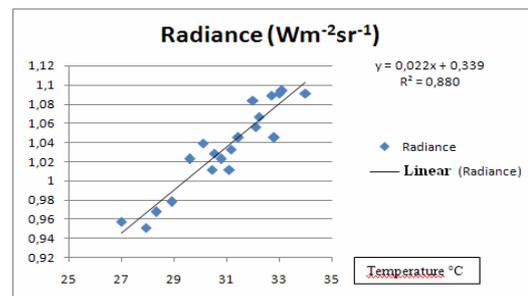Correlation of radiance values and temperature data is %88 and its formula is: y = 0,222x + 0,339.

Figure 12. The relationship between temperature and radiance.

4. CONCLUSIONS

In this study, 25 September, 1987, 18 July, 1997 and 28 June, 2007 Landsat Thematic Mapper satellite sensor images of Istanbul are used to disclose the growth of the city, and urban heat islands which occurs over the city because of the urbanization.

Istanbul's population has doubled in last two decades. The growth of the city, that is to say urbanization, is shown by the Landsat satellites images' classification for urban area.

Increasing of the pavements, structures and dark surfaces, which mean decreasing of the vegetation and forests, cause to rise of surface temperature over the city than surrounding area. Therefore, urban heat islands occur over the city. Urban heat islands can be detected with meteorological data or satellites thermal band images. Classification of the thermal channel images of Istanbul have shown that urban heat islands are related with the urbanization. Moreover, urban heat islands have occurred especially in last 20 years in Istanbul.

The relationship with the urbanization and the heat island have shown by, when the urban boundaries of the Istanbul which are belong to 1987, 1997 and 2007, are added on thermal classification of the images.

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