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RESEARCH ARTICLE

URBANIZATIONEFFECT ON URBAN HEAT ISLAND, A CASE STUDY SAKARYA

Mahnaz Gümrükçüoğlu

Department of Environmental Engineering, Sakarya, University Turkey

A R T I C L E I N F O

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A B S T R A C T

Urbanization is causing a marked temperature increase in cities compared to rural areas by affecting parameters such as temperature, speed of wind and humidity, and is intensifying the heat island of the city. In this study, we present the changes in temperature, precipitation, wind and relative humidity in the city of Sakarya and determine the formation of urban heat island by comparing the data of two different counties. For the determination of differences between Adapazarı and Geyve counties- being the study areas - the monthly, annual and seasonal averages of minimum, average and maximum temperatures and changes in wind and humidity data of both stations were examined. The increase and decrease trends of these changes are indicated using linear regression, and its correlation with the increase of population and formation of heat island has been determined. Urban-rural stations are evaluated as a result, the effect of urbanization appears to become evident especially in maximum-minimum temperature difference series. However, there is an inverse relationship in wind, rainfall and humidity values. It is possible to mention with regard to these values that the temperature increasing, in other words, heat island effect emerges in Adapazarı compared to the surrounding rural area.

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INTRODUCTION

Urban heat island, the most widely known form of local anthropogenic climate change, can be defined as the higher temperature of the city compared to the surrounding rural areas (Streutker, 2003). The roads, buildings and vehicles in cities release energy, which is stored throughout the day and causes excessive heating of the environment. Materials such as asphalt, stone, concrete and glass, which cover the surface, are more capable of absorbing the sunlight in cities than rural areas. Differentiation is observed in temperature values under the same weather conditions depending on the material difference; for example, asphalt 42^{o}C, soil 31^{o}C, grass ground 29^{o}C (Oke, 1982). In addition, high structures and unplanned building decrease wind speed at levels close to ground, and these generate urban heat island effect (Oke, 1973). It is emphasized that wind speed has decreased by 20-30% in cities, and while yearly average relative humidity has decreased by 6%, this decrease is %8 in summer, and 2% in winter (Tayanç and Toros 1997). Urban heat island has distinct seasonal behavior, usually greatest in the summer, weakest in the winter (Ghanzafari *et al*., 2009). According to the time of day and the season, urban areas are usually about 3-4^{o}C warmer than rural areas.This difference increases during clear and calm weather conditions, and decreases during cloudy and windy weather. Urban heat island magnitude depends on population, meteorological parameters and city size. The relative geographic location, physical and morphological structure, population, and spatial distribution of the population of every city affect formation of urban heat islands.The effects of city climates on the global climate, human health and quality of life increase the importance of these changes within the city (Tayanç and Toros 1997).

Oke conducted the first significant study of city heat islands (Oke, 1982).Çiçek specifies in his study that increasing energy consumption and urban buildings and decreasing green fields cause climatic change (Çiçek, 2004). Yamashita, in his research performed in Tokyo, proved the formation of heat islands at all the stations (Yamashita, 1986).Gomez *et al*. studied the heat island in Valencia, Spain, and the effect of green areas on distribution of urban temperature (Gomez *et al*., 1998).In addition, the effect of rural variation was researched in the Phoenix, Arizona urban heat island study (Hawkins *et al*., 2004). In his study, Fujibe assessed the long-term temperature trends of 60 stations in Japan (Fujibe, 1995).Karaca *et al*. researched the temperature trends at stations within Ankara and Istanbul and in rural areas around them, and determined the formation of heat island in Istanbul (Karaca *et al*., 1995). Moreover, sample studies have also been performed regarding the determination of urban heat islands in cities such as Athens, (Livada *et al*., 2002), Guadalajara, Mexico (Tereshchenko and Filanov, 2001), Pune, India (Deosthali, 2000), Granada, Spain (Monta *et al*., 2000), Tel-Aviv, Israel (Saaroni *et al*., 2000); Fairbanks, Alaska (Magee *et al*., 1999), Vancouver, Canada(Runnels and Oke, 2000).

The purpose of this study is to reveal the rapid increase of population and urbanization in the province of Sakarya, the parameters of temperature, wind, precipitation and relative humidity, and thus how the climate of the city is affected, and to determine the formation of urban heat island. In the study, by using the monthly minimum, average and maximum temperature values, relative humidity values, precipitation and wind data of Adapazarı and Geyve meteorology stations, the differences between the two stations was examined using the linear regression method. Consequently, the effects of increased population and rapidly developing urbanization, the increase in temperatures -especially minimum temperatures- and decrease in wind speed reveal the formation of heat island at Sakarya. By revealing the relationship between meteorological parameters - such as temperature, wind and humidity and urbanization - the effects of urban heat island and the importance of planned urbanization to decrease these and for the formation of sustainable cities are emphasized.

MATERIAL AND METHOD

The study areas are the Adapazarı and Geyve counties of the province of Sakarya (Fig 1). Adapazarı represents the flat area in the middle of the province of Sakarya, Adapazarı is a typical plain city on a young alluvial filling where the spreed is rather in north-south direction and Geyve represents the rougher section to the south.The climate of the area is mild, with a high rate of humidity. The winters are moderately cold with plenty of rain and the summers are hot. The coldest months are January and February, and the hottest June and August. Annual average temperature is 14.1 °C. The lowest temperature measured was -14.5 °C, and the highest 41.8 °C. Annual average humidity rate is 71.7%, and annual average wind speed is 1.0 m/s (Turkish Met. Service 2008).

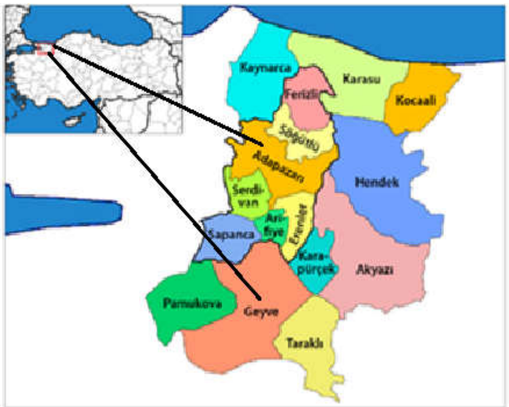

Figure 1 Study area

Adapazarı was taken as the urban area due to its central location and high population, and Geyve was chosen as the rural area. Minimum, maximum and daily average temperature data are used in urban heat island studies. The minimum temperatures are important as they are usually the best indicators of heat islands [3]. Maximum temperatures are important for creating of press on health and environment, because of this parameters are investigated. The monthly minimum, average and maximum temperature values, relative humidity and precipitation amounts and wind speed data of Adapazarı and Geyve meteorology stations between 1980 and 2011 were obtained from the Sakarya General Directorate of Meteorology Affairs. The latitude of Adapazarı meteorology station is 40° 41', and its longitude is 30° 26'. Its elevation is 31m above sea level (Envi. Report, 2008) while the Geyve meteorology station is 124 m. They are about 36 km apart. The data of Adapazarı and Geyve were assessed synchronously as from 1980. By taking the monthly, annual and seasonal averages of the minimum, average and maximum temperatures of both stations, we established whether there were increases or decreases during the years in question. Moreover, for the determination of urban heat island, we calculated the differences between the minimum, average and maximum temperatures of Adapazarı and Geyve. In addition, we also examined the changes in wind speed, precipitation and humidity data at both stations and these changes were analyzed. The increase and decrease trends of these changes are indicated using linear regression, and its correlation with the increase of population and formation of heat island has been determined.

As data relevant to an increase in population cause changes in the dispersion of urban structures and land use, they are important in the examination of the formation of heat island. AlsoPopulation growth increases heating- and traffic-based emissions. Therefore, the population data for Adapazarı and Geyve since 1965 were obtained from the Turkish Statistical Institute. The population of Adapazarı was 251680 in 2011. 95% of that number represents the population of the city. And Population density is $760/km^2$, whereas the provincial overall is 173.At the same time, the population of Geyve was 46892, 45% of it in the city. According to these data, we assessed the correlation between the increase in population and the increase in temperatures (Statistical Inst., 2008).

RESULTS

When the annual averages of minimum, average and maximum temperatures at Adapazarı and Geyve stations between the years 1980-2011 are examined, it is observed that the monthly and annual averages of Adapazarı are higher compared to Geyve (Fig2).It was found that the annual average and minimum temperature values showed an increase as from 1994, and that the maximum temperature values showed an increase as from 1997.

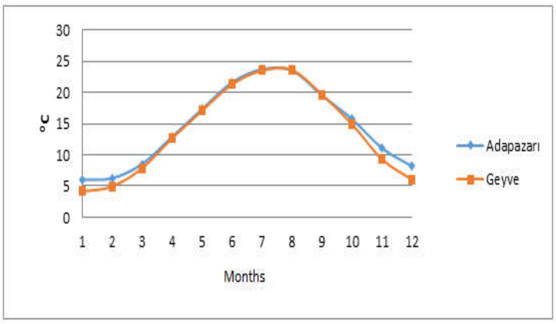

Figure 2 Monthly Average Temperatures at Adapazarı and Geyve (1980-2011)

Minimum Temperatures

Urbanization and urban heat islands show their true effect in night temperatures when the temperatures drop to their minimum levels.When the minimum temperatures are examined, the minimum annual temperature average at Adapazarı is between 8.8 °C and 12.3 °C. It is between 6.7 °C and 10.1 °C at Geyve. Annual minimum temperature average of Adapazarı between 1980 and 2011 was 10.2 °C, and 8.4 °C at Geyve. Monthly, seasonal and annual regression analyses were made for minimum temperature differences. When we address it seasonally, while an increase of 0.39°C/10 years is observed in spring regarding minimum temperatures, an increase of 0.37°C/10 years is observed in the month of May. In winter, an increase of 0.51°C/10 years is observed. Autumn shows an increase of 0.49ºC/10 years. While summer shows an increase of 0.55ºC/10 years, the rate of increase for June is 0.46°C/10 years. When the annual differences are considered, the general rate of increase over 10 years was found to be 0.48°C (Fig3). This results previous urban island studies that the minimum temperatures show a notable positive trend.

of increase such as 0.40°C/10 years is observed in the spring. The summer season generally shows a decrease of 0.045ºC/10 years. An increase trend of 0.32ºC/10 is observed in the autumn season, and an increase trend of 0.29°C/10 years is observed in winter.

The R² values of these trends are low especially in winter and slightly higher in summer. The lowest R² value is observed in September by 0.18, and the highest R² value is observed in June by 0.61. It is observed that the R² value of annual maximum temperature differences is 0.43 and that the general increase rate of 10 years is 0.24 °C.

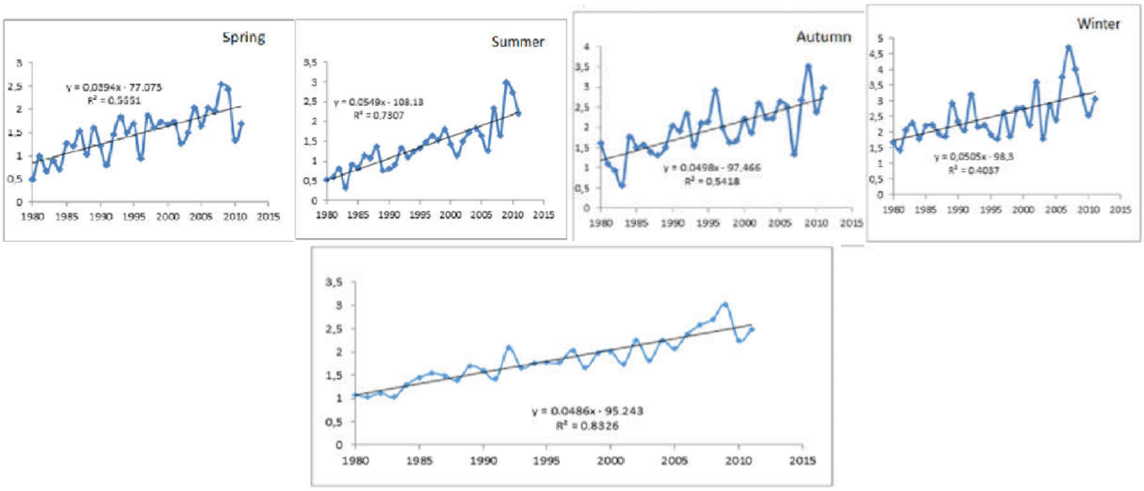

Figure 3 Seasonal and Annual Regression Analyses of Minimum Temperature Differences of Adapazarı-Geyve

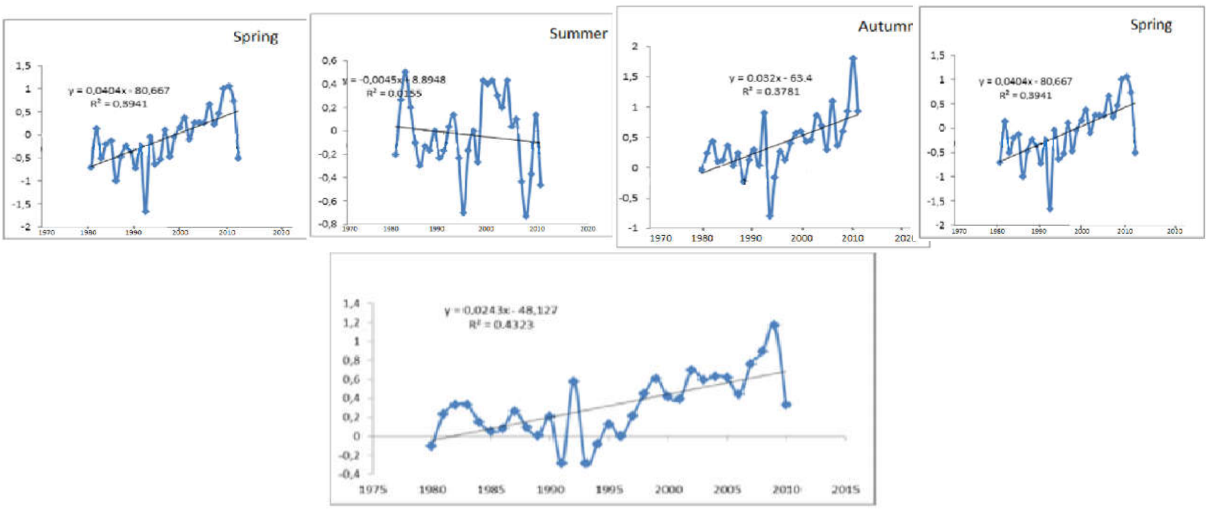

Figure 4 Seasonal and Annual Regression Analyses of Maximum Temperature Differences of Adapazarı – Geyve

Maximum Temperature

While the maximum temperature changed between 17.8ºC–22.5ºC at Adapazarı, it changed between 17.9ºC–21.8ºC at Geyve. In other words, the daily temperatures at Geyve are higher than those at Adapazarı. In fact, the expected condition is to have higher temperatures at the Adapazarı station whose urban functions are greater. Especially in autumn and winter, there are years in which the average of Geyveis higher than Adapazarı (Fig4). Regarding maximum temperatures, a trend

When the linear regression trend analyses of maximum temperature differences are examined by month, the increase shows continuity except for June and August. In particular, the negative value of ΔT at the hottest times of the day indicates that the rural area is warmer than the city.

Average Temparature

The average temperatures at Adapazarı are between 13.5ºC – 16.5ºC. In Geyve, the change is between 13.1ºC-15.4ºC. The difference observed in average temperatures - measured at Adapazarı and Geyve stations - does not indicate a huge increase or decrease in spring. When spring is considered in general, it has an increase of 0.27ºC/10years and 0.27 R^2 value (Fig5). In May, an increase of 0.18°C/10 years is observed in general. The 0.24ºC/10 years increase in summer has a predictive coefficient of 0.44. The increase is 0.31ºC/10 years in autumn, and the R^2 value is 0.15. 0.29ºC/10 years increase is observed in winter, with an R^2 value of 0.31. It is observed that the R^2 value is 0.19 in annual average temperatures, and that the general increase rate is 0.34°C/10 years.

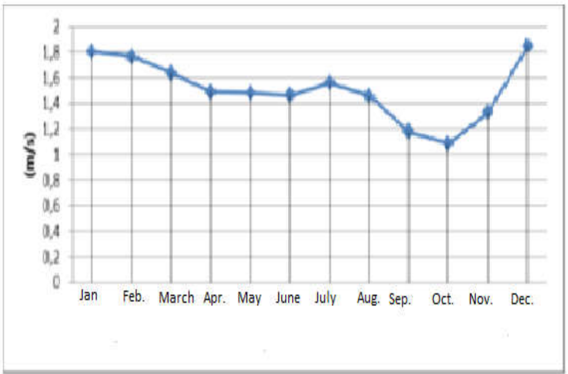

Figure 6 Wind Speeds of the Adapazarı

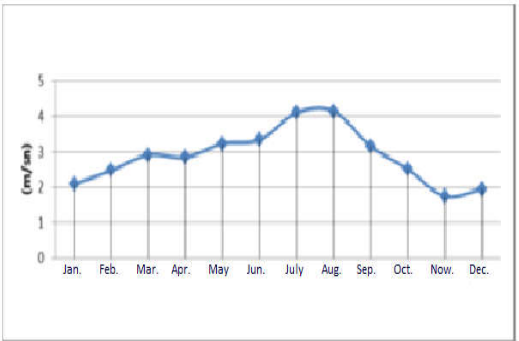

Figure 7 Wind Speeds of the Geyve

Wind Speeds

When the monthly average wind speeds at the stations are examined, it is observed that monthly averages are generally lower at Adapazarı compared to Geyve. The month in which the average wind speed is the highest at Adapazarı is December (1.85 m/s), and the lowest is October (1.09 m/s). At Geyve, they are respectively August (4.15 m/s) and December (0.1 m/s). A decrease of 0.03 m/s in annual average wind speed is observed in the ten year period. Wind speed is high in winter on Adapazarı and in summer on Geyve (Fig 6, 7).

Based on the urban population, calculation of the wind speed required for non-occurrence of heat island effect according to the formula suggested by Oke and Hannel (formula 1) reveals 8.2m/sec. for overall Sakarya.

U= 3.4logP-11.6(m/sn) (1)

U= speed

P= population

Relative Humudity

The average relative humidity at Adapazari between 1985 and 2006 was measured at 69% as the lowest in June, and at 76% as the highest in October.

The relative humidity at Geyve was recorded as 68% in June, and at 79% in November as the highest rate. While the R^2 value of annual relative humidity average at Adapazarı is 0.029, it is 0.023 at Geyve. It is observed that the annual relative humidity at Adapazarı has an increasing trend. According to this, the increase trend of Adapazarı in the 10 year period is 0.8%, while for Geyve it is 0.2%.Because of antropogenic humidity, relative humidity is high in winter and at night on both areas.

Precipitation

Figure 8 shows the total amount of precipitation in Adapazarı and Gevye. Yearly average

Precipitation in Sakarya between 1980 and 2010 is 846.26mm, and 607.76mm in Gevye. The lowest amount of total precipitation in measured years in Adapazarı was recorded in 2007 with 609.7 mm of precipitation. Whereas the highest total amount of precipitation was in 1997 when 1172.7mm of precipitation was recorded. According to the data obtained from the stations in Gevye, on the other hand, the lowest amount of precipitation was in 1986 when 464,2 mm of precipitation was recorded while the highest amount of precipitation was recorded in 1997 with 801.3 mm. The rate of increase of precipitation in Adapazarı is 8,7 mm/10 years. The predictive coefficient of this value is 0.0031. This value is 0.0048 in Gevye. Of the total precipitation in Adapazarı, 32% occurs in winter, 22% in spring, 26% in fall, and 20% in summer. Similar rates apply to Gevye.Regression analyses do not reveal any significant increase or decrease in precipitation over years (Fig 8).

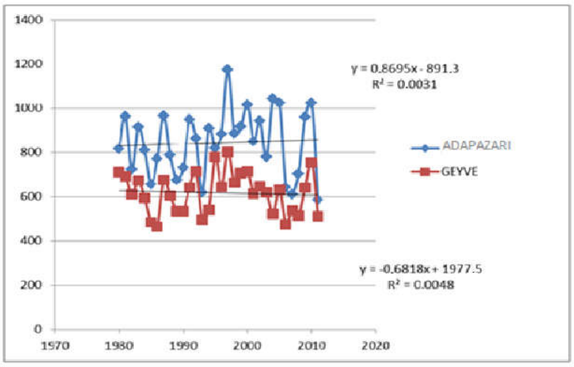

Figure 8 Annual Precipitations of the Adapazarı and Geyve

Population

The size of the urban heat island is closely related to the population density. When the growth of population at Adapazarı and Geyve is examined, while the trend of increase of population is 12724 at Adapazarı, it is 360.24 at Geyve. A more rapid increase is observed at Adapazarı. In Figures 6 and 7, we show the growth of populations in the centers of Adapazarı and Geyve between 1965 and 2011. In addition to the increase in population from year to year, the speed of that increase is also growing (Fig 9, 10).

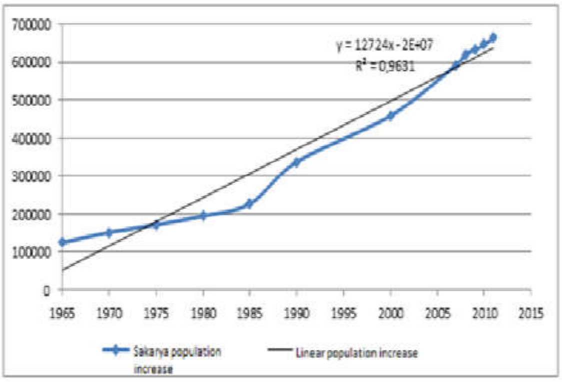

Figure 9 Growth of Population at Adapazarı as from 1965 until 2011

Using the formula developed for European cities by Oke, it is possible to determine the urban heat island as a function of the population (Oke, 1973) (1).

UHI = 2.01 log N – 4.06 (1)

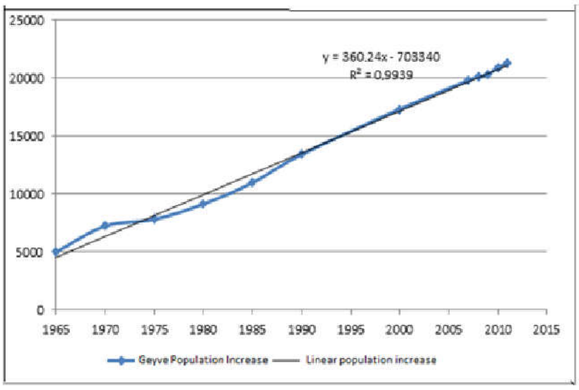

Figure 10 Growth of Population at Geyve as from 1965 until 2011

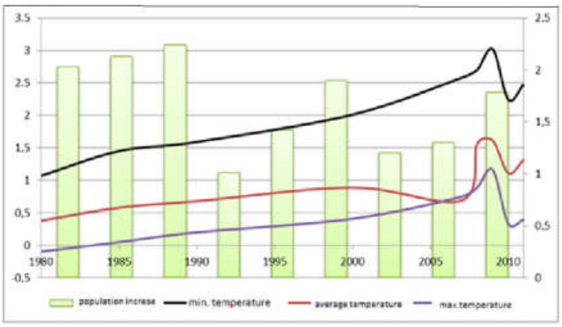

Figure 11 Changes of temperature at Adapazarı depending on the speed of increase of population

UHI = Urban Heat Island

N = Population of the City

When this formula is applied to the city of Sakarya, we obtain this result:

UHI Sakarya = 2.01log 888556– 4.06= 7.9^{o}C

As understood from this result, the city of Sakarya has a temperature difference of 7.9C compared to the surrounding rural areas. Of course, many factors such as its topographical structure, climate, urban growth, macro form, and clear-green field system affect the heat island at the province of Sakarya.

The result obtained from this formula provides general information. However, a difference of 7.9^{o}C cannot be underestimated when considering the conditions of comfort of living. As a result of all this development, the population of the city has reached 888556, and it faces many difficulties such as infrastructure and settlement problems being primarily the result of the population density and unplanned development.

The difference in minimum temperatures shows a positive correlation with the increase in population (Fig11).
Figure 11 is here

DISCUSSION

Annual average temperature and minimum temperature values showed an increase from 1994, and maximum temperature values showed an increase from 1997. The areas representing the city have a warmer climate in winter compared to rural areas as the result of increasing population and rapidly developing urbanization. The trend of increase of minimum temperatures is due to the fact that Adapazarı does not cool down very much at nights because of the effect of urban heat island. Vertical and tall buildings asphalt and concrete surfaces in the cities obstruct the retroreflection of sunrays. When the carbon dioxide and dust in the atmosphere are added, the cooling down of the city at night decreases still further. Along with the increasing population, the increase of urbanization (in other words, the increase in building), vehicles and human activity, and the decrease in wind speeds are causing the increase differences at minimum temperatures between Adapazarı and the rural area. In previous studies, the effect of urbanization on temperature and the greater effect of minimum temperature from urbanization compared to maximum temperature have been revealed (Tayanç and Toros, 1997). The results obtained in this study are in parallel with these findings. In this case, the formation of heat island at Adapazarı can be specified.

In the analyses, it was considered that the effect of heat island is most noticeable at periods in which the difference of temperature between the two stations is more than 1.0°C. In particular, if it is accepted that the minimum temperatures are the best indicator for the formation of heat islands, the existence of heat island can be specified as the minimum temperature difference of summer periods of some years being over 1^{0}C throughout the whole examination period except for a couple of months.

Regarding maximum temperature differences, it is observed that the increase shows continuity except for June and August and thus the rate of increase is high. Also having an increase in maximum temperature indicates that the effect of the city is not limited to nighttime but is also affected during the day. When the city and rural areas are compared, it is observed that maximum temperature in summer does not increase much at locations where vegetation cover is dense as the humidity is high (Yılmaz, 2013). In addition, in winter months the rural area of Geyve is warmer compared to Adapazarı in respect of maximum temperatures. In addition, in the afternoon or the hottest hours of the day, ΔT is negative, thus indicating that the rural area is warmer compared to the city. Thus, Geyve –

despite being a rural area - had been warmer than Adapazarı in some years.

By defusing the heat in the direction of the wind, the wind mitigates the effect of urban heat island (Oke, 1973). The reason for a decrease in wind speed and increase in the number of non-windy days is the absorption of wind energy by the friction generated due to buildings. Even if there are not many tall buildings in the area, the intensity of buildings increasing along with the population slows the wind speed at Adapazarı. The decreasing wind speed is among the most significant factors playing a role in the increase in temperature. When a relationship is established between the formation of heat island and wind speed, the effect of heat island increases at periods when the wind speed is below 0.5 m/sec.The wind velocity required for non-occurrence of urban heat island effect is 8.2m/sec. for Sakarya.

When the humidity values of Adapazarı and Geyve are assessed, it can be seen that the highest relative humidity in city and rural areas occurs in winter, while the lowest value occurs in summer. This condition is in conformity with the high anthropogenic humidity generation of the city in winter. In summer and winter, the relative humidity is high both in the city and at rural areas at night, and low in daytime.

Many studies including urban and rural precipitations show that urban precipitation is 10% higher than rural precipitation. Subsequent studies reveal that the major cause for increase in amounts of urban precipitation is light winds in city centers (Kadıoğlu, 2000). Furthermore, the warm air over cities due to the heat islands formed by cities increase the instability of atmosphere over urban areas. Uneven surfaces in cities cause air systems at lower levels to slow down and stay longer (Lutgens and Tarbuck, 1989). Changes in precipitation trends in our country have been generally analyzed on regional basis. A significant correlation could not be established between urbanization and change of precipitation in a small number of studies where such correlation is analyzed were not able to find a correlation between yearly precipitation and urbanization in their studies that surveyed regional climate change and the effects of urbanization (Tayanç and Toros, 1997). The results we have yielded in our study is in parallelism with these data. The regression analyses we have conducted do not reveal any significant trend of increase in precipitation in overall Sakarya. A comparison of data obtained from two stations reveals that the amount of precipitation in Adapazarı, which is an urban area, is higher than in Gevye.

Although Geyve County–which was selected as the rural area and whose population is increasing-differs from Adapazarı in respect of geographical conditions and vegetation cover, a complete comparison between the rural area and the city was prevented as it got close to levels of the city because of issues such as industry and traffic. When the stations selected for comparison show a complete urban or rural characteristic, more accurate results are obtained in respect of temperature differences and heat island. The scarcity of meteorology stations at rural settlements is an important deficiency in such studies.

CONCLUSION AND SUGESTIONS

Urban heat island is occurrence of global climate change in local scale, and has adverse effects on well-being of humans and other creatures as well as life quality and energy consumption of humans. A comparison of temperatures in heat islands to those of surrounding rural areas provides a clear indication of the effects of heat islands. The primary reason for this is the difference between urban and rural surface materials in terms of their storage of heat.

Evaluation of the data obtained from the meteorological stations in Adapazarı and Gevye, which are defined as urban and rural stations respectively reveals that the effects of urbanization becomes obvious in the series of differences between maximum and minimum temperature. On the other hand, there is an inverse relationship between the values of wind and humidity. A statistically significant urban impact was not observed in precipitation series. Based on these values, it would be fair to say that the city of Sakarya is subject to a heat increase, i.e. heat island effect, compared to its surrounding rural area.

The purpose of this study is to identify the meteorological parameters and their correlations with population growth to understand the importance of well-planned urbanization and industrialization for establishment of healthy, habitable, and sustainable cities and to apply the numeric data related to this importance to the example of Sakarya.

In order to prevent the formation of heat islands and their negative effects, it is obligatory to increase green fields within cities and to prevent harmful emissions and the destruction of forests. Moreover, measures such as roof gardens and white roofs, have begun to be implemented in many cities in the world, with the support of local authoritiesPreference of light colors for the urban surfaces (pavements, building surfaces, asphalt roads, roofs, etc.) to be built is a correct one for reduction of the heat island effect. Development of structures to drain pollution caused by sources of emission as well as expansion and especially preservation of green areas are important for draining are among the important measures to be taken (Behfar *et al*., 20139.It is clear that the negativities arising in cities in respect of the quality of life and natural values can be decreased by climate science based and planned approaches, which will not decrease the wind speed thus making urbanization coherent with nature. Moreover, it is necessary to determine the effect of cities on global warming - one of the most significant problems of today - and to make assessments accordingly.

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