Evaluating the effects of UHI on climate parameters (A case study for Mashhad, Khorrasan)

S. Ghazanfari, M. Naseri, F. Faridani, H. Aboutorabi, A. Farid

Abstract**—**Urban expansion, pollution growth, and development of major industrial activities in metropolitan areas impacted local climates of major towns. Transforming big cities into heat islands is one of the most important results of micro-climate change. In this study, variation of some of the important climate factors (such as precipitation, temperature, relative humidity, and percentage of cloudiness) was reviewed in order to study micro-climate changes. The city of Mashhad selected for this study, as metropolitan area. The study performed by comparing the climate parameters of this city with the neighboring regions, which placed at the same climate categories. According to the effective role of rainfall in the urban weather modification and decreasing of pollutions, rainfall variation will be more important and sensitive. The result of this research shows that rainfall variation follows the change of temperature trend. A significant correlation between temperature and precipitation changes showed the effect of heat island on urban climate parameters. The urban heat island phenomenon increases the hot season rainfalls when we have decreasing effects on cold season.

Keywords**—**Urban Heat Island, Air pollution, Microclimate change, climate parameters, Metropolitan areas

I. Introduction

MOST of researchers believe that the global temperature has been growing since 19th century [11]. In other hand, a phenomenon called Urban Heat Island (UHI) caused faster growth in city temperatures. Increasing the immigration of people to towns and expansion of urbanism will increase the gradient of temperature growth in the future. According to statistics by the United Nations, more than 80% of global population will be living in the major cities to 2025 (United Nations, 2003); the problem will be worse when cities started to be warmer. The heat island phenomenon has big effect on air pollution, pollution management, regional temperature, and energy consumption growth in the air conditioner, and also public health within urban areas.

The temperature difference between cities and neighboring regions was generated from difference in absorbed energy. In the cities, dark-colored textures like asphalt, concrete, and other construction materials were caused decreasing in albedo coefficient, and therefore increasing in absorbed energy. Some methods of decreasing the influence of heat island phenomenon are planting trees, expanding the urban landscape, and using constructional materials with high albedo rate. More than 150 years ago, for the first time in some European cities, the heat island phenomenon discovered [8]. In many areas of the world heat island phenomenon and its impact have been investigated individually [12, 19].

Although, the effects of heat island phenomenon in comparison with global warming is in the second rank; lots of investigations show that this phenomenon microclimate scale is significant and can't be neglected [9, 22,23]. For instance, between the years of 1901 to 1984, in the North America region the difference between temperature of different cities with populations more than 100,000 and their rural neighboring regions, was 0.1 °C in ten years [13].

There are many solutions to mitigation UHI effects. Some solutions try to reduce the green house gases to avoid the harmful effects. Renewable energy is one of the solutions in towns. Non-fossil fuel energy options could help humanity combat climate change and also provide the opportunity for sustainable energy solutions. Non-fossil fuel energy options are diverse, ranging from renewable energies such as solar, wind, geothermal, hydropower, biomass, ocean, tidal, and wave energy through to nuclear energy. The latter shouldn't be a renewable resource, but it avoids green house gas emissions and thus, contributes to efforts to avoid climate change. Renewable energy resources are normally free of green house gas emissions; although some of them such as biomass could lead to such emissions if not managed carefully [16].

The other study, which has been done on integrating urban heat island mitigation and environment resource management, is using multivariable method. The results show that fifteen factors should be deduced from four themes. These four themes are included: (1) land development and building greening, (2) the natural resource maintenance, (3) keeping good environment resource, and (4) concerning natural ventilation and energy saving [14].

Several researchers have noted that the urban heat-island have a significant impact on meso-scale circulation, which is resulting convection and precipitation [17].

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The last 30 years of study shows that the urban regions affect the clouds and precipitations [4].
Recently, some researchers implemented the urban canopy parameterization in the fifth-generation Pennsylvania State University, national center for atmospheric research meso-scale model (MM5;[6]) to improve meteorological factors in the urban boundary layer[18]. Instead of dynamical and thermal effects by the urbanization, aerosols also can play important roles for the precipitation formation [1,20,**46**7].
Recently, one study has been done for Simulation Indicates Aerosols Distribution Influenced by Urban Building Forms [2].
Therefore, the urban heat-island effect would have substantial impacts on the precipitation, air quality, and climate around urban areas.
According to the recent research, rainfall in the warm seasons increased between 9 to 17 percent in cities [3, 15]. Many urban meteorological experiments on the influences of big cities on mid-scale atmosphere variation and convectional precipitations were done in the US since 1970 [9]. The studies confirm the effect of heat island phenomenon on urban region rainfalls such as growth of precipitation in summer time [10, 21]. In this research, variation of some important climate factors (precipitation, temperature, relative humidity, and percentage of cloudiness) was reviewed due to the microclimate changes. The city of Mashhad was selected as study area. This study was investigated by comparing the climate parameters of city of Mashhad with the neighboring regions, which was placed in the same climate category.

II. Materials and Methods

The most common approach to study the heat island phenomenon is comparing urban area with neighboring rural regions. Most of the studies in this case have been done by calculating the UHI index [8]. The UHI index is used to study the increase of temperature trend that caused by heat island, comparing with rural neighboring areas. This index showed as below:

$$UHI = T_{av} - T_{ar} \quad (1)$$

In this equation, T_{av} is the average temperature of town, T_{ar} is the average temperature of rural region (outside of affected area) for a given year. UHI index was calculated for the whole number of years.

Data series of the synoptic and climatology stations of city of Mashhad, Golmakan, Sabzevar, and Sarakhs cities were used. The characteristics of these stations are given in below Table.

Table 1- Stations Characteristics

STATION	Lat. (°, ")	Lon. (°, ")	El. (m)	Established
Mashhad	36 16	59 38	999.2	1951
Golmakan	36 29	59 17	1176	1987
Sarakhs	36 32	61 10	235	1984
Sabzevar	36 12	57 43	977.6	1954

The precipitation, average, minimum, and maximum temperatures, relative humidity, and Cloudiness data were obtained from Iranian meteorological organization archive. In order to find the trend of a time series, the data were used; they should evaluate whether they have normal value or not [5]. For this purpose, the software JMP (v.4.0.4) was used in this study.

III. Results and Discussion

A. Temperature

The distribution of temperature was shown in Table 2 and also the analysis of variance of this data set was analyzed (See Table 3).

Table 2- Distribution Characteristic of Temperature Data

Moment	Value
Mean	13.91
Std. Dev.	1.02
Std. Err. Mean	0.003
Upper 95% Mean	13.92
Lower 95% Mean	13.91
Variance	1.03
Skewness	-0.15
Kurtosis	0.31

Table 3- Temperature Data's ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	15.95	15.95	21.03
Error	51	38.68	0.75	Prob > F
C. Total	52	54.63		<.0001

Figure 1 shows the increasing in temperature trend related to the global warming for different stations according to their climate conditions.

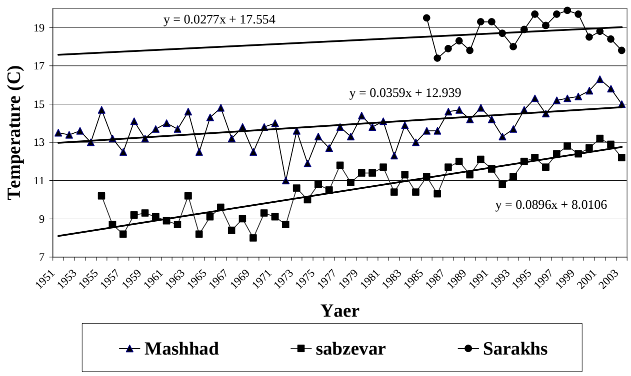

Figure 1 - The trend of Temperature in Different Stations

The temperature variations gradients for city of Mashhad between 1951 – 1985 and 1986 -2003 were compared with each other (Figure 2).

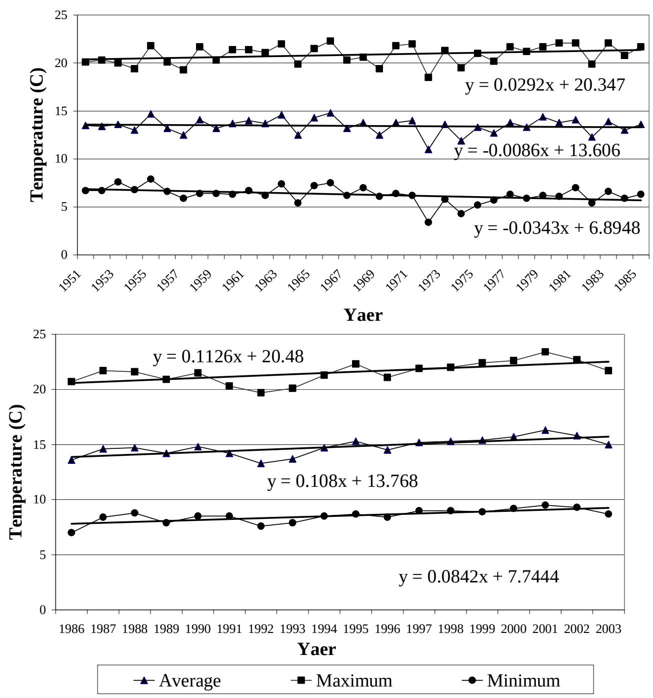

Figure 2 - Comparison of temperature gradient and variation in Mashhad for years of 1951-1985 and 1986-2003.

In addition, the gradient of average, minimum, and maximum temperature growth trend were compared with Golmakan station for years of 1986-2003. The Golmakan station is the closest synoptic station to Mashhad station; the data of Mashhad station compared with above station. Figure 3 shows the trend of minimum, maximum, and average temperatures of Golmakan station during 1987-2003.

The UHI index for Mashhad was calculated by using the data of Mashhad and Golmakan stations for 1987 through 2003 (Figure 4).

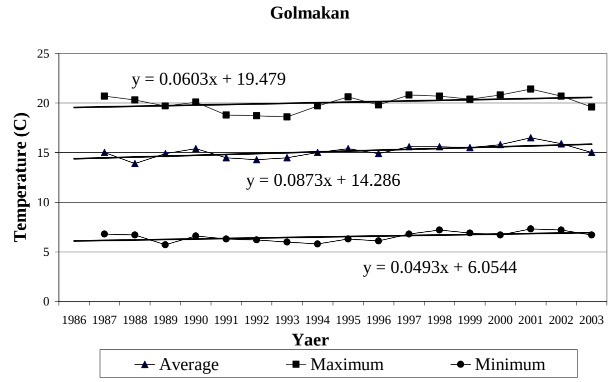

Figure 3 - Temperature Variation at Golmakan Station

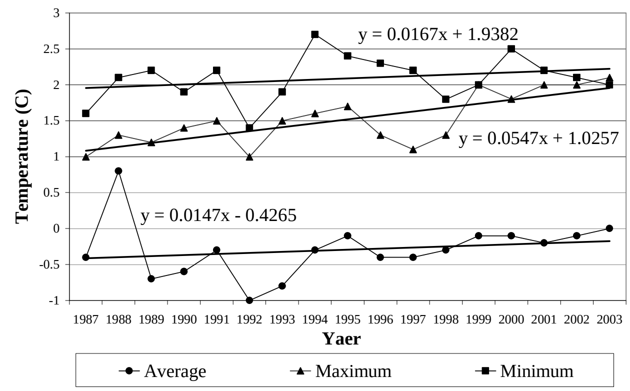

Figure 4 - UHI Index for Mashhad Station

In order to make the comparison, Golmakan station data were used. The variation trend of meteorological parameters including temperature, precipitation, cloudiness, and relative humidity were sorted by seasons during 1987 to 2003.

Figure 5 depicts the comparison between seasonal and annual temperature variation slops for town of Mashhad for 1951 to 1985 and also 1986 to 2003.

A comparison of seasonal and annual temperature variation slops for Mashhad and Golmakan stations has also been done for 1986-2003. Figure 6 shows the results.

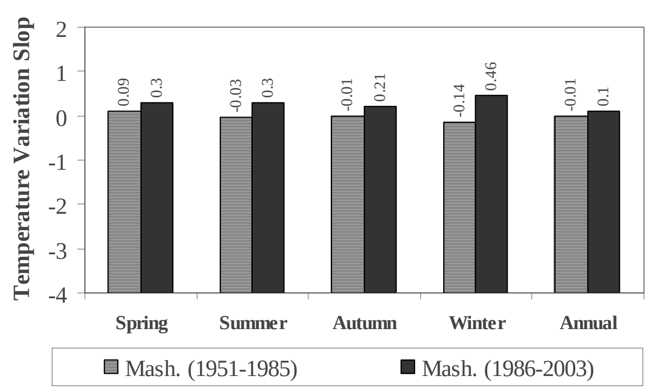

Figure 5 – The comparison of seasonal and annual temperature

variation slops in town of Mashhad for years of 1951-1985 and 1986-2003.

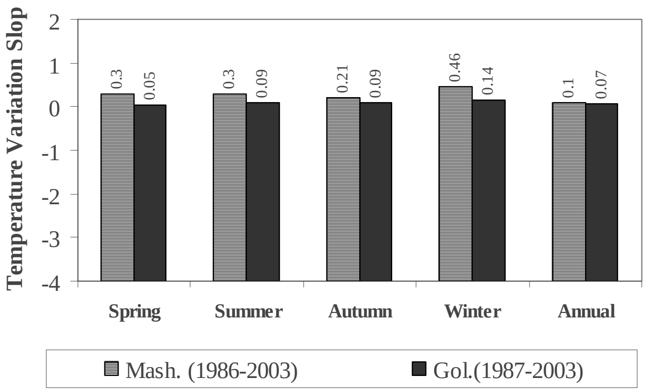

Figure 6 – The comparison of seasonal and annual temperature variation slops for Mashhad and Golmakan stations in 1986 to 2003.

B. Precipitation

The distribution characteristics and ANOVA results for precipitation data are given in Tables 4 and 5.

Table 4- Distribution Characteristic of Precipitation Data

Moment	Value
Mean	254.93
Std. Dev.	71.24
Std. Err. Mean	0.22
Upper 95% Mean	255.37
Lower 95% Mean	254.50
Variance	5075.85
Skewness	0.40
Kurtosis	-0.57

Table 5- Precipitation Data's ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1305.19	1305.19	0.25
Error	51	267529.91	5245.68	Prob > F
C. Total	52	268835.10		0.6201

The seasonal variation of precipitation trend for years 1950-1985 were compared with the same for years of 1986-2003. Figure 7 shows seasonal rainfall trends.

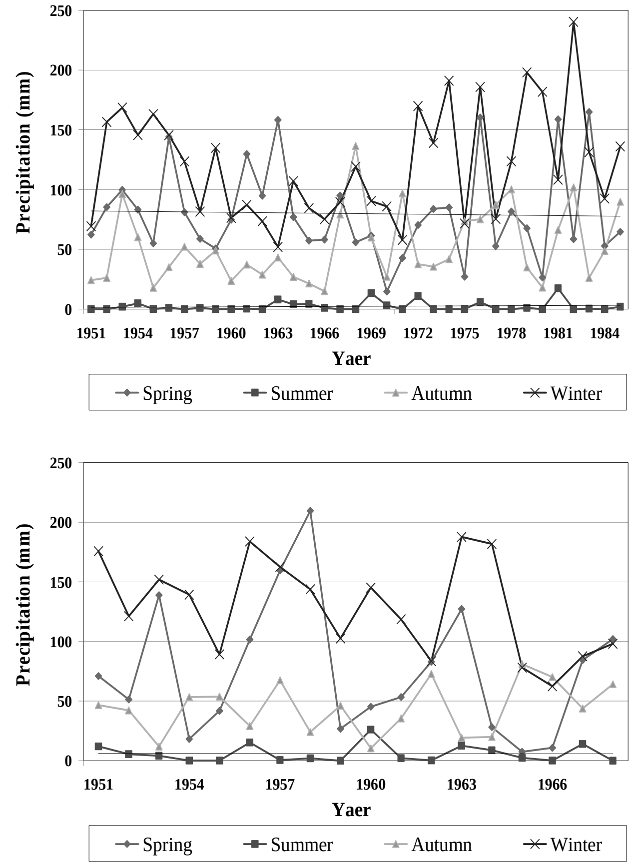

Figure 7 - Comparison of seasonal precipitation variation in Mashhad for years of 1951-1985 and 1986-2003.

The seasonal and annual precipitation variation slops were compared in town of Mashhad for years of 1951-1985 and 1986-2003 (see Figure 8).

In figure 9, a comparison of seasonal and annual precipitation variation slops has been done for Mashhad and Golmakan stations during 1986 to 2003.

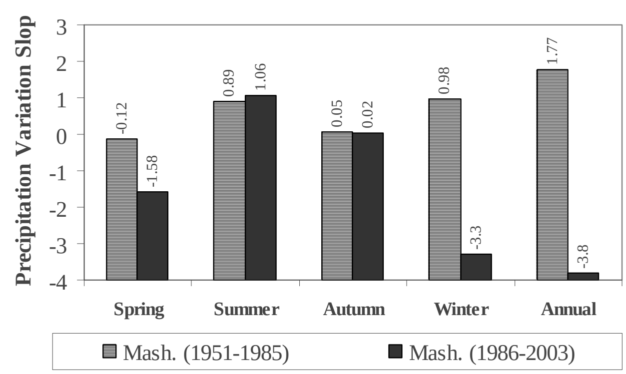

Figure 8 – The comparison of seasonal and annual precipitation variation slops in Mashhad city for years of 1951-1985 and 1986-2003.

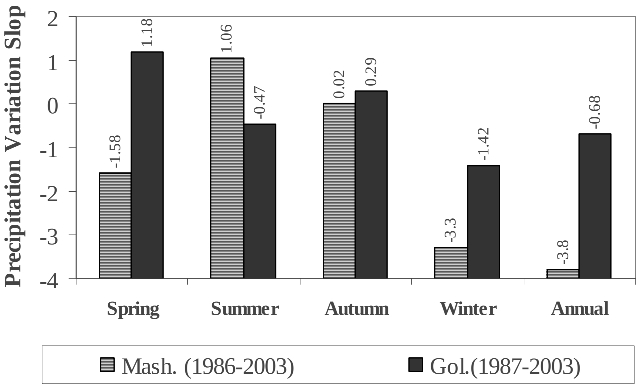

Figure 9 – The comparison of seasonal and annual precipitation variation slops for Mashhad and Golmakan stations (1986-2003).

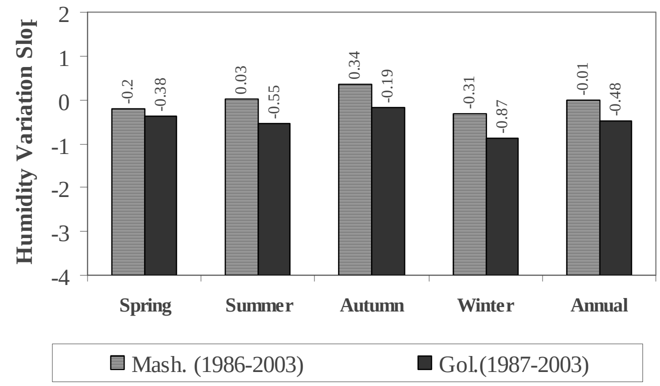

Figure 11 – The comparison of seasonal and annual humidity variation slops in Mashhad and Golmakan stations (1986-2003).

C. Humidity

The seasonal variation of humidity trend for years 1950-1985 were compared; which the same comparison has also been performed for 1986 to 2003. Figure 10 shows the comparison of seasonal and annual humidity variation slops in city of Mashhad for years of 1951-1985 and 1986-2003.

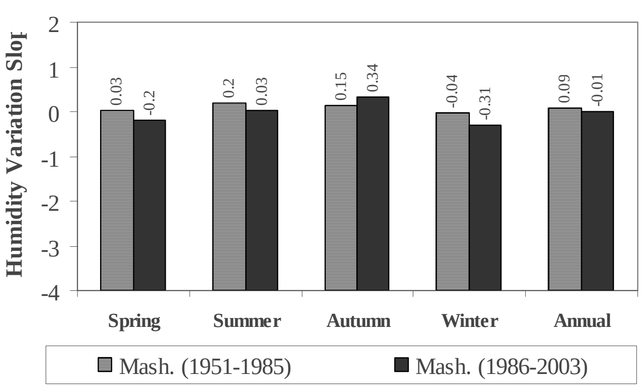

Figure 10 – The comparison of seasonal and annual humidity variation slops in city of Mashhad for years of 1951-1985 and 1986-2003.

The seasonal variation of humidity trend was compared between two stations (Mashhad and Golmakan) during 1986 to 2003. Figure 11 shows the comparison of seasonal and annual humidity variation slops in Mashhad and Golmakan Stations.

D. The number of cloudy days

Finally, the number of cloudy days' data was used to find the UHI effects on climatic parameters. This dataset was obtained from meteorological organization archive center.

The seasonal variation of number of cloudy days' trend for years 1950-1985 were compared; which the same comparison has also been done for 1986 to 2003. The seasonal variation of trend parameter for years 1950-1985 were compared with time of 1986-2003. Figure 12 shows the comparison of seasonal and annual data variation slops in town of Mashhad for years of 1951-1985 and 1986-2003.

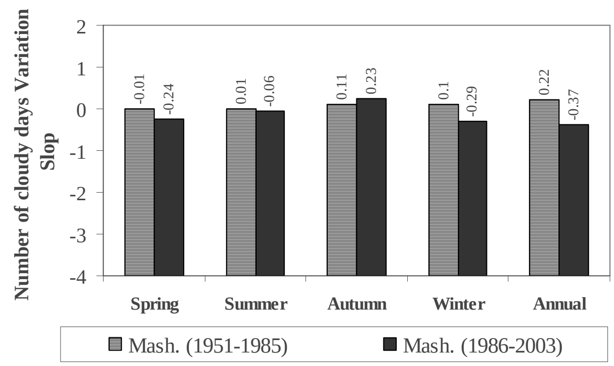

Figure 12 – The comparison of seasonal and annual number of cloudy days' variation slops in town of Mashhad for years of 1951-1985 and 1986-2003.

The seasonal variation of number of cloudy days' trend for Mashhad station in 1986 to 2003 was compared with Golmakan station for the same period of time. Figure 11 shows the comparison of seasonal and annual data variation slops in Mashhad and Golmakan Stations.

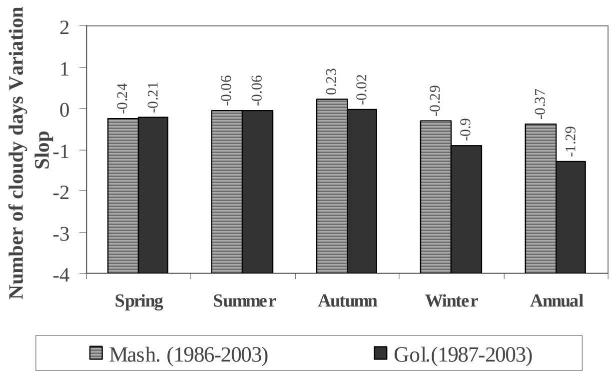

Figure 13 – The comparison of seasonal and annual number of cloudy days' variation slops in Mashhad and Golmakan stations (1986-2003).

IV. Conclusions

A comparison, which shows the effect of UHI on temperature trend after years of 1986, has been depicted on figure 14. This comparison was shown that UHI is more effective than global warming for increasing of temperature. This finding has been proved from the differences between Mashhad and Golmakan stations for the same years.

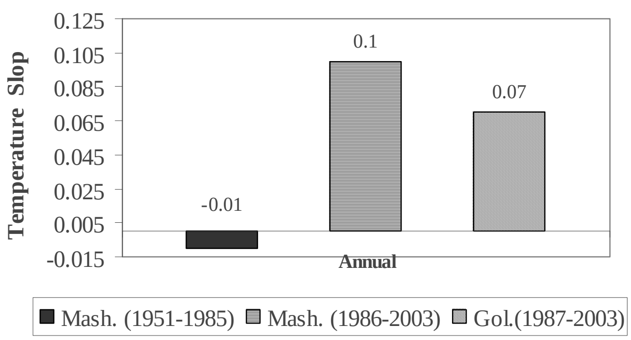

Figure 14 – The comparison of annual temperature variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for 1986-2003.

The comparison between years of 1950-1985 and 1986-2003, the effect of UHI on annual precipitation trend can be found. Figure 15 is a Comparison of annual precipitation variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for 1986-2003.

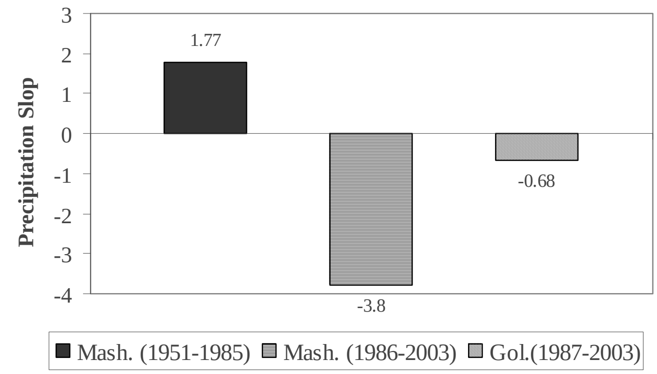

Figure 15 – The comparison of annual precipitation variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for 1986-2003.

Increasing in temperature trend normally caused a decreasing for humidity. Figure 16 is a comparison of annual humidity variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for 1986-2003.

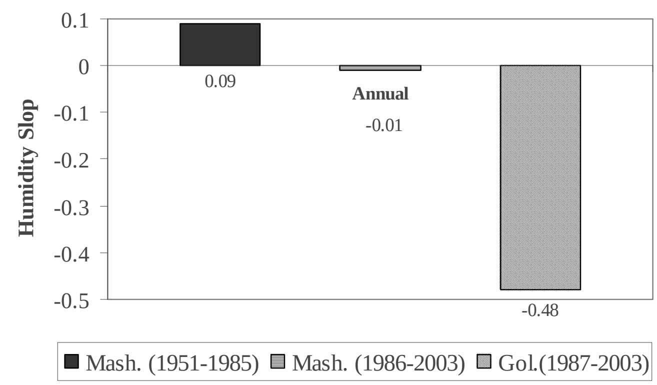

Figure 16 – The comparison of annual humidity variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for years of 1986-2003.

Figure 17 shows a comparison of annual number of cloudy days' variation slops in Mashhad for years of 1951-1985 and 1986-2003, and Golmakan stations for 1986-2003.

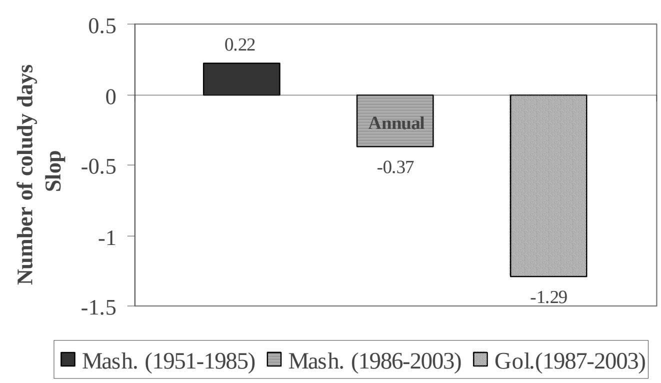

Figure 17 – The comparison of annual number of cloudy days' variation slops in Mashhad for years of 1951-1985 and 1986-2003 and Golmakan stations for 1986-2003.

In Table 5, the annual variation trend of temperature, precipitation, cloudiness, and relative humidity for Mashhad station during two periods of 1951 – 1985 and 1986 – 2003 were compared with Golmakan station for years of 1987 to 2003. According to the temperature variation during these years for all stations (Figure 1), the influence of global warming on temperature growth trend is clear.

The analysis of temperature data for Mashhad station (Figure 2) showed that, since 1986 heat island phenomenon has effective role on temperature growth trend, similar to other Stations, which there is no significant change in this trend.

By comparing the trend of maximum, minimum, and average temperatures growth in Mashhad station (Figure 2), it showed that minimum temperature was increased with greater slope compare to other temperatures and this trend has not been explored in Golmakan station. Similar results were reported in the previous studies [19].

Studies that were done by UHI index, confirmed the previous results regarding the effects of heat island phenomenon for 1986 and later for city of Mashhad.

According to many references, rainfall process is different in warm season compare to cold season; so the trend of temperature, relative humidity, and cloudiness variation, sorted by the seasons.

The results that obtained from Table 5, it shows that temperature variation gradient for years of 1986 to 2003 in Mashhad station for all seasons, was greater than temperature variation gradient for both stations in 1951 to 1985.

Also, relative humidity variation gradient during 1986 – 2003 was much less than the trend for 1951 - 1985, which can be explained by temperature increasing. The cloudiness variation gradient in Mashhad station for years of 1986 to 2003, compared with cloudiness variation gradient in Golmakan station has been increased, which this completely inversed of the precipitation issue. So, it is concluded that although cloudiness trend in Mashhad station was greater than Golmakan station but the influence of heat island of Mashhad caused greater precipitation trend in Mashhad than Golmakan (Table 5).

Table 5 - Variation Gradient of Meteorological Parameters Sorted by Station and Seasons

	Temperature			Precipitation			Humidity			Number of cloudy days		
	Mash. (1951-1985)	Mash. (1986-2003)	Gol. (1987-2003)	Mash. (1951-1985)	Mash. (1986-2003)	Gol. (1987-2003)	Mash. (1951-1985)	Mash. (1986-2003)	Gol. (1987-2003)	Mash. (1951-1985)	Mash. (1986-2003)	Gol. (198-2003)
Spring	0.09	0.30	0.05	-0.12	-1.58	1.18	0.03	-0.20	-0.38	-0.01	-0.24	-0.21
Summer	-0.03	0.30	0.09	0.89	1.06	-0.47	0.20	0.03	-0.55	0.01	-0.06	-0.06
Autumn	-0.01	0.21	0.09	0.05	0.02	0.29	0.15	0.34	-0.19	0.11	0.23	-0.02
Winter	-0.14	0.46	0.14	0.98	-3.30	-1.42	-0.04	-0.31	-0.87	0.10	-0.29	-0.90
Annual	-0.01	0.10	0.07	1.77	-3.80	-0.68	0.09	-0.01	-0.48	0.22	-0.37	-1.29

The results of table 5 for rainfall in these stations showed that precipitation in Mashhad station has greater gradient for all seasons except summer time. This issue has been approved for years of 1951 - 1985 and 1986 – 2003. Thus, the heat island phenomenon in cold seasons was caused rainfall decreasing, and in hot seasons it caused increasing [11, 21]. In the case of annual precipitation, the slope of graph has been decreased and it's related to the heat island phenomenon for city of Mashhad.

The pollution in big cities showed that in cold seasons, precipitation decreased air pollution in big cities; thus, it could be concluded, which heat island phenomenon in city of Mashhad, affecting the total annual precipitation, which is a positive feedback and extends its influence.

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