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URBAN SPRAWL AND CLIMATIC CHANGES IN TEHRAN

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ABCTRACT

Urban sprawl beginning in the developed countries around 1950 is currently experienced in almost all countries. Many studies on the effects of urban sprawl indicate the emergence of harmful effects of this phenomenon. One of the most important environmental effects is the changes in climate. The purpose of this research was to identify the relation between urban sprawl components of Tehran with changes in climate variables. To this end, two data sets have been used to study the relation between these elements and components. The first data set included climatic elements such as rainfall, temperature, the percent of relative humidity and the percent of calm wind, as well as its mean speed for a period of 54 years (1953-2006). The second set of data was formed by components relevant to urban sprawl such as city area, private cars per capita, population density and number of urban population. Pearson correlation and multiple regression methods have been applied to compare and identify the relation between climatic components with urban sprawl indices. Results of correlation indicate that among the 5 aforementioned climatic components, annual rainfall and the mean of wind speed do not appear to have significant relation with sprawl, but the oscillations in percent of relative humidity and percent of calm wind seem to have a significant relation with Tehran sprawl. Consequently and using multivariate regression, it was concluded that the most important factor in the increasing temperature of Tehran, is the number of cars; the most important factor in increasing the percent of relative humidity is the area of Tehran, whereas the increase of the percent of calm wind may be attributed to the increase of population.

Key words: Urban Sprawl, Climate Change, Metropolis, Population Density, Tehran

INTRODUCTION

Today, the relationships between human societies and their natural environment has been strongly affected by urbanization and urban development. Cities can be considered as ecological units and studied within the framework of a data-retrieval system. That is, to meet various needs of citizens, the city needs inevitable to provide massive data in key inputs, the most important of which are energy, food and water. Considering an increasing urban population, the result of applying such data is to obtain retrievals in the form of environmental effects such as climatic change, water pollution, air pollution, noise pollution, thermal pollution and changes in the water cycle system due to waste and other impacts (Tavallaie, 1994; Shakoor *et al*., 2008; Golmohammadi et al., 2009; Makhelouf, 2009; Mohammadi, 2009).

One of the most important phenomena linked to urbanism and urbanization which could alter the relations between humans and the environment and that is endowed with great harmful and destructive effects, is urban sprawl. Therefore, in the recent decades, urban sprawl is considered as one of the most challengeable subjects. This form which is now seen not only in the developed countries but also in the developing countries, has great undesirable socioeconomic and environmental effects such as air pollution

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(Pourahmad *et al*., 2007), degradation or pollution of soil resources (Zhang, 2007), reduction of water quality, reduction or degradation of coastal, lake and aquatic ecosystems (Southerland, 2000), destruction of productive farming lands around the cities (Zhang, 2000; Brabec and Smith, 2002; Jeffrey and Foley, 2003; Tan *et al.*, 2005; Zanganeh Shahraki, 2007), the increase of ecological footprint (Muniz and Galindo, 2005), the increase of economic and social disparity or the decrease of same access to urban amenities and services (Burton, 2001), absence of landscape protection (Jim, 2004), reduction of social capital and consequently social relationship (Brueckner and Largey, 2007), destruction of forest cover (Mcdonald and Rudel, 2005), and finally climatic changes and expedition of global warming process due to great dependency to automobile (Hamin and Guran, 2008).

Of particular concern in these 'sprawled' cities is both the loss of the surrounding natural land, as urban development spreads rapidly into previously productive or environmentally significant areas, as well as increasing concerns about the environmental effects of automobile emissions, particularly in relation to climate change (Arbury, 2005). In Iran and for different reasons, many of large, medium-size or even small cities have been affected by rapid processes of urban sprawl. Tehran, the capital of the Iran, may be considered as an example of these expanded cities, and has become the main target of immigration due to its large number of attractive factors. Besides rapid population growth, Tehran also experiences rapid physical growth. This phenomenon presents very undesirable effects on different aspects of the city. One of the most important environmental phenomena which is occurring in Tehran, is changes in the local climate.

In tracing and searching the results of climate change in Tehran, this research intends to study the effect of urban sprawl of the city. Therefore, in the present paper at first Tehran's sprawl and associated spatial changes were studied. Second, the trend of each climatic parameter (daily temperature mean, annual rainfall, percentage of relative humidity, average annual wind speed and the percentage of days with calm wind) has been estimated for a duration of 54 years (1953 to 2006) using a significance table, and the significance level for each climatic parameter has been determined. Finally the relation between climatic indices and city expansion indices has been studied to determine their significance and type of statistical relation. In this sense the effects of these two phenomena (urban sprawl and changes in climate) between each other were discerned.

MATERIALS AND METHODS

In the present research, two types of data have been used. The first type of data includes the climate components mentioned above (annual average rainfall, etc.) The second set corresponds to components relevant to urban sprawl, among which, urban area, number of private cars (per 1000 persons), population density and urban population. These parameters were selected for their relevance and data availability, considering that the most important index of dispersion of an sprawl is density (Gordon and Richardson, 1997) when urban sprawl is understood as the sporadic expansion of the city and the increase of the built environment. On the other hand, areas of urban sprawl are also characterized as highly dependent on automobiles for transportation, a condition known as automobile dependency (Edwin, 2003). Since the purpose of this research was to find out the effect of parameters on climatic elements and finally the emergence of changes as climatic oscillations, by using diagrams, descriptive statistical methods and also using Pearson correlation equations and multiple regressions, climatic elements and parameters related to urban sprawl of Tehran have been analyzed. Due to limitation in census data, figures for 1956, 1966, 1976, 1986, 1996, and 2006 have been used.

RESULTS

Urban sprawl in Tehran

Nelson *et al*. (1995: 1) summarized the various definitions of urban sprawl to create a working definition of the concept as: "…unplanned, uncontrolled, and uncoordinated single use development that does not provide for a functional mix of uses and/or is not functionally related to surrounding land uses and which variously appears as low-density, ribbon or strip, scattered, leapfrog, or isolated development". Dispersed

development, also referred to as urban growth or sprawl, is a pattern of low density development spread over previously rural landscapes)Southerland, 2005) or as mixtures of urban and rural land uses)Hara *et al*., 2005).

Urban sprawl occurs in a city when the growth of area and physical development is much larger than the growth of population. Considering these definitions, the analysis of the process of growth and expansion of Tehran in different periods indicates that for different reasons, this city is characterized by disintegrated and sprawl-like growth during the recent decades. In Agha Mohammad Khan's age (1822) Tehran was selected as Iran's capital (Habibi and Hurcade, 2005). In the first map of Tehran by French Mesu Kershish, the city had 6 gateways, 4 quarters and 100000 people surrounded by a wall. During this time, Tehran had an area of 4 square kilometers 1/3 of which devoted to residential fabrics and 2/3 devoted to farming and gardening (Mehdizadeh, 2003). In 1921, the population was 210000, for a city area of 7.2 square kilometers. The physical growth of the city was still slow and Tehran was relatively compact, with a very high population density (291 persons per hectare). Since the 1920s and, for different reasons, the physical and population growth of the city accelerated. In the first official census (1956), population reached 1510000 persons and the city area also increased to 100 km^2 (Iranian Statistics Center, 1986). This rapid growth continued with greater intensity in the following decades. Due to rapid growth, a council for the supervision on the expansion of Tehran, including 10 ministers and 3 department managers, was established under the supervision of the acting prime minister to control and prevent irregular expansion and make a plan for its future based on the act dated 1973. However, in practice this council failed to control the growth. In 1980, the Tehran municipality was forced to expand the scope of its services, changing legal expansions from 225 to 520 km^2, and also increase the number of municipal districts from 12 to 20 (Mashhadizadeh Dehaghani, 2002). By this year, more than 120 villages and 2 cities were absorbed by Tehran. The process of rapid growth has been repeated in the next periods.

In the latest official national census (2006), Tehran had a population of 7900000 extended in more than 800 km^2. For the last 85 years, the population of this city has multiplied by 37, while in the same period its area has been increased by 100. The population density of the city in all periods, except for the recent period, presents a descending trend from 291 in 1921 to 95 persons per hectare in 2006 (Table 1). Besides rapid physical growth, the city expansion has been unplanned, desultory and dispersed which are the typical characteristics of sprawl (Fig. 1).

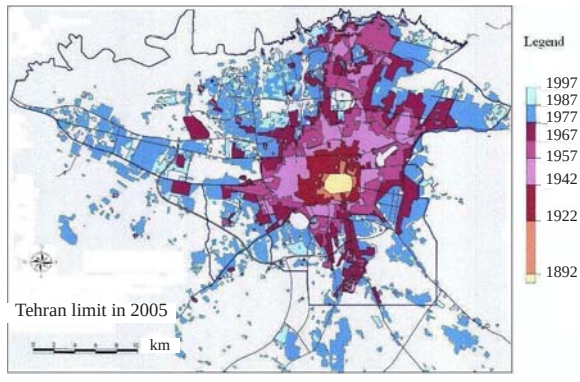

Fig. 1: The growth stages of Tehran
(Zanganeh Shahraki, 2007)

Table1: Changes of population, area, density and numbers of private cars in Tehran for different years

Year	1921	1931	1941	1956	1966	1976	1986	1996	2000	2006
Population(million)	0.21	0.3	0.69	1.51	2.71	4.5	6.04	6.7	7.02	7.711
Area(hectare)	720	2420	4500	10000	19000	32000	62000	73950	78900	80000
Density(p/ha)	291.6	124	154	151	143	141	97.4	91	88.9	96.3
Private car(number for 1000 people)	–	–	–	5	25	31	61	74	83	90

Long-Term changes of climatic components

In order to determine changes in climate variables in relation to long-term averages, trends of these changes were measured for three 18-year segments and compared to the long-term mean. The trend in annual average rainfall showed an increase but it was not found to be statistically significant. In Fig.1, the trend of daily temperature is presented. A value of r =0.7 indicates that the increasing temperature of Tehran is fully significant. Also, the highest value is the long-term mean in the third course. Therefore, the trend of daily temperature for different months shows that the highest level of significance belongs to summer months. The trend of annual relative humidity is shown in Fig. 2. In this case the correlation is r =0.3 for a significance level of 2%. According to the literature on urban heat island, one important effect of urbanization is the decrease of relative humidity of cities. The higher the temperature is, the more would the capacity of air mass for absorbing humidity. This factor causes the decrease of the ratio of relative humidity to air mass. But the remarkable increasing trend of relative humidity for Tehran seems to contradict this statement. This increasing humidity for the average of the first segment is 40%, for the second segment is 41% and for the third segment is 42.33%. What is interesting about this trend is that it appears to be clearer in summer and for the recent periods. Fig. 3 shows annual averages of wind speed. A coefficient of r =0.31 has been calculated for this case, with a significant correlation of 2%, meaning that wind speed decreases with passing of time. It may be concluded that the values of wind speed for the third segment (1989-2006) are the lowest in relation to the long-term mean. Fig. 4, representing calm wind, corroborates the decrease of the mean of wind speed and the increase of calm wind with a significant and increasing trend with an r =0.83.

Since the purpose of this research was to study changes in climatic variables, the type of climate of Tehran during the last decades was evaluated. For this purpose, the climatic variables of each year were calculated and a trend was obtained, by using the Grosczynski climate determination

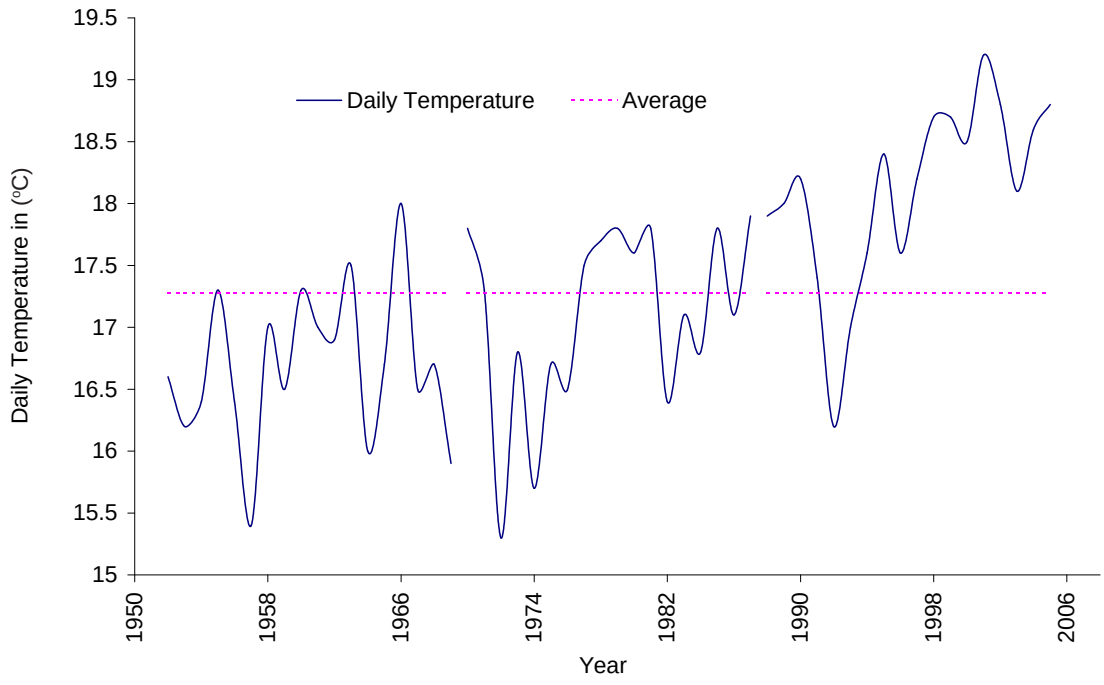

Fig. 2: Trend of the changes of annual mean of daily temperature of Tehran in proportion to long-term mean for the years 1950-2006

method. Grosczynski has shown a relation (expressed in Eq.1), by which, the continentality coefficient of different regions may be calculated. Based on this equation, continentality equals a maximum of 100 as marine conditions equal zero.

In order to calculate the type of annual climate of Tehran based on the Grosczynski method, Eq. 1 has been used:

$$C = \frac{1.3\,A}{\text{Sin } l} - 36.3 \qquad (1)$$

A= oscillation of temperature (the mean of the minimum. temperature in the coldest month of the year – the mean of maximum. temperature of the warmest month of the year)

C= continentality coefficient based on percent

l = latitude

Grosczynski has presented the scope of each type of climate as presented in Table (2).

Fig.6 shows changes in climate variables for a period of 54 years. In general and in accordance with data for this period, C coefficient for the long term period (1953-2006) of Tehran is 48.34%, meaning that Tehran is located in semi-continental climatic area. However, this coefficient is 49.58% for the first (1953-1970), 49.72% for the second (1971-1988) and 45.63% for the third (1989-2006) segments. Although for all segments, the climate of Tehran can de defined as semi-continental ,values for the third segment especially seem to suggest that the climate of Tehran is moving towards more marine and humid conditions. This trend is significant at 2% and . The significant increase in the percentage of relative humidity appears to make this result reliable.

In this part, and in order to show the relation between climatic components and urban sprawl in the Tehran, correlations have been used. For this purpose, relation between population density and climatic parameters were studied, as follows:

As Table (3) shows, there is a significant relation (level of 2%) between temperature and population density. This relation can be explained in the way

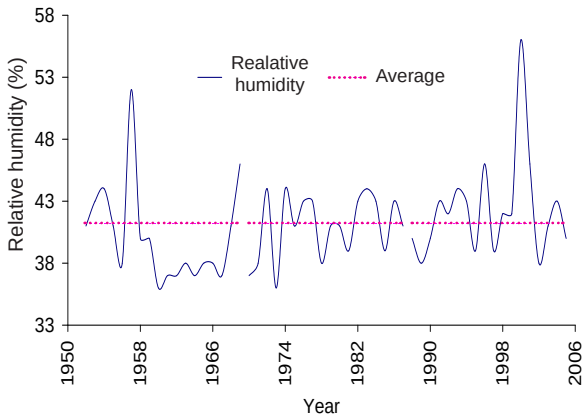

Fig. 3: Trend of changes of annual mean of the percentage of relative humidity of Tehran in proportion to long-term mean for the years 1950-2006

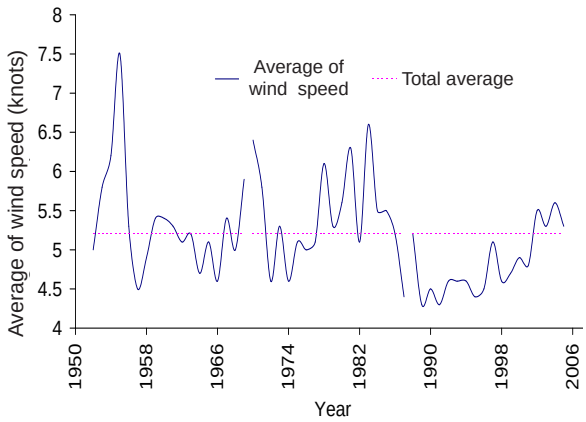

Fig. 4: Trends of annual average wind speed of Tehran in relation to long-term average (1950-2006)

Table 2: Scope of Grosczynski climate categorization

0‹C‹20	High Marine climate
20‹C‹30	Marine climate
30‹C‹40	Semi-Marine climate
40‹C‹50	Semi-Continental climate
50‹C‹60	Continental climate
C‹60	High Continental climate

that urban development and increase of streets, asphalts, etc prompted by sprawl, cause a high absorption of radiation energy. With the absorption of more radiation, reflectivity is prevented, and the temperature of city augments. The premise is that lower density and detached housing tends to be larger than multi unit developments, requiring more energy to heat and cool, and additional energy output to establish and maintain electricity transmission and distribution (Ewing and Rong, 2008; Randolph, 2008).

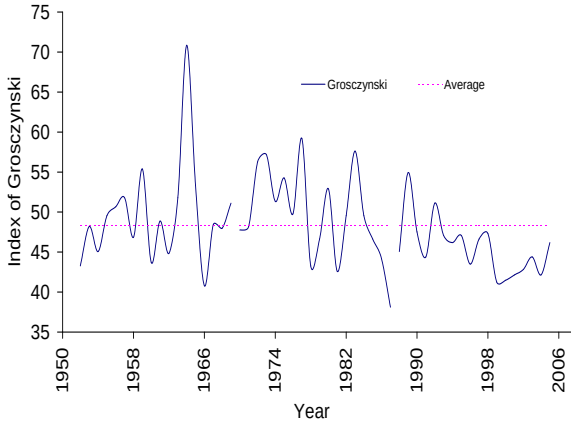

Fig. 6: Trend of annual mean changes of Grosczynski climatic index for Tehran in proportion to long-term mean for the years (1950-2006)

Although a statistically significant relation could not be provided between the population density of Tehran and rainfall values and average wind speed, such relation exists in the cases of relative humidity (r =-0.81) and calm wind (r =-0.88). Therefore, a decrease of urban density in Tehran in the recent decade appears to be related to increasing trends for values of temperature, relative humidity and calm wind.

On the other hand results of studying the relation between the population of Tehran and climatic components showed that. (Table 3), proportion to the increase of population of Tehran in different periods, daily temperature has also increased with in the level of 1%, as well as relative humidity with in the level of 2% and percent of calm wind with in the level of 0.001. However and as in the case of density, there was no significant relation between population and annual rainfall and the mean of wind speed.

It appears then that population exerts a remarkable effect on the increase of annual temperature, the percent of relative humidity and percent of calm wind. Among these effects the consumption of fossil fuel and heating equipment may be mentioned. These factors intensify the heat island and glasshouse conditions of the city and finally hasten increasing trends in temperature.

But there was also a direct and significant relation between the expansion of Tehran and climatic components. Observations of daily temperature and relative humidity, which are significant at 1%, and 2%, and the percent of calm wind with the level of 0.001% indicate a significant relation between them and the sprawl component of Tehran. But as before, no significant relation appears with regard to annual rainfall and the mean of wind speed.

Relation between temperature and city expansion was explained in different ways. For example the expansion of the built environment would increase friction of wind speed. The increase of calm wind may be the result of the lack of mixing of city air and its stagnation increasing temperature. Today, building materials are used to attract more energy and prevent waste. These factors together with other processes have accelerated the increasing trend of temperature.

Correlation has also been sought between the number of automobiles and climatic components (Table 3). A direct relation between the number of automobiles and climatic components was observed, although these coefficients are not as significant as the relation between the mean of wind speed and annual rainfall. However, the significance level for other components is interesting to note. Daily temperature and the percent of calm wind in approximate level of significance of 1% had a good reliability and relative humidity almost reached a significance level of 2%.

Today with the increase of automobiles and the release of pollutants and greenhouse gases, the release of water vapor and its emission in city air has also increased. Because of urban sprawl, urban distances have increased, causing more usage of motor vehicles. Therefore the decrease of

density, irregular urban sprawl and its relation with transportation have caused changes in the climate of Tehran in two ways: 1) the increase of distances in city commuting, and 2) more usage of private cars and the lack of proper public transportation in all areas of the city.

Indeed and because of the increase of urban sprawl of Tehran, the distance between the place of work and the house of citizens' has increased. According to data from office of deputy of traffic and transportation of Tehran municipality, the mean of distance of urban travels in Tehran in 1976 was 2.4 km, while in 2000 it reached 8.7 km (Transportation and Traffic Studies in Municipality of Tehran, 2003).

Besides the increase of distance in city commuting, the type of transportation also changed s with urban sprawl. That is, on the one hand, cycling and walking tend to decrease and there is more inclination for using private cars. In this regard it could be mentioned that while until 1986, the share of private cars in transportation of Tehran was 41%, in 2006 it increased to 58% and this figure continues to increase (Fig. 7).

The subway of Tehran, operating since 1995 covers just a small portion of the city, however, Buses have been more successful than the subway, but not enough to give service to the whole city. The results of all these factors (the increase of distance in city commuting and the increase in the use of private cars), is the increase of consuming fossil fuels used in transportation. In 1976, the daily consumption of various fossil fuels (petrol, gasoline and CNG) in Tehran was 6,000,000 liters; by 1996 it had amounted to 16,500,000 liters, and in 2006 it reached 32,000,000 liters (Fuels and Oil Products Company of Iran, 2007)). The increase of consumption of fossil fuels in transportation section has caused the emission of greenhouse gases in the city air.

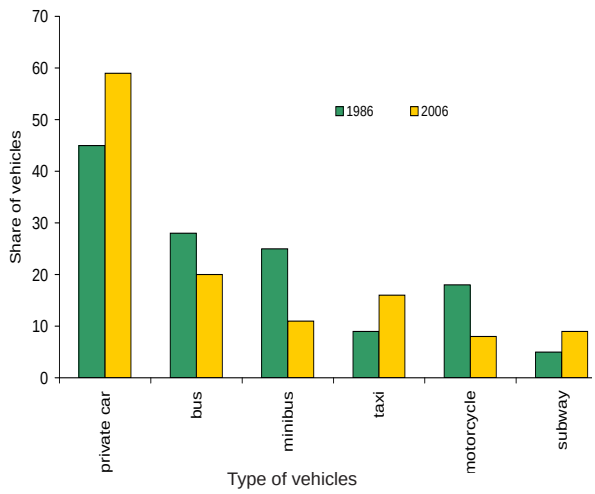

Fig. 7: the share of different transportation systems in Tehran between 1986-2006

There are two important reasons of why population density may reduce the ecological impact of mobility. Higher density patterns reduce average distances between home and place of work; also, high densities may be more amenable to public transport (Banister,1998). Ewing, Bartholomew, Winkelman, Walters, and Chen (2008) argue that we need to build more compactly to reduce vehicle miles traveled (VMT). Based on a summary of existing literature, the text identifies five key factors of urban design that will assist in reducing VMT: Density, Diversity, Design, Destination accessibility, and Distance to transit (Ewing *et al*., 2008).

Newman and Kenworthy's (1989) tested the influence of population density levels on the consumption of gasoline. Other studies also show that compact areas could decrease the usage of private cars to 70%. Furthermore the distances of commuting to work in comparison with sprawling and low-density cities can be reduced up to 75% (Masnavi, 2002).

Sometimes when the number of components is more than two, their relationships can be indicated in multiple regression equations. In these equations, changes of one variable depend on other variables and can be explained spatially. In the previous section, using the considered data, the effect of each component including population, density, city expansion and number of automobiles has been identified separately with re-

Table 3: Correlation values between climatic components and urban sprawl components of Tehran city multiple regressions

	Density	Population	Area	Private car
Rainfall	-0.6	0.58	0.61	0.6
Percentage of relative humidity (%)	-0.81	0.83	0.85	0.85
Wind speed (knots)	0.10	-0.03	-0.05	-0.06
Percent of calm wind (%)	-0.88	0.94	0.93	0.92
Daily temperature(°C)	0.95	0.88	0.91	0.93

gard to each climatic component. According to Pearson correlation coefficients it has been determined that there is no relation between the value of annual rainfall and the mean of wind speed and population and density variables. In this phase, the purpose is to study correlations between the sum of independent variables of population, density, city area and number of automobiles with each climatic components of daily temperature, percentage of relative humidity and percentage of calm wind as dependent variables. To this end, multiple regression method has been applied.

In order to calculate relations between dependent and independent variables, the stepwise method usually used in geographic studies has been applied. Therefore correlation was made separately between each climatic component with independent variables of city and results can be seen in Tables (4) and (5).

In the first step, regression between temperature components and sprawl variables of Tehran was calculated. In the output, the value of R square was 0.84%; in other words, the considered variables cover almost 84% of temperature changes. Of these variables, the most important factor for temperature changes was the number of automobiles per capita. The related equation is as follows:

Table 4: Statistical values and model summary for urban sprawl variables of Tehran and climatic components using SPSS software

Predictors: (constant)	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Car	1	.920	0.847	.817	.46113
Area	2	.850	.723	.667	3.499
People	3	.940	.884	.861	5.21974

Table 5: Statistical values and urban sprawl coefficients for variables of Tehran and climatic components using SPSS software

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	15.665	.351		44.577	.000
Car	.030	.006	.920	5.264	.003
(Constant)	36.062	2.772		10.8503.011	.000
Area	0.000173	.000	0.850	3.611	.015
(Constant)	2.070	5.104		.0406	.702
People	5.6E-006	.000	0.940	6.179	.002

$$Y= 15.665+.03X \quad (2)$$

In the next step, regression between the component of the percent of relative humidity and sprawl variables of Tehran was calculated. In the output, the value of R Square was 0.72%. In this regard, the variable of urban area had a highest effect on the component of the percent of relative humidity. The area devoted to urban green spaces and parks in Tehran, increased by 48% between 1986 and 2006. This could be a possible cause for the increase of relative humidity by evapotranspiration of plants. The related equation is as follows:

$$Y= 36.062+ 0.000173X \quad (3)$$

Finally, regression between components of the percent of calm wind and sprawl variables of Tehran was also calculated. In this case, the value of R Square was 0.88%. Among the variables of sprawl variance of Tehran, population had the highest effect on the component of wind calm percent. The related equation is as follows:

$$Y= 2.07+ 5.6\times10X \quad (4)$$

Regression between the value of population and each sprawl components of Tehran was calculated to determine the reliability of this part. The output shows that the highest correlation with has been extracted for population and area. It could be interpreted that the increase of population will cause an increase of city expansion. The increase in the built environment will increase wind friction and the decrease of wind speed and the increase of percent of calm wind.

Authors expected that the factor “area” would be the most important factor in the output, which was not the case. The importance of area may be hidden in population and the characteristics of population data may be such that the greatest effect on the percent of calm wind is population (as measurement unit number of people per hectare was used) in comparison with expansion.

DISCUSSION

The purpose of this research was to identify the relation between urban sprawl components of Tehran and changes in climate variables. To this end, two types of data were used as: climatic elements such as rainfall, temperature, percent of relative humidity, percent of calm wind and average speed, and components related to urban sprawl including city area, private cars per capita, and urban population and its density. The results of the present research indicate the presence of oscillations and changes of climate variables especially in the recent decades. These changes have caused the climate of Tehran city to become more humid and warmer. Since significant relations between changes of annual temperature, percent of relative humidity and percent of calm wind and urban sprawl components were obtained.

It could be argued that urban sprawl may have an influence in climatic oscillations especially in the recent decades. But since the effect of Tehran sprawl components on the changes of climatic parameters has differed in significance, multiple regression method was also applied.

Considering the final output obtained from multiple regression method, it can be deduced that the most effective factor in increasing temperature of Tehran could be the increase in the number of automobiles. On its part, the most effective factor in the increase of relative humidity of Tehran appears to have been the expansion of city area. while the most important factor which is effective in the increase of percent of calm wind has been population which could be attributed to the characteristics of statistical data of population in regard to number and measurement unit. Finally, climatic conditions greatly depend on different phenomena that advanced models are incapable of forecasting.

Authors do not claim that one or some urban factors are the controlling factors for climatic conditions, but that they could be relevant in climatic conditions of the city even though their effect could be small.

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