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Recognition of Tehran Weather Types

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Abstract: In order to recognize Tehran weather types, 22 atmospheric variables are studied for Tehran synoptic station from January 1, 1978 to December 31, 2004. Cluster analysis on the standardized matrix of data and linking days on the basis of ward method shows that Tehran has four Weather Types (WT). These are- 1) Cold, frosty, rainy WT, 2) Moderate WT, 3) Warm, dry WT and 4) Cold, windy WT. Based on this study results, warm and dry WT is the most dominant and durable and cold, frosty, rainy WT is the least frequent and short-lived weather types in Tehran. Only 25.4% days of a year, moderate WT can be seen. Warm and dry period involves almost 40% days of a year Because of the dominance of Azores subtropical high pressure, Tehran's weather is much stable around this time and only warm, dry WT occurs. Because of relative increase of the warm and dry weather type in this period, Tehran's weather has become warmer.

Key words: Synoptic climatology, weather type, cluster analysis, sequentially, occurrence index

INTRODUCTION

A weather type is a representative of the weathers that are similar to each other in terms of discriminant atmospheric variables. If analyzing weather types is done in daily extent, a weather type will include days that have similar weathers. Occurrence of a weather type in a definite region depends on air masses that entered the region on one hand and the result of influence of geographical conditions (topography, adjacency with water masses and etc.,) of that region on the other hand. Because geographical conditions of region are usually constant, different weather types that come in and go away from a region are function of air masses that enter the region. Thus, time series of weather types of a region is related to the air masses that cover a large area including the subject region. It is on the basis of this logic that in climatology literature, after stationary analysis of weather types in temporal dimension, spatial analysis of weather types will become important itself (Kalkstein *et al*., 1996). Clearly, the concept of weather type is not a simple topic to be considered along with other synoptic climatology categories; but it is an important concept which is valuable as a theory. By this theory, new concepts will be introduced and available climatology concepts and categories will find new definitions and novel concepts.

Since, one of the main aims of synoptic climatology is identifying weather types, climatology literature is rich in this aspect. Bissolli *et al*. (2006), after studying weather types in Germany and comparing it with tornado occurrence, concluded that there is a significant correlation between frequency of stormy days and weather type. Morabitoa *et al*. (2006) studied the relation between winter weather types of Florence, Italy and myocardial infarction through synoptic method and they showed that although because of methodological limitations they cannot generalize their findings to other geographical regions; it seems that there is a statistical relationship between weather types and myocardial infarction in Florence. Fowler and Kilsby (2002) have studied relation of hydrologic droughts of Yorkshire of Britain with Lamb weather types and they found that sometimes droughts are results of atmospheric conditions and thus, they have relation with weather types and sometimes they are results of mal-management. Littmann (2000) has classified the data of pressure and geopotential height of 500 hpa using cluster analysis and has studied the relationship between resultant weather types and Mediterranean Basin rainfall. He has identified 20 different weather types and believes that these types explain Mediterranean rainfall patterns to a high degree. Krichak *et al*. (2000) have studied the relation of synoptic patterns and wet and dry conditions in the Eastern Mediterranean. They have showed that anomalies of sea level pressure and geopotential height of 500 hpa explain occurrence of wet and dry conditions in the Eastern Mediterranean. Kalkstein *et al*. (1998) have used analysis of air masses as a tool for studying climate change. They believe that analysis of air mass frequency is a more

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useful method for explaining of climate change than the trend analysis of climatic variables. Sheridan (2002) has reviewed spatial synoptic classification from different aspects and he believes that this method is a useful method for environmental studies. He also found a strong relationship between weather types of North America and teleconnection indices i.e. North Atlantic Oscillation (NAO) and Pacific Ocean-North America (PNA); Sheridan (2003). Rainham *et al.* (2005) paid attention to mortality in Toronto in Canada using spatial synoptic classification. Their study showed that weather quality (weather pollution) is in general a function of synoptic type but in order to understand the relationship of atmospheric conditions and health, more studies are needed.

MATERIALS AND METHODS

Study area: Tehran, the capital city of Iran, is located in Tehran province. The city has more than 7 million people and it is the most populated city in the country. Figure 1 shows the location of Tehran. Geographical conditions of Tehran are stable approximately. Therefore, entrance of air masses causes occurrence of different weather types in Tehran. Present objective is to study these weather types. Data sources: the data of 22 variables from January 1, 1978 to December 31, 2004 are provided in a matrix in p mode (atmospheric variables in columns and days in rows) (Fig. 2).

The atmospheric variables should be used to identify weather types that are representative of temperature and humidity conditions. Among different variables that are measured in synoptic station of Tehran, 22 variables were selected that they are listed in Table 1. The data of these 22 variables (1978 to 2004) are provided in a matrix in p mode (atmospheric variables on columns and days on rows) (Fig. 2). So, data matrix has the size of 9862×22. Since, the data have different units (Celsius degree, millimeter, percent, degree, Knot), it is necessary to standardize it before doing any analysis, so that weight of all variables in separating synoptic types could be the same. Of course before standardization, the speed and direction of wind convert to u-v wind components to prevent problem of wind speed and direction standardization. The following equation has been used to standardize the variables (Johnson and Wichern, 2001).

$$STND_{ij} = \frac{Data_{ij} - Min_j}{Max_j - Min_j} \quad (1)$$

where, $STND_{ij}$ is standardized amount of the jth variable in the ith day, $Data_{ij}$ is the jth variable in the ith day, Min_j

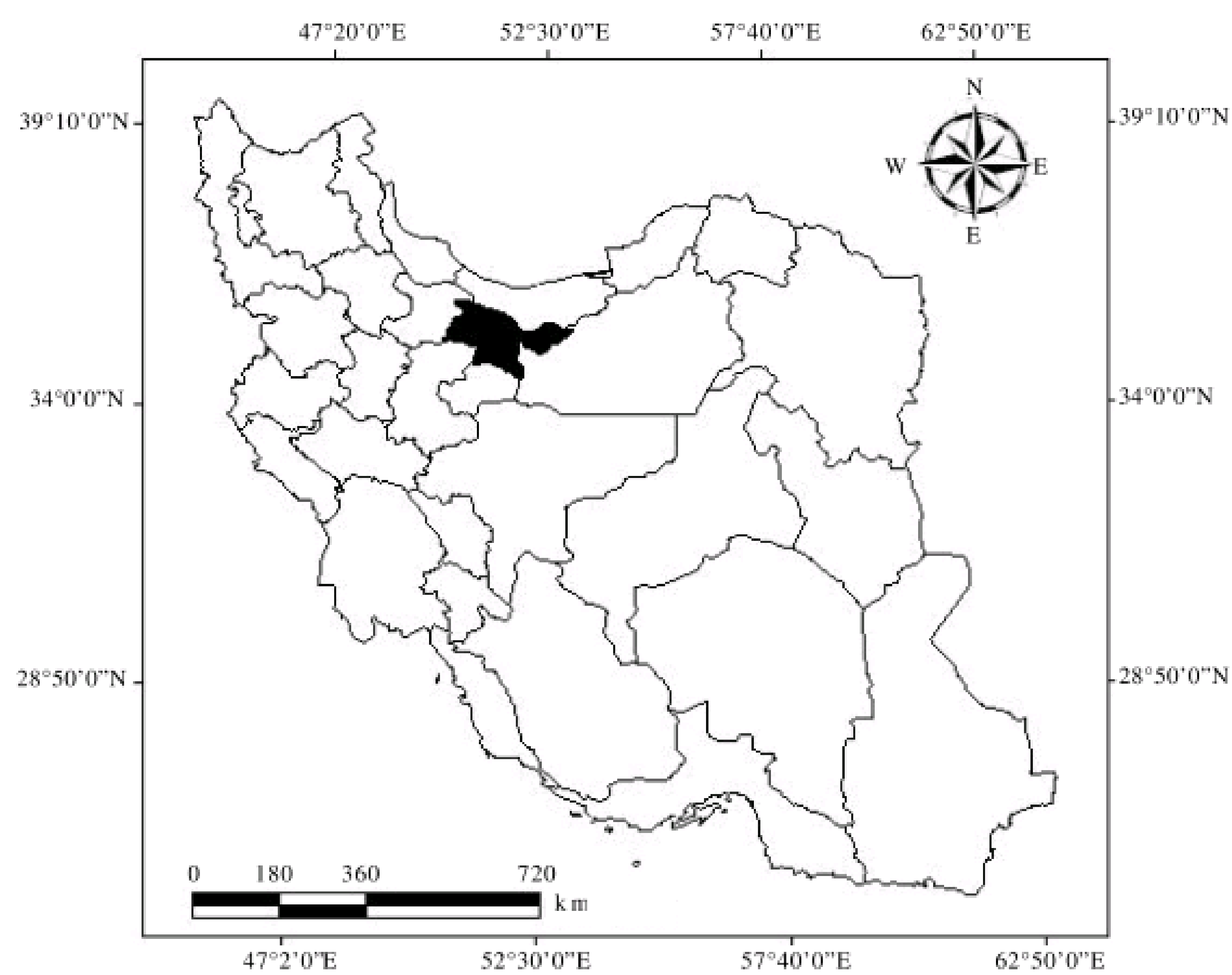

Fig. 1: Location of Tehran in Iran that highlighted by black color

YEAR	MONTH	DAY	DRY03	DRY09	DRY15	DRYMD	WET03	WET09	WET15	WETMD	MAXDT	MENDT	MINDT	RRRMD	RHM03	RHM09	RHM15	RHMMD	M03	M09	M15	A03	A09	A15
1978	1	1	-0.2	9.0	5.0	4.7	-1.8	4.4	2.4	1.6	11.0	5.5	0.0	0.0	67.0	44.0	62.0	56.6	0.0	-1.4	0.0	0.0	3.8	0.0
1978	1	2	2.2	9.6	7.4	5.9	-0.4	4.8	4.0	2.7	12.0	6.5	1.0	0.0	60.0	44.0	55.0	57.4	0.0	0.0	0.0	0.0	0.0	0.0
1978	1	3	2.4	11.0	7.6	6.3	0.8	6.0	4.2	3.4	11.0	6.0	1.0	0.0	75.0	44.0	57.0	61.5	0.0	-3.0	0.0	0.0	5.2	0.0
1978	1	4	6.0	7.4	4.6	6.2	3.0	3.6	3.0	3.3	11.0	7.5	4.0	1.0	59.0	50.0	76.0	62.0	0.0	-6.4	15.0	0.0	7.7	-5.5
1978	1	5	1.4	7.4	5.2	4.6	-0.2	2.2	1.6	1.3	9.0	5.0	1.0	5.0	74.0	32.0	49.0	52.6	9.0	16.0	18.0	1.7	0.0	0.0
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2004	12	27	1.2	5.8	3.4	3.9	-0.4	2.4	1.2	0.8	8.0	4.3	0.6	0.0	73.0	53.0	66.0	56.8	5.2	16.7	7.7	3.0	3.0	-9.2
2004	12	28	0.6	6.0	2.4	2.5	-1.8	1.8	0.0	-0.3	7.2	3.4	-0.4	0.0	58.0	43.0	61.0	57.3	3.9	6.9	9.8	0.7	4.0	-1.7
2004	12	29	0.2	5.6	5.0	3.6	-1.8	1.2	0.8	0.1	9.0	4.0	-1.0	0.0	64.0	39.0	40.0	48.5	0.0	4.6	0.0	0.0	3.9	0.0
2004	12	30	-0.4	6.8	7.0	4.2	-2.0	2.4	3.2	1.1	10.0	4.8	-0.4	0.0	70.0	42.0	50.0	55.5	0.0	8.0	0.0	0.0	0.0	0.0
2004	12	31	2.4	11.2	10.0	7.7	0.4	5.8	6.0	4.0	15.2	8.6	2.0	0.0	67.0	41.0	53.0	54.6	0.0	2.0	0.0	0.0	3.5	0.0

Fig. 2: Sample of first and last rows of data matrix

Table 1: List of basic data for identifying synoptic types of Tehran station

Row	Symbol	Description	Unit
1	DRY03	Dry bulb temperature at 03 UTC	Celsius degree (°C)
2	DRY09	Dry bulb temperature at 09 UTC	Celsius degree (°C)
3	DRY15	Dry bulb temperature at 15 UTC	Celsius degree (°C)
4	DRYMD	Mean daily of dry bulb temperature	Celsius degree (°C)
5	WET03	Wet bulb temperature	Celsius degree (°C)
6	WET09	Wet bulb temperature at 09 UTC	Celsius degree (°C)
7	WET15	Wet bulb temperature at 15 UTC	Celsius degree (°C)
8	WETMD	Mean daily of wet bulb temperature	Celsius degree (°C)
9	MAXDT	Maximum of daily temperature	Celsius degree (°C)
10	MENDT	Mean of temperature	Celsius degree (°C)
11	MINDT	Minimum of daily temperature	Celsius degree (°C)
12	RRRMD	Daily rainfall	Millimeter
13	RHM03	Relative humidity at 03UTC	Percent
14	RHM09	Relative humidity at 09UTC	Percent
15	RHM15	Relative humidity at 15UTC	Percent
16	RHMD	Mean daily of relative humidity	Percent
17	M03	Wind speed at 03UTC	Knot
18	M09	Wind speed at 09UTC	Knot
19	M15	Wind speed at 15UTC	Knot
20	A03	Wind direction at 03UTC	Degree
21	A09	Wind direction at 09UTC	Degree
22	A15	Wind direction at 15UTC	Degree

is the minimum value of the jth variable and Max_j is the maximum value of jth variable. After standardization, rows with a gap (even for one variable), were omitted from matrix and so, the final matrix of size 9823×22 was obtained ($stnd_{9823\times22}$). This matrix was the basis of calculation of dissimilarities using Euclidean distance method.

Before classification, we do not have any idea about the number of weather types, so cluster analysis for identifying weather types seems practical. In this case, for example k variables belongs to one day (t_1), is compared with k variables belongs to another day (t_2), in order to find degree of dissimilarity. Then, all days were clustered according to degree of dissimilarity. Therefore, there are two important steps in cluster analysis: first step is calculating the degree of dissimilarity of variables and the second step is how to link variables according to their degree of dissimilarity.

Depending on the methods that we choose for calculating the degree of dissimilarity of variables and linkage of them, a cluster analysis can be implemented in different ways. In this study, a hierarchical cluster analysis with ward linkage method was used for identifying weather types. In order to calculate degree of dissimilarity, Euclidean distance have been used and for linking items that show the highest dissimilarity, the ward linkage method was used. It is clear that for n observations n(n-1)/2 distance are considerable. Suppose x_r is observation vector on r and x_s is observation vector on s; so, Euclidean distance is calculated using the following equation (Johnson and Wichern, 2001):

$$d_{rs}^2 = (X_r - X_s)(X_r - X_s)' \quad (2)$$

In ward method, s and r are linked if the variance increase due to agglomeration is minimal in comparison with combining them with any other group (Johnson and Wichern, 2001), that is:

$$d(r,s) = \frac{n_r n_s d_{rs}^2}{(n_r + n_s)} \quad (3)$$

Here, d_{rs}^2 is the distance between group r and group s that is obtained from centroid linkage method. In climatological studies, ward linkage method primarily is used; because in this case, inter group variance will be minimized and homogeneity of resulted groups will be maximized. After clustering analysis based on ward linkage method, the weather classification carried out according to characteristics of temperature, wind direction and speed, humidity, precipitation in each cluster.

RESULTS AND DISCUSSION

The study of air masses is important for forecasting air and information about climate circumstances. The air masses determine daily humidity and thermal circumstances. Repetition of these circumstances in long time results in climate formation. The air masses that enter to a region are depending on general circulation. Therefore different regions according to geographic situation have different air masses types. The 27 individual weather types for Scotland, classified at a daily resolution by Mayes (1991), were categorized into five groups using cluster analysis. Schwartz (1991) classifies weather types over the North-central USA and six weather types are identified.

Tehran weather types: Applying a cluster analysis on standardized matrix and linking days using ward method, showed that Tehran has 4 distinctive weather types (Fig. 3, Table 2). The nominate of each weather types carried out according to characteristics of temperature, wind (direction and speed), humidity and precipitation in each cluster.

Cold, frosty, rainy type: This type is active for 17.3% of year, from 15th October to 15th April (Fig. 4, Table 3). Temperature of day is almost 8.1°C and at night is about 1.4°C. In 39.6% of time that this type occurs, there is frost. This type is very important because in 44.6% accompany with precipitation and daily precipitation mean approximately 6/1 mm. During recent decades decrease frequency of this type (Fig. 8). In 29% of cases that this type is seen; there is morning fog (Table 3). But after sunrise, relative humidity decreases considerably and the weather is dry.

Moderate type: Tehran weather at the end of summer and early autumn on one hand and at the end of winter to nearly late spring on the other hand can be moderate (Fig. 5). This type is seen from 15th September to the beginning of December and from 15th February to 15th June (Fig. 5). In the time of this type dominance that is observed in 25.4% of years, Tehran has moderate days. During this period temperature varies from 14.6° to 24.6°C. In the dominance time of this type almost all atmospheric variables are closer to the total mean. During the past decades, frequency of this type has had a very good stability (Fig. 9).

Warm, dry type: This type is the most dominant observable weather type Tehran. This type is seen from

Table 2: Tehran weather types

Type	Weather
1	Cold, frosty, rainy
2	Moderate
3	Hot, dry
4	Cold , windy

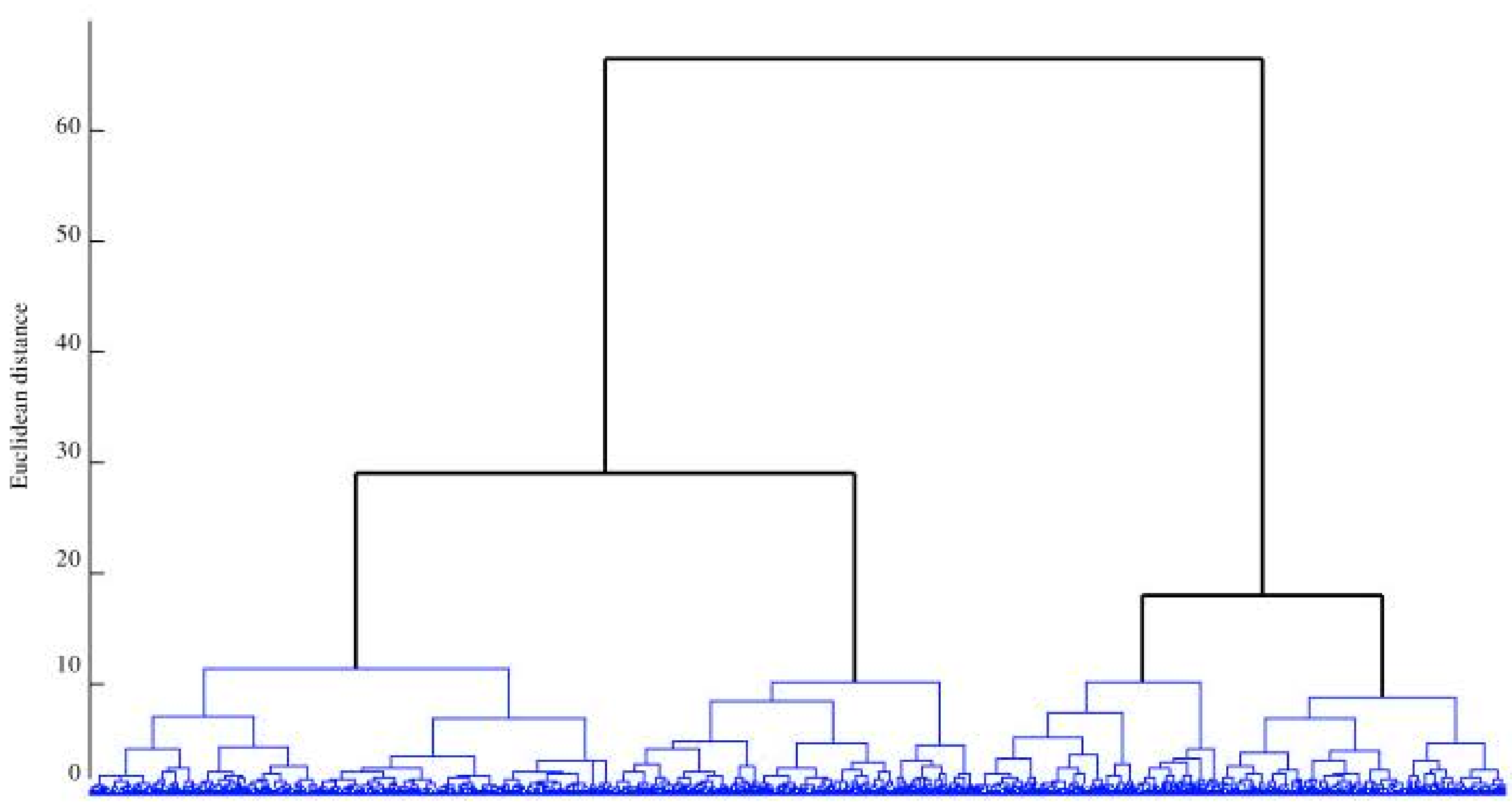

Fig. 3: Dendrogram of 4 weather types of Tehran

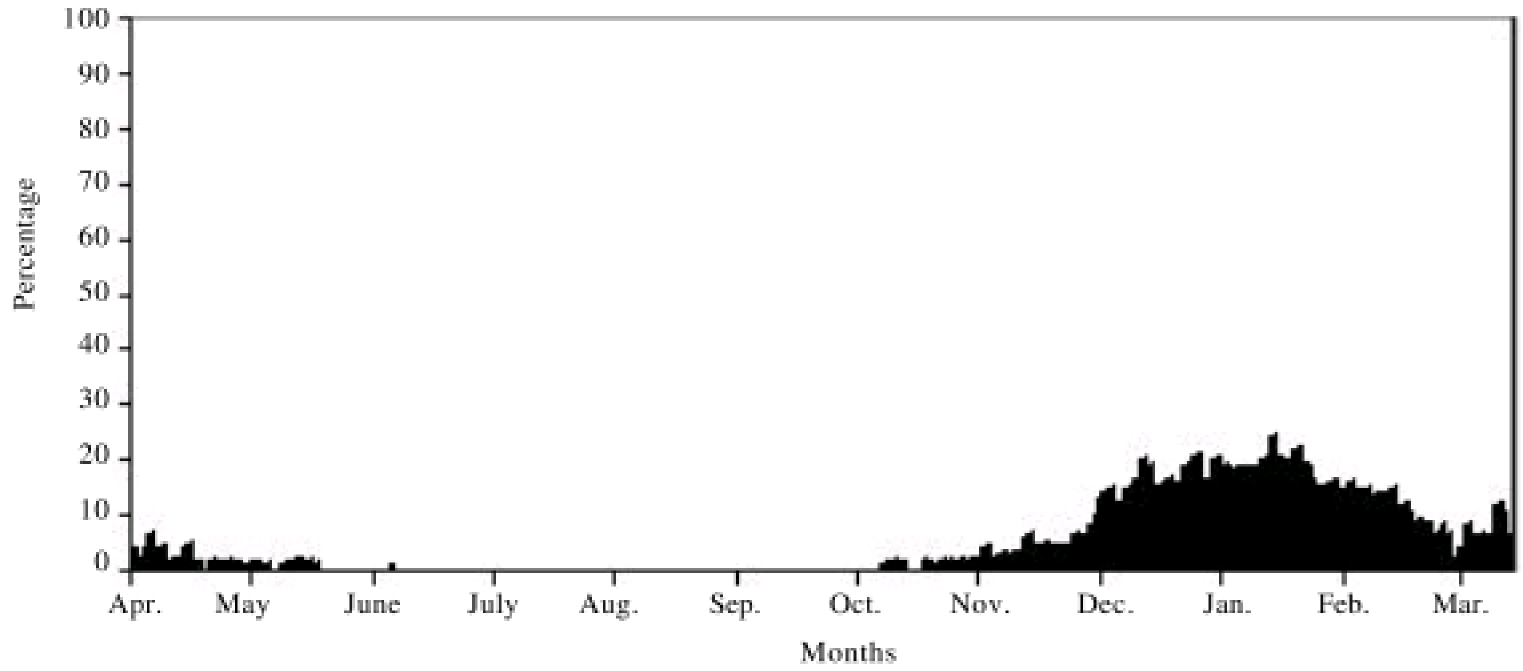

Fig. 4: Monthly frequency percent of weather type No. 1

Table 3: Characteristics of 4 weather types of Tehran

Synoptic type No.	Occurrence frequency (%)	Precipitation probability (%)	Frosty probability (%)	Morning fog probability (%)	Mean of precipitation in a rainy day	Wind probability (%)	Beginning time of type	Peak time of type	End time of type
1	17/4	44/6	39/6	0/29	6/1	51	15th October	27th January	15th April
2	25/4	17/5	0	0	1/9	66	15th September 15th February	10th May 2th November	1th December 15th June
3	39/6	4/2	0	0/02	1/2	71/9	20th April	15th August to 15th September	20th October
4	20/4	15/8	11/8	0/05	2/4	61/7	15th October	15th February	15th April

Synoptic type No.	Dry bulb temperature 03	Dry bulb temperature 09	Dry bulb temperature 15	Mean of dry bulb temperature	Wet bulb temperature 03	Wet bulb temperature 09	Wet bulb temperature 15	Mean of Wet bulb temperature	Mean of Maximum temperature	Mean daily of temperature	Mean of Minimum temperature
1	2/4	6/2	5	4/3	1	4/4	2/8	2/3	8/1	4/8	1/4
2	14/3	21/4	20/4	18/3	8/9	12	11/6	10/7	23/6	18/3	13/3
3	23/8	31/7	32/2	28/6	14/8	17/5	17/5	16/5	34/3	28/4	22/6
4	5/1	11/6	10/2	8/7	2/3	5/7	5	4/2	13/6	8/9	4/3
Mean	11/3	17/7	16/9	15	6/8	9/7	9/2	8/4	19/9	15/1	10/4

Synoptic type No.	Mean daily of precipitation	Relative humidity 03	Relative humidity 09	Relative humidity 15	Daily relative humidity	Wind speed 09	Wind speed 09	Wind speed 15	Wind direction 03	Wind direction 09	Wind direction 15
1	2/7	76/7	63/4	69/2	70/6	6/4	7/2	7/7	164	177/6	147/1
2	0/4	47/5	29/4	31/9	37/5	7/1	9/9	9/1	153/2	161	154/7
3	0/05	36/3	21/3	19/9	27	6/2	8/7	8/2	148	217/9	211/4
4	0/39	60	37/2	41/6	47/7	7/8	10/1	9/3	137/6	151/6	144/4
Mean	0/8	51/4	37/8	40/7	45/7	6/9	9	8/6	150/4	177	164/4

20th April to 20th of November (Fig. 6). In the dominance time of this type, it has never been seen a weather except hot and dry weather in Tehran (Fig. 6). Temperature varies between 22.6° to 34.3°C during day and night. Relative humidity minimizes (Table 3). Frequency of this weather type relatively has increased during the last decades in Tehran (Fig. 10).

Cold, windy weather type: In autumn and spring, from 15th October 15th May there is cold weather and wind in Tehran (Fig. 7). In dominance time of this type that its frequency is about 20.4%, temperature is varying between 4.3° and 13.6°C during day and night and by passing the day wind speed increases (Table 3). It seems that during past decades frequency of this type has been reduced (Fig. 11).

Daily variety of weather types: As, we saw in explaining monthly frequency occurrence of weather types, each weather type tends to be active in certain months. In other words, weather types have seasonal behavior. Because of this, some of the types of weather disagree with some others and have much harmony with the rest. But, there are some types that can appear after each type of weather and may connect disagreeing patterns. These two different kinds of behavior can mean that in some days of year, we should expect a certain weather type on one hand and it means that in some days there can be many weather types on the other hand. Measuring degree of weather type variety on each day of year, beside theoretical value, can also help forecasting from practical view. So, we attempt to introduce a scale for measuring degree of daily variety of weather types. In this study,

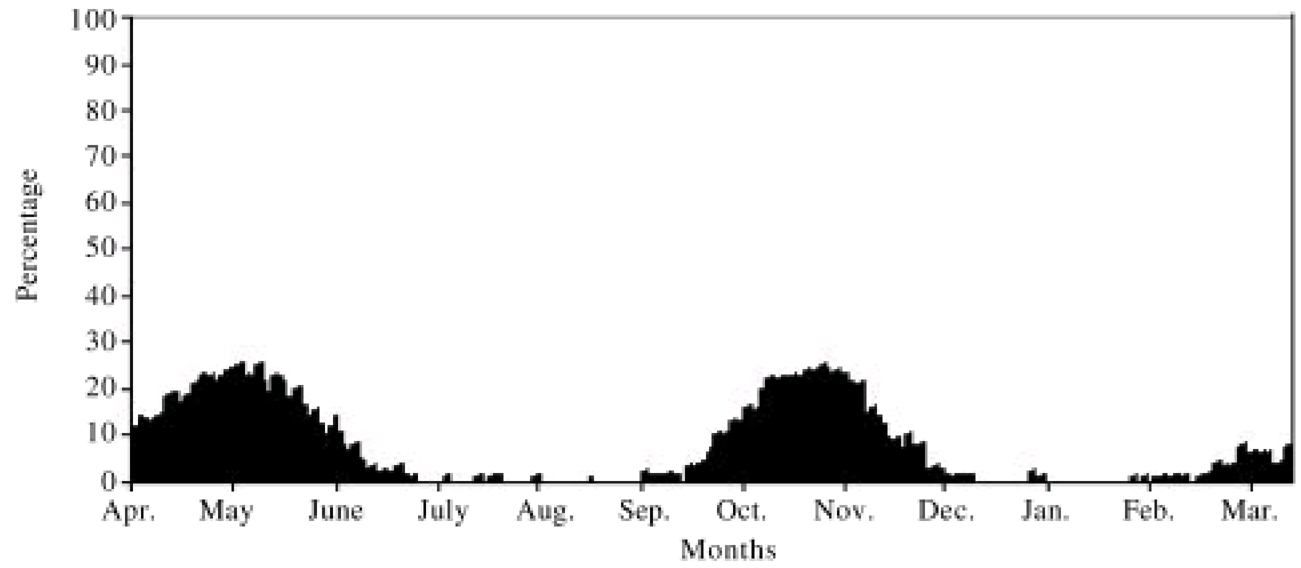

Fig. 5: Monthly frequency percent of weather type No. 2

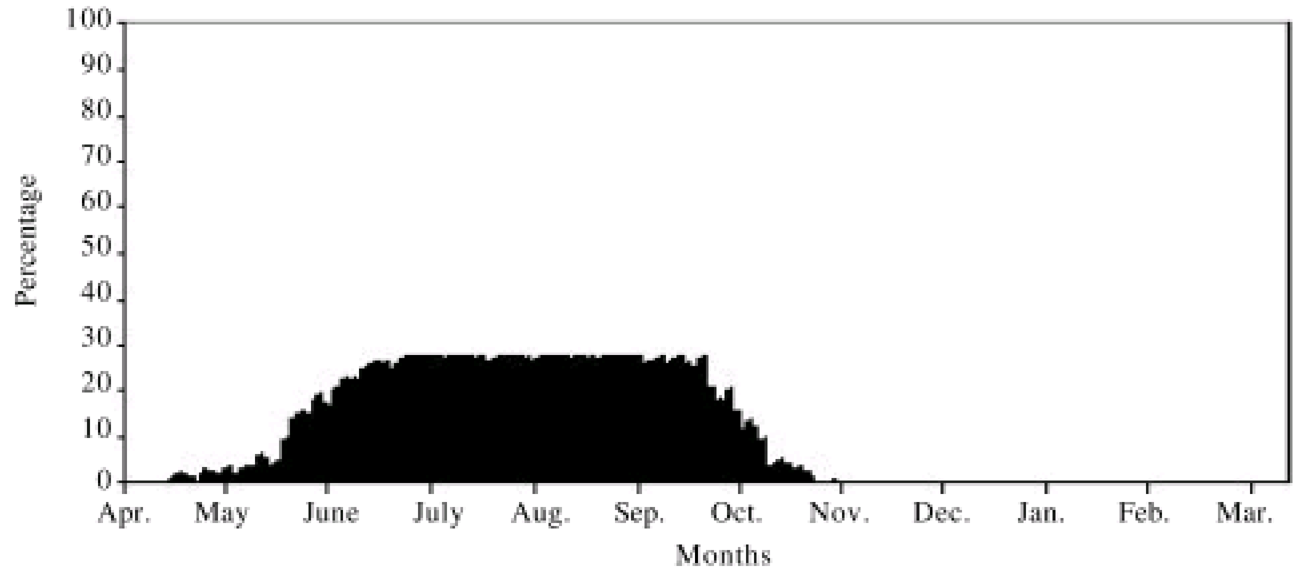

Fig. 6: Monthly frequency percent of weather type No. 3

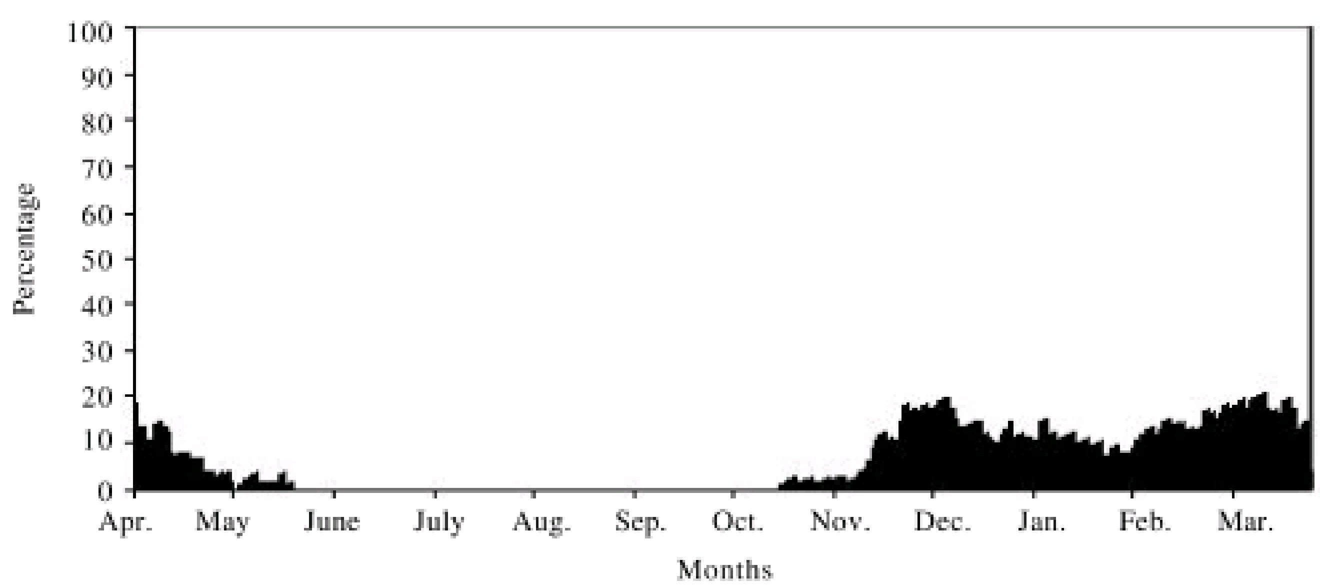

Fig. 7: Monthly frequency percent of weather type No. 4

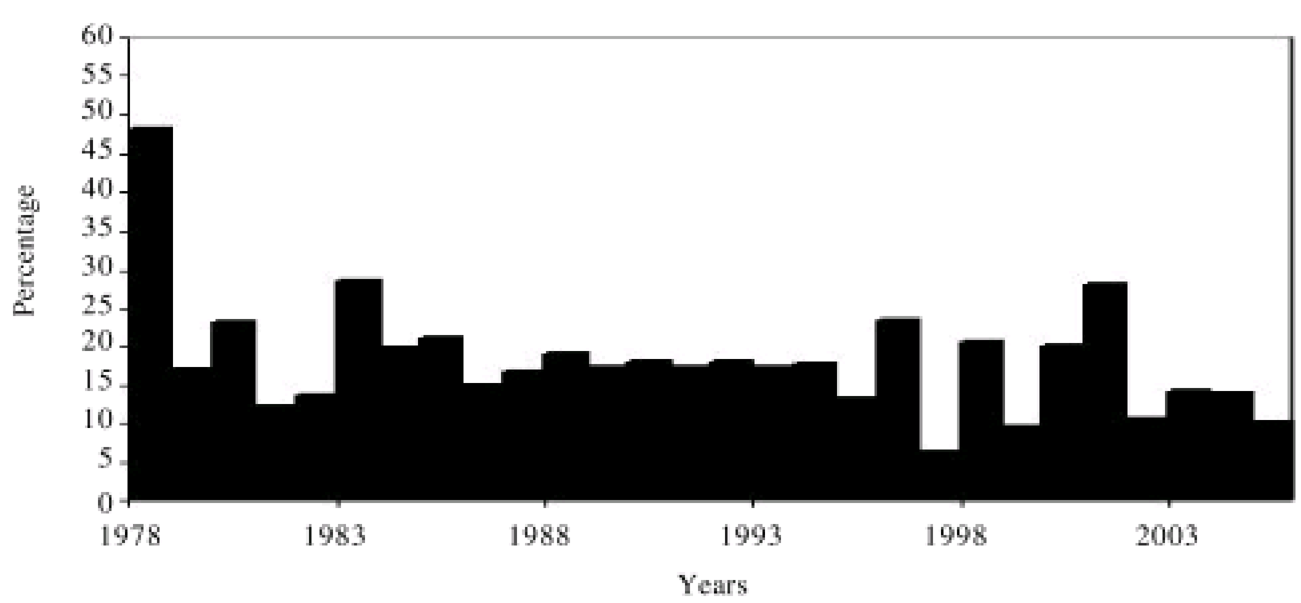

Fig. 8: Annual frequency percent of weather type No. 1

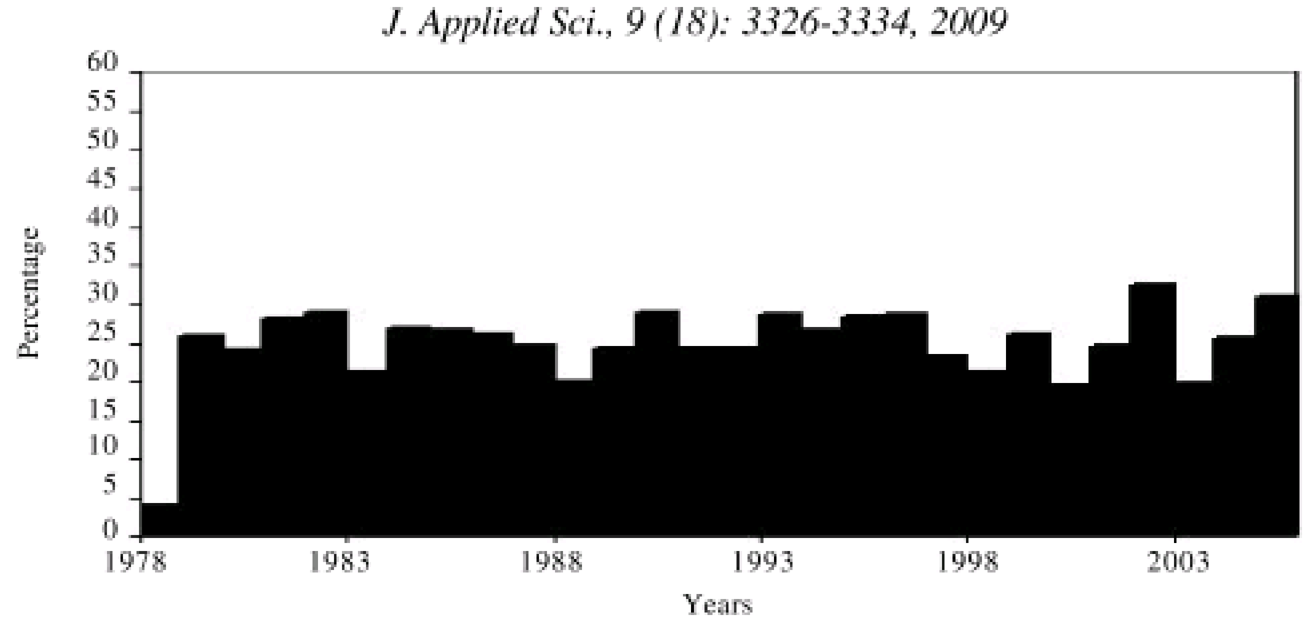

Fig. 9: Annual frequency percent of weather type No. 2

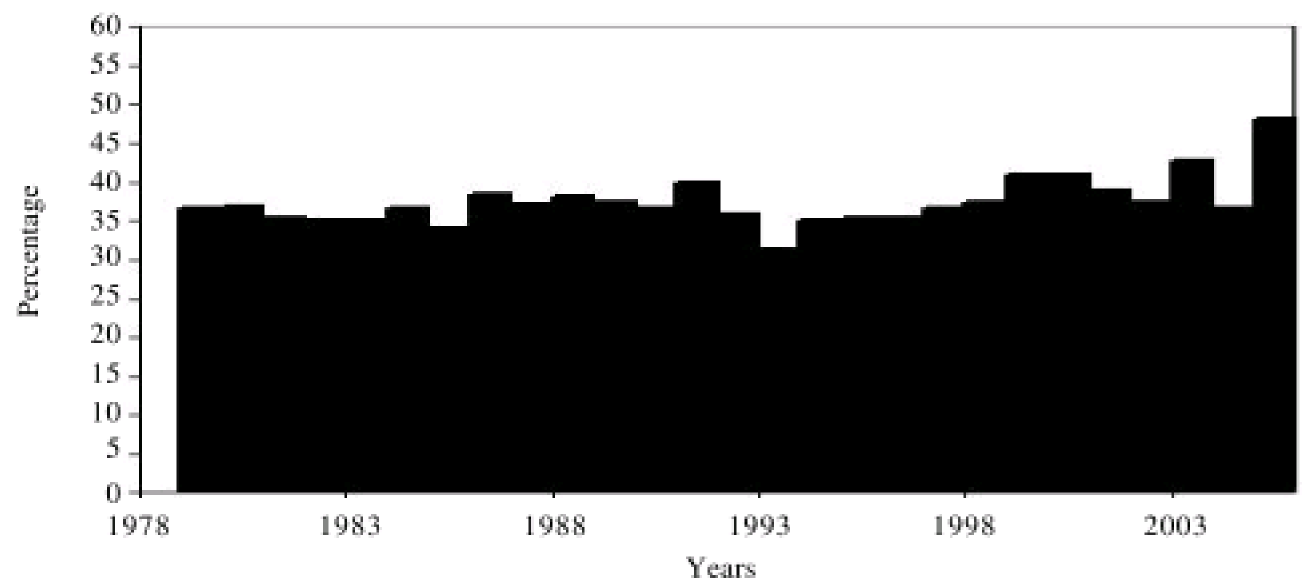

Fig. 10: Annual frequency percent of weather type No. 3

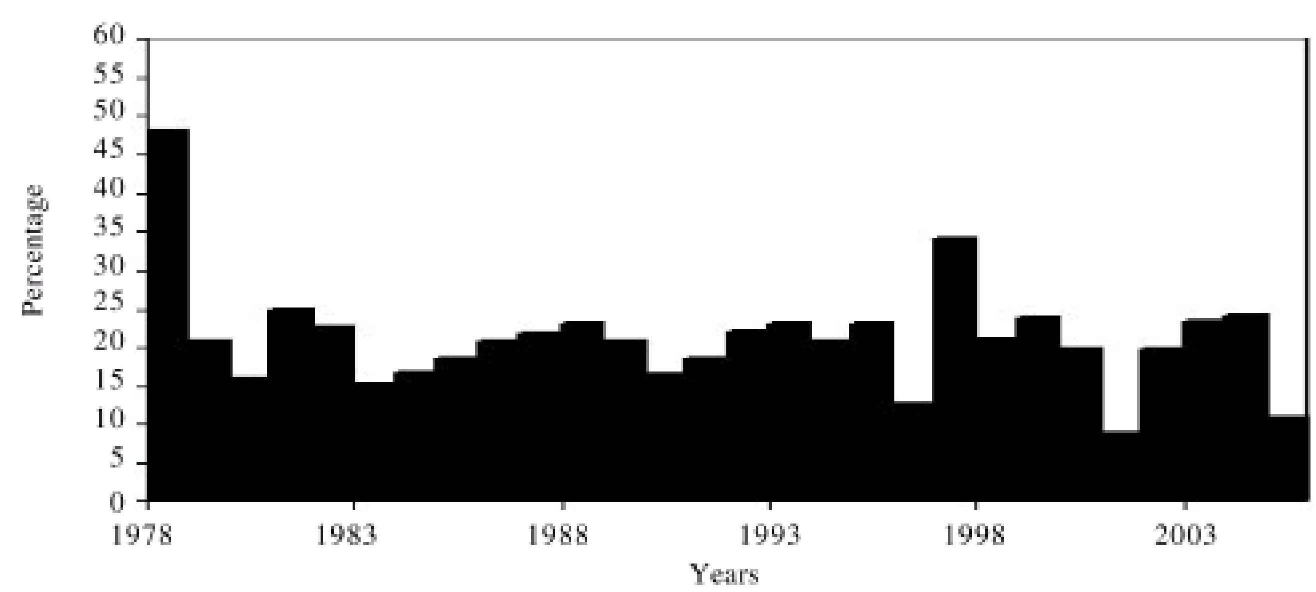

Fig. 11: Annual frequency percent of weather type No. 4

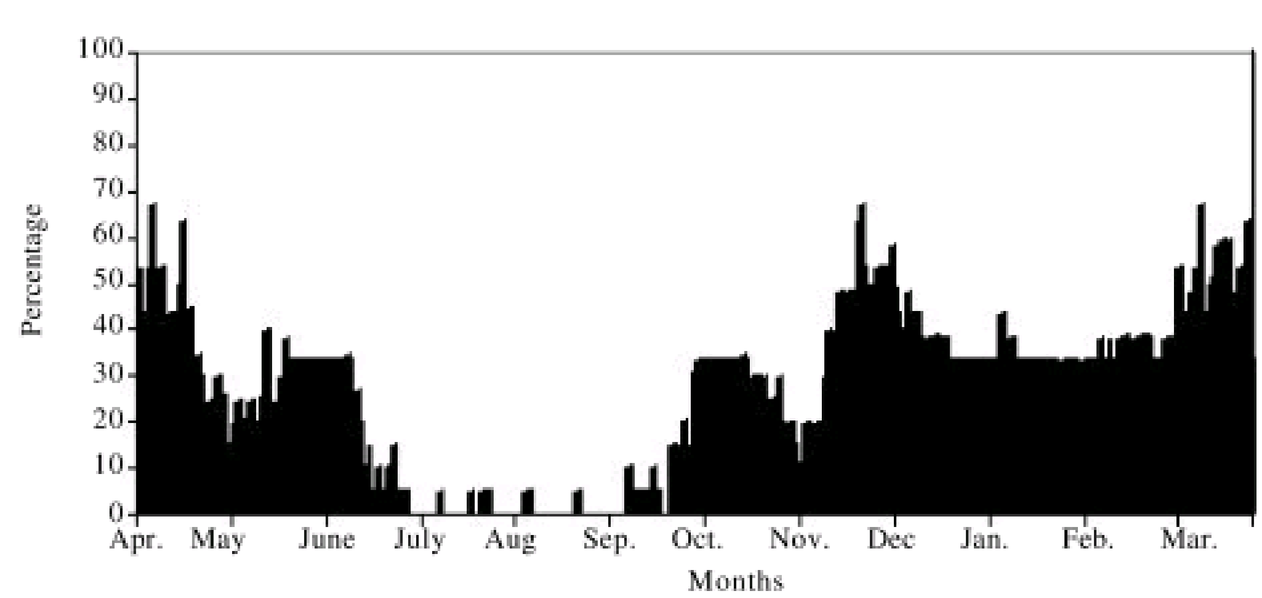

Fig. 12: Occurrence variety percent of weather types in each day of year

because the base of classification of weather types has been daily data, we determine degree of weather type variety for daily comparison. Assume that we can attribute a certain weather type to each of days of a year and assume that there are m different weather types. In addition, assume that we are studying N different years. If n_{ij} is frequency of ith weather type in jth day, then it can be written (Massodian, 2007):

$$R_{ij} = \frac{n_{ij}}{N} \times 100 \quad (4)$$

where, n_{ij} is frequency percentage of the ith weather type in the jth day. In this case, we can determine the degree of each of the types of weather variety in the following way (Massodian, 2007):

$$D_i = 1 - \frac{1}{K} \sum_{j=1}^{m} \left| R_{ij} - \frac{100}{m} \right| \quad (5)$$

Where:

$$K = 200 \frac{m-1}{m} \quad (6)$$

In our problem, number of weather Types is four (m = 4) and the number of considered years is twenty seven (N = 27). So, D_i can obtain degree of weather type variety for ith day, i for ordinary years varies between 1 to 365 and for leap years varies between 1 to 366. For a day that in all considered years had same weather type, D is equal to zero. In other words, this certain day just accepts one weather type and it does not have weather type variety. In opposite, for a day that has accepted all weather types and frequency percent of occurrence for all weather types has been the same on it; D will be one: that is, such a day has maximum of weather type variety. Therefore, D varies between zero and one. Zero introduces complete monotony and one introduces complete variety of occurrence weather types in a certain day. In warm period of the year, Tehran is under dominance Azores subtropical dynamic high pressure. In the dominance time of this system, warm, dry weather type and hot, dry weather type occurs in Tehran; because of this, weather variety in warm period of the year is little. In cold period of the year that by progressing westerly winds to South latitude, Tehran rests in direction of westerly winds' waves; dependent on station location relative to waves axis, more spread spectrum of weather types can be seen in Tehran (Fig. 12).

Sequentiality: One of the important characteristics of weather types is their sequentiality condition. Sequentiality means the number of times that a weather type can be seen after itself or after another weather type. By studying sequentiality we can identify disagreeable weather types and subsequent weather types. We call weather types i and j disagreeable; when after observing weather type i, weather type j never be observed. Studying sequentiality of weather type number 1 makes it clear that this type is disagreeable with weather types 2 and 3. On the other hand, the most probable weather type after observing weather type number 1 is the weather type number 4. The other important characteristic that can be determined by sequentiality counting of weather types is stability of each weather type. Obviously, the probability of observing a weather type after occurrence the same type is more because similar weather types tend to appear after each other. Even some of weather types that are middle limit completely opposite weather types have transition duty.

If occurrence frequency of each type after another weather type (sequentiality) is presented on percentage basis, we can obtain a criterion for integration of weather types. For example, assume that weather type number 4 has been seen during 3642 days and in all cases except one time (in the last day) has been repeated after itself; in this case, this pattern has been occurred during the 27 year period one time and for 3642 days and it has complete integration; while it could for example, occur 244 times and each time almost for 15 days that in this case. It has had less integration. This pattern has been repeated in 95% cases after itself (Table 4). This characteristic can be expressed in a precise way. If N is the number of days that a weather type has been observed and n is times of observing that weather type, then we can express occurrence index as follows (Massodian, 2007):

$$OI = 1 - \frac{n}{N} \quad (7)$$

In the case of completely separated weather types, this index will be zero and for completely continual pattern it will be 1-1/N. Calculation of the occurrence index of the types of weather of Tehran (OI) shows that the occurrence index of the 4 types of weather that have occurred 75, 80, 93 and 71%, respectively. These types

Table 4: Sequentiality percent of Tehran weather types

Type No.	1	2	3	4
1	74/4	1/4	0	19/9
2	3/9	80/4	6/7	9
3	0	9/8	93/3	0
4	21/5	8/4	0	71/1
Total	100	100	100	100

Table 5: Occurrence characteristics of Tehran weather type

Type No.	1	2	3	4
Dominant mean	3/9	5	14/8	3/4
Standard deviation	5/3	6/5	30/9	3/5
Variability	135	129	209	102
Maximum	43	44	135	31
Minimum	1	1	1	1
Occurrence	433	490	244	571
Frequency	1706	2488	3632	1997
Occurrence index	0/75	0/80	0/93	0/71

have had almost 4, 5, 15 and 3/5 day durability each time and their maximum permanence has been 43, 44, 135 and 31 days, respectively (Table 5).

CONCLUSION

In this study cluster analysis and linking days on the basis of ward method on the standardized matrix of data are employed in order to recognition Tehran weather types. The results showed that Tehran has 4 weather types (WT) including: 1) Cold, frosty, rainy WT, 2) Moderate WT, 3) Warm, dry WT and 4) Cold, windy WT. Tehran has a cold, frosty and rainy winters (weather type 1) and it has warm and dry summers (weather type 3). Only in 25.4% days of a year, moderate climate can be seen (weather type 2). In warm and dry period that involves almost 40% of days a year, because of dominance of Azores subtropical high pressure, Tehran climate has much stability and just weather type 3 occur. The dominant of warm and dry weather types in most days of year rather than other weather types and increase of relative frequency of this weather types in recent years shows that Tehran has a dry climate and become warmer The characteristics and annual frequency percent of weather type 1 is testimony to this matter. By increasing temperature and dislocation snowline to higher heights, in fact necessary water resources for continuing lives may be at risk. For further studies the recognition circulation patterns that result in these weather types may be very useful for better planning and management resources that effected by circumstances atmospheric.

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