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Bioclimatic classification of Isfahan province using multivariate statistical methods

L. Yaghmaei,[a] S. Soltani[a]* and M. Khodagholi[b]
[a] *Department of Natural Resources, Isfahan University of Technology, Isfahan, 84156-83111, Iran*
[b] *Isfahan Research Center of Natural Resources, Isfahan, Iran*

ABSTRACT: The purpose of the present study is to determine bioclimatic zones in Isfahan province using multivariate statistical method. Thirty-nine climatic variables, which were more important in plant ecological conditions (especially *Artemisia sieberi* and *Artemisia aucheri* that include more than half of rangeland surface in Isfahan province), were selected and investigated with factor analysis. Results of factor analysis showed the first three factors that explain 92.3% of total variance in selected variables were precipitation, temperature and radiation and wind with 41.91, 40.18 and 10.23% of variance, respectively. According to results and using hierarchical cluster analysis in Ward's method, bioclimatic classification in Isfahan province was performed and seven bioclimatic zones were found. In addition, to compare the results of this study with the other climatic classification methods, Isfahan province was classified by four traditional climatic classification methods (Koppen, Gaussen, Emberger and De Martonne) and its results were compared to climatic classification by multivariate statistical method. It showed that multivariate statistical method gives better classification in comparison with other methods. Beside that precipitation is the most important factor in vegetation distribution of humid and cold and sub-humid and cold regions in west and south parts of Isfahan province. In addition, temperature is the most important factor in vegetation distribution of hyper warm-arid and warm-arid climatic regions in eastern low elevation parts of province. Furthermore, dominant species were determined for each climatic region. Copyright © 2008 Royal Meteorological Society

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1. Introduction

Analyzing relations between plant species and environment is a very old subject and climate importance has been known in the distribution of vegetation. Distribution of vegetation is closely coupled with climate; the climate controls distribution of vegetation and the vegetation type reflects regional climates (Woodward 1987). Paleobotanic investigations show that plant community regions have been displaced with climate change, and vegetation distribution pattern has been a controversial subject in biogeographical research for many years (Brovkin *et al.*, 1997). Most climatic classifications, which have been carried out in relation to bioclimatic region, are based on variables such as temperature, precipitation or both of them together. Since climate is a complex phenomenon two or three elements cannot describe climate of a region; therefore in climate classification several factors should be considered (Fang *et al.*, 2002). Multivariate statistical methods have different abilities such as using many climatic variables, reducing dimensions of data and performing high flexibility in selecting variables according to the aim of the study. These methods could also classify climatic regions quantitatively and supply a good alternative for traditional methods. There has been a great deal of efforts taken regarding climatic classification. Wahl 1919 (cited in Seyedan and Mohammadi, 1997) investigated relationships between climate and vegetation cover, emphasizing on the distribution of vegetation, and determined five climatic regions with ten subdivisions worldwide. Crutezberg (1950) studied climate and its relationship with vegetation cover worldwide. In this study, annual climatic fluctuations based on iso-humid and iso-snow cover were investigated in four general climatic regions. Amigo and Ramirez (1998) classified bioclimatic regions in Chile. They found a strong relation between climate and distribution of plant species and determined five big bioclimatic zones in Chile.

Javanshir (1975) classified bioregions of Iran based on the climate and vegetation cover, which are listed as follows: Hircaninan region, Arasbaran region, Zagros region, Iranian-Touranian region (divided into mountains and plain subdivisions) and Khalij-Omani region.

DeGaetano and Schulman (1990) classified agricultural climates of USA and Canada using the principal component analysis and cluster analysis. Primary variables in this classification included maximum temperature, minimum temperature, relative humidity, wind speed, number

* Correspondence to: S. Soltani, Department of Natural resources, Isfahan University of Technology, Isfahan, Iran.
E-mail: ssoltani@cc.iut.ac.ir

of shiny hours and precipitation. This classification has similarities with boundary of natural perennial species in accordance with the use of many variables.

Ahmed (1997) classified the climatic condition of Saudi Arabia by factor analysis and cluster analysis. In this study, in Saudi Arabia 9 climatic regions were recognized and named using 14 climatic variables.

Jorn and Winter (1998) studied climatic zones of Puerto Rico using the principal component analysis. Principal component analysis with varimax rotation made five principal components that explain nearly 99% of variance and finally by using this method four climatic regions were recognized with different vegetative covers.

Lolis *et al.* (1999) investigated the spatial covariability of the climatic parameters in the Greek area by using the method of factor analysis. They classified winter and summer climatic parameters into four and three groups, respectively. The parameters of each group presented similar distribution in space (high spatial covariability). Finally results of this study showed that the spatial distribution of these climatic parameters depend on latitude, continentality and leeward or windward of the various areas.

Yurdanur *et al.* (2003) specified climatic regions of Turkey using cluster analysis. In this study, five different techniques were applied initially to decide the most suitable method for the region. They concluded that Ward's method was the most likely one to yield acceptable results. In this study, seven different climatic zones were found.

Yanling *et al.* (2007) presented a new method of vegetation–climate classification in China using *C*-coefficient (which is a combined coefficient of climatic variables). They produced a map indicating the distribution of vegetation zones in China by this method.

The aim of the present research is bioclimatic classification of Isfahan province (located in central part of Iran) by applying statistical multivariate method and comparing the results with Koppen, Gaussen, Emberger and De Martonne climate classification methods.

2. Data and methods

2.1. Study area

The study area is Isfahan province (located in central part of Iran) covering about 106 175 km^2. This area is located at 30°42′ to 34°30′N and 49°36′ to 55 °E (Figure 1). Altitude varies between 707 and 4000 m. Significant changes in altitude and their effects on climatic elements have caused different climatic conditions from hyper arid to humid to be dominant in this province and made various habitats with different characteristics for the existence and distribution of diverse plant species.

2.2. Data

For determining bioclimatic zones of Isfahan province, variables that were more important in plants' ecological conditions of study area (especially *Artemisia sieberi* and *Artemisia aucheri*, which include almost half of vegetation cover of Isfahan province) were selected. Selection criteria of climatic variables in this research are as follows:

(1). In the study area, most climatic variables have a maximum and minimum during the year, and they show many changes in the first and second half of the year. The minimum and maximum of these variables occur in January and July. Therefore, these months were considered as representatives of the first and second sixth months (cold and warm half) of the year.

(2). Investigations showed that March and April are mostly effective months on plants growing in this region (especially dominant species: *A. sieberi* and *A. aucheri*). These species are completely under the influence of temperature and humidity in these months.

(3). Spring rainfall is important for growing and establishing plant species of this region, because it occurs in their growing season. Autumn rainfall is important to release the essence from some dominant species such as *A. sieberi* and *A. aucheri*.

Figure 1. Isfahan province location in Iran. This figure is available in colour online at www.interscience.wiley.com/ijoc

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Winter rainfall is important to soil moisture storage for next growing season. Because of negligible precipitation in summer, it was not considered. In addition, rainy days and days with equal to or more than 5–10 mm precipitation of annual, January and April were selected based on their importance in plant growth in the study area.

(4). Temperature is a main and important factor in distribution of plant community. This factor is effective in plant growing, transpiration, intensity of photosynthesis, seed production, etc. (Gardner *et al*., 1985). This variable is considered as annual, January, March and July.

(5). Maximum and minimum temperature thresholds have an important role in physiological activities of plants (Gardner *et al*., 1985). Therefore these variables are considered as annual, January, March and July.

(6). Wind is an important ecological factor that is effective on pollination and seed distribution (Sabeti, 1962). So this variable is considered as annual and autumn.

(7). Radiation is very effective on plant activities and has a direct effect on photosynthesis and hormone production and indirect effect on transpiration and seed germination (Sabeti, 1962). This variable has been considered as annual, March and July shining hours.

(8). Relative humidity has an important effect on plant growth and regulating transpiration (Sabeti, 1962). This variable has been considered as annual, January and April.

(9). Because frost affects the start and stop of metabolic activities, the number of frost days in annual, January and March was considered.

(10). Annual snowy days were considered, because snow is an effective factor in increasing soil moisture and snowy regions have a shorter growing season than other regions (Gardner *et al*., 1985). Furthermore, dominant species of high mountain and snowy regions are woody shrubs.

(11). Potential evapotranspiration is effective in plant water demand. Variations of this factor have most effects on plant distribution. Transpiration rate is a response of plant to soil and air temperature, relative humidity, soil moisture, growth stage and depth of root extended. Most bioclimatic classification methods considered this variable as an important factor (Sabeti, 1962). Therefore this variable was considered as annual, July and summer.

For the above explanations, 39 climatic variables for statistical analysis were selected and are listed in Table I.

Table I. Climatic variables used for multivariate statistical method in Isfahan province.

Selected climatic variable	Selected climatic variable
Winter precipitation	Annual mean minimum temperature
Spring precipitation	January mean maximum temperature
Autumn precipitation	March mean maximum temperature
Annual precipitation	Annual mean maximum temperature
January precipitation	January frost days
April precipitation	March frost days
January rainy days	Annual frost days
April rainy days	January mean relative humidity
Annual rainy days	April mean relative humidity
January rainy days with equal or more than 10 mm	Annual mean relative humidity
April rainy days with equal or more than 10 mm	March shining hours
Annual rainy days with equal or more than 10 mm	July shining hours
January rainy days with equal or more than 5 mm	Annual shining hours
April rainy days with equal or more than 5 mm	Summer potential evapotranspiration
Annual rainy days with equal or more than 5 mm	July potential evapotranspiration
January mean temperature	Annual potential evapotranspiration
July mean temperature	Autumn wind speed
Annual mean temperature	Annual wind speed
January mean minimum temperature	Annual snowy days
March mean minimum temperature	

3. Methods

According to the explanations given in the previous section, 39 variables were selected (indicated in Table I). Data records of these variables were collected from 92 weather stations within and around regions of the province released by Iran Meteorological Organization. Record duration in all stations is 1951–2000. Accuracy and quality of data were controlled. In general, results of climatic analysis are extendable and suitable to extended zones, when the point data are converted to regional data using interpolation methods (Hasani, 1998). From density and variability of selected variables, a network of 14×14 km was determined for Isfahan province (523 cells were created in this network). On the basis of this network, a matrix with 39 columns (variables) and 523 rows (locations) was constructed.

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The amount of climatic variables was estimated by the Kriging method for each location (nodes of Kriging network) and they were used as inputs for factor analysis to assess climatic conditions of Isfahan province. As the climatic parameters were measured in different units, it is very helpful for 39 series (climatic variables) to be standardized, in order to obtain zero mean and unit variance. After construction standardized the matrix, factor analysis was performed. Factor analysis is a statistical procedure used to uncover relationships among many variables. This allows numerous intercorrelated variables to be condensed into fewer dimensions called factors. The final purpose of factor analysis is factor loading and factor score matrixes, upon which all interpretations are being performed. Factor loading is describing correlation between factors and original variables, which are used to construct factors, and the factor score shows spatial pattern of factors in space (Gareth and Wheeler, 1997). Therefore, it is used for plotting factors' map and it is a basic input for cluster analysis.

In this study, factor analysis was performed by principal component analysis and varimax rotation method on original data matrix and decreased 39 climatic variables to 3 factors. Since the purpose of this study is to determine bioclimatic zones in Isfahan province, hierarchical cluster analysis with Ward's method was performed on factor score matrix. Cluster analysis includes algorithms and different methods for classifying similar factors in related groups and classification is done based on similarity or dissimilarity (Everitt *et al*., 2001). The aim of making clusters or groups is to put those which have little variance and diversity into one group (Farshadfar, 2001). By applying cluster analysis, factor score matrix was divided into several groups. Then by using discriminant analysis, cell scores that have been in the same group were summed. It showed the factors that had more scores compared with others in each region or zone. By using cluster analysis with Ward's method, seven clusters (bioclimatic regions) were determined for Isfahan province. Total scores and number of original climatic elements were used to nominate each region. Next using vegetation cover map (Isfahan Research Center of Natural Resources, 2001) and digital elevation map of Isfahan province, dominant species and mean elevation for each of 523 cells were determined. Interactive relation between every factor and original climatic variable were analysed in each bioclimatic region. Since factor score of each climatic region is the resultant of primary climatic variables, factor scores can determine most important climatic characteristics of regions. To compare this method with traditional methods, climatic maps of Isfahan province using Koppen, Gaussan, Emberger and De martonne methods were provided and compared by results of multivariate statistical method.

4. Results

The first step in performance of factor analysis is to investigate its efficiency by Kaiser–Mayer–Olkin coefficient. Kaiser admitted that coefficient between 0.8 and 0.9 is good (Farshadfar, 2001). KMO coefficient of this research is 0.831 and shows that the use of factor analysis is good. By applying factor analysis on original data matrix, three factors with Eigen values greater than 1 were selected (the factors explaining a very small percentage of total variance is neglected). Therefore, we can say bioclimatic condition of Isfahan province is the result of these three factors that explain 92.32% of the total original data variance. Eigen values and variance percentage for each factor has been shown in Table II.

There is another matrix that is a result of factor analysis and varimax rotation. This matrix is called factor loading matrix, which shows correlation between variables and factors. Factor loading matrix was arranged by absolute values, then values greater than ± 0.7 were selected and others removed (Table III). Spatial distribution of each factors was plotted as isopleths map as shown in Figures 2, 3 and 4. Since the factor scores are standardized (with spatial average and variance equal to 0 and 1, respectively, and about 68.3% of values are between $\overline{X} + \sigma$ and $\overline{X} - \sigma$) and in order to specify variations of higher and lower scores than those of the spatial average of climatic factors, the isopleths of 0, 1 and -1 are drawn with bold lines in Figures 2, 3 and 4. Positive scores indicate areas where the climatic factors are higher than the spatial average values, while negative scores indicate areas where these parameters are lower than the spatial average values. On the basis of the above explanations, these factors were obtained and named.

4.1. Precipitation factor

This factor explains 41.91% of total variance of the original variables. Fifteen variables have positive correlation greater than 0.7 with this factor (Table III). There is a strong correlation between this factor and variables such as total winter precipitation, April rainfall, number of days with equal or more than 10 mm precipitation in April, and annual precipitation. The spatial distribution of this factor (Figure 2) shows variations between less than -0.5 in southeastern (Gavkhoni playa near Kohpaye and Naeen) to 4 in western province. Since the factor scores are standardized, positive scores indicate areas where the precipitation parameters present higher than the spatial average values, while negative scores indicate areas where these parameters present lower than

Table II. Eigen value, percentage and cumulative percent of variance for factors.

Factor	Eigen value	Percentage of variance	Cumulative variance
1	16.34	41.91	41.91
2	15.67	40.18	82.09
3	3.99	10.23	92.32

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Table III. Rotated loading factor matrix.

Variables	Precipitation factor	Temperature factor	Radiation and wind factor
Winter precipitation	0.965		
April precipitation	0.953		
April rainy days with equal or more than 10 mm	0.940		
Annual precipitation	0.929		
January precipitation	0.928		
Annual rainy days with equal or more than 10 mm	0.926		
Spring precipitation	0.914		
Autumn precipitation	0.903		
January rainy days with equal or more than 10 mm	0.893		
Annual rainy days with equal or more than 5 mm	0.887		
January rainy days with equal or more than 5 mm	0.873		
April rainy days with equal or more than 5 mm	0.862		
January rainy days	0.859		
Annual rainy days	0.791		
April rainy days	0.795		
Annual snowy days	0.695[a]		
January frost days		−0.943	
Annual frost days		−0.937	
March frost days		−0.849	
Annual mean relative humidity		−0.748	
April mean relative humidity		−0.737	
Annual mean minimum temperature		0.919	
Summer potential evapotranspiration		0.913	
July potential evapotranspiration		0.902	
Annual potential evapotranspiration		0.900	
March mean minimum temperature		0.879	
January mean minimum temperature		0.868	
July mean temperature		0.854	
Annual mean temperature		0.854	
Annual mean maximum temperature		0.791	
January mean temperature		0.733	
March mean maximum temperature		0.699	
January mean maximum temperature		0.653[a]	
January mean relative humidity		−0.657[a]	
Annual shining hours			0.919
March shining hours			0.844
Annual wind speed			0.786
July shining hours			0.773
Autumn wind speed			0.583[a]

[a] Variables less than ±0.7 are not considered.

the spatial average values. The areas with factor scores higher than 1 or lower than −1 are the regions where the correlated parameters with this factor are more important. In other words, in these regions, these factors are considered as the principal climatic factors. These values in precipitation factor map separate western and southern parts of province such as Fereidan and Semirom from eastern arid regions such as Naein and Anarak. High amount of this factor could be seen in the western (Koohrang) and southern (Semirom) regions of the province (4 and 3-standard deviation higher than average of province, respectively), because these regions are located in high mountains of Zagros and are situated on the route of moisture air masses that enter into Iran from the west (these regions supply water resources for the Zayandehrood and the North Karoon Rivers).

4.2. Temperature factor

This factor explains 40.18% of total variance of the original variables. Table III shows that there is a strong and positive correlation greater than 0.7 between this factor and variables such as average annual minimum temperature and potential evapotranspiration in summer, July potential evapotranspiration and annual potential evapotranspiration. For this reason, this factor is named temperature factor in Isfahan province.

Since the factor scores are standardized, the value of 0 (mean value) in temperature factor map separate eastern and northeastern parts of province from western and southwestern parts of province. Spatial distribution of temperature factor (Figure 3) shows western parts of province (Freidan) to have the lowest score about −1.8, and the eastern parts (Khoor-Biabanak) to have

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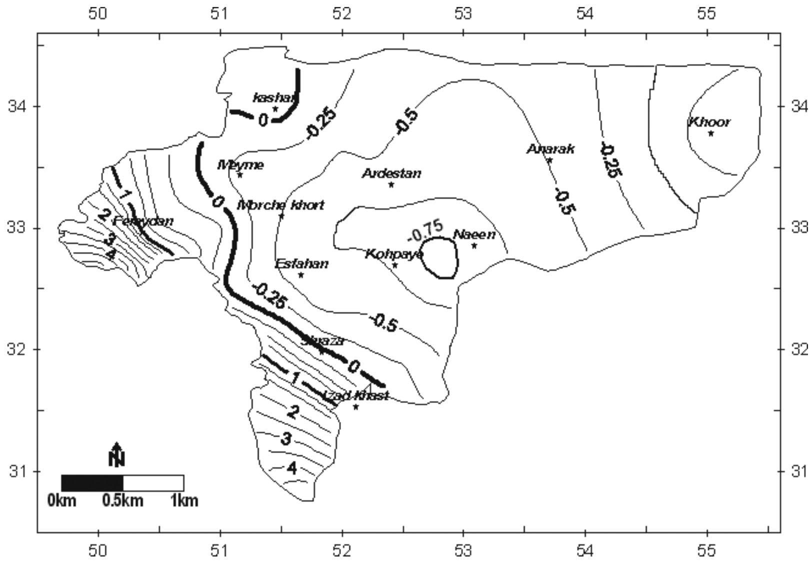

Figure 2. Spatial distribution of precipitation factor in Isfahan province.

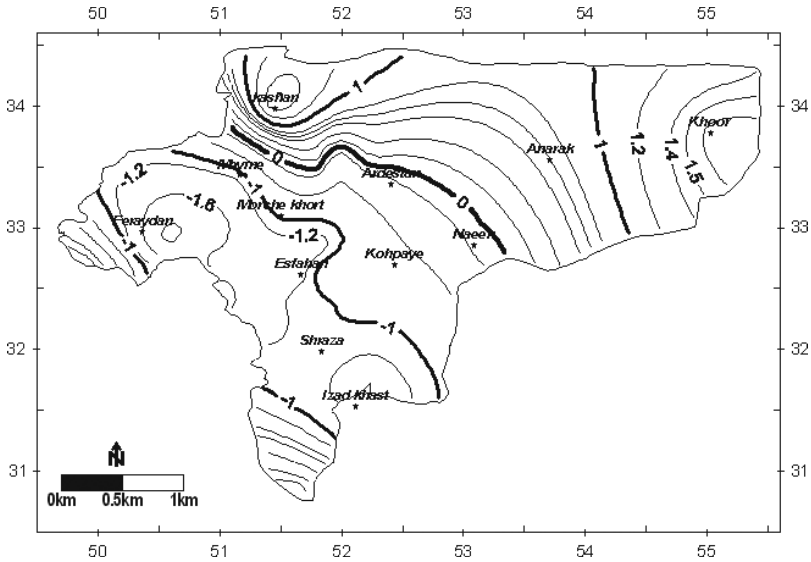

Figure 3. Spatial distribution of temperature factor in Isfahan province.

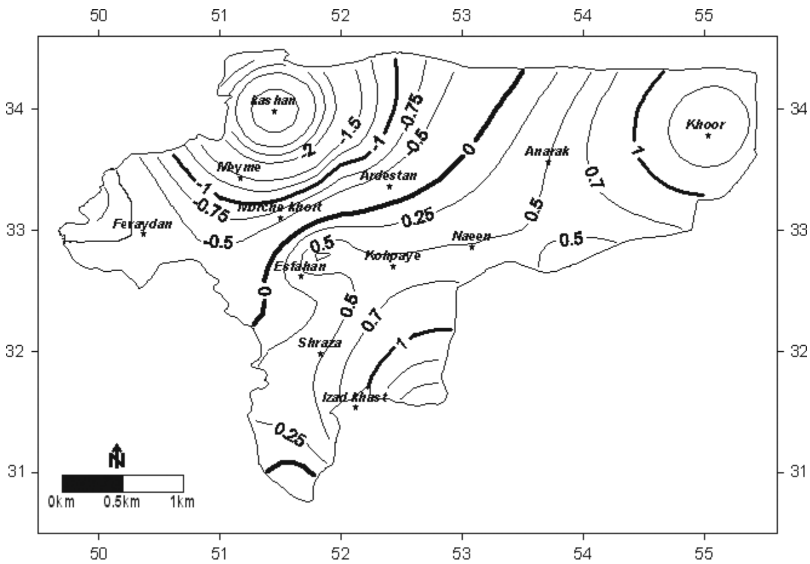

Figure 4. Spatial distribution of radiation and wind factor in Isfahan province.

the highest score about 1.6 in comparison with other parts of province. This factor has a high negative correlation with variables such as annual frost days and annual relative humidity. Figure 3 shows that the opposite is valid for the eastern and western areas. Therefore, frost days and relative humidity increase towards western and southwestern, while temperature and potential evapotranspiration increase towards eastern and northeastern of province.

4.3. Radiation and wind factor

This factor explains 10.230% of total variance of the original variables. Annual shiny hours, March shiny hours, annual wind speed and July shiny hours have positive correlation greater than 0.7 with this factor. Table III shows correlation of this factor with annual wind speed to be equal +0.786. In general, windy regions have high radiation and low number of rainy and cloudy days (negative correlation with precipitation factor shows this relation). For this reason, this factor is named radiation and wind factor. Figure 4 shows spatial distribution of radiation and wind factor. Since the factor scores are standardized, the value of 0 (mean value) in radiation and wind factor map separates the eastern and the southeastern parts from the western and northern parts in Isfahan province. On the basis of distribution of radiation and wind factor (Figure 4), the opposite is valid for the western and the eastern areas. Therefore, shiny hours and wind speed in the eastern parts of province, such as Khoor have highest amount (1.5 standard deviations above average of the whole province) and Kashan and western highlands, such as Fereidan, have lowest amount (score equal to −2) in comparison with other parts of province.

5. Bioclimatic classification of Isfahan province

Classification is a method that clustered observations based upon degree of similarity of them. Thus, observations of any group have the maximum similarity together and have the highest difference between other groups. Climatologists have used cluster analysis to recognize homogeneous climate regions. Using hierarchical cluster analysis with Ward's method on factor scores can classify Isfahan province into seven bioclimatic zones (Figure 5). Factor scores of each zone were used to name the climatic zones, because factor scores show that which one of the factors has more domination in each zone. Also regarding more weight of first and second factors, these factors were used for naming climatic zones. Seven bioclimatic zones of Isfahan province are shown in Figure 5. Factor scores and important climatic variables of each zone are listed in Table IV. Next, using four traditional methods of climatic classification (Koppen, Gaussen, Emberger and De martonne), Isfahan province was classified. Results of these methods are summarized in Figure 6 and Table V. Finally, the results of multivariate method were compared with traditional methods.

Characteristics of each bioclimatic zone and its comparison with traditional methods are explained in the following sections.

5.1. Humid and cold region

This area of 385 736 ha (3.65% of province) is located in western and southern highlands regions of the province (Figure 5). Average height of this region is 2498 m, which is the highest among climatic regions. From Table IV it is seen that in this region precipitation factor has the highest and radiation and wind factor has the lowest score in comparison with other areas inside Isfahan province. Annual mean temperature is 11.9 °C and annual rainfall is 742 mm. This region with

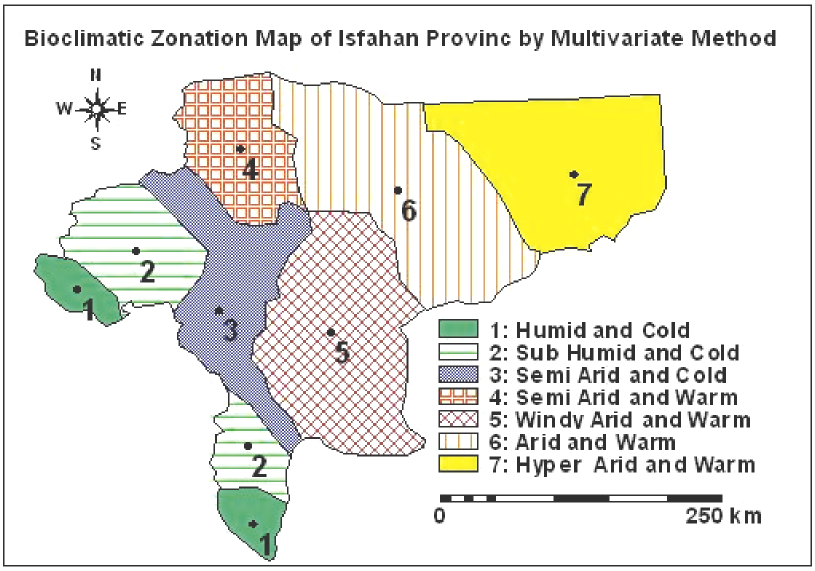

Figure 5. Bioclimatic zones of Isfahan province using multivariate statistical method. This figure is available in colour online at www.interscience.wiley.com/ijoc

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Table IV. Factor scores and important climatic variables in seven bioclimatic regions in Isfahan province.

Bioclimatic regions	Precipitation factor	Temperature factor	Radiation and wind factor	Annual mean temperature	Annual mean maximum temperature	Annual mean minimum temperature	Annual precipitation	Winter precipitation	Spring precipitation	Autumn precipitation	Annual rainy days	Annual mean relative humidity	Annual wind speed	Annual shining hours	Annual snowy days	Annual frosty days	Annual potential evapotranspiration
Cold and humid	3.877	0.3705	−0.072	11.96	19.21	5.97	741.9	383.2	183.5	221	68.5	47.6	1.1	3070	25.3	93.9	719.4
Sub-cold and humid	1.123	−1.123	−0.13	11.02	18.31	5.43	361.1	173.9	92.2	115.3	57.3	48.9	1.15	3109	19.7	104.6	683.7
Semi-cold and arid	−0.241	−1.10	−0.388	13.83	21.86	6.32	169.1	178.6	45.3	49.9	46.1	46.9	1.1	3102	10.3	100.3	793.5
Semi-arid and warm	−0.131	0.726	−2.31	16.5	24.08	10.52	128.4	68.6	40.9	28.9	40.1	42.4	0.60	2946	6.4	62.6	975.5
Windy arid and warm	−0.541	0.782	0.609	16.9	25.11	8.78	100.8	51.7	28.7	25.3	41.9	42.8	1.52	3221	5.1	85.5	1050.2
Arid and warm	−0.526	0.553	−0.137	18.19	26.1	10.98	58.7	40.8	24.6	5.1	32.0	38.7	1.0	3197	2.6	59.7	1098.5
Hyper arid and warm	0.0478	1.22	0.898	19.21	26.5	12.40	58.9	40.7	25.03	4.4	35.4	33.3	1.22	3293	3.0	44.3	1203.9

characteristics such as severe cold, high precipitation and short-term growing season has provided conditions in which only species resistant to these conditions (severe cold and freezing) can spread. Species such as *Astragalus adscendens* and *Agropyron* spp. can be seen in this region and here *A. adscendens* is the dominant species.

In De martonne method, this region is divided into hyper humid, humid and Mediterranean climates in western parts of the province and the southern parts are divided to humid and sub-humid climates. In Emberger method, it belongs to mountainous, cold humid, and semi-cold humid climates. In Koppen method, it belongs to Mediterranean and continental humid climates and in Gaussen method, it belongs to dry and warm Mediterranean and cold steppe climates.

5.2. Sub-humid and cold region

An area of 1 319 622 ha (nearly 12.43% of the province) covers some of the western parts of study area such as Freidan, Damaneh, Khansar, Golpaygan and the southern parts such as Hamgin (Figure 5). Average height of this region is 2349 m. Factor scores show some changes to humid and cold region. Precipitation and temperature factor scores decreases, therefore this region is called sub-humid and cold region. Annual mean temperature is 11.02 °C and annual rainfall is 361 mm. Vegetation cover of this climatic region has more diversity than the previous region and it is because the improvement in climatic conditions such as growing period that increases. However, there is no important difference between dominant species in this region and the previous region, but the main difference is existence of *A. aucheri* in this climate. Some of the important species in this region are *Daphne mucronata*, *Bromus tomentellus* and different species of *Astraglus* and *Agropyron*. In De martonne method, this region is divided into Mediterranean and semi-arid climates, in Emberger method it is divided into semi-cold and dry and semi-humid and cold climates, in Koppen method it is divided into Mediterranean and humid continental climates and in Gaussen method it belongs to cold steppe and dry and warm Mediterranean climates.

5.3. Semi-arid and cold region

This region of 1 400 831 ha (near 13.19% of province) includes some parts of northwest such as Meime and Morchekhort, central parts such as Isfahan and small parts of south such as Shahreza (Figure 5). Average height of this area is 1932 m. Factor scores in Table IV show a significant decrease in precipitation factor compared with the two previous regions, but temperature factor remains negative. Annual mean temperature is 13.8 °C and annual rainfall is 169 mm. Dominant species are *Stipa arabica*, *A. sieberi*, *Scariola orientalis*, *Euphorbia* spp., and *Noea mucranata*. This area in De martonne, Emberger, Koppen and Gaussen climate classifications belongs to arid, cold arid, subtropical steppe and low semi-desertic, respectively.

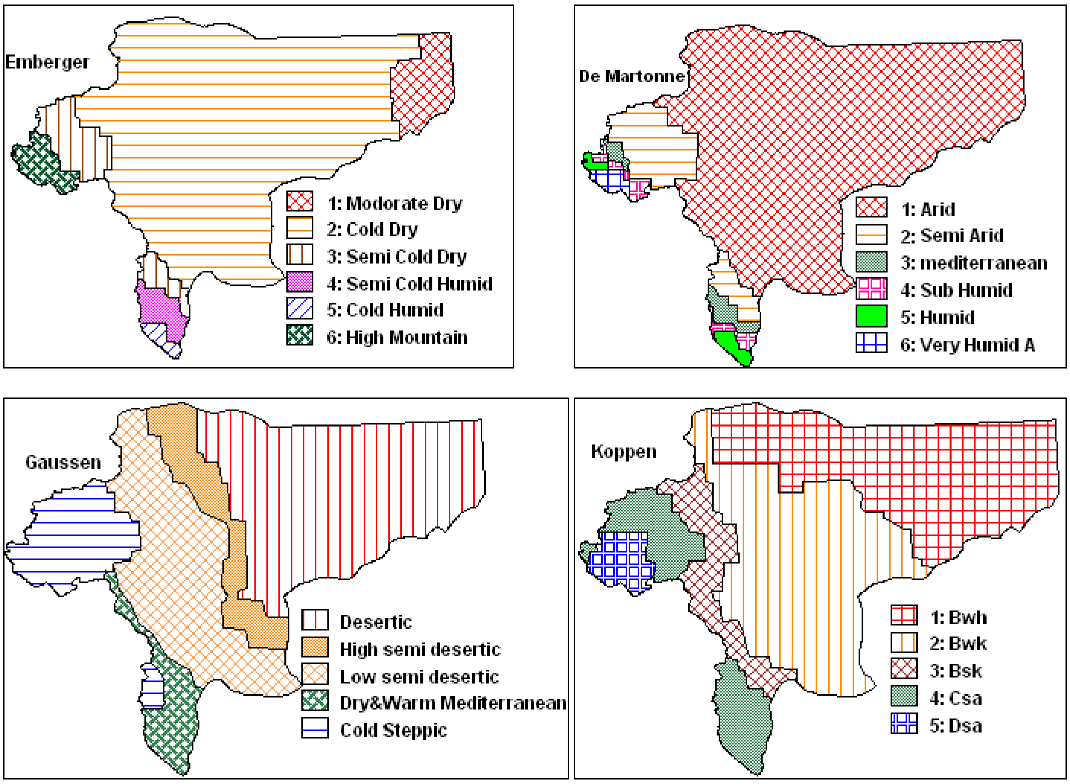

Figure 6. Climatic classification of Isfahan province using Koppen, Gaussen, Emberger and De martonne methods. This figure is available in colour online at www.interscience.wiley.com/ijoc

Table V. Percent area of bioclimatic zones in traditional climatic classification (Isfahan Provinces).

De martonne	Emberger	Gaussen	Koppen
Arid (83%)	Cold arid (80.1%)	Desert (45%)	Bwh (37.7%)
Semi-arid (10%)	Moderate arid (5.4%)	High semi-desert (8.5%)	Bwk (36%)
Mediterranean (2%)	Semi-cold dry (7.3%)	Low semi-desert (27.1%)	Bsk (10%)
Semi-humid (2.3%)	Semi-cold humid (3%)	Dry warm mediterranean (7.7%)	Csa (12.3%)
Humid (1.4%)	Cold humid (1.2%)	Cold steppe (11.7%)	Dsa (4%)
Very humid (1.3%)	High mountain (3%)		

5.4. Semi-arid and warm region

This region of 893 283 ha (about 8.41% of province area) includes northern parts of the province such as Kashan and Natanz cities (Figure 5). The average height of this area is 1470 m. Factor scores in Table IV shows that temperature factor is significant in this region. The main difference between this region and the previous region lies in the temperature factor. Annual mean temperature in semi-arid and warm region is about 3 °C, which greater than semi-cold and arid region. Annual mean temperature is 16.5 °C and annual rainfall is 128.4 mm in this bioclimatic zone. Despite sparse and low-density vegetation cover (because of deficit precipitation and excessive evapotranspiration), the dominant species of this region is *Artemisia*, which covers more than half of the area up to 2100 m, i.e. *A. sieberi*, and in highland regions the dominant species is *A. aucheri*. Other dominant species in this region are *B. tomentellus* and *S. arabica*. This region in De martonne, Emberger, Koppen and Gaussen climatic classifications belongs to arid, cold arid, desertic cold and dry and low and high semi-desertic, respectively.

5.5. Windy arid and warm region

This area of 2 113 994 ha (near 19.88% of province area) and average height of 1726.5 m includes parts of central and southeast of the province, and cities such as Naein, Ardestan and Varzaneh are located in this area (Figure 5). In this region, precipitation factor is negative; temperature factor is positive and high. Moreover, radiation and wind factor and wind speed are positive and high in this bioclimatic zone (about +0.609) while this factor has negative score in most parts of the province. Therefore, this region is named windy arid and warm (Table IV). Annual mean temperature is 16.9 °C and annual rainfall is 100.8 mm. Scarcity of precipitation and excessive evapotranspiration have caused special species to grow and distribute in this region. *A. sieberi*

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has a high percent of vegetation cover in this area, but because of restricted climatic conditions and low height *A. aucheri* was not found in this region. Heat, radiation, high aridity and wind are restricted conditions for vegetation cover of this region. Therefore, growth of resistant species such as *Anabasis aphylla*, *S. orientalis*, *Ephedra* spp., and *Hamada salicornica* have increased. This region in De martonne, Emberger, Koppen and Gaussen climatic classifications belongs to arid, cold arid, cold and arid desertic and desertic climates, respectively.

5.6. Arid and warm region

This region with an area of 2 436 229 ha (22.94% of total area in the province) and average height of 1100.3 m is the largest bioclimatic zone in Isfahan province. Table IV shows that in this region, precipitation factor has the lowest amount (−0.526) compared to the other bioclimatic zones and it represents severe aridity of this region. Because of severe aridity and the high amount of annual mean temperature (18.2 °C), arid and warm was selected to name this region. Annual mean temperature is 18.3 °C and annual rainfall is 58.7 mm. Because of low precipitation, high temperature and high potential evapotranspiration, only consistent species with these climatic conditions can grow and spread across the region. Dominant species of this zone is *A. sieberi* that is covering about 55% of vegetation cover of the region. Other dominant species are *Convolvulus fractious*, *S. orientalis*, *Stipa barbata*, *Stipa grostis* and *N. mucranata*. This region in De martonne, Emberger, Koppen and Gaussen methods belongs to arid, cold arid, arid and warm desertic and desertic climates respectively.

5.7. Hyper arid and warm region

This region with an area of 2 070 795 ha (about 19.5% of total area) and average height of 926 m includes the eastern parts of the province such as Khoor-Biabanak (Figure 5). In this region, temperature factor is a very important factor, so that this factor has the highest score compared with other bioclimatic regions in the province. In addition, annual precipitation is very low (58.9 mm) and annual potential evapotranspiration is the highest amount (1263.9 mm) in this region. Therefore this region is called hyper arid and warm. Annual mean temperature is 19.2 °C in this region. Restricted conditions have caused the decrease of species diversity in this bioclimatic region so that only adaptive species to these conditions such as *Calligonum* spp., *Zygophyloum* spp. and *Salsola* spp. can be seen as dominant species. This climatic region belongs to arid, semi-arid, desertic and arid and warm desertic climates by different classifications of De martonne, Emberger, Koppen and Gaussen, respectively.

6. Discussion and conclusion

On the basis of these results, precipitation, temperature and radiation and wind factors have a major role in distribution of plant species habitat of Isfahan province among climatic factors. These factors explain 41.91, 46.18 and 10.23% of total variance of the original variables (respectively) and altogether explain 92.3% of total variance. These results have agreement with those obtained by other researchers such as Amigo and Ramirez (1998); Tan (2002); Khodagholi (2005) and Hossell *et al.* (2003). For example, Hessel *et al.* (2003) found that climatic factors that separate different parts of Ireland and Britain are rainfall, temperature, wind speed, power evaporation and shiny hours that explain approximately 97% of total variance of the original variables.

Precipitation factor has the highest percentage of variance among other climatic factors. This factor has the highest positive score and is very influential in the western and southern highland parts of Isfahan province (in humid and cold and sub-humid and cold bioclimatic regions with average height of 2423 m). Therefore, precipitation factor is the most important climatic factor in vegetation distribution in these regions. Score of temperature factor is very low in this area and there is adaptation between existing species and climatic conditions such as cold winters with long-term frost and short-term growing season. Also temperature is an important factor in low height parts of the eastern province with 1100 m average height (in hyper arid and warm, arid and warm regions) as it has the highest positive score compared to other bioclimatic regions. In these regions, temperature is the most important climatic factor in vegetation distribution and existent species in the region have made adaptation with climatic conditions such as high mean temperature, high evapotranspiration and scarcity of precipitation.

Also bioclimatic classification of the province by four traditional methods (koppen, Gaussen, Emberger and De martonne) shows that in these methods most parts of the province are located in a single climate zone that most of them are in central and eastern parts of the province but they have a better separation in western parts. Maybe the reason is that there is a little height change in the center and east compare to the west and south of study area. The height variation can be an important factor in precipitation and temperature change and the above methods need more change in temperature and precipitation, so separation of the western and southern parts of the province has performed well. However, in spite of the climatic differences, these methods are unable to separate central and eastern parts. In De martonne method more than 82% of Isfahan province is located in arid climate, whereas this area by multivariate statistical methods has been divided into four bioclimatic regions as hyper arid and warm, arid and warm, windy arid and warm, and semi-arid and warm. Four bioclimatic zones mentioned above have more compatibility with climatic characteristics of these regions. Precipitation and temperature characteristics describe climatic differences in these four zones (Table IV). Furthermore, semi-arid and cold zone (in multivariate method) have been classified in arid group by De martonne method. Because annual mean temperature of 13.8 °C and annual

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rainfall of 169 mm, the climate in this region is not arid climate. Western and southern regions of the province, which are classified into humid and cold and sub-humid and cold in multivariate method, are classified as semi-arid, Mediterranean, sub-humid, humid and hyper humid in De martonne method that indicate these parts are separated better than other parts in this method. More than 80% of the province area is located in cold dry climate by Emberger method, but in reviewing this area by multivariate method, it has been divided into five bioclimatic regions with different climatic characteristics such as hyper arid and warm, arid and warm, windy arid and warm, semi-arid and warm, and semi-arid and cold. Most of these regions are in northeastern and central parts of the province. In Emberger method, sub-humid and cold and humid and cold bioclimatic regions of the multivariate method are classified as semi-cold dry, and semi-cold humid and mountainous climates, respectively. On the basis of Isfahan climatic characteristics, west parts of the province has a better separation by Emberger method just like De martonne method but Emberger method could not separate central and eastern of the province well. In Koppen method, most of the province has been classified as cold and arid desertic, in multivariate method it is divided into four bioclimatic zones including windy arid and warm, semi-arid and warm, arid and warm, and semi-arid and cold. Hyper arid and warm climate in multivariate method is classified into arid and warm desertic in Koppen method, which is similar to both methods. Western and southern parts such as humid and sub-humid and cold regions of multivariate method in Koppen method have been located in Mediterranean and humid continental climates. Results showed that Koppen bioclimatic classification has better compatibility with multivariate method. In Gaussen method, 45% of Isfahan province is classified to desertic climate that includes hyper arid and warm, arid and warm and windy warm and arid climates in multivariate method. Some parts of semi-arid and cold, semi-arid and warm and arid and warm are classified into high semi-desertic in Gaussen method. All of the sub-humid and cold and humid and cold areas are classified as cold steppe and arid and warm Mediterranean. This shows the weakness of Gaussen method in separating these parts especially in mountainous areas. There are many differences between some climatic variables, which are located in unique bioclimatic zone by traditional classifications (Koppen, Gaussen, Emberger and De martonne). For example, two regions with more than 200 mm and less than 60 mm annual precipitation have been located in the same climate. Maybe it is because a few climatic variables such as precipitation and temperature (with large interval for bioclimatic separation) are used in traditional classification methods but other climatic variables such as shiny hour, wind speed, potential evapotranspiration, etc., which have effects on determining climate of a region, were not considered.

This research shows much more efficiency of multivariate statistical method in specifying the weight of each climatic factor on distribution of plant species and bioclimatic classification compared with the traditional classification methods. Ahmed (1997) used multivariate statistical methods, cluster and factor analysis in classifying Saudi Arabia bioclimatic and compared them with traditional bioclimatic classifications such as Gaussen and De martonne. He concluded that multivariate statistical method has divided this country into nine different bioclimatic regions, while traditional bioclimatic classification methods have divided the whole country into two or three bioclimatic regions. Finally, he concluded that objectivity and diversity of using climatic variables in multivariate statistical methods shows that this method has more advantages than traditional methods such as De martonne, Koppen and Gaussen. Results from study by Ahmed (1997) have agreed with obtained results of Isfahan province climatic classification using multivariate statistical methods. Gerstengarb *et al.* (1999) investigated the efficiency of hierarchical cluster analysis in Europe's climatic classification. Using modified cluster analysis in Europe's climatic classification showed this technique to be a better separator of climatic regions.

Dominant species in each bioclimatic zone of multivariate statistical method in Isfahan province have adaptation with climatic conditions of that region. For example, *H. salicornica* is a dominant species of arid and warm region, which was adapted with the climatic conditions of this region.

Bioclimatic classification in Isfahan province was performed in a large scale in which only macroclimatic effects on vegetation cover was considered. If more factors (such as soil and topography) had been determined in this research, predicting results of bioclimatic classification could get better. However, this research has made a basic study for future researches on bioclimatic classifications.

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