Climatic Zonation and the Related Variables, Emphasizing Aerosol Parameters in Hamedan, Lorestan, and Markazi Provinces

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ABSTRACT
Nowadays, the occurrence of dust storms threatens both financial and environmental resources. During recent years, atmosphere of the western and southwestern regions of Iran has been occupied by these storms. This research is aimed to provide climatic zoning for Lorestan, Hamedan, and Markazi provinces with an emphasis on the variables related to a climatic element of wind was done. For this purpose, at first, a database of climatic factors (temperature, humidity, precipitation, sundial, etc.) was developed for the statistical period 1991-2010 by Excel and SPSS software packages. The principal components statistical method was utilized to reduce the dimension of the data matrix and, from among the resulting components, 6 components were selected as the principal components to determine the climatic zoning in the western region of Iran using variance and scree plot. The iso-cluster method in ArcGIS software was used for the climatic zoning of the considered area. Results showed that the studied area, during the days with dust in the air, was composed of 7 climatic zones, with an emphasis on the parameters associated with wind. Finally, map of the climatic zones was generated for the considered area in ArcGIS software.

Keywords: dust, principal components, ArcGIS, Lorestan, Hamedan, Markazi.

INTRODUCTION
Dust is a natural phenomenon which often occurs in parts of the world with arid regions and vast deserts. Vast deserts in Saudi Arabia, Iraq, Iran, and Syria are among the examples of these areas. Prolonged drought periods can increase the risk of this phenomenon, which could reduce air quality and sometimes degrade visibility to 50 m in some areas. It may also have adverse effects on human health, especially for those individuals with respiratory problems. Iran is located among the warm and dry lands in the world, has desert climate, and faces many dust storms. Nonetheless, no comprehensive research has been conducted in this area thus far. Examining the available studies on various regions of the world about dust shows that some studies have focused on the origin of storms, based on terrestrial or satellite data using statistical
methods, while others have opted for synoptic methods. Wind speed is one of the climatic factors, which is responsible for transporting dust particles from dry deserts in Iraq and Saudi Arabia to most of the western and southwestern provinces of Iran. In the classification of climates in a zone, first, the criteria for classification must be determined and then the boundary between the climatic regions or groups must be considered (Kaviani and Alijani, 2001). In previous climatic zoning, one or two climatic parameters are usually used; a climatic zone is a situation which is resulted from the combination of all climatic elements. Significant developments in the statistics and emergence of new technologies have made it possible to perform complex calculations and combine raw climatic data using statistical software and geographical information system (GIS). Principal components analysis (PCA) and factor analysis (FA) methods are among the most important multivariate statistical methods (Powel, 2002). Multivariate statistical methods with features such as the possibility of employing a large number of climatic variables, reducing size of the data, and providing considerable flexibility in choosing different variables considering different goals are able to properly and quantitatively identify and classify different climatic zones and are considered a good alternative for traditional and static methods (Khodagholi, 2005).

In this study, in order to identify the climatic zones related to the wind speed and dusty days, a database consisting of the most important monthly and annual climatic parameters was created; then, using factor analysis method, the number of variables was reduced, the interaction between the primary variables was determined, and effect and intensity of each extracted factor were identified in different locations. In the next step, using a weight or score of a factor in the studied area, these points were divided into homogeneous areas using cluster analysis method and finally the final map of the area was generated by the zoning technique in ArcGIS. Singh (1999) studied the principal components of years with high, normal, and low levels of precipitation in India using cluster analysis method. In another research, Hessel et al. (1999) classified the bioclimates in the Britain and Ireland based on 89 bioclimatic and climatic variables. Using principal component analysis, 89 primary variables were converted into 7 components such that these components expressed 96.6% of the variance in the original variables. Component scores were zoned by cluster analysis method and the relevant maps were plotted. Then, in each of the obtained zones, vegetation that was mainly tree species was specified. The largest clusters were related to the downstream areas with low altitude, while the smallest clusters were related to the highlands where changes in the climatic elements are very different at a small scale. To evaluate efficiency of statistical methods and geographic information systems, Godfrey (2000) provided zoning for agricultural climates in the state of Idaho, USA. The variables used in this study included a data matrix consisting of 55 variables and 14269 locations, which was reduced to 5 components by principal component analysis method. By hierarchical method, component scores were allocated to the clusters and divided into homogeneous regions. Finally, Godfrey found that the multivariate methods and geographic information systems are efficiently capable of identifying and classifying the homogeneous agricultural climatic zones. Alijani (1995) examined the spatial and temporal variations at the height of 500 hPa in the Mediterranean region and its effect on Iran's climate using principal components method and concluded that the Mediterranean trough has negative and positive correlation with precipitation and temperature in Iran, respectively, and the effects of this trough also moves with its movement.
Unal et al. (2003) defined the climatic regions of Turkey by mathematical cluster analysis methods. Research data were obtained from 113 climatic stations for temperature (average, minimum, and maximum) and total precipitation from 1951 to 1998. Hierarchical cluster analysis method was selected to perform the zoning process.

In this study, 5 different methods were implemented primarily to determine the most appropriate method for the area and the applied method was concluded to yield the best and most acceptable results. Finally, 7 climatic regions were obtained for this area. Philip (2008) studied the daily patterns of temperature and pressure in Europe and classified these patterns based on the clustering method on a monthly basis. Sabir et al. (2009) analyzed the precipitation data in Pakistan obtained from 32 weather stations during 1980-2006 based on factor analysis method; finally, using the applied method, they determined and clustered 6 precipitation regions.

Yilmaz et al. (2010) classified the surface water in Kizilirmak basin, which is one of the most polluted surface water in Turkey, based on water quality parameters by cluster analysis method. Masoudian (2003) used 27 climatic elements within an annual time scale to perform factor and cluster analyses and to provide zoning for the climatic regions of Iran. Based on this research, climate in Iran was composed of 6 factors. Arranged in the order of importance, these factors included heat, humidity and cloud, precipitation, wind, as well as dust and thunder. He finally identified 15 different climates along with their corresponding areas.

Khodagholi (2004) studied the most important climatic elements influencing the distribution of plant population and finally provided bioclimatic zoning for vegetation in Zayanderud river basin. Yaghmaie et al. (2009) studied the effect of different climatic factors on the expansion of forest types in Chaharmahal and Bakhtiar Province by multivariate statistical methods.

Razeie and Azizi (2009) determined the homogeneous precipitation regions in western Iran. In this study, the average values of 9 variables dependent on the precipitation during 1965-2000 obtained from 140 weather stations distributed across the region were calculated and used in the analysis. By principal component analysis (with R vector), the mentioned variables were reduced to 4 components and rotated using varimax rotation.

Then, using hierarchical clustering method, the stations used in this analysis were classified based on the applied method in terms of the standard scores for the obtained components and the western part of Iran was divided into four homogeneous precipitation sub-regions. Results showed that the topographic pattern and the latitude play an important role in demarcation and spatial differences between regions.

Lashni Zand et al. (2013) used multivariate factor analysis method in order to provide a climatic classification of the country; first, they considered 7 climatic factors, among which they extracted 3 including heat, humidity, and precipitation that could describe 92% of total variance of the climatic variation in the country. Then, using different clustering methods, the climatic classification of Iran was carried out.

**MATERIALS AND METHODS**

Area of the study included Lorestan, Hamedan, and Markazi provinces with the total area exceeding 76615.5 km². As shown in Figure 1, longitude and latitude of the area are 46 48 to 51 01 E and 33 41 to 35 47 N located in the west part of the country, respectively.

The point with the lowest altitude in the region is located in the west part of the region with the altitude of 150 m, while the highest point is Mount Ashtarak and Mount Ashtarankouh with the altitude of 4080 m above sea level and part of the Zagros Mountains.
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Figure 1: Geographical location of the studied region and weather stations on the map of Iran

In this study, the daily data from Iran Meteorological Organization (IRIMO) were used which included climatic data from 8 synoptic stations (Figure 1) in order to create a database. First, the data were divided into 2 sets: one containing the data obtained on a daily basis regardless of the dust phenomenon and the other including the data recorded on dusty days. Then, a matrix with 8×313 dimensions was obtained for both sets of data (8 and 313 indicate the number of stations and the mentioned variables considered on the monthly and annual bases). This matrix, which was composed of 25 climatic elements, was arranged based on monthly and annual data.

Then, by the output of principal components method for both sets of data, it was observed that the data sets had more variance coverage for the dusty days. At the next stage, in order to rotate the data matrix and obtain more accurate results, size of the matrix was reduced to a matrix with 8×119 dimensions. These 119 variables were parameters with greater contribution to variation of wind speed and dust from a meteorological point of view. Finally, the climatic zones were identified and given a name with an emphasis on the factors that had the most important role in formation of the climate type in the region and consequently the considered maps were prepared in the ArcGIS software.

Introducing Iso-cluster Method

The Iso Cluster tool uses a modified iterative optimization clustering procedure, also known as the migrating means technique. The algorithm separates all cells into the user-specified number of distinct unimodal groups in the multidimensional space of the input bands. This tool is most often used in preparation for unsupervised classification.

The iso cluster algorithm is an iterative process for computing the minimum Euclidean distance when assigning each candidate cell to a cluster. The process starts with arbitrary means being assigned by the software, one for each cluster (you dictate the number of clusters). Every cell is assigned to the closest of these means (all in the multidimensional attribute space). New means are recalculated for each cluster based on the membership of cells from the iteration. The process is repeated: each cell is assigned to the closest mean in multidimensional attribute space, and new means are calculated for each cluster based on the membership of cells from the iteration. You can specify the number of iterations of the process through Number of iterations. This value should be large enough to ensure that, after running the specified number of iterations, the migration of cells from one cluster to another is
minimal; therefore, all the clusters become stable. When increasing the number of clusters, the number of iterations should also increase. (Lashnizand et al., 2013).

**RESULTS**

In order to reduce dimension of the original data matrix, principal component analysis method was applied. In general, there is relatively high correlation between climatic variables. This feature makes it possible to reduce dimension of the original data matrix using principal component analysis. Also, in order to better interpret the factors, varimax method was used. Using principal components technique, the climatic parameters were reduced to 16 factors with the value of more than 1, after the analysis and rotation of the factors were performed. In total, these 16 factors explained 98.2% of the behavior of the climatic parameters in the studied area, 6 of which had a more important role in clustering and zoning the west part of Iran according to score and variance of the factors. The percentage variance of each factor was respectively as follows: 36.03, 15.70, 10.59, 7.71, 6.41, and 6.19; approximately the remaining 28.2% of the total variance was related to factors 7 to 16 which were not considered effective due to their negligible impact and role in zoning the area. In order to ensure that the number of the extracted factors is sufficient, scree plot was used. Figure 2 shows that slope of the first factor is greater than that of the second factor. Then, the slope continues to decrease such that, after factor 7, the curve becomes almost a horizontal line.

But, since 6 initial factors had the highest effect on climate of the region, these factors were used for the next analysis. This matrix which has 6 factors and 119 rows is known as factor scores matrix which shows spatial patterns of the factors at regional level was used for plotting the maps of the factors and also as the primary data for the cluster analysis method.

![Scree plot of the monthly factors in the west region of Iran](image)

**Table 1:** Principal components and percentage variance expressed in terms of total variance

<table>
<thead>
<tr>
<th>Factor</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
<th>Factor 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total factors loading</td>
<td>36.03</td>
<td>15.70</td>
<td>10.59</td>
<td>7.71</td>
<td>6.41</td>
<td>6.19</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>32.66</td>
<td>15.67</td>
<td>10.58</td>
<td>7.09</td>
<td>5.85</td>
<td>5.15</td>
</tr>
<tr>
<td>Cumulative relative diffraction</td>
<td>32.66</td>
<td>48.34</td>
<td>58.92</td>
<td>66.01</td>
<td>71.87</td>
<td>77.02</td>
</tr>
</tbody>
</table>
Naming the Components: In the case of accumulation around one factor, the correlation between the findings and internal relationship of the variables is manifested as a positive, or conversely negative, relationship; therefore, factors can be named on the above-mentioned basis. The factors extracted in this regard included:

1. **Extreme Temperature Factor**
   This component alone explained 36.03% of total variance. With coefficients greater than 0.8%, the variables “monthly mean temperature”, “absolute minimum monthly temperature”, and “absolute maximum monthly temperature” had respectively and directly the greatest contribution for explaining total variations.

2. **Wind Factor**
   This component alone explained 15.7% of total variance. With coefficients greater than 0.96%, variables “average speed” and “maximum monthly speed” had respectively and directly the greatest contribution for explaining total variations.

3. **Average Temperature Factor**
   This component alone explained 10.59% of total variance. With coefficients greater than 0.88%, variables “monthly mean temperature” and “absolute minimum temperature” had respectively and directly the greatest contribution for explaining total variations.

4. **Pressure Factor**
   This component alone explained 7.71% of total variance. With coefficients greater than 0.91%, variable “mean pressure” converted into sea and earth levels had respectively and directly the greatest contribution for explaining total variations.

5. **Thermal-radiation Factor**
   This component alone explained 6.41% of total variance. With coefficients greater than 0.73%, variables “daily mean temperature” and “monthly average radiation” had respectively and directly the greatest contribution for explaining total variations.

6. **Humidity Factor**
   This component alone explained 6.41% of total variance. With coefficients greater than 0.71%, variables “mean relative humidity” and “cloudiness” had respectively and directly the greatest contribution for explaining total variations. Factors 7 to 16 explained 33% of total variance.

- **Climatic Zoning of Hamadan, Lorestan, and Markazi provinces:**
  The main objective of this research is to provide climatic zoning for the western part of Iran; thus, the climatic classification resulted from clustering method cannot be considered a completely appropriate basis for the climatic zoning of the western region, since it only classifies the selected meteorological stations in this region and the obtained results cannot be generalized to other locations. Therefore, after performing comparative studies and using kriging method, the first 6 components obtained from the analysis and rotation of the primary variables were converted into raster maps in ArcGIS software as the most appropriate method of interpolation. After this step, the resulting raster maps were applied as an input for the iso-cluster unsupervised classification technique and different climatic zoning maps were prepared for the western region in the country.

**Table 2:** Classifying factors scores in different climatic zones of Hamadan, Lorestan, and Markazi provinces
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<table>
<thead>
<tr>
<th>Factor 1: Extreme temperature</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freezing cold and frosty</td>
<td>0.06 to -0.97</td>
<td>1-1</td>
</tr>
<tr>
<td>Normal temperature and freezing condition</td>
<td>1.1 to 0.07</td>
<td>1-2</td>
</tr>
<tr>
<td>Warm with low freezing</td>
<td>2.14 to 1.11</td>
<td>1-2</td>
</tr>
<tr>
<td>Very warm with very low freezing</td>
<td>3.18 to 2.15</td>
<td>1-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 2: Wind speed</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>-2.97 to -4.16</td>
<td>2-1</td>
</tr>
<tr>
<td>Normal</td>
<td>-1.78 to -2.98</td>
<td>2-2</td>
</tr>
<tr>
<td>Relatively severe</td>
<td>-0.59 to -1.79</td>
<td>2-3</td>
</tr>
<tr>
<td>Severe</td>
<td>0.61 to -0.60</td>
<td>2-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 3: Average temperature</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>-1.63 to -2.60</td>
<td>3-1</td>
</tr>
<tr>
<td>Mild</td>
<td>-0.67 to -1.64</td>
<td>3-2</td>
</tr>
<tr>
<td>Warm</td>
<td>0.28 to -0.68</td>
<td>3-3</td>
</tr>
<tr>
<td>Very warm</td>
<td>1.26 to 0.29</td>
<td>3-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 4: Pressure</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pressure gradient</td>
<td>0.63 to -0.55</td>
<td>4-1</td>
</tr>
<tr>
<td>Gentle pressure gradient</td>
<td>1.81 to 0.64</td>
<td>4-2</td>
</tr>
<tr>
<td>Low pressure</td>
<td>3 to 1.82</td>
<td>4-3</td>
</tr>
<tr>
<td>Absolute low pressure</td>
<td>4.19 to 3.0</td>
<td>4-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 5: Radiation-thermal</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low heat and radiation</td>
<td>-2.07 to -3.26</td>
<td>5-1</td>
</tr>
<tr>
<td>Normal radiation and heat</td>
<td>-0.89 to -2.08</td>
<td>5-2</td>
</tr>
<tr>
<td>Warm with high radiation</td>
<td>0.28 to -0.90</td>
<td>5-3</td>
</tr>
<tr>
<td>Very Warm with severe radiation</td>
<td>1.50 to 0.29</td>
<td>5-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 6: Humidity</th>
<th>Factor score</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very humid with low evaporation</td>
<td>-1.60 to -2.70</td>
<td>6-1</td>
</tr>
<tr>
<td>Humid with low evaporation</td>
<td>-0.60 to -1.61</td>
<td>6-2</td>
</tr>
<tr>
<td>Normal humidity and evaporation</td>
<td>0.38 to -0.61</td>
<td>6-3</td>
</tr>
<tr>
<td>Dry with high evaporation</td>
<td>1.42 to 0.39</td>
<td>6-4</td>
</tr>
</tbody>
</table>

Among the numerous prepared maps, Figure 3 shows the climatic zoning map of Hamedan, Lorestan, and Markazi provinces as the most appropriate climatic zoning for the studied area using the 6 principal climatic factors due to their high conformity with real climatic conditions in the region and the research objectives. In order to name the zones in this study, the factor scores of each zone were utilized (Table 2),
since the factor scores indicate the factors with the most significant role in each zone. Also, due to higher weights of the first 6 factors than other factors for the naming process and particularly considering the purpose and subject of the research, the wind factors were mostly used among the 6 factors.

Figure 3: Climatic zoning map of Hamedan, Lorestan, and Markazi provinces using 6 principal climatic factors

In order to name each climatic zone in the region and analyze characteristics of each climatic zone, the spatial distribution and dispersion of each factor in the climatic zones were determined in ArcGIS using comparative and spatial study of the raster maps obtained from zoning the 6 principal factors. According to the zoning map drawn in Figure 3 and Table 2 which shows the significance of each factor in climatic zones, in this section, the climatic zones of the studied region and their characteristics are described:

Zone 1, southern area: Very warm with high pressure gradient and severe wind

As is evident from the zoning map of the studied area, this zone is located in the southern part of the studied area and covers the most central areas and some areas in the western part of Lorestan Province. By studying the maps relating to the 6 principal factors as well as factor scores for each zone (Table 2), it became clear that this region had a very warm climate with high pressure gradient and severe wind.

Zone 2, southwest area: Warm with mild to severe wind and pressure gradient

This area which covers southwest part of the studied area includes small areas in the west part of Lorestan Province. By studying the maps relating to the 6 principal factors and the factor scores for each zone (Table 2), this zone was observed to have a warm climate with pressure gradient and mild to severe winds.

Zone 3, western and central areas: Warm with high pressure gradient and severe wind

This area which covers the west and central parts of the studied area includes northern and central areas of Lorestan Province and some other southern and southwestern parts of Hamedan Province. By examining the maps relating to the 6 principal factors and the factor scores for each zone (Table 2), this zone was found to belong to the class of warm climate with high pressure gradient and severe wind.

Zone 4, northern and central area: Cold with high pressure gradient and severe wind

This area which covers the most northern and central parts of the studied area includes some of the northern and eastern parts of Hamedan Province and some of the eastern parts of Lorestan Province. By studying the maps related
to the 6 principal factors and the factor scores for each zone (Table 2), this zone was found to have a cold climate with high pressure gradient and severe wind.

**Zone 5, south east area:** Moderate and cold with high pressure gradient and severe wind
This area covers most of the eastern parts of Lorestan Province, southern areas of Markazi Province, and some parts in the south-east of Hamedan Province. By examining the maps relating to the 6 principal factors and the factor scores for each zone (Table 2), this zone was found to be located in the class of moderate and cold climatic zone with severe pressure gradient.

**Zone 6, north and east areas:** Cold with high pressure gradient and relatively severe wind
This area covers some eastern parts of Hamedan Province and most central and southern parts of Markazi Province. By examining the maps relating to the 6 principal factors and the factor scores for each zone (Table 2), this zone was found to have cold climate with high pressure gradient and relatively severe wind.

**Zone 7, northeast area:** Very cold with high pressure gradient and mild wind
This area includes some northern and north-eastern parts of Markazi Province and covers the north-eastern region of the studied area. By studying the maps related to 6 principal factors and factor scores for each zone (Table 2), it was found to be located in the very cold climatic zone with severe pressure gradient.

**DISCUSSION:**

In the present study, it was found that principal component analysis method (rotated factor analysis) is a useful tool for identifying the climatic zones in the studied area. Results of principal components associated with wind parameters on monthly and annual bases during the dusty days revealed that the 6 principal factors played an important role in creating the climatic zones. These factors were, respectively, as follows: limit temperature, wind-humidity speed, average temperature, pressure, radiation-thermal and humidity. The first 6 components, obtained from the analysis and rotation of the original variables, were converted into raster maps in ArcGIS software using kriging method as the most appropriate interpolation method. After this step, the resulting raster maps were used as inputs for iso-cluster unsupervised classification technique and different climatic zoning maps were prepared for the western part of Iran.

Also, in the previous studies conducted by other researchers, wind has been introduced as one of the main factors in determining the climatic characteristics of the studied areas. Thus, in vegetation bioclimatic zoning of Karun river basin, Khodagholi (2007) identified 5 factors, one of which was wind. Also, the identified factors were in agreement with the results by other authors such as Araya et al. (2010), Azimi et al. (2009), Philip (2008), Pineda-Martine et al. (2007), Gerami Motlagh and Shabankari (2006), Din Pajoh (2003), and Hossel et al. (2003).

Climatic zoning of Hamedan, Markazi, and Lorestan provinces was carried out using factor scores and complete linkage method, which showed acceptable conformity with climate of the existing regions.

Results of principal component analysis method demonstrated that the most important climatic factor in the studied area based on the climatic parameter “wind” during dusty days were temperature and humidity. According to geographical area in the western part of Iran, temperature and humidity factors were manifested in 4 factors. According to the results obtained about characteristics of the wind climatic element and its increasing trend during the recent years, it is recommended to install anemometers and other required equipment in most areas of the region and to continuously monitor dust variations in the areas outside the studied stations, especially in the western boundary areas of Iran in order to
provide careful planning for identifying the origin of dust particles and to find the best ways to fight against them.

REFERENCES


