GIS Based Considerations for Development in Different Iranian Climatic Regions

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Abstract: In order to develop a climate model for Iran, monthly mean climatic variables from 117 synoptic stations were obtained from the Iranian Meteorological Organization. These variables were reduced to six orthogonal factors using factor analysis. The stations were then divided into six groups using cluster analysis. Within each climatic group, the lowest and highest thresholds for each factor were identified. The factor scores of the stations within each factor were interpolated across the country applying Inverse Squared Distance Weight in the ArcGIS environment. Based on the factor scores, six conditional functions were defined to allocate each pixel to a region. In order to simplify the models, one index variable was substituted for each factor. Then, through Discriminant Analysis, the constants and coefficients of the models were determined. The final models were evaluated against some examples, one of which, Yazd, was demonstrated fully.

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1. Introduction

The complex physical conditions of Iran including topography, vegetation cover and landscape have created a diverse climate pattern. The very hot and dry climate of the interior areas changes suddenly to the wet and moderate coastal climates of the Caspian coastal areas to the north of the Alborz mountains. The cold climates of Zagros are replaced by the warm desert climates to the east. If we accept that the climate is a very important factor in the development and progress of the country, it is important that it should be recognized and understood in any planning and policy decisions (Shie,1994). Climate is the long time prevailing synoptic conditions of an area, which is composed of different meteorological elements such as temperature, precipitation, humidity, etc. In order to understand it, all meteorological elements should be summarized statistically over time. This means processing huge amounts of data. Planners cannot develop a separate program for each individual weather station and it is therefore the task of the climatologists to classify weather stations and to identify climatic regions. Many studies have been conducted on this subject during the first half of the 20th century. Different models were developed by established climatologists such as Koeppen and De Martonne. These models use few weather variables and lack the totality of the climate. Due to some shortcomings inherent in these models, new multivariate models have been developed following the introduction of computers. The work of Fovell and Fovell (1993) is one of the basic and fundamental studies in using clustering to identify the climatic regions of the United States (Razavian,2001). In fact, all these multi-variate models are regionalization rather than actual climate identification models. The main characteristic of a model is its predictive power. None of the multi-variate regionalization are able to predict the climate of an unknown station. With the use of new data, changes to the previous schemes and repeated classification are required. Therefore, we use the term climatic model to develop an algorithm, based on existing data through which we can determine the climate of an unknown station. Several statistical studies utilizing clustering techniques have been conducted in Iran. Alijani (1993) explained the clustering method in the classification of Azarbijan thermal regions. Haidary and Alijani (1999) used 58 variables to classify the climate of Iran through the use of Principal Component and Cluster analyses. None of these multi-variate works are climate modelling, but regionalization. Any updating of the data through time requires the reclassification of the stations. On the other hand, although the works of Koeppen and others are criticized for their limited variables, adequate multi-variate substitutes have not yet been developed (Badr, 2000).

2. Data and methods

In order to develop a model of the climate of Iran, mean monthly values of 15 meteorological variables (169 monthly components in total) of 117 synoptic stations of Iran were obtained in the quality controlled format from the website of the Iranian Meteorological Organization (Bear, 1999).

The final models should be defined in a way that each could depict the characteristics of a specific climate type. In order to achieve this basic knowledge the country was classified into different climatic regions. These regions acted as the basis for the development of the models. Within the GIS environment, through the use of geostatistics, a specific model was defined for each region (climate type). The general procedure was as follows:

1. In order to achieve the climatic totality 169 monthly climatic components were selected.

However, since most of these variables and=or components were correlated, in order to reduce them to a few orthogonal factors, factor analysis with Varimax rotation was carried out.

This created the orthogonal factors or indices needed for regionalization.

2. Through the implementation of the cluster analysis, the 117 stations were clustered according to factor scores and distinctive regions were determined. In each region the lowest and highest thresholds of each factor score were identified. As mentioned earlier, these regions were the basis for the derivation of the final climatic models. These regions were based on the point data of 117 stations. Therefore, there were no data for the vast areas between the stations.

3. A layer with the point format was developed in the ArcGIS environment according to the geographical coordinates of the stations. Although the projections in Iran are mostly in the UTM system, since Iran covers four UTM zones, to minimize the interpolation errors the created geographic layer was transferred to the Lambert projection. Then, the factor score data were tabulated in this layer.

4. The tabulated factor scores of the station points were interpolated to the whole country through the implementation of the squared inverse distance weight (IDW) interpolation. procedure. This procedure showed the least Root Mean Square Error (RMSE). Therefore, a digital map layer for the whole country was produced in which each cell of 5000 by 5000 meters possessed a digital value in each factor. This is the most important contribution of ArcGIS to climatic modeling.

5. To solve the problem of the factors and develop a simpler model, a variable was selected for each factor according to the following criteria:

– having the highest loading with the factor,

– being one of the most common meteorological elements,

– the regions or polygons resulted from the selected variable coincide completely with the regions developed from the functions of the factor scores.

This process was achieved after several iterations and is the main criteria in selecting the indices. The important rationale behind this step is to simplify the factors and choose a very simple variable to facilitate the use of the final model (Habibi,and Purahmand, 2001).

6. The final models of the regions were produced using discriminate analysis. In this way, each region has a unique model. These models are used to allocate any individual station in the suitable climate group. To this end, the coefficient of the station is computed in each of the models and the station is allocated to the model with the highest coefficient

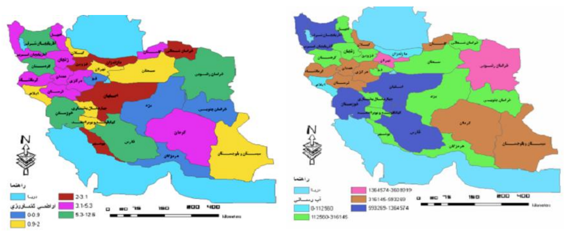

Fig. 1.Location map of Iran and the used weather stations

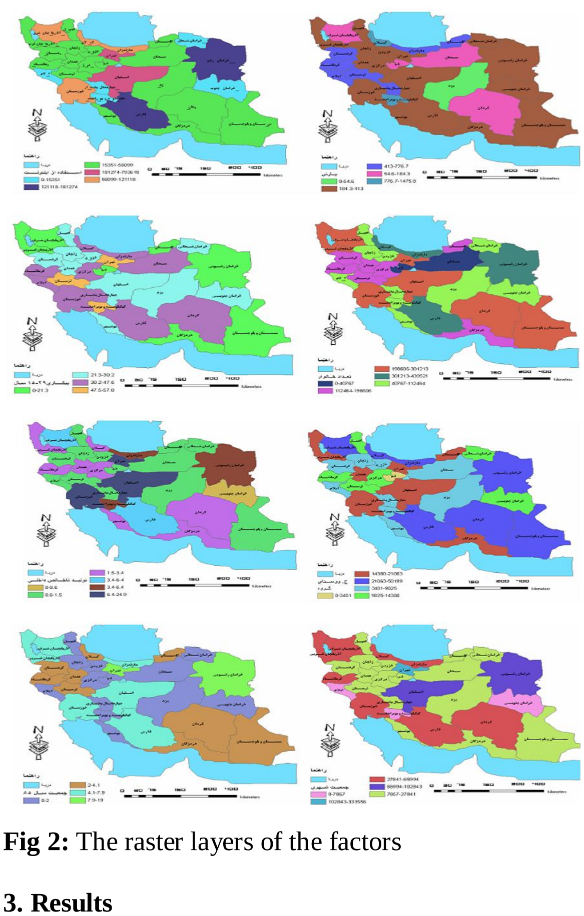

Fig 2: The raster layers of the factors

3. Results

The implementation of PCA (Principal Component Analysis) with the Varimax rotation to the 169 monthly climatic components of 117 stations resulted in six orthogonal components (Table 1).

Table 1: The explained variance of the components

Components	Eigenvalue	Variance in %	Cumulative variance	Factor scores
Temperature	55.705	31.831	31.831	−1.76 to 1.91
Humidity	30.137	17.221	49.053	−1.73 to 2.13
Mean wind speed	18.904	10.802	59.855	−2.7 to 1.92
Warm period rain	14.797	8.455	68.310	−1.39 to 5.34
Cold period rain	14.453	8.259	76.569	−1.46 to 5.7
Prevailing wind speed	11.573	6.613	83.182	−2 to 3.26

The extracted components explained about 83% of the total variance. Only those factors were selected that explained at least 5% of the total variance. These components are as follows:

Temperature: All of the heat measures are included in this factor. This factor explained 31.8% of the total variance. Its scores were low over the mountains and high in the central deserts.

Humidity: This component explained about 17% of the total variance and includes relative humidity indicating the moisture content of the atmosphere. It shows higher scores over the coastal areas of the south and north and negative values in the interior deserts (Adam, 2006).

Wind speed: This factor includes mean annual wind speed and explained 10.8% of the total variance. Its intensity is higher in the central parts of the country and decreases towards the national boundaries.

Warm season rains: Total rains of summer and autumn accounted for 8.4% of the total variance.

This factor is very important over the Caspian coastal areas (Modiri, 1999).

Cold season rains: The spatial importance of the cold season rains is less than that of the warm season, because these rains are distributed across the country. This factor is highlighted over the

Zagros Mountains and accounts for 7.3% of the total variance.

4. Climate regions

Hierarchical Clustering with the ward linkage method was used to classify the station point values into seven climate types.

The lowest and highest values of the factor scores within each type are shown in Table 2.

Table 2: Threshold values of the factors in each region

Regions	Temperature	Humidity	Mean wind speed	Warm period rain	Cold period rain	Prevailing wind velocity
First	−1.762, −0.308	−0.772, 1.685	−1.564, 1.706	−0.85, 0.127	−1.466, 1.057	−2.011, 1.048
Second	−1.672, −0.114	−0.754, 1.745	−1.496, 1.463	−0.763, 0.619	−1.414, 1.826	−0.25, 3.273
Third	−1.442, 0.453	−1.087, 0.109	−1.685, 1.316	−1.395, 0.182	0.352, 5.76	−1.339, 0.141
Fourth	−0.676, 1.335	−1.734, −0.176	−0.194, 1.858	−0.299, 1.308	−1.078, 0.122	−1.34, 1.58
Fifth	−0.344, 1.913	−1.406, 1.08	−2.7, 0.145	−1.38, 0.881	−1.254, 1.362	−0.957, 2.509
Sixth	1.308, 1.796	1.013, 2.131	−0.289, 2.221	−1.305, 0.486	−0.659, 0.708	−0.656, 1.694
Seventh	0.09, 0.633	0.866, 1.903	−1.499, 1.676	1.073, 5.351	−0.1, 2.176	−1.341, 0.242

These values are used as the thresholds for determining the climatic model of each type or region. By using the conditional functions of the ArcGIS environment and according to these threshold values, a function was defined for each region. For example the function, i.e., the model of the first region (the mountain region) is as follows:

$$\mathbf{Con}[(-1.762<\mathbf{fac.1}<-0.114)+(-0.772<\mathbf{fac.2}<1.745)+(-1.564<\mathbf{fac.3}<1.706)+(-0.85<\mathbf{fac.4}<0.619)+(-1.466<\mathbf{fac.5}<1.826)+(-2.011<\mathbf{fac.6}<3.273)].$$

In this function ‘‘Con’’ represents conditional function, and ‘‘fac.’’ represents factor. The lower and upper thresholds are taken from Table 2.

In contrast to the classic statistical methods, instead of sparse point data the pixel values of the rastered factor scores with very high resolution were used in these functions.

Application of these functions defined each cell of the raster layers of the factors in its corresponding region or type. Accordingly, several scattered or neighboring polygons were produced for each region. The first and second regions showed more than 95% overlap and hence were combined into one region. Finally, the polygons of all six regions were merged into one layer, producing the climate regions of the country. Due to the very fine spatial resolution of 5 km, the software was able to draw the regional boundaries very precisely. This ability of GIS has solved the long-lasting problem of precise boundary identification. The white areas on this map indicate the discrepancies occurring through merging, which are very small. In contrast to the classic statistical methods, instead of sparse point data the pixel values of the rastered factor scores with very high resolution were used in these functions. Application of these functions defined each cell of the raster layers of the factors in its corresponding region or type (Naghibi, 2006). Accordingly, several scattered or neighboring polygons were produced for each region. The first and second regions showed more than 95% overlap and hence were combined into one region. Finally, the polygons of all six regions were merged into one layer, producing the climate regions of the country. Due to the very fine spatial resolution of 5 km, the software was able to draw the regional boundaries very precisely. This ability of GIS has solved the long-lasting problem of precise boundary identification (Rahnarnaii, 1990). The white areas on this map indicate the discrepancies occurring through merging, which are very small and negligible. The factorial functions of all regions are listed below:

Mountain (M)

$$\mathbf{Con}[(-1.762<\mathbf{fac.1}<-0.114)+(-0.772<\mathbf{fac.2}<1.745)+(-1.564<\mathbf{fac.3}<1.706)+(-0.85<\mathbf{fac.4}<0.619)+(-1.466<\mathbf{fac.5}<1.826)+(-2.011<\mathbf{fac.6}<3.273)]$$

Semi Mountain (SM)

$$\mathbf{Con}[1.442<\mathbf{fac.1}<0.453)+(-1.087<\mathbf{fac.2}<0.109)+(-1.685<\mathbf{fac.3}<1.316)+(-1.395<\mathbf{fac.4}<-0.182)+(0.352<\mathbf{fac.5}<5.76)+(-1.339<\mathbf{fac.6}<0.141)]$$

Desert (D)

$$\mathbf{Con}[(-0.676<\mathbf{fac.1}<1.335)+(-1.734<\mathbf{fac.2}<-0.176)+(-0.194<\mathbf{fac.3}<1.858)+(-0.299<\mathbf{fac.4}<1.308)+(-1.078<\mathbf{fac.5}<0.122)+(-1.34<\mathbf{fac.6}<1.58)]$$

Semi Desert (SD)

$$\mathbf{Con}[(-0.344<\mathbf{fac.1}<1.913)+(-1.401<\mathbf{fac.2}<1.08)+(-2.7<\mathbf{fac.3}<0.145)+(-1.38<\mathbf{fac.4}<0.881)+(-1.254<\mathbf{fac.5}<1.362)+(-0.957<\mathbf{fac.6}<2.509)]$$

Coastal Desert (CD)

$$\mathbf{Con}[(1.308<\mathbf{fac.1}<1.796)+(1.013<\mathbf{fac.2}<2.131)+(-0.289<\mathbf{fac.3}<2.221)+(-1.305<\mathbf{fac.4}<-0.486)+(-0.659<\mathbf{fac.5}<0.708)+(-0.656<\mathbf{fac.6}<1.694)]$$

Coastal Wet (CW)

$$\mathbf{Con}[(0.09<\mathbf{fac.1}<0.633)+(0.866<\mathbf{fac.2}<1.903)+(-1.499<\mathbf{fac.3}<1.676)+(1.073<\mathbf{fac.4}<5.351)+(-0.1<\mathbf{fac.5}<2.176)+(-1.341<\mathbf{fac.6}<0.242)]$$

Climate indices

The models defined according to the factors have a main limitation. Each factor is composed of several variables whose share in the factor is difficult to determine. On the other hand, implementing all these variables means that the model does not summarize any information which is in contrast to the nature of modeling process. In fact, a classification scheme is as good as it is simple. For this reason we tried to select from each factor a representative variable (Rasuli, 2004).This variable is called an index. The representative index variable for each factor was selected according to the procedure outlined in the methodology section. The final six selected indices are as follows:

1 Mean annual minimum air temperature (Tm) for the first factor.

2 Mean annual minimum relative humidity (RHm) for the second factor.

3 Mean annual wind speed in knots WSmean for the third factor.

4 Mean greatest daily precipitation of June to November period (GDPs) for factor four.

5 Mean monthly precipitation of January to April period (Pc) for factor five.

6 Mean speed (in knots) of annual prevailing wind (PWS) for factor six.

These indices were placed in the model of the respective factor. The polygons produced by these indices corresponded to the ones of the factors. Several different variables were used to generate the corresponding polygons. This repeated work was conducted in the GIS environment. Selecting both the indices and their thresholds was the most difficult and sensitive part of the research. The main criteria as mentioned earlier was the correspondence of the new classes with the primary regions (those created from the factors). This is achieved through several computerized iterations.

On the final map each cell has a values for the indices. The thresholds of the indices for each region are presented in Table 3. According to these new thresholds the general form of the functions of the climate classes is written as:

$$\mathbf{Con}[(L<\mathbf{T_m}<U)+(L<\mathbf{RH_m}<U)+(L<\mathbf{WS_{mean}}<U)+(L<\mathbf{GDP_s}<U)+(L<\mathbf{P_c}<U)+(L<\mathbf{PWS}<U)]$$

In this formula L and U represents the lower and upper thresholds, respectively.

Table 3: The thresholds of the indices of the regional models

Regions	T_m	RH_m	WS_{mean}	GDP_s	P_c	PWS
Mountain	0.9–11.3	23.08–58.5	2.3–7.5	10.17–66	16.3–100	5.8–15.4
Semi Mountain	2.5–13	23–32.5	2.4–5.1	9.3–27	50–200	6.55–9
Desert	4.5–18.5	15.5–43.85	4–7.5	5–50	10.6–61	11–12.8
Semi Desert	5.6–21.5	18–53	1.1–6.7	4–70	14–100	5.8–14
Coastal Desert	18–23.5	35–58.5	4.8–7.5	14–30	16.5–40	8–12
Coastal Wet	11–13	52–67	1.8–5.1	66–212	65–120	5–10

The thresholds of Table 3 were replaced in this formula and the functions of each climate class were defined as follows.

Mountain

$$\mathbf{Con}[(0.9<\mathbf{T_m}<11.3)+(23.08<\mathbf{RH_m}<58.5)+(2.3<\mathbf{WS_{mean}}<7.5)+(10.17<\mathbf{GDP_s}<66)+(16.3<\mathbf{P_c}<100)+(5.8<\mathbf{PWS}<15.4)]$$

Semi Mountain

$$\mathbf{Con}[(2.5<\mathbf{T_m}<13)+(23<\mathbf{RH_m}<32.5)+(2.4<\mathbf{WS_{mean}}<5.1)+(9.3<\mathbf{GDP_s}<27)+(50<\mathbf{P_c}<200)+(6.55<\mathbf{PWS}<9)]$$

Desert

$$\mathbf{Con}[(4.5<\mathbf{T_m}<18.5)+(15.5<\mathbf{RH_m}<43.85)+(4<\mathbf{WS_{mean}}<7.5)+(5<\mathbf{GDP_s}<50)+(10.6<\mathbf{P_c}<61)+(11<\mathbf{PWS}<12.8)]$$

Semi Desert

$$\mathbf{Con}[(5.6<\mathbf{T_m}<21.5)+(18<\mathbf{RH_m}<53)+(1.1<\mathbf{WS_{mean}}<6.7)+(4<\mathbf{GDP_s}<70)+(14<\mathbf{P_c}<100)+(5.8<\mathbf{PWS}<14)]$$

Coastal Desert

$$\mathbf{Con}[(18<\mathbf{T_m}<23.5)+(35<\mathbf{RH_m}<58.5)+(4.8<\mathbf{WS_{mean}}<7.5)+(14<\mathbf{GDP_s}<30)+(16.5<\mathbf{P_c}<40)+(8<\mathbf{PWS}<12)]$$

Coastal Wet

$$\mathbf{Con}[(11<\mathbf{T_m}<13)+(52<\mathbf{RH_m}<67)+(1.8<\mathbf{WS_{mean}}<5.1)+(66<\mathbf{GDP_s}<212)+(65<\mathbf{P_c}<120)+(5<\mathbf{PWS}<10)]$$

5. Climate model

We have so far tried to establish basic climate regions upon which the algorithms of the climate model can be established. The six indices used to define the regions are the main parameters comprising the climate of Iran. Therefore, the model of the climate of Iran was based upon these parameters. We developed a model which could include any individual station into a correct climate region or type by using these indices. The selection of the climate type of a station is possible from its characteristics over the selected indices. This process was done using Discriminant Analysis of the SPSS software. This software can allocate an individual station into a predefined set of classes. This methodology produced some classification coefficients by which the models were developed for each type based upon the indices employed. Then the scores of the models are summed separately. The individual station was allocated to a type whose sum was higher than the others. The coefficients and constants of the regions or in our words climate types are shown in Table 4.

Table 4: Coefficients and constants of the climate models

Indices	M	SM	D	SD	CD	CW
T_m	1.496	2.233	1.901	2.991	4.248	2.927
RH_m	1.866	1.744	1.220	1.568	2.929	2.905
WS_{mean}	−0.801	−1.548	0.492	−2.128	−0.025	−3.030
GDP_s	−0.227	−0.282	−0.182	−0.229	−0.408	0.047
P_c	0.174	0.351	0.133	0.190	0.246	0.233
PWS	2.327	2.054	1.975	2.834	1.821	2.027
Constant	−50.597	−59.223	−36.509	−56.230	−134.726	−131.991

By substituting these coefficients into the equations of the climate types the final climate models were defined as follows:

Mountain

$$\mathbf{M} = -50.6 + 1.496\mathbf{T_m} + 1.866\mathbf{RH_m} - 0.801\mathbf{WS_{mean}} - 0.23\mathbf{GDP_s} + 0.174\mathbf{P_c} + 2.327\mathbf{PWS}$$

Semi Mountain

$$\mathbf{SM} = -59.22 + 2.23\mathbf{T_m} + 1.74\mathbf{RH_m} - 1.55\mathbf{WS_{mean}} - 0.282\mathbf{GDP_s} + 0.351\mathbf{P_c} + 2.054\mathbf{PWS}$$

Desert

$$\mathbf{D} = -39.5 + 1.9\mathbf{T_m} + 1.22\mathbf{RH_m} + 0.492\mathbf{WS_{mean}} - 0.182\mathbf{GDP_s} + 0.133\mathbf{P_c} + 1.97\mathbf{PWS}$$

Semi Desert

$$\mathbf{SD} = -56.23 - 3\mathbf{T_m} + 1.57\mathbf{RH_m} - 2.13\mathbf{WS_{mean}} - 0.23\mathbf{GDP_s} + 0.19\mathbf{P_c} + 2.83\mathbf{PWS}$$

Coastal Desert

$$\mathbf{CD} = -134.72 + 4.25\mathbf{T_m} + 2.93\mathbf{RH_m} - 0.025\mathbf{WS_{mean}} - 0.41\mathbf{GDP_s} + 0.25\mathbf{P_c} + 1.82\mathbf{PWS}$$

Coastal Wet

$$\mathbf{CW} = -131.99 + 2.93\mathbf{T_m} + 2.9\mathbf{RH_m} - 3.03\mathbf{WS_{mean}} + 0.05\mathbf{GDP_s} + 0.233\mathbf{P_c} + 2.3\mathbf{PWS}$$

As a working example, the climate of Yazd is determined here. The values of the indices for Yazd are listed in Table 5.

Table 5: The climatic values of Yazd in the climatic indices

Indices	Yazd
T_m	11.4
RH_m	20.67
WS_{mean}	4.92
GDP_s	9.42
P_c	10.6
PWS	8.32
Constant	−131.991

6. Conclusions

Both the procedure followed in this study and the resulting climate classification models are unique.

The methodology utilized a combined package of classic statistics, geo statistics, and GIS. All these collaborated well in developing our final model. Using the classic statistics a base frame or knowledge of the climate of the country was developed, because this work was the first research in this field and a general picture of the climate was required. Without this basic picture a realistic model could not be developed. The resulting six climate types are reasonable and resemble the findings of previous work. At the second stage point values were interpolated across the country, which we believe is unique and has not been carried out in previous climate regionalization studies.

This methodology improved the spatial resolution of the model output. Due to the use of spatial autocorrelation functions with the radius of 5 km, we were able to generate very detailed spatial variations of the climate over the country. Accordingly, the regional boundaries were drawn with the higher degree of precision. This is very important in areas with diverse topography such as Iran.

The main advance of this study is the use of GIS to develop climate indices for a station, and the implementation of conditional functions and iteration processes of the ArcGIS environment to interpolate climate information over data sparse areas. The process of definition of these indices utilized classic regionalization and ArcGIS conditional functions within the ArcGIS environment. The climate classes are presented as a live map in the ArcGIS environment. Discriminant Analysis has provided great assistance in developing indices into a statistical model and defining their weights in the final models. It is also due to the potential of Discriminant Analysis that we could define the climate type of a station from only six climate types for the entire country. We tried to develop a model to define the climate going beyond Koeppen and others. Although we ascribe shortcomings to their work, no climatic multi-element model to understand the totality of the climate had been developed. This study has achieved this task to some degree. It has demonstrated the usefulness of GIS in handling the spatial problems, and has stated that climatologists can improve their climate classifications using statistical and geo statistical methods provided by GIS.

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