International Journal of the Physical Sciences Vol. 7(23), pp. 2994-3008, 15 June, 2012
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS12.308
ISSN 1992 - 1950 ©2012 Academic Journals

Full Length Research Paper

A new approach to technique for order-preference by similarity to ideal solution (TOPSIS) method for determining and ranking drought: A case study of Shiraz station

Gholamreza Roshan[1]*, Gafar Mirkatouli[1] and Ali Shakoor[2]

[1]Department of Geography, Golestan University, Gorgan, Iran.
[2]Department of Geography, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran.

Accepted 3 August, 2011

In this research, using technique for order-preference by similarity to ideal solution (TOPSIS) index, drought phenomenon is determined and ranked. For this purpose, using 5 atmospheric elements including temperature, wind, precipitation days, annual precipitation, precipitation concentration index (PCI), droughts occurred in Shiraz station for 20-year statistical period (1983-2003) have been determined and ranked. In TOPSIS method, having employed more climate elements as compared with the earlier more simple methods, drought phenomenon is considered systematically. Finally, in order to validate the suggested method, the output data of rainfall anomaly index (RAI), decadal precipitation index (DPI) and standard index of annul precipitation (SIAP) methods have been compared for most stations of the country using TOPSIS. The obtained results prove the validity of the suggested method, so that the correlation of this method with 3 methods of RAI, SIAP, DPI with regard to Shiraz station outputs has been calculated to be r= 0.8.

Key words: TOPSIS method, climatic drought, ranking, Shiraz station.

INTRODUCTION

Drought, as one of the most important natural disasters, in the form of precipitation deficiency and temperature rise, has faced human activities yield in different cultural, economic and social areas with recession. There is a significant difference between dryness and drought. Dryness is the permanent feature of a region which is the result of the lack of adequate precipitation. However, drought is considered as a temporary atmospheric feature and occurs just when precipitation amount is under the normal range (Khoshakhlagh and Roshan, 2006; NDMC, 1995). The degree of influence of drought is not the same for a specific region in different periods, so that, it has more intensity in some periods and less intensity in other periods. Consequently, in determining and ranking drought of a station for a statistical period, we could identify climate oscillation of the concerned climatological station for different years. Therefore, if calculated indexes have decreasing (increasing) trends, they will indicate tendency to hot and dry (cold and wet) climate. In an attempt to have a precise definition and evaluation of drought, various indexes and models have been presented. For example, Bahlme and Mooley drought index (BMDI) could be mentioned. This index is presented as:

*Corresponding author. E-mail: *Corresponding author. Email: ghr.rowshan@gmail.com; Mobile: +00989171350305.

Abbreviations: PCI, Precipitation concentration index; **TOPSIS,** technique for order-preference by similarity to ideal solution; **RAI,** rainfall anomaly index; **SIAP,** standard index of annul precipitation; **DPI,** decadal precipitation index; **BMDI,** Bahlme and Mooley drought index; **PDSI,** Palmer drought severity index; **SPI,** standardized precipitation index; **MADM/MCDM,** multi attribute or multi-criteria decision making; **DM,** decision makers; **PIS,** positive ideal solution; **NIS,** negative ideal solution; **AHP,** analytical hierarchical process.

$$Mi = (p_i - \bar{p}) \times 100 / sd \quad .$$

In this index, monthly precipitation variables and standard deviation have been used (Bahim and Mooley, 1980; Spiliotopoulos and Michalopoulou, 2000; Keyantash and Dracup, 2002). Among other methods for drought calculation, we could mention Palmer drought severity index (PDSI). Detailed procedure of computing the PDSI is described elsewhere (e.g., Palmer, 1965; Alley, 1984; Karl, 1986). PDSI is referred as an index of meteorological drought, the computation procedure considers monthly precipitation, evapotranspiration and soil moisture conditions, and these meteorological variables determine hydrological and agricultural drought (Szép et al., 2005; Mika et al., 2005; Makra et al., 2002).

Furthermore, we could mention standardized precipitation index (SPI). SPI5 only uses monthly precipitation data, and it has been designed to distinguish precipitation deficiency in multiple time scales (3, 6, 12, 24, 48 months) (Elsa et al., 2006; Paulo and Pereira, 2006; McKee, 1993). But technique for order performance by similarity to ideal solution (TOPSIS) is a useful technique in dealing with multi attribute or multi-criteria decision making (MADM/MCDM) problems in the real world (Hwang and Yoon, 1981). It helps decision maker(s) (DMs) organize the problems to be solved, and carry out analysis, comparisons and rankings of the alternatives. Accordingly, the selection of a suitable alternative(s) will be made. However, many decision making problems within organizations will be a collabo-rative effort. Hence, this study will extend TOPSIS to a group decision environment to fit real work. A complete and efficient procedure for decision making will then be provided. The basic idea of TOPSIS is rather straightforward. It originates from the concept of a displaced ideal point from which the compromise solution has the shortest distance (Belenson and Kapur, 1973; Zeleny, 1974). Hwang and Yoon (1981).further propose that the ranking of alternatives will be based on the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) or nadir. TOPSIS simultaneously considers the distances to both PIS and NIS, and a preference order is ranked according to their relative closeness, and a combination of these two distance measures. According to Kim et al. (1997) and our observations, 4 TOPSIS advantages are addressed: (i) a sound logic that represents the rationale of human choice; (ii) a scalar value that accounts for both the best and worst alternatives simultaneously; (iii) a simple computation process that can be easily programmed into a spreadsheet; and (iv) the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions. These advantages make TOPSIS a major MADM technique as compared with other related techniques such as analytical hierarchical process (AHP) and ELECTRE (refer to Hwang and Yoon, 1981). In fact, TOPSIS is a utility based method that compares each alternative directly depending on data in the evaluation matrices and weights (Cheng et al., 2002). Besides, according to the simulation comparison from Zanakis et al. (1998), TOPSIS has the fewest rank reversals among the eight methods in the category. Thus, TOPSIS is chosen as the main body of development. Because MADM is a practical tool for selection and ranking of a number of alternatives, its applications are numerous. TOPSIS has been deemed one of the major decision making techniques within the Asian Pacific area. In recent years, TOPSIS has been successfully applied to the areas of human resources management (Chen and Tzeng, 2004), transportation (Janic, 2003), product design (Kwong and Tam, 2002), manufacturing (Milani, 2005), water management (Srdjevic et al., 2004), quality control (Yang and Chou, 2005), and location analysis (Yoon and Hwang, 1985). In addition, the concept of TOPSIS has also been connected to multi-objective decision making (Lai, 1994) and group decision making (Shih et al., 2001). The high flexibility of this concept is able to accommodate further extension to make better choices in various situations. This is the motivation of our study. It is not uncommon for certain groups to constantly make complex decisions within organizations. However, for using any MADM technique, e.g., TOPSIS, it is usually assumed that the decision information is provided in advance by a team or a task group. Thus, Shih et al. (2004) proposed post-work to enhance TOPSIS as a problem-solving tool. However, this compensation needs a group decision support system to fulfill its objectives. To simplify the decision making activities, we will suggest an integrated group TOPSIS procedure for solving real-world problems, with the goal of making effective decisions (Wang and Elhag, 2006; Mahmoud et al., 2007; Hsu-Shih et al., 2007).

Due to its logical reasoning, TOPSIS has solved many real-world problems, especially in recent years in the Asian Pacific region (Hsu-Shih et al., 2007). Its applications are various, and Table 1 illustrates 11 typical applicable areas. In addition, the attributes and alternatives involved are also listed in the corresponding cases. This advantage will accommodate many applications in the near future.

For the first time, in this research by entering different climate data in TOPSIS algorithm, the determination and ranking of statistical years of a station with regard to drought has been done. Each system consists of some components (years), these components are interrelated and affects each other, and considering the interaction between these components, the drought rank of each year is calculated. The purpose of this research is to evaluate the feasibility for the application of TOPSIS method in ranking and determining drought.

In this research, first TOPSIS computational method is presented in general, and then drought calculation is

Table 1. The application of TOPSIS method in different scientific areas (Shin et al., 2007).

S/No.	Application area	No. of attributes	No. of alternatives	Proposed by
1	Company financial ratios comparison	4 attributes	7 alternatives	Deng et al. (2000)
2	Expatriate host country selection	6 major attributes (25 sub-attributes)	10 alternatives	Chen and Tzeng (2004)
3	Facility location selection	5 attributes	4 alternatives	Chu (2002)
4	Gear material selection	5 attributes	9 alternatives	Milani et al. (2005)
5	High-speed transport system selection	15 attributes	3 alternatives	Janic (2003)
6	Manufacturing plant location analysis	5 major attributes (16 sub-attributes)	5 alternatives	Yoon and Hwang (1985)
7	Multiple response selection	2 attributes (or responses)	18 alternatives (or scenarios)	Yang and Chou (2005)
8	Rapid prototyping-process selection	6 attributes	6 alternatives	Byun and Lee (2005)
9	Robot selection	4 attributes	27 alternatives	Parkan and Wu (1999)
10	Solid waste management	12 attributes	11alternatives	Cheng et al. (2002)
11	Waste management	6 attributes (with 3 demand points)	12 alternatives (or scenarios)	Srdjevic et al. (2004)

explained step by step through TOPSIS. Consequently, drought of the studied region is analyzed with TOPSIS and then the results are discussed, and finally, the overall results are expressed and the suggestions are presented.

METHODOLOGY

TOPSIS method

TOPSIS method is presented in Chen and Hwang (1992), with reference to Hwang and Yoon (1981). TOPSIS is a multiple criteria method to identify solutions from a finite set of alternatives. The basic principle is that the chosen alternative should have the shortest distance from the PIS and the farthest distance from the NIS. The procedure of TOPSIS can be expressed in a series of steps:

(1) Calculate the normalized decision matrix. The normalized value n_{ij} is calculated as

$$n_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2}, \quad i = 1, \ldots, m, \ \ j = 1, \ldots, n.$$

(2) Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_j n_{ij}, \quad i = 1, \ldots, m, \ \ j = 1, \ldots, n,$$

Where w_j is the positive ideal and negative ideal solution
(3) Determine the positive ideal and negative ideal solution

$$A^+ = \{v_1^+, \ldots, v_n^+\} = \{(\max_j v_{ij} | i \in I), (\min_j v_{ij} | i \in J)\},$$
$$A^- = \{v_1^-, \ldots, v_n^-\} = \{(\min_j v_{ij} | i \in I), (\max_j v_{ij} | i \in J)\},$$

Where I, is associated with benefit criteria, and J is associated with cost criteria
(4) Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as:

$$d_i^+ = \left\{ \sum_{j=1}^{n} (v_{ij} - v_j^+)^2 \right\}^{\frac{1}{2}}, \quad i = 1, \ldots, m,$$

Similarly, the separation from the negative ideal solution is given as:

$$d_i^- = \left\{ \sum_{j=1}^{n} (v_{ij} - v_j^-)^2 \right\}^{\frac{1}{2}}, \quad i = 1, \ldots, m,$$

(5) Calculate the relative closeness to the ideal solution. The relative closeness of the alternative Ai with respect to A^+ is defined as:

$$R_i = d_i^- / (d_i^+ + d_i^-), \quad i = 1, \ldots, m.$$

Since $d_i^- \geqslant 0$ and $d_i^+ \geqslant 0$, then, clearly, $R_i \in [0, 1]$.

(6) Rank the preference order. For ranking alternatives using this index, we can rank alternatives in decreasing order.

The basic principle of TOPSIS method is that the chosen alternative should have the "shortest distance" from the PIS and the "farthest distance" from the NIS. The TOPSIS method introduces two "reference" points, but it does not consider the relative importance of the distances from these points (Shanian and Savadogo, 2006; Jahanshahloo et al., 2006; Chen and Hwang, 1992; Hwang and Yoon, 1981).

Application of TOPSIS method in drought

In this research, using TOPSIS method, determining and ranking of the drought has been done. The years have been marked with A_2 and indexes which are specified as climate parameters, have been shown with R_i. In this method, 5 climate parameters are used

for different years of a station, these parameters include temperature, wind, precipitation days, annual precipitation, precipitation concentration index (PCI), which have been shown as follows:
R_1 = the mean annual temperature in Celsius degree
R_2 = the mean annual average wind speed in km/h
R_3 = total annual precipitation days
R_4 = total annual precipitation in mm.
R_5 = precipitation concentration index

Precipitation concentration index

In order to identify the manner of precipitation distribution during different months of the year, PCI is calculated for different years of a station. This index was introduced by Oliver in 1980; it actually evaluates precipitation changes within a year or precipitation distribution during the year. PCI has been recently modified and employed by Deluis et al. (2000, 2001). In this research, the modified form of this index shown in relation (1).

$$PCI = 100 \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \quad (1)$$

where Pi is the precipitation of i^{th} month in each year. PCI indicates how monthly precipitation is distributed during year. The dispersion range of this index is from 0-100. The values less than 10 indicate steady distribution of precipitation in all months and 100 indicates total annual precipitation concentration in a special month. Precipitation concentration values of 11 to 20 indicates that precipitation in the studied station has a specified seasonal regime, and the values above 20 also indicate sever rainfall changes within the year and precipitation concentration in a limited months of the year (Deluis et al, 2000).

Determining the weight of each parameter in drought

As it is obvious, each climate parameter has different share in drought, so it is necessary to specify the weight of each of these indexes in drought, therefore, the weight of these indexes would be obtained as a total vector;

$$W = (w_{1,} + w_2 .....w_5),$$

where W_i is the weight of i^{th} index, so that the sum of W_1 to W_5 would be one and it is defined as follows:

$$W_{1+.........} W_5 = 1$$

$$\sum_{i=1}^{5} w_i = 1$$

Consequently, in order to determine the weight of each parameter, the following procedures have been used:

Entropy technique

Since, any expert may present special weight for climate variables, and it leads to difference in the final output, in order to align the views, entropy technique has been employed. Entropy is a major concept in physics, social sciences and information theory, and it indicates the amount of uncertainty of the expected information content of a message. In other words, entropy in information theory is a measure for the amount of uncertainly expressed by a discrete probability distribution (p_i), so that such uncertainty, in case of distribution dissemination, is much more than the time when frequency distribution is more pointed. In other words, in entropy technique higher weight is allocated to climate elements such as precipitation, wind, precipitation days which have higher range as compared with temperature. Therefore, this uncertainty and high range in climate elements have decisive role in elements weighting. So, this uncertainty is described as follows (the beginning value is calculated with E):

$$E \approx S\{p_1, p_2, ...p_n\} = -K \sum_{i=1}^{n} [p_i . \ln p_i] \quad (2)$$

In relation (1) k is a positive constant which is used for making up $0 \le E \le 1$

E value is from p_i probable distribution and has been calculated in statistical method, and in case of equality of p_i s, that is $(p_i = 1/n)$, the maximum value would be obtained as follows:

$$-k\left\{(\ln \frac{1}{n})(\frac{n}{n})\right\} = -k \ln \frac{1}{n} = \left\{\frac{1}{n} \ln \frac{1}{n} + \frac{1}{n} \ln \frac{1}{n} + ...\frac{1}{n} \ln \frac{1}{n}\right\} - k \sum_{i=1}^{n} pi. \ln pi = -k \quad (3)$$

A decision matrix includes information that entropy could be used as a measure for its evaluation. A decision matrix could be considered as follows:

	R_1	R_2	R_3	R_4	R_5
A_1	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}
A_2	r_{21}	r_{22}	r_{23}	r_{24}	r_{25}
.	.				
.	.				
A_m	r_{m1}	r_{m2}	r_{m3}	r_{m4}	r_{m5}

The present information content of this matrix is initially as (p_{ij}) and is calculated as follow:

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} : \quad \forall i, \ j \quad (4)$$

and it would be as follow per each feature for E_j from p_{ij} series:

$$\sum_{i=1}^{m} [p_{ij} . \ln p_{ij}] : \ \forall j \ E_j = -k \quad (5)$$

where $k = \frac{1}{\ln m}$

Now, uncertainty or lack of degree of assurance (d_j) from the information obtained from j th index is as follows:

$$d_j = 1 - E_j : \forall j \tag{6}$$

and finally, for weights (w_j) from the present indexes, it would be as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} : \forall j \tag{7}$$

In examples where entropy technique has been used to extract weights of climate variables, it has been proved that entropy technique has allocated more weight to wind in knot unit, therefore, in order to modify these weights, it is better that the wind is calculated based on km/h in entropy technique.

In this step, the significance of the weight of each index (climate parameters) should be studied in matrix R (climate data of all years), so for this purpose, in order to calculate weight of each climate parameter, matrix R should be multiplied in vector W, however, as the mentioned multiplication is not definable, so, in this case, vector W is considered as a 4x4 matrix which is shown as follows:

$$v = R_{m\times 5} \times W_{4\times 5} = \begin{bmatrix} r_{1_1} & r_{1_2} & r_{1_3} & r_{1_4} & r_{1_5} \\ r_{2_1} & r_{2_2} & r_{2_3} & r_{2_4} & r_{2_5} \\ r_{3_1} & r_{3_2} & r_{3_3} & r_{3_4} & r_{3_5} \\ .. & & & & \\ ... & & & & \\ ... & & & & \\ r_{m_1} & \dots & & & r_{m_5} \end{bmatrix} \times \begin{bmatrix} W_1 & 0 & 0 & 0 & 0 \\ 0 & W_2 & 0 & 0 & 0 \\ 0 & 0 & W_3 & 0 & 0 \\ 0 & 0 & 0 & W_4 & 0 \\ 0 & 0 & 0 & 0 & w_5 \end{bmatrix} = \begin{bmatrix} v_{1_1} & v_{1_2} & v_{1_3} & v_{1_4} & v_{1_5} \\ ... & & & & \\ ... & & & & \\ ... & & & & \\ ... & & & & \\ v_{m_1} & v_{m_2} & v_{m_3} & v_{m_4} & v_{m_5} \end{bmatrix} \tag{8}$$

In the above relation, R is the initial matrix, W is the design matrix that the element on its main diameter is vector w, and it is shown as the following equation:

$$w = (w_1 + ...w_5)$$

In problem solving, atmospheric elements act differently in drought event. For example, temperature, wind and PCI in relation with drought phenomenon have reverse function to precipitation and precipitation days. In a way that high values of temperature, wind and PCI opposing small values of precipitation and precipitation days cause the increase of drought severity. In other words, the less precipitation and the more temperature are, the probability for the occurrence of drought and its severity is increased. Therefore, this reverse process should be coordinated among effective elements. Therefore, in this phase, the effect of parameters process should be assimilated and normalized. For this reason, parameters, the increasing tendency of which is effective in non-occurrence of drought are considered as positive indexes and parameters, the decreasing tendency of which is effective in the lack of drought are considered as negative index.

Normalization of positive indexes

In each 5 selected climate parameters the increasing trend of which is effective in the occurrence of wet years, its maximum value in the concerning years is selected, then all data of other years are divided by it, which certainly, the resulting answer in a year which has had the maximum value of data, would be one. Here, it is noteworthy that positive indexes include mean annual precipitation, and precipitation days. At this stage, it is necessary to explain that in order to calculate F1s, which are normalization criterion for positive indexes, matrix v data (coefficients obtained from climate data and their weight) is used:

$$= R_{i\,j} \,/\, R_{i\,j^{MAX}} \quad F_1 \tag{9}$$

$F_1 =$ The ratio of the value of each positive index to the maximum of the same positive index.

$R_{i\,j} =$ The value of each positive index for each year

$R_{i\,j^{Max}} =$ Maximum of each positive index.

Normalizing negative indexes

For each selected climate parameter, the decreasing trend of which is effective in non-occurrence of drought, the minimum value of its data is selected among the total data of the years and it is divided by the data of other years. Therefore, the highest value of calculated data is related to the year which has the minimum value. It is noteworthy to mention that; negative index in this method is the element of mean annual temperature, mean annual average wind speed, and PCI index. In this stage, to calculate F_2 (the criteria for normalizing negative index), like F_1, data derived from matrix v (coefficients from climate data and their weights) has been used. Therefore, it is clear that the primary data value has been corrected in this way and substituted in relations:

$$F_2 = R_{i\,j^{MIN}} \,/\, R_{i\,j} \tag{10}$$

$F_2 =$ the ratio of the lowest value of negative index to data of each negative index

$R_{i\,j}^{\min}$ = the minimum value of any negative index for the minimal year

$R_{i\,j} =$ Value for each negative index for each definite year

In this part, it is necessary to introduce and identify the ideal year (it has the highest value in positive indexes and the lowest value in negative indexes) in order to rank other year according to this year. To achieve this goal, stage 4 should be done.

At this part, the ideal year (the best year) which is indicated with symbol $\overset{*}{A}$ is calculated and defined as follows:

$\overset{*}{A} \cong (I_1, I_2 .....I_4)$, $\overset{*}{I}_I = \max_I (\min) r_{ij}$, $\overset{*}{A} =$ Ideal choose (year), I = Climate parameters

With regard to selecting the ideal year, it should be mentioned that this choice is relative, because there is no year in which all parameters have the best priority. Therefore in introducing this year almost equal mark ($\cong$) is used.

It is obvious that there is no ideal choice in practice, hence for ranking years with regard to drought in approximately near reality way, it is operated as follows:

First, two negative and positive ideal points which are indicated as $\overset{+}{A}$ and $\overset{-}{A}$ are defined as follows:

$$\overset{+}{A} = \max{}_I (\min) vij = (v_1{}^+, \ldots\ldots\ldots v_5{}^+)$$

$$A^- = \min{}_I (\max) vij = (\overset{-}{v}_1, \ldots\ldots v_5{}^-)$$

Here, the character $\overset{+}{A}$ and $\overset{-}{A}$, means respectively the highest and the lowest rate of positive and negative index for each climate parameter.

Now we obtain the distance of each year from negative and positive ideal, for this purpose following stages are used:

$$d_I^+ = \sqrt{\ } \{ \sum_{j=1} (vij - \overset{+}{v}j)^2 \} \tag{11}$$

$$d_I^- = \sqrt{\ } \{ \sum_{j=1} (vij - \overset{-}{v}j)^2 \} \tag{12}$$

$d_I^+ =$ mth from positive ideal - i year distance

$d_I^- =$ mth from negative ideal - i year distance

$j =$ Climate variable

$v =$ Climate parameter value of j for year $\boldsymbol{i}$

At the final stage, after calculating d_i^+ and d_i^- for each year, eventually for calculating drought and ranking it for each year, positive and negative ideal points of the following relation have been used:

$$cl_i = d_i^- / (d_i^+ + d_i^-) \tag{13}$$

$cl_i =$ Ranking index

It should be mentioned that, the output cl varies from 1 to zero, so that the more cl coefficient is, it indicates wet condition and the less cl coefficient is, it indicates more dry condition.

THE STUDIED REGION

In this research, Shiraz station was selected as sample station and different stages of TOPSIS was applied on its climate data. In general, Fars province is located in the southwest of Iran and Shiraz city is the center of this province. Shiraz station is in the latitude of 29 36 N and longitude of 52 32 E and with the height from sea level is 1488 M. The mean annual temperature of this station is 18.47 centigrade, the average precipitation is 336 mm and its climate is in semi-arid area. The location of this station on Iran is shown in Figure 1.

At this stage, after identifying related weights for semi-arid station of Shiraz using entropy technique, Table 2 has been extracted, and following that, using initial and raw data of Shiraz station in Table 3, final result obtained from multiplication of matrix R in vector W for climate values of Shiraz station is presented in Table 4. For this purpose, A.D years have been converted to water year, that water year in Iran starts in October and ends in September.

Normalizing positive indexes

As the positive index and its normalization was introduced in procedures, now the obtained results from relation (10) for Shiraz station is calculated, and presented in Table 5.

Normalizing negative index

At this stage, the obtained results of relation (10), with regard to temperature negative index is calculated for Shiraz station, which could be seen in Table 6.

Now, after determining ideal years with regard to Table 7, we should obtain distances of each year from the positive and negative ideal for Shiraz station using relations (11) and (12). The calculated values of d_I^- & d_I^+) for this station are presented in Table 8.

In this part, after calculating the distances of each year from positive and negative ideals for Shiraz station, cl coefficient is calculated for each year based on relation (13). The result is presented in Table 9 and the years have been ranked accordingly.

VALIDATION OF THE SUGGESTED METHOD

This part is twofold; the first part is the comparison of the mentioned method with previous methods, and the second part, using empirical data, the proposed approach is validated.

Validation of the proposed method using current drought methods

For this purpose, the obtained results from TOPSIS method have been compared with standard index of annual precipitation (SIAP) valid index of drought. The purpose of choosing SIAP index is its more efficiency than (EPI, SPI, BMDI, rainfall anomaly index (RAI), deciles of precipitation index (DPI), and PNPI) indexes in

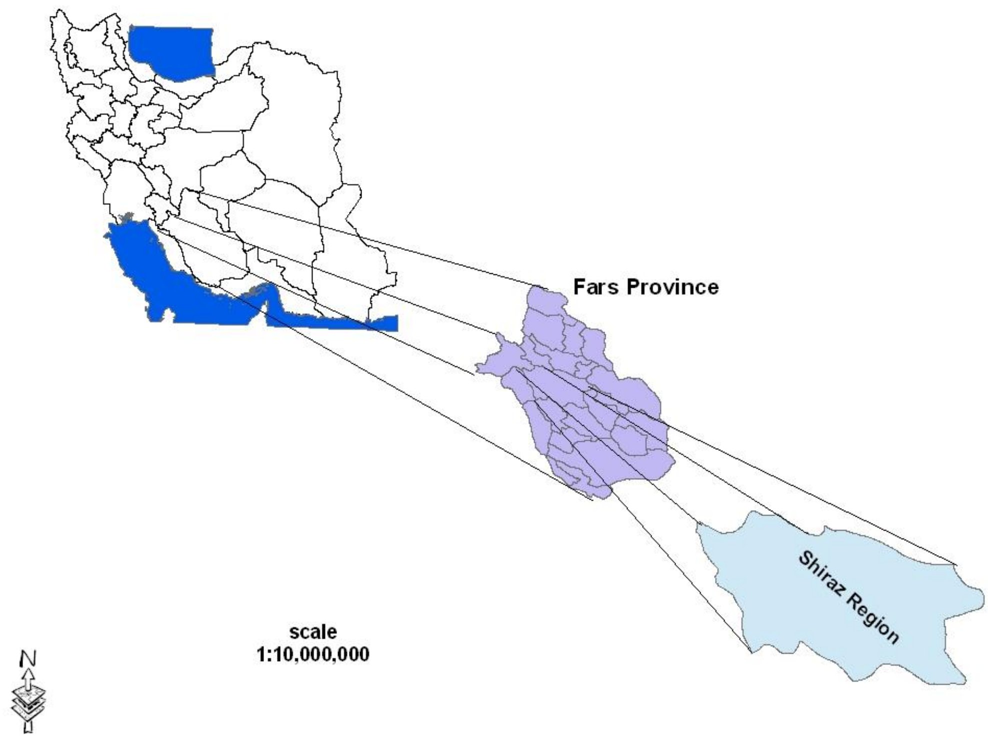

Figure 1. The location of Shiraz station in Iran.

Table 2. Climate variable weights for Shiraz station.

Climate variable	Weight
Temperature	0.10
Precipitation	0.30
Number of precipitation	0.19
PCI	0.28
Wind	0.13

calculating meteorological drought for some meteorological station of Iran (Khalili and Bazrafshan: 2003). In addition, RAI and DPI indexes have been used, which will be explained at follows:

SIAP Index or Annual Precipitation Index Criteria

The formula of this index is presented as follows:

$$SIAP = {(P_i - \overline{P})}/{SD} \quad (14)$$

In this formula P_i is the precipitation of the considered hydrology year, $\overline{P}$ is the long-term mean precipitation, and finally SD is the standard deviation of precipitation series. Drought class range of this method is presented in Table 12.

Rainfall Anomaly Index

This index assesses certain month or year rainfall on linear scale, which is obtained from data series. The index calculation process is as follows:

A): calculation of long-term mean of monthly precipitation ($\overline{p}$) at the considered station.

B): Mean extraction of 10 maximum value of precipitation occurred in the studied period, which is indicated with $\overline{m}$.

C): mean extraction of 10 minimum value of monthly precipitation ($\overline{x}$) with long-term mean.

D): comparison of the date of annual precipitation (p_i) with long-term precipitation. If, $p_i \succ \overline{p}$, then RAI is determined from relation (15), and if $p_i \prec \overline{p}$ it is determined from relation (16).

$$RAI = 3[(p_i - \overline{p})/(\overline{m} - \overline{p})] \quad (15)$$

$$RAI = -3[(p_i - \overline{p})/(\overline{x} - \overline{p})] \quad (16)$$

In the first case, anomalies are positive and in second case they are negative. Attributing threshold +3 and -3, respectively to the mean of 10 maximum positive anomaly values and 10 minimum anomaly

Table 3. The value of initial and raw climate data for Shiraz Station, from water year 1983-2003.

Year/Climate element	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
Temperature	17.73	18.02	17.73	18.44	18.54	18.19	18.58	18.61	16.9	17.73
Wind	9.7	9.1	8.3	7.8	7.5	6.8	7.1	6.7	6.6	5.8
Precipitation days	39	46	56	45	47	38	41	48	69	72
Precipitation	191.7	249.6	236.7	466.2	395.2	193.9	376.1	368.8	305.5	577.3
PCI	36	33.5	27.4	35.3	23.7	29.4	24	40.7	22.9	27.9

Year/Climate elements	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Temperature	19.08	18.31	18.4	18.67	18.71	19.93	19.7	19.4	19.37	19.28
Wind	5.9	6.4	7.3	8.3	8.3	8.2	8.2	8	8.2	7.7
Precipitation days	39	65	67	51	76	45	29	42	49	65
Precipitation	189	477.9	612.4	208.9	451.2	312.6	193.4	239.3	388.6	328.3
PCI	38.2	22	20.2	30.5	19.6	36.5	75.4	27.2	24.3	25.1

Table 4. Obtained results from multiplication of climate parameter on their weight.

Year/Parameter	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
Temperature (r_1)	2.66	2.7	2.66	2.77	2.78	2.73	2.79	2.79	2.54	2.66
Wind (r_2)	1.25	1.18	1.08	1.01	0.98	0.89	0.92	0.87	0.86	0.75
Precipitation days (r_3)	11.70	13.80	16.80	13.50	14.10	11.40	12.30	14.40	20.70	21.60
Annual precipitation (r_4)	65.2	84.90	80.5	158.5	134.4	65.9	127.9	125.40	103.9	196.3
PCI (r_5)	7.9	7.4	6	7.8	5.2	6.5	5.3	8.9	5	6.1

Year/Parameter	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Temperature (r_1)	2.86	2.75	2.76	2.80	2.81	2.99	2.96	2.91	2.91	2.89
Wind (r_2)	0.77	0.83	0.95	1.08	1.08	1.06	1.07	1.04	1.06	1.01
Precipitation days (r_3)	11.70	19.50	20.1	15.30	22.80	13.50	8.70	12.60	14.70	19.50
Annual precipitation (r_4)	64.3	162.5	208.2	71	153.4	106.3	65.8	81.4	132.1	111.6
PCI (r_5)	8.4	4.8	4.4	6.7	4.3	8	16.6	6	5.3	5.5

Table 5. Normalized values of positive indexes for Shiraz station.

Year/Negative parameter	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
Number of precipitation days F_{1_1}	0.51	0.61	0.74	0.59	0.62	0.5	0.54	0.63	0.91	0.95
Annual precipitation F_{1_2}	0.51	0.61	0.74	0.59	0.62	0.5	0.54	0.63	0.91	0.95
Year/Negative parameter	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**
Number of precipitation days F_{1_1}	0.51	0.86	0.88	0.67	1	0.59	0.38	0.55	0.64	0.86
Annual precipitation F_{1_2}	0.51	0.86	0.88	0.67	1	0.59	0.38	0.55	0.64	0.86

Table 6. Normalized values of negative indexes, for Shiraz station.

Year/Negative parameter	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
F_{2_1} temperature	1	0.95	0.94	0.95	0.92	0.91	0.93	0.91	0.91	1.00
F_{2_2} wind	0.6	0.63	0.7	0.74	0.77	0.84	0.82	0.86	0.87	1
F_{2_3} PCI	0.54	0.6	0.71	0.55	0.83	0.67	0.81	0.48	0.86	0.7
Year/Negative parameter	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**
F_{2_1} temperature	0.95	0.89	0.92	0.92	0.91	0.90	0.85	0.86	0.87	0.87
F_{2_2} wind	0.98	0.91	0.79	0.7	0.69	0.71	0.7	0.73	0.71	0.75
F_{2_3} PCI	0.51	0.89	0.97	0.64	1	0.54	0.26	0.72	0.81	0.78

values of rainfall, 9 class of abnormality ranging from extremely wet to extremely drought. The range of drought rank of this method is indicated in Table 12.

Decadal precipitation index (DPI)

With this method, it is specified that precipitation of a certain month or year is placed in which interval of successive decadal annually or monthly precipitation series. Hence, for this purpose, first we set the precipitation data in ascending manner, then the probability of precipitation in a specific

Table 7. Positive and negative Ideals.

Climate parameter	Temperature	Wind	Annual precipitation	Precipitation days	PCI
$\overset{+}{A}$	1	1	1	1	1
$\overset{-}{A}$	0.85	0.6	0.31	0.38	0.26

Table 8. Calculated values of d_I^- **and** d_I^+ for Shiraz station.

Year	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
di^-	0.33	0.42	0.60	0.60	0.72	0.50	0.69	0.52	0.87	1.04
di^+	1.04	0.9	0.79	0.70	0.60	0.93	0.66	0.77	0.55	0.31
Year	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**
di^-	0.48	0.97	1.13	0.49	1.06	0.42	0.10	0.51	0.70	0.75
di^+	0.98	0.31	0.26	0.88	0.41	0.85	1.23	0.86	0.63	0.60

Table 9. Calculated coefficients of cl for the years.

Year	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
cl coefficient	0.24	0.32	0.43	0.46	0.55	0.35	0.51	0.40	0.62	0.77
Ranking	2	3	10	11	14	6	12	9	16	19
Year	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**
cl coeffiecient	0.33	0.76	0.81	0.36	0.72	0.33	0.08	0.37	0.52	0.56
Ranking	4	18	20	7	17	5	1	8	13	15

year or month is determined from relation (17) (Gips and Maher, 1967).

$$P_i = \frac{i}{N+1} \times 100 \qquad (17)$$

In this part it is necessary to state that, after calculating the results of the proposed approach

Table 10. Raw and initial data of climate variables and empirical data for validation of mentioned drought methods in determining the driest year.

Method	Year	Temperature	Humidity	Precipitation	No. of precipitation	PCI	Wind	Discharge	Wheat
Three mentioned method	1993-1994	19.08	37.00	189	39	38.2	5.9	17.8	258.1
TOPSIS	1999-2000	19.70	30.92	193.4	29	75.4	8.2	10.9	106.7

with RAI, DPI, SIAP methods and comparison of these results with TOPSIS, it has been proved that in all above methods (four methods) the wet year (1995-1996) was common, but the most severe drought was different. So that, in three methods of SIAP, DPI, RAI the most severe drought was related to year (1993-1994), but the most severe drought has been calculated through TOPSIS method in year (1999-2000). Now to validate the mentioned methods, we referred to the raw and initial data of climate variables and empirical data. Therefore, with referring to raw data of this year, it has been proved that this condition indicates the validity of the results obtained from TOPSIS method as compared with three mentioned methods (Table 10).

As it is clarified in Figures 2, 3 and 4, the trends graphs of three methods of SIAP, RAI, DPI for year 2002-2003 is descending. But this situation in TOPSIS graph is reverse. Therefore, we are referring to climate variables and empirical data in the considered year and the two previous years, and again the data show the validity of the present trend in TOPSIS method as compared with three other methods (Table 11).

Introducing the range of drought classes in TOPSIS method

In this part, considering the high correlation of obtained results from TOPSIS method with three other indexes, and using interpolation between the coefficients between these methods, the range of drought classes within the proposed method has been summarized in Table 12.

Validating the proposed method using Data (discharge and agricultural yields)

At this stage, in order to validate the proposed method with empirical data, the correlation has been made between annual discharge values and dry wheat product with output results of mentioned drought indexes, in Shiraz station to identify an index, which has the closest relation with agricultural and hydrologic drought. Therefore, for this purpose, the water year, which starts from October and ends in September, is used.

Now for this purpose, correlation has been done between annual discharge and drought indexes. After taking correlation between annual discharge and the considered drought index, it has been concluded that the highest correlation with $r = 0.86$ is between TOPSIS drought index and annual discharge. However, following down in this method, correlation has been taken for drought index and dry wheat value for Shiraz station. It should be noted that in this part, the average dry wheat yield efficiency in every water year has been used, and the unit performance of wheat yield is Kg per hectares. After reviewing correlation between drought indexes data and the yield of wheat product, the highest correlation is again achieved between TOPSIS drought index and the yield of dry wheat product with correlation $r = 0.81$ (Table 13).

In general, considering the output results regarding correlation between discharge (cubic meter per second) and annual wheat product with drought indexes (Kg per hectares), it could be expressed that TOPSIS drought index indicates more accuracy in determining drought intensity for Shiraz station, as compared with other drought indexes. Therefore it is more efficient than three other drought methods.

DISCUSSION AND CONCLUSION

In this method, through using 5 atmospheric elements of the mean annual temperature, the mean annual average wind speed, total annual precipitation days, annual precipitation and mean PCI, drought determination and ranking has been done. Therefore, in this method as compared with previous simpler methods, more variables have been used. In this method, in addition to indirect attention to means, special attention is given to extreme values.

In TOPSIS method, because of chain relationship between values of different atmospheric values of different years for determining and ranking drought, systematic approach has been considered as one of the important elements.

One of the positive points of this method, in addition to determining drought (wet year) is its ranking in statistical period.

Using more and more accessible variables, this method has more efficiency than Palmer and other methods, which requires access to parameters such as soil moisture. Because lack of developed facilities and also data such as soil moisture is an important factor in

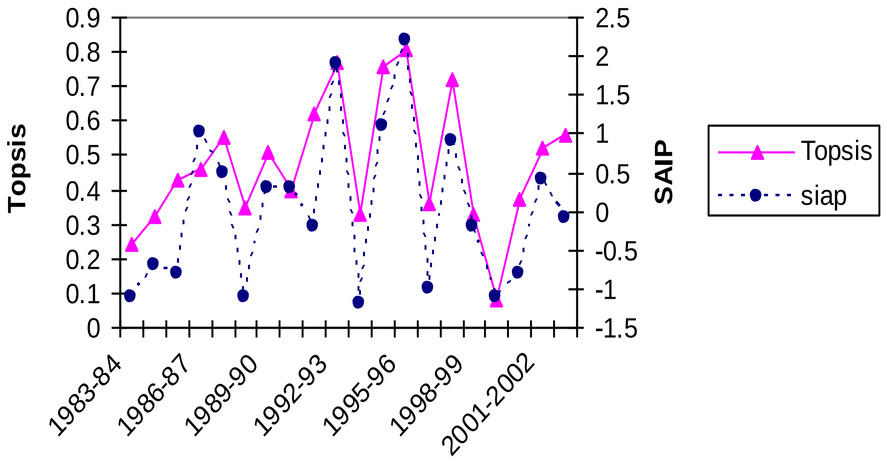

Figure 2. Comparison of SIAP index values with TOPSIS index.

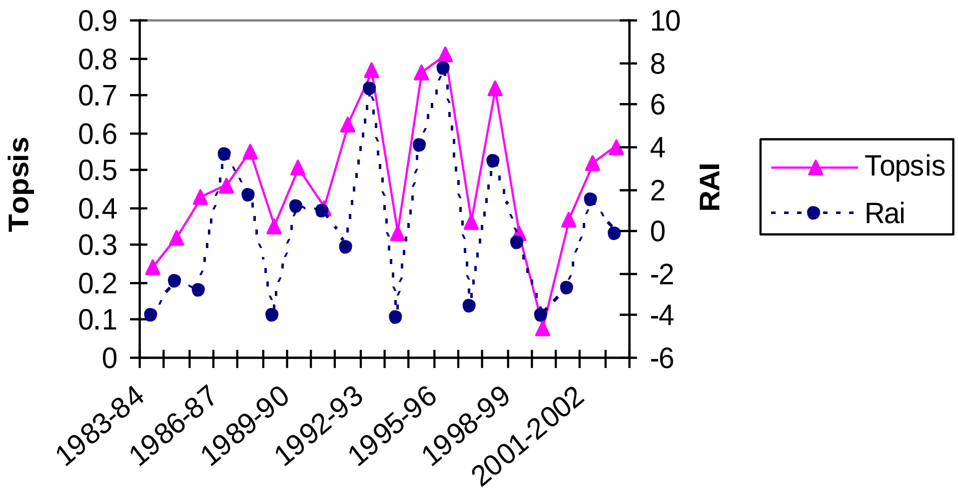

Figure 3. Comparison of RAI Index values with TOPSIS index.

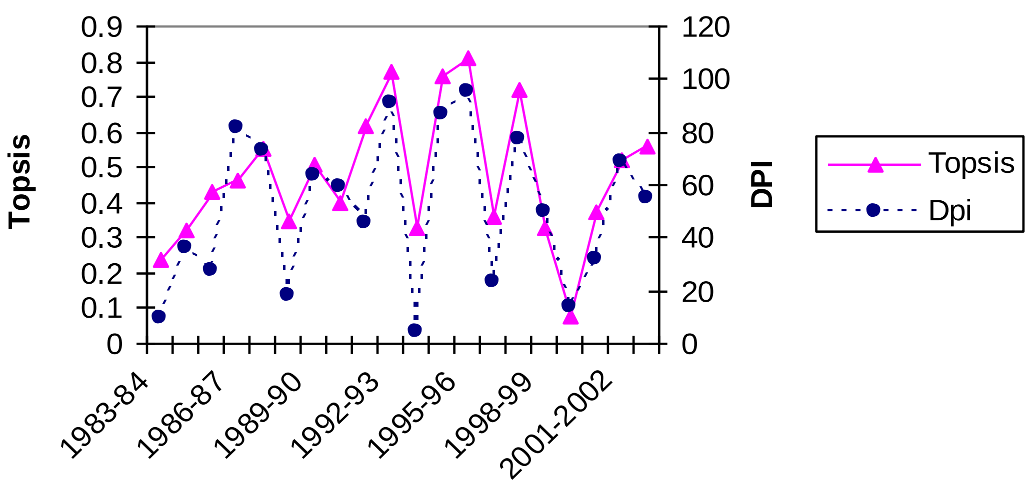

Figure 4. Comparison of DIP index values with TOPSIS index.

Table 11. Raw and initial data of climate variables and empirical data for validating the mentioned trends in above drought index for the years 2002-2003.

Year	Temperature	Humidity	Precipitation	No. of precipitation	PCI	Wind	Discharge	Wheat
2000-2001	19.4	36.8	239.3	42.0	27.2	8.0	10.5	106.7
2001-2002	19.4	37.1	388.6	49.0	24.3	8.2	9	486.8
2002-2003	19.3	37.8	328.3	65.0	25.1	7.7	41	766.8

Table 12. Introducing the range of drought index classes.

Severe drought class	DPI	RAI	Rainfall amount indexed annually SIAP	TOPSIS
Extreme wet	More than 0.90	More than 2	Over 1/28	Over 91
Severe wet	0.80 to 0.90	2.1 to 2	1/28 to 84	81 to 90
Medium wet	0.70 to 0.80	1.2 to 2.1	84 to 52	71 to 80
Weak wet	0.60 to 0.70	3. to 1.2	52 to 25	61 to 70
Normal	0.60 to 0.40	+.3 to -.3	+0/25 to -0/25	41 to 60
Weak drought	0.30 to 0.40	-.3 to -1.2	-0/25 to –0/52	31 to 40
Medium drought	0.20 to 0.30	-1.2 to -2.1	-0/52 to -0/84	21 to 30
Severe drought	0.10 to 0.20	-2.1 to -2	-0/84 to -01/28	11 to 20
Extreme drought	Less than 0.10	Less than -2	Less than -1/28	10 and less than 10

Table 13. Correlation between drought index values with annual discharge and dry wheat yield in Shiraz station.

Water year	Annual discharge (m/s)	Dry wheat yield (kg/h)	TOPSIS	RAI	SIAP	DPI
1983-84	13.4	322.9	0.24	-4.12	-1.1	9.09
1984-85	15.8	391.1	0.32	-2.47	-0.7	36.36
1985-86	17.8	574	0.43	-2.84	-0.8	27.27
1986-87	32.7	594	0.46	3.61	1	81.82
1987-88	27.7	679.2	0.55	1.64	0.5	72.73
1988-89	16.8	495.1	0.35	-4.06	-1.1	18.18
1989-90	28.2	339.8	0.51	1.1	0.3	63.64
1990-91	24	721.9	0.4	0.9	0.3	59.09
1991-92	48.3	931.8	0.62	-0.88	-0.2	45.45
1992-93	59	738.7	0.77	6.71	1.9	90.91
1993-94	17.8	258.1	0.33	-4.2	-1.2	4.55
1994-95	42.4	746.1	0.76	3.94	1.1	86.36
1995-96	38.8	939.3	0.81	7.68	2.2	95.45
996-97	16	526.5	0.36	-3.63	-1	22.73
1997-98	37.2	834.3	0.72	3.19	0.9	77.27
1998-99	23.3	141	0.33	-0.68	-0.2	50
1999-2000	10.5	106.7	0.08	-4.07	-1.1	13.64
2000-2001	9	486.8	0.37	-2.77	-0.8	31.82
2001-2002	41	766.8	0.52	1.45	0.4	68.18
2002-2003	13.4	982.4	0.56	-0.23	-0.1	54.55
Correlation with annual discharge	-	-	0.86	0.82	0.82	0.79
Correlation with wheat	-	-	0.81	0.61	0.61	0.63

incorrect calculations.

In TOPSIS method, in addition to using annual data, monthly and daily data could be used and there is no limitation in this regard.

Comparing drought indexes for more accurate determination of drought severity, using annual discharge and the yield of dry wheat product in Shiraz station, we come to the conclusion that with regard to the high correlation between TOPSIS index output and empirical data, this index has more efficiency and accuracy in determining drought severity in Shiraz station.

After calculating and ranking drought in different years for Shiraz station, the result is obtained that based on TOPSIS ranking coefficient, water years 1999-2000 with coefficient of 0.08 are identified as the driest years and the years 1995-1996 with coefficient of 0.81 are the wet years of Shiraz station. Eventually, considering co-efficients cl for recent years of Shiraz, the point become clear that the mentioned station have a weak and almost random trend toward more humid climate.

SUGGESTIONS

Finally, it is recommended that specialists and experts in meteorological and climatology areas as well as other disciplinary should apply TOPSIS method for issues such as climate change, periods of torrential, global warming, changes of oceanic phenomena and similar affairs.

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