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Using variable fuzzy set theory and information entropy for air pollution risk assessment in Beijing, China

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***Abstract*—Considering that the air pollution risk assessment is a variable fuzzy concept with multiple indicators and classes and there is the limit for the weight value of variable fuzzy evaluation method, the variable fuzzy mathematics method and the information entropy are combined to evaluate the air pollution risk of different seasons in sixteen districts of Beijing in 2009. The multi-objective group decision-making problem under air pollution risk has been solved by variable fuzzy method and the weight problem has been modified by information entropy, which makes the evaluating results more objective. From quantitative assessment, the air pollution risk of winter season in south seven districts of Beijing was on the margin in 2009. Beijing needs to optimize energy structure by introducing and developing the use of cleaner high-quality energy to decrease air pollution risk grade on winter.**

Keywords-air pollution risk assessment; variable fuzzy set theory; information entropy; Beijing

I. INTRODUCTION

Air pollution is one of the major urban environmental problems in Beijing of China as a consequence of rapid urban growth and population increasing. Because the urban air pollution would bring significant threats to human health and the environment [1], the air pollution risk assessment is important to this metropolis. However, as in all environmental risk assessments, due to inconsistency and distinction of each air pollutant risk factor, there is a vagueness or fuzziness in air pollution risk. Fuzziness makes the use of sharp boundaries in classification schemes hard to justify. This fuzziness led some environmental researchers to look for advanced assessment methods based on fuzzy theory and a number of researchers have developed fuzzy theory in various environmental areas [2, 3, 4, 5, 6].

Variable fuzzy set theory is based on both probability theory and fuzzy theory and is usually used to assess the multi-objective group decision-making problem under risk [7]. This theory has been used to evaluate the flood risk [8], water resources [9], and water quality [10]. This method provides a new idea and approach for solving multi-objective decision-making problem among uncertain system and it is also applicable for air pollution risk assessment. However, the scientific character of weight value is not clear when applying variable fuzzy set theory in risk assessment. Especially, the weight value which usually contains the information of the individual indicator only but has nothing to do with the relationship between assessment objects.

To solve this problem, the information entropy has been introduced [11]. As a measurement of the disorder degree of a system, information entropy can measure the amount of useful information with the provided data and has been widely used in many fields [12, 13]. When the difference of the evaluating objects on the same indicator is large, the entropy is small, which illustrates that this indicator provides more useful information and this indicator's weight should be set relatively large. On the other hand, if the difference is small, the entropy is large, and the corresponding weight would be small [14]. Hence, the entropy theory is a comparatively objective way to determine the weight [15].

Based on the concept mentioned earlier, this paper combines information entropy method with variable fuzzy set theory to evaluate the air pollution risk of different seasons in sixteen districts of Beijing in 2009. The organization of this paper is as follows: Section 2 describes the general variable fuzzy set theory and the information entropy methods; Section 3 evaluates the air pollution risk by using the combination of these methods and discusses the evaluating results; and Section 4 presents the conclusions.

II. METHODOLOGIES

A. Variable fuzzy set method

Variable fuzzy set theory is based on both probability theory and fuzzy theory and provides a new idea and approach for solving multi-objective decision-making problem among uncertain system [7, 8]. The procedure of variable fuzzy evaluation is described as follows:

Assume $X = (x_1, x_{2,} \cdots, x_n)$ be a finite set of n feasible alternatives in air pollution risk with m criteria to be considered, then the decision-making matrix can be denoted as $X = (x_{ij})_{m \times n}$, where x_{ij} is the value of the i th criterion for the j th alternative for all $i = 1,2,\cdots,m$ and $j = 1,2,\cdots,n$.

According Chen [7, 16] and Zhao and Chen [9], all values in X could be assessed in the priority intervals between consecutive rankings and let the priority criterion matrix I_{ab} be

$$I_{ab} = [a_{ih}, b_{ih}] = \begin{bmatrix} [a_{11}, b_{11}] & [a_{12}, b_{12}] & \cdots & [a_{1c}, b_{1c}] \\ [a_{21}, b_{21}] & [a_{22}, b_{22}] & \cdots & [a_{2c}, b_{2c}] \\ \vdots & \vdots & \cdots & \vdots \\ [b_{m1}, b_{m1}] & [a_{m2}, b_{m2}] & \cdots & [a_{mc}, b_{mc}] \end{bmatrix}$$

where a_{ih} and b_{ih} is priority lower limit value and the priority upper limit value of the x_{ij} alternative belonging to the h th ranking for all $h = 1,2,\cdots,c$, respectively. According the known priority interval, the certain interval can be determined and let the certain interval matrix I_{cd} be

$$I_{cd} = [c_{ih}, d_{ih}] = \begin{bmatrix} [c_{11}, d_{11}] & [c_{12}, d_{12}] & \cdots & [c_{1c}, d_{1c}] \\ [c_{21}, d_{21}] & [c_{22}, d_{22}] & \cdots & [c_{2c}, d_{2c}] \\ \vdots & \vdots & \cdots & \vdots \\ [c_{m1}, d_{m1}] & [c_{m2}, d_{m2}] & \cdots & [c_{mc}, d_{mc}] \end{bmatrix}$$

where c_{ih} and d_{ih} is certain lower limit value and the certain upper limit value of the x_{ij} alternative belonging to the h th ranking, respectively, and which values are determined by lower limit value and upper limit value of neighboring interval in I_{ab} matrix [7, 16]. Let M is point value of the relative membership $\mu_A(x_{ij})_h = 1$ in priority intervals $[a_{ih}, b_{ih}]$ and let M be

$$M = M_{ih} = \begin{vmatrix} M_{11} & M_{12} & \cdots & M_{1c} \\ M_{21} & M_{22} & \cdots & M_{2c} \\ \vdots & \vdots & \cdots & \vdots \\ M_{m1} & M_{m2} & \cdots & M_{mc} \end{vmatrix}$$

M can be determined by midpoint value of intervals $[a_{ih}, b_{ih}]$ [7, 16]. Comparing x_{ij} and M_{ih} , if x_{ij} locates at left side of M ($x_{ij} < M_{ih}$), its difference function is

$$\begin{cases} \mu_A(x_{ij})_h = 0.5(1 + \dfrac{x_{ij} - a_{ih}}{M_{ih} - a_{ih}}) & x_{ij} \in [a_{ih}, M_{ih}] \\ \mu_A(x_{ij})_h = 0.5(1 - \dfrac{x_{ij} - a_{ih}}{c_{ih} - a_{ih}}) & x_{ij} \in [c_{ih}, a_{ih}] \\ \mu_A(x_{ij})_h = 0 & x_{ij} \notin [c_{ih}, M_{ih}] \end{cases} \tag{1}$$

and if x_{ij} locates at right side of M_{ih} ($x_{ij} > M_{ih}$), its difference function is

$$\begin{cases} \mu_A(x_{ij})_h = 0.5(1 + \dfrac{x_{ij} - b_{ih}}{M_{ih} - b_{ih}}) & x_{ij} \in [M_{ih}, b_{ih}] \\ \mu_A(x_{ij})_h = 0.5(1 - \dfrac{x_{ij} - b_{ih}}{d_{ih} - b_{ih}}) & x_{ij} \in [b_{ih}, d_{ih}] \\ \mu_A(x_{ij})_h = 0 & x_{ij} \notin [M_{ih}, d_{ih}] \end{cases} \tag{2}$$

According to equations (1) and (2), we can obtain values of relative membership function U_A and let U_A be

$$U_A = \mu_A(x_{ij})_h = \begin{bmatrix} \mu_A(x_{11})_1 & \mu_A(x_{12})_2 & \cdots & \mu_A(x_{1n})_c \\ \mu_A(x_{21})_1 & \mu_A(x_{22})_2 & \cdots & \mu_A(x_{2n})_c \\ \vdots & \vdots & \vdots & \vdots \\ \mu_A(x_{m1})_1 & \mu_A(x_{m2})_2 & \cdots & \mu_A(x_{mn})_c \end{bmatrix}$$

According Chen [7, 16], and Zhao and Chen [9], the relative membership grade of the different rank can be calculated by variable fuzzy evaluation model and the model is

$${}_j u'_h = \frac{1}{1 + \left(\dfrac{\sum_{i=1}^{m} [w_i (1 - \mu_A(x_{ij})_h)]^p}{\sum_{i=1}^{m} [w_i \mu_A(x_{ij})_h)]^p} \right)^{\frac{\alpha}{p}}} \tag{3}$$

where α is rule parameter for model optimization, it is the least first power criterion when $\alpha = 1$, and it is the least squared criterion when $\alpha = 2$; p is distance parameter, it is Hamming distance when $p = 1$, and it is Euclidean distance when $p = 2$; w_i is index weight; m is recognition feature index. According equation (3) and normalization processing, the relative membership grade set can be obtained and let the set be

$$U = ({}_j u_h) \tag{4}$$

The eigenvalue vector of air pollution risk rank can be calculated by rank eigenvalue equation [7, 16] and let rank eigenvalue equation be

$$H = (1,2,\cdots,c) \cdot U \tag{5}$$

B. *New weight with information entropy*

The weight determination is one of the important parts in the fuzzy evaluation, because it has a deep effect on the assessment results. The information entropy method is used in the fuzzy comprehensive evaluation to determinate the weight, which calculates through the following formula:

To normalize x_{ij} in X set and obtain the B set, and let $B = (b_{ij})_{m \times n}$. When the number is bigger, the result is better, the normalization equation is

$$b_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \tag{6}$$

When the number is smaller, the result is better, the normalization equation is

$$b_{ij} = \frac{\max\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \tag{7}$$

To b_{ij} , let the entropy be

$$H_i = -\frac{1}{\ln m} \sum_{j=1}^{m} f_{ij} \ln f_{ij} \tag{8}$$

where $f_{ij} = b_{ij} / \sum_{j=1}^{m} b_{ij}$ and $0 \le H_i \le 1$. Obviously, when $f_{ij} = 0$, $\ln f_{ij}$ is insignificance. So to modify f_{ij} as:

$$f_{ij} = (1 + b_{ij}) / \sum_{j=1}^{m} (1 + b_{ij}) \tag{9}$$

Then, the entropy weight can be defined as:

$$w_i = \frac{1 - H_i}{n - \sum_{i=1}^{n} H_i} \tag{10}$$

where $0 \le w_i \le 1$ and $\sum_{i=1}^{n} w_i = 1$

C. *Evaluating indicator and criterion*

1) *Evaluating indicator*

According to the regional ecological risk assessment indexes, we select risk degree (x_1), reliability (x_2), riskiness (x_3), resilience (x_4), permanence (x_5) and integral loss (x_6) as evaluating indicators. Daily air pollution index (API) in sixteen districts of Beijing in 2009 is counted to calculate these indicators and the air pollution risk ranks of different seasons in different districts are assessed in Beijing. The following is the indicator calculation:

a) Risk degree

Risk degree = standard deviation of API / sample average of API.

b) Reliability

When API is I or II, the air quality is safe. Reliability = number of safe days / total days (one month).

c) Riskiness

Riskiness = 1 – reliability, namely, the percentage of number of air pollution (API = III, IV or V) days by total days (one month).

d) Resilience

Resilience is the percentage of number of days from air pollution to air safety by total days (one month).

e) Permanence

Permanence is the percentage of number of air safety in the next day on the premise that air quality is safe at the first day by total days (one month).

f) Integral loss

We define the loss of air mild pollution (API = III) is 0.5 and the loss of air moderate and heavy pollution (API = IV or V) is 1. Integral loss = 0.5 * number of air mild pollution days / total days (one month) + 1 * number of air moderate and heavy pollution days / total days (one month).

Beijing has obvious season change and this change has brought influence to the air quality, therefore, we need to assess the air pollution risk in different seasons. According the climatic characteristics of Beijing, spring is from Feb. to Apr., summer is from May to Jul., autumn is from Aug. to Oct, and winter is from Nov. to Jan. The evaluating indicators of every season are the arithmetic mean of the included months, and these indicators are listed in Table 1.

2) Evaluating criterion

The risk grades of air pollution risk are classed as extremely low risk (1), low risk (2), moderate risk (3), high risk (4) and extremely high risk (5). Extremely low risk is negligible, low risk is acceptable, moderate risk is marginal, high risk is serious and extremely high risk is unbearable. For every evaluating indicator, the criteria of the risk grades are determined by value range of each indicator (Table 1) and are listed in Table 2.

III. RESULTS AND DISCUSSION

According to the air pollution risk criteria (Table 2), the priority criterion matrix could be given as:

$$I_{ab} = [a_{ih}, b_{ih}] = \begin{bmatrix} [0,0.2] & [0.2,0.4] & [0.4,0.8] & [0.8,1] & [1,2] \\ [1,0.8] & [0.8,0.6] & [0.6,0.4] & [0.4,0.2] & [0.2,0] \\ [0,0.2] & [0.2,0.4] & [0.4,0.6] & [0.6,0.8] & [0.8,1] \\ [1,0.8] & [0.8,0.6] & [0.6,0.4] & [0.4,0.2] & [0.2,0] \\ [1,0.8] & [0.8,0.6] & [0.6,0.4] & [0.4,0.2] & [0.2,0] \\ [0,0.2] & [0.2,0.4] & [0.4,0.6] & [0.6,0.8] & [0.8,1] \end{bmatrix}$$

where i is the number of evaluating indicators and $i = 1,2,\cdots,6$; h is risk grade and $h = 1,2,\cdots,5$. The certain interval matrix I_{cd} can be determined by lower limit value and upper limit value of neighboring interval in I_{ab} matrix and I_{cd} could be given as:

$$I_{cd} = [c_{ih}, d_{ih}] = \begin{bmatrix} [0,0.4] & [0,0.6] & [0.2,1] & [0.6,1.2] & [0.8,2] \\ [1,0.6] & [1,0.4] & [0.8,0.2] & [0.6,0] & [0.4,0] \\ [0,0.4] & [0,0.6] & [0.2,0.8] & [0.4,1] & [0.6,1] \\ [1,0.6] & [1,0.4] & [0.8,0.2] & [0.6,0] & [0.4,0] \\ [1,0.6] & [1,0.4] & [0.8,0.2] & [0.6,0] & [0.4,0] \\ [0,0.4] & [0,0.6] & [0.2,0.8] & [0.4,1] & [0.6,1] \end{bmatrix}$$

where $i = 1,2,\cdots,6$ and $h = 1,2,\cdots,5$. When the relative membership $\mu_A(x_{ij})_h = 1$ in priority intervals, M can be determined by midpoint value of intervals $[a_{ih}, b_{ih}]$ and M be:

$$M = M_{ih} = \begin{bmatrix} 0 & 0.2 & 0.6 & 1 & 2 \\ 1 & 0.8 & 0.5 & 0.2 & 0 \\ 0 & 0.2 & 0.5 & 0.8 & 1 \\ 1 & 0.8 & 0.5 & 0.2 & 0 \\ 1 & 0.8 & 0.5 & 0.2 & 0 \\ 0 & 0.2 & 0.5 & 0.8 & 1 \end{bmatrix}$$

where $i = 1,2,\cdots,6$ and $h = 1,2,\cdots,5$.

Next, the weight of each evaluating indicator needs to be calculated. At first, to normalize x_{ij} in Table 1 by equation (6) or (7) and obtain the B of different seasons in sixteen districts of Beijing in 2009. The different season B sets are given as:

$$B_{spring} = \left\{ \begin{matrix} 0.4094 & 0.4980 & 0.4980 & 0.1650 & 0.6136 & 0.4593 \\ 0.0585 & 0.3401 & 0.3401 & 0.2395 & 0.2803 & 0.2889 \\ 0.0994 & 0.4291 & 0.4291 & 0.0744 & 0.5227 & 0.3556 \\ 0.0819 & 0.5223 & 0.5223 & 0.3398 & 0.5076 & 0.4593 \\ 0.5673 & 0.1943 & 0.1943 & 0.0485 & 0.1970 & 0.2074 \\ 0.5556 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.2281 & 0.2713 & 0.2713 & 0.0129 & 0.3030 & 0.2519 \\ 0.5789 & 0.2510 & 0.2470 & 0.0129 & 0.2424 & 0.2222 \\ 0.0000 & 0.1377 & 0.1377 & 0.1197 & 0.1288 & 0.0889 \\ 1.0000 & 0.5385 & 0.5385 & 0.5566 & 0.4091 & 0.5407 \\ 0.6550 & 0.4089 & 0.4089 & 0.2136 & 0.4697 & 0.3778 \\ 0.8012 & 0.4980 & 0.4980 & 0.3333 & 0.5530 & 0.5407 \\ 0.4503 & 0.0891 & 0.0891 & 0.1424 & 0.0303 & 0.0815 \\ 0.7018 & 1.0000 & 1.0000 & 0.0259 & 1.0000 & 1.0000 \\ 0.8363 & 0.5425 & 0.5385 & 0.2136 & 0.5909 & 0.5407 \\ 0.9240 & 0.6397 & 0.6397 & 0.1456 & 0.9470 & 0.6667 \\ 0.4035 & 0.5385 & 0.5385 & 1.0000 & 0.1742 & 0.5333 \end{matrix} \right\}$$

$$B_{summer} = \left\{ \begin{matrix} 0.9196 & 0.5607 & 0.5607 & 0.3150 & 0.6812 & 0.5914 \\ 0.8593 & 0.6243 & 0.6243 & 0.2885 & 0.7899 & 0.6129 \\ 0.8894 & 0.5318 & 0.5318 & 0.3899 & 0.5580 & 0.5591 \\ 0.7136 & 0.4393 & 0.4335 & 0.1057 & 0.7536 & 0.4086 \\ 0.9095 & 0.2312 & 0.2312 & 0.2070 & 0.4928 & 0.2796 \\ 0.9648 & 0.1618 & 0.1618 & 0.2709 & 0.2536 & 0.1828 \\ 0.9899 & 0.0636 & 0.0636 & 0.2401 & 0.0797 & 0.1290 \\ 1.0000 & 0.3121 & 0.3121 & 0.1101 & 0.5725 & 0.3548 \\ 0.8894 & 0.0000 & 0.0000 & 0.2863 & 0.0000 & 0.0000 \\ 0.6482 & 0.5607 & 0.5607 & 0.2379 & 0.7754 & 0.5269 \\ 0.8141 & 0.1214 & 0.1214 & 0.0000 & 0.5435 & 0.1720 \\ 0.5980 & 1.0000 & 1.0000 & 0.7555 & 1.0000 & 1.0000 \\ 0.9196 & 0.5665 & 0.5607 & 0.5793 & 0.5072 & 0.5699 \\ 0.0000 & 0.9364 & 0.9364 & 0.8040 & 0.9493 & 0.8710 \\ 0.4925 & 1.0000 & 1.0000 & 1.0000 & 0.8478 & 0.9355 \\ 0.6482 & 1.0000 & 1.0000 & 0.0198 & 0.9783 & 0.9892 \\ 0.5980 & 0.9422 & 0.9364 & 0.7555 & 0.8841 & 0.9355 \end{matrix} \right\}$$

And then the entropy of each evaluating indicator can be calculated by equation (8):

$$H_{spring} = (0.9924, 0.9952, 0.9952, 0.9937, 0.9933, 0.9948)$$

$$H_{summur} = (0.9963, 0.9913, 0.9913, 0.9925, 0.9941, 0.9925)$$

$$H_{autumn} = (0.9947, 0.9934, 0.9934, 0.9915, 0.9946, 0.9934)$$

$$B_{autumn} = \begin{Bmatrix} 0.8378 & 0.5932 & 0.5932 & 0.1802 & 0.6261 & 0.5918 \\ 0.8649 & 0.3898 & 0.3898 & 0.2132 & 0.4369 & 0.3878 \\ 0.6847 & 0.4441 & 0.4441 & 0.3046 & 0.4820 & 0.4422 \\ 0.7568 & 0.4271 & 0.4271 & 0.2259 & 0.5000 & 0.4218 \\ 0.7117 & 0.5559 & 0.5559 & 0.2284 & 0.6441 & 0.5510 \\ 0.9189 & 0.3322 & 0.3322 & 0.0330 & 0.4775 & 0.3333 \\ 0.8018 & 0.0000 & 0.0000 & 0.3071 & 0.0000 & 0.0000 \\ 0.6306 & 0.4068 & 0.4068 & 0.2868 & 0.4414 & 0.4082 \\ 1.0000 & 0.0746 & 0.0746 & 0.0558 & 0.1757 & 0.0680 \\ 0.9009 & 0.2237 & 0.2237 & 0.0000 & 0.3739 & 0.2245 \\ 0.5766 & 0.4102 & 0.4102 & 0.0609 & 0.5360 & 0.4082 \\ 0.4144 & 0.9424 & 0.9424 & 0.8452 & 0.9369 & 0.9456 \\ 0.8649 & 0.3492 & 0.3458 & 0.2716 & 0.4459 & 0.3469 \\ 0.0000 & 0.8508 & 0.8508 & 0.5990 & 0.8649 & 0.8503 \\ 0.4775 & 0.7390 & 0.7390 & 0.1548 & 0.9099 & 0.7415 \\ 0.3874 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 \\ 0.1171 & 0.9627 & 0.9627 & 0.9010 & 0.9685 & 0.9592 \end{Bmatrix}$$

$$B_{winter} = \begin{Bmatrix} 0.7762 & 0.6481 & 0.6491 & 0.2678 & 0.8619 & 0.6414 \\ 0.7190 & 0.4428 & 0.4444 & 0.1475 & 0.7476 & 0.4091 \\ 0.6238 & 0.5044 & 0.5058 & 0.2596 & 0.7524 & 0.4495 \\ 0.6667 & 0.5689 & 0.5702 & 0.4262 & 0.6524 & 0.5303 \\ 0.9714 & 0.4457 & 0.4474 & 0.3716 & 0.4810 & 0.4495 \\ 0.7571 & 0.2991 & 0.3012 & 0.0710 & 0.6429 & 0.2727 \\ 0.7476 & 0.2991 & 0.3012 & 0.1776 & 0.5524 & 0.2879 \\ 0.8524 & 0.3284 & 0.3304 & 0.2732 & 0.4905 & 0.3384 \\ 1.0000 & 0.1730 & 0.1754 & 0.2432 & 0.1810 & 0.0960 \\ 0.9619 & 0.2053 & 0.2076 & 0.0082 & 0.5667 & 0.1212 \\ 0.5333 & 0.6481 & 0.6491 & 0.4754 & 0.7333 & 0.6414 \\ 0.6095 & 0.9208 & 0.9181 & 0.8497 & 0.8762 & 0.9293 \\ 0.8762 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.9795 & 0.9795 & 0.9290 & 0.9857 & 0.9848 \\ 0.5000 & 0.6804 & 0.6813 & 0.6148 & 0.5952 & 0.6414 \\ 0.7619 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 \\ 0.7524 & 0.8974 & 0.8977 & 0.4426 & 0.9048 & 0.9091 \end{Bmatrix}$$

$$H_{winter} = (0.9966, 0.9936, 0.9936, 0.9921, 0.9954, 0.9928)$$

The weigh of each evaluating indicator in different season can be obtained by equation (10):

$$w_{spring} = (0.2147, 0.1356, 0.1356, 0.1780, 0.1893, 0.1469)$$

$$w_{summer} = (0.0881, 0.2071, 0.2071, 0.1786, 0.1405, 0.1786)$$

$$w_{autumn} = (0.1359, 0.1692, 0.1692, 0.2179, 0.1385, 0.1692)$$

$$w_{winter} = (0.0947, 0.1783, 0.1783, 0.2201, 0.1281, 0.2006)$$

TABLE 2. The air pollution risk criteria of evaluating INDICATORS

	Risk Grade				
	1	*2*	*3*	*4*	*5*
Risk degree (x_1)	$\le$ 0.2	0.2-0.4	0.4-0.8	0.8-1.0	$\ge$ 1.0
Reliability (x_2)	$\ge$ 0.8	0.6-0.8	0.4-0.6	0.2-0.4	$\le$ 0.2
Riskiness (x_3)	$\le$ 0.2	0.2-0.4	0.4-0.6	0.6-0.8	$\ge$ 0.8
Resilience (x_4)	$\ge$ 0.8	0.6-0.8	0.4-0.6	0.2-0.4	$\le$ 0.2
Permanence (x_5)	$\ge$0.8	0.6-0.8	0.4-0.6	0.2-0.4	$\le$ 0.2
Integral loss (x_6)	$\le$ 0.2	0.2-0.4	0.4-0.6	0.6-0.8	$\ge$ 0.8

Finally, comparing the evaluating indicators x_{ij} (Table 1) and M_{ih} , the difference functions (equation (1) or (2)) are selected, the membership function in different seasons is calculated and the relative membership function U_A is built and the relative membership grade of the different rank is calculated by equation (3). Each relative membership grade is normalized and the relative membership grade set U is obtained (Table 3). The air pollution risk rank eigenvalue vector can be calculated by equation (5) and the risk grades of four seasons are judged in different districts of Beijing in 2009 (Fig. 1). The air pollution risk grades were extremely low or low and the risk grades were negligible or acceptable on spring, summer and autumn in sixteen districts of Beijing in 2009 (Fig. 1). However, the air pollution risk grade was moderate and the risk grade was marginal on winter in south districts (Mentougou, Shijingshan, Fengtai, Dongcheng, Fangshn, Daxing and Tongzhou) of Beijing in 2009 (Fig. 1).

According the evaluating results, the air pollution risk rank eigenvalue ranges of four seasons in different districts are relatively small and the difference value of spring is 0.57, summer is 0.76, autumn is 0.56 and winter is 0.48, respectively, which show the evaluating results are credible. From the evaluating results, the air pollution risk grades were low on spring, summer and autumn that shows the air quality was safe in these seasons in Beijing in 2009. Since Olympic Games in 2008, Beijing has controlled air pollution and improved air quality, which have decreased the air pollution risk. However, coal is used to heat homes/buildings for several months of the winter in Beijing that make the urban air pollution is much worse. Besides, the prevailing wind direction of winter is northwester that causes more air pollution in south districts than others. Therefore, the air pollution risk grade is moderate on winter in south districts of Beijing and this risk is marginal. With population increasing, Beijing needs to optimize energy structure by introducing and developing the use of cleaner high-quality energy such as natural gas and electricity to decrease air pollution risk grade on winter.

IV. CONCLUSIONS

In this paper, the variable fuzzy mathematics method and information entropy are combined to assessment the air pollution risk of different seasons in sixteen districts of Beijng in 2009. The multi-objective group decision-making problem under air pollution risk has been solved by variable fuzzy method and the weight problem has been modified by information entropy, which makes the evaluating results more objective. From quantitative assessment, the air pollution risk of winter season in south seven districts of Beijing was on the margin in 2009 though the government has taken measures to improve air quality since 2008. With the city continued expansion and population increasing, Beijing needs to optimize energy structure by introducing and developing the use of cleaner high-quality energy to decrease air pollution risk grade on winter.

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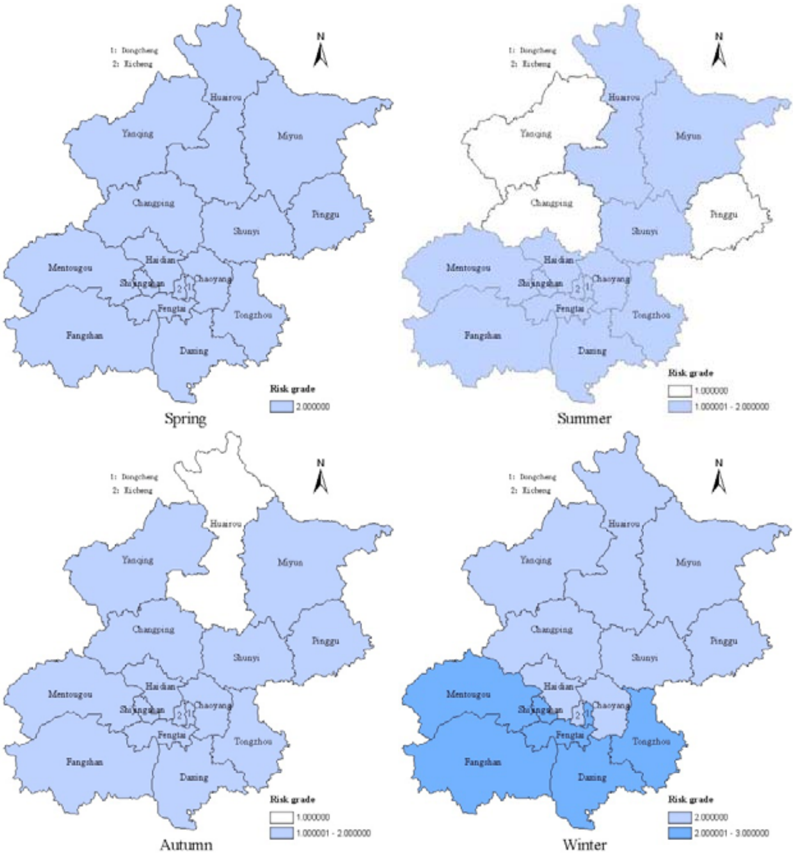

Fig. 1 The air pollution risk grades of different seasons in sixteen districts of Beijing in 2009

TABLE 1 THE EVALUATING INDICATORS OF EVERY SEASON IN DIFFERENT DISTRICTS OF BEIJING IN 2009.

Districts	**Risk degree (x_1)**				**Reliability (x_2)**				**Riskiness (x_3)**			
	Spring	*Summer*	*Autumn*	*Winter*	*Spring*	*Summer*	*Autumn*	*Winter*	*Spring*	*Summer*	*Autumn*	*Winter*
Dongcheng	0.535	0.340	0.312	0.643	0.771	0.826	0.744	0.625	0.229	0.174	0.256	0.375
Xicheng	0.528	0.334	0.332	0.663	0.793	0.810	0.760	0.646	0.207	0.190	0.240	0.354
Chaoyang	0.531	0.369	0.324	0.654	0.816	0.794	0.755	0.668	0.184	0.207	0.245	0.332
Haidian	0.448	0.330	0.329	0.590	0.735	0.758	0.793	0.626	0.265	0.242	0.207	0.374
Fengtai	0.450	0.319	0.306	0.635	0.687	0.746	0.727	0.576	0.313	0.254	0.273	0.424
Shijingshan	0.506	0.314	0.319	0.637	0.754	0.729	0.629	0.576	0.246	0.271	0.371	0.424
Mentougou	0.446	0.312	0.338	0.615	0.749	0.772	0.749	0.586	0.252	0.228	0.251	0.414
Fangshan	0.545	0.334	0.297	0.584	0.721	0.718	0.651	0.533	0.279	0.282	0.349	0.467
Tongzhou	0.374	0.382	0.308	0.592	0.820	0.815	0.695	0.544	0.180	0.185	0.305	0.456
Shunyi	0.433	0.349	0.344	0.682	0.788	0.739	0.750	0.695	0.212	0.261	0.250	0.305
Changping	0.408	0.392	0.362	0.666	0.810	0.891	0.907	0.788	0.190	0.109	0.093	0.213
Daxing	0.468	0.328	0.312	0.610	0.709	0.816	0.732	0.474	0.291	0.185	0.269	0.527
Miyun	0.425	0.511	0.408	0.794	0.934	0.880	0.880	0.808	0.066	0.120	0.120	0.192
Pinggu	0.402	0.413	0.355	0.689	0.821	0.891	0.847	0.706	0.180	0.109	0.153	0.294
Huairou	0.387	0.382	0.365	0.634	0.845	0.891	0.924	0.815	0.155	0.109	0.076	0.185
Yanqing	0.476	0.392	0.395	0.636	0.820	0.881	0.913	0.780	0.180	0.120	0.087	0.220

Districts	**Resilience (x_4)**				**Permanence (x_5)**				**Integral loss (x_6)**			
	Spring	*Summer*	*Autumn*	*Winter*	*Spring*	*Summer*	*Autumn*	*Winter*	*Spring*	*Summer*	*Autumn*	*Winter*
Dongcheng	0.591	0.566	0.523	0.311	0.832	0.882	0.815	0.814	0.129	0.090	0.128	0.215
Xicheng	0.540	0.612	0.559	0.352	0.864	0.850	0.825	0.815	0.120	0.095	0.120	0.207
Chaoyang	0.622	0.483	0.528	0.413	0.862	0.877	0.829	0.794	0.106	0.109	0.123	0.191
Haidian	0.532	0.529	0.529	0.393	0.821	0.841	0.861	0.758	0.140	0.121	0.104	0.207
Fengtai	0.517	0.558	0.452	0.283	0.795	0.808	0.824	0.792	0.168	0.130	0.136	0.242
Shijingshan	0.521	0.544	0.560	0.322	0.835	0.784	0.718	0.773	0.134	0.135	0.185	0.239
Mentougou	0.521	0.485	0.552	0.357	0.827	0.852	0.816	0.760	0.138	0.114	0.125	0.229
Fangshan	0.554	0.565	0.461	0.346	0.812	0.773	0.757	0.695	0.156	0.147	0.175	0.277
Tongzhou	0.689	0.543	0.439	0.260	0.849	0.880	0.801	0.776	0.095	0.098	0.152	0.272
Shunyi	0.583	0.435	0.463	0.431	0.857	0.848	0.837	0.811	0.117	0.131	0.125	0.169
Changping	0.620	0.778	0.772	0.568	0.868	0.911	0.926	0.841	0.095	0.054	0.046	0.112
Daxing	0.561	0.698	0.546	0.257	0.799	0.843	0.817	0.657	0.157	0.094	0.134	0.296
Miyun	0.525	0.800	0.675	0.597	0.927	0.904	0.910	0.864	0.033	0.066	0.060	0.101
Pinggu	0.583	0.889	0.500	0.482	0.873	0.890	0.920	0.782	0.095	0.060	0.076	0.169
Huairou	0.562	0.444	0.833	0.623	0.920	0.908	0.940	0.867	0.078	0.055	0.038	0.098
Yanqing	0.826	0.778	0.794	0.419	0.818	0.895	0.933	0.847	0.096	0.060	0.044	0.116

TABLE 3 The relative membership GRADE by using different parameters

Districts	**Seasons**	$\alpha=1$		$\alpha=2$	
		$p=1$	$p=2$	$p=1$	$p=2$
Dongcheng	Spring	(0.2894,0.8866,0.7914,0.0144,0)	(0.2863,0.7634,0.9723,0.0312,0)	(0.2255,1.188,0.5412,0,0)	(0.2343,0.9036,0.9414,0.0004,0)
	Summer	(0.4645,0.7536,0.4326,0.058,0)	(0.4258,0.669,0.6288,0.1208,0)	(0.5899,0.7432,0.1146,0.0012,0)	(0.5602,0.6608,0.3234,0.006,0)
	Autumn	(0.2762,0.9292,0.6756,0.136,0)	(0.2569,0.7884,0.8376,0.2788,0)	(0.2141,1.3058,0.393,0.0076,0)	(0.2084,1.0554,0.7614,0.0404,0)
	Winter	(0.1577,0.7786,0.7965,0.5812,0.2105)	(0.1678,0.6506,0.6684,0.8368,0.3750)	(0.0724,1.2254,0.7530,0.2396,0.0200)	(0.1046,0.988,0.6213,0.7116,0.0815)
Xicheng	Spring	(0.3028,0.8036,0.8187,0.09,0)	(0.2884,0.6846,0.9663,0.1888,0)	(0.2718,1.031,0.6357,0.0036,0)	(0.2643,0.7808,1.023,0.0172,0)
	Summer	(0.4523,0.8728,0.3336,0,0)	(0.4322,0.7982,0.5061,0,0)	(0.5094,0.9426,0.0582,0,0)	(0.5122,0.8632,0.1686,0,0)
	Autumn	(0.2949,0.9868,0.5793,0.0744,0)	(0.2796,0.859,0.753,0.1596,0)	(0.2328,1.3652,0.2523,0.002,0)	(0.2346,1.1622,0.5442,0.0112,0)
	Winter	(0.1775,0.817,0.7839,0.52,0.1135)	(0.1843,0.6962,0.6924,0.7748,0.2155)	(0.0899,1.277,0.681,0.1744,0.005)	(0.1208,1.061,0.6234,0.5452,0.023)
Chaoyang	Spring	(0.3844,0.7224,0.7632,0)	(0.3492,0.641,0.9909,0,0)	(0.4472,0.773,0.4989,0,0)	(0.3708,0.607,0.9771,0,0)
	Summer	(0.3393,0.9172,0.4842,0.1632,0)	(0.3124,0.7928,0.6375,0.3144,0)	(0.3355,1.2088,0.1722,0.0108,0)	(0.3302,1.0436,0.4041,0.0528,0)
	Autumn	(0.2861,0.931,0.6498,0.1272,0)	(0.2655,0.7922,0.819,0.262,0)	(0.2309,1.2984,0.3546,0.0068,0)	(0.2237,1.0574,0.7167,0.0348,0)
	Winter	(0.2001,0.8232,0.8598,0.4068,0)	(0.2102,0.7052,0.8166,0.6596,0)	(0.1105,1.208,0.7866,0.0932,0)	(0.1475,0.9908,0.8238,0.330)
Haidian	Spring	(0.2531,0.8742,0.8508,0.1052,0)	(0.2547,0.7528,0.9429,0.2184,0)	(0.1718,1.2024,0.6777,0.0048,0)	(0.1953,0.9552,0.9639,0.0232,0)
	Summer	(0.3125,0.962,0.543,0,0)	(0.297,0.8542,0.6717,0,0)	(0.2724,1.3058,0.2208,0,0)	(0.2781,1.1488,0.4272,0,0)
	Autumn	(0.3186,0.9282,0.5601,0.1224,0)	(0.2885,0.7826,0.771,0.2528,0)	(0.2924,1.2494,0.2442,0.006,0)	(0.2722,1.024,0.6234,0.0324,0)
	Winter	(0.1452,0.878,0.9465,0.388,0.0165)	(0.1722,0.7422,0.8367,0.6844,0.0335)	(0.048,1.2564,0.9135,0.0768,0)	(0.09,1.0706,0.8583,0.3544,0.0005)
Fengtai	Spring	(0.193,0.9398,0.9207,0.1204,0)	(0.2089,0.8176,0.9594,0.2504,0)	(0.0872,1.2918,0.7965,0.006,0)	(0.1203,1.085,0.9888,0.0304,0)
	Summer	(0.3006,1.0214,0.5196,0.062,0)	(0.2939,0.9226,0.6357,0.132,0)	(0.2373,1.3982,0.1899,0.0016,0)	(0.2538,1.2566,0.3483,0.0072,0)
	Autumn	(0.2748,0.8752,0.6606,0.2696,0)	(0.2503,0.7226,0.7809,0.5124,0)	(0.2245,1.2698,0.3951,0.0356,0)	(0.218,0.9972,0.7179,0.1764,0)
	Winter	(0.1128,0.7404,0.9057,0.6544,0.258)	(0.1372,0.6082,0.7506,0.8672,0.4585)	(0.0333,1.0818,1.0236,0.3144,0.03)	(0.0661,0.8624,0.8355,0.7928,0.13)
Shijingshan	Spring	(0.2667,0.8028,0.906,0.1196,0)	(0.2626,0.6858,0.9984,0.2468,0)	(0.2029,1.0444,0.8199,0.0064,0)	(0.2162,0.8016,1.1259,0.0308,0)
	Summer	(0.2647,1.0466,0.5766,0.0788,0)	(0.2664,0.9272,0.6831,0.1688,0)	(0.1859,1.455,0.258,0.0024,0)	(0.2102,1.2846,0.4329,0.0128,0)
	Autumn	(0.1618,0.9938,0.9663,0.0768,0)	(0.1855,0.8772,1.0029,0.166,0)	(0.0522,1.3548,0.8097,0.002,0)	(0.0814,1.1682,0.9948,0.0116,0)
	Winter	(0.1114,0.7486,0.9879,0.5996,0.1755)	(0.1401,0.6308,0.8211,0.8216,0.327)	(0.0302,1.0368,1.1676,0.2388,0.0125)	(0.0649,0.88,0.9633,0.6496,0.0575)
Mentougou	Spring	(0.2599,0.863,0.8358,0.12,0)	(0.2571,0.7388,0.9351,0.2472,0)	(0.1862,1.184,0.6606,0.006,0)	(0.2042,0.9332,0.9645,0.0308,0)
	Summer	(0.3249,0.9258,0.5157,0,0)	(0.2995,0.8026,0.6618,0,0)	(0.3073,1.2452,0.2019,0,0)	(0.3016,1.076,0.4416,0,0)
	Autumn	(0.282,0.9734,0.6285,0.0872,0)	(0.2688,0.8446,0.7878,0.1852,0)	(0.2131,1.3638,0.3126,0.0028,0)	(0.2174,1.1462,0.6165,0.0156,0)
	Winter	(0.1155,0.788,1.0326,0.5052,0.1)	(0.1487,0.669,0.8637,0.7616,0.1925)	(0.0303,1.0702,1.1904,0.148,0.0035)	(0.0693,0.9334,1.0059,0.5008,0.0175)
Fangshan	Spring	(0.2422,0.8226,0.9849,0.0728,0)	(0.2499,0.7098,1.0692,0.1548,0)	(0.1528,1.0588,0.9519,0.002,0)	(0.1789,0.8144,1.2333,0.0108,0)
	Summer	(0.2527,1.0714,0.597,0.0508,0)	(0.261,0.9712,0.6765,0.1116,0)	(0.1603,1.4986,0.2706,0.0008,0)	(0.1897,1.3512,0.4002,0.0052,0)
	Autumn	(0.1899,0.9112,0.8742,0.2528,0)	(0.1933,0.75,0.9249,0.4936,0)	(0.0887,1.3118,0.7443,0.0296,0)	(0.111,1.0264,1.0122,0.1536,0)
	Winter	(0.0742,0.6104,1.308,0.6428,0.1195)	(0.1048,0.5692,1.065,0.8332,0.2365)	(0.011,0.5876,1.8924,0.2536,0.005)	(0.0295,0.6262,1.5087,0.5976,0.0255)
Tongzhou	Spring	(0.4105,0.9078,0.4065,0,0)	(0.3701,0.8578,0.6033,0,0)	(0.4318,1.073,0.0951,0,0)	(0.3834,1.054,0.2691,0,0)

	Summer	(0.4359,0.7382,0.5127,0.0964,0)	(0.397,0.649,0.6912,0.1924,0)	(0.5557,0.7646,0.183,0.0036,0)	(0.5178,0.6632,0.4389,0.0172,0)
	Autumn	(0.2479,0.8722,0.72,0.304,0)	(0.2318,0.7186,0.7998,0.5696,0)	(0.177,1.2952,0.4908,0.0468,0)	(0.1832,1.007,0.7683,0.2288,0)
	Winter	(0.0929,0.64,1.0353,0.7308,0.297)	(0.1156,0.5478,0.8349,0.91,0.5235)	(0.0218,0.793,1.4082,0.4164,0.041)	(0.0443,0.6848,1.065,0.8924,0.176)
Shunyi	Spring	(0.3089,0.9534,0.6231,0.0264,0)	(0.3021,0.8272,0.8094,0.0584,0)	(0.253,1.299,0.2922,0.0004,0)	(0.26611.06060.60990.00120)
	Summer	(0.3054,0.8998,0.5475,0,0)	(0.285,0.7926,0.6102,0,0)	(0.2747,1.2768,0.2397,0,0)	(0.2793,1.1268,0.3741,0,0)
	Autumn	(0.2835,0.8674,0.6639,0.246,0)	(0.2584,0.719,0.7938,0.47,0)	(0.2415,1.2364,0.399,0.0288,0)	(0.2329,0.9702,0.7389,0.1428,0)
	Winter	(0.2396,0.7602,0.8394,0.402,0)	(0.2369,0.6728,0.8211,0.612,0)	(0.1793,1.0724,0.7818,0.0956,0)	(0.1985,0.9022,0.8421,0.2788,0)
Changping	Spring	(0.3866,0.8466,0.57,0,0)	(0.356,0.7726,0.7731,0,0)	(0.4142,1.0194,0.2280,0)	(0.3750.90280.520800)
	Summer	(0.5977,0.7082,0.1446,0,0)	(0.5651,0.7034,0.2496,0,0)	(0.7326,0.529,0.0087,0,0)	(0.7031,0.5736,0.03,0,0)
	Autumn	(0.5684,0.7362,0.1905,0,0)	(0.5058,0.7734,0.3228,0,0)	(0.6944,0.6004,0.0159,0,0)	(0.612,0.739,0.0555,0,0)
	Winter	(0.3236,0.9068,0.5862,0.1104,0)	(0.3111,0.8148,0.72210.1632,0)	(0.2988,1.2214,0.2679,0.0048,0)	(0.3024,1.059,0.4953,0.012,0)
Daxing	Spring	(0.2139,0.995,0.8223,0.0576,0)	(0.2283,0.8698,0.9165,0.1256,0)	(0.108,1.3904,0.5892,0.0012,0)	(0.13951.15940.83760.00680)
	Summer	(0.4768,0.9072,0.2088,0,0)	(0.4654,0.856,0.3201,0,0)	(0.522,0.9432,0.0192,0,0)	(0.5325,0.8996,0.0531,0,0)
	Autumn	(0.2743,0.9636,0.6582,0.098,0)	(0.26,0.835,0.8124,0.2072,0)	(0.202,1.3584,0.3537,0.004,0)	(0.2033,1.1354,0.6717,0.0204,0)
	Winter	(0.055,0.4694,1.236,0.9472,0.307)	(0.08,0.4646,0.9573,1.0344,0.55)	(0.0065,0.353,1.8852,0.7216,0.041)	(0.0179,0.437,1.3368,1.1248,0.184)
Miyun	Spring	(0.4837,0.4518,0.7776,0.1252,0)	(0.39510.45660.93990.25320)	(0.70720.24340.50850.00640)	(0.52930.29520.94560.03160)
	Summer	(0.5459,0.7714,0.2055,0,0)	(0.4959,0.7524,0.3834,0,0)	(0.6723,0.6432,0.0183,0,0)	(0.6204,0.704,0.0828,0,0)
	Autumn	(0.5082,0.717,0.3999,0,0)	(0.4512,0.7218,0.5634,0,0)	(0.6603,0.6194,0.09,0,0)	(0.5714,0.7082,0.2235,0,0)
	Winter	(0.4185,0.745,0.4848,0.1896,0)	(0.3678,0.6738,0.6342,0.336,0)	(0.533,0.8144,0.1677,0.0156,0)	(0.4713,0.773,0.3807,0.0608,0)
Pinggu	Spring	(0.3852,0.796,0.6282,0.03,0)	(0.3515,0.7208,0.8169,0.0632,0)	(0.4326,0.9334,0.3018,0.0004,0)	(0.3838,0.813,0.6279,0.0016,0)
	Summer	(0.684,0.538,0.1407,0,0)	(0.6536,0.5006,0.2883,0,0)	(0.8713,0.2522,0.0078,0,0)	(0.8671,0.2394,0.0396,0,0)
	Autumn	(0.42,0.5818,0.7221,0.194,0)	(0.3507,0.502,0.9141,0.3744,0)	(0.585,0.5028,0.4776,0.0176,0)	(0.4467,0.413,0.9792,0.0816,0)
	Winter	(0.2161,0.8446,0.8772,0.2768,0)	(0.2238,0.733,0.906,0.4308,0)	(0.1287,1.191,0.7989,0.038,0)	(0.1596,0.977,0.9708,0.1132,0)
Huairou	Spring	(0.4254,0.6878,0.6432,0.0648,0)	(0.373,0.6376,0.8232,0.1352,0)	(0.55230.6770.32640.00160)	(0.45650.63720.66840.00840)
	Summer	(0.544,0.4552,0.4851,0.2672,0)	(0.4652,0.393,0.6471,0.4904,0)	(0.8258,0.2306,0.1548,0.0292,0)	(0.7303,0.2088,0.3918,0.1384,0)
	Autumn	(0.6758,0.5376,0.1662,0,0)	(0.6052,0.56,0.3444,0,0)	(0.8674,0.2578,0.0111,0,0)	(0.8154,0.3284,0.0612,0,0)
	Winter	(0.4357,0.7492,0.5451,0.0316,0)	(0.3967,0.7178,0.684,0.0656,0)	(0.5452,0.772,0.2061,0.0004,0)	(0.4826,0.7722,0.3927,0.0016,0)
Yanqing	Spring	(0.4645,0.7748,0.4443,0,0)	(0.3968,0.689,0.7761,0,0)	(0.5768,0.7674,0.1182,0,0)	(0.4782,0.6938,0.5247,0,0)
	Summer	(0.5805,0.7426,0.1446,0,0)	(0.5532,0.727,0.2499,0,0)	(0.7024,0.5894,0.0087,0,0)	(0.6819,0.616,0.03,0,0)
	Autumn	(0.5762,0.722,0.1884,0,0)	(0.5019,0.7588,0.3561,0,0)	(0.7075,0.5746,0.0156,0,0)	(0.6124,0.7276,0.0714,0,0)
	Winter	(0.3233,0.7726,0.5967,0.366,0)	(0.292,0.6732,0.6651,0.5988,0)	(0.3497,1.046,0.327,0.0732,0)	(0.3233,0.8852,0.5052,0.2624,0)