ATMOSPHERIC ENVIRONMENTAL QUALITY ASSESSMENT
METHOD BASED ON ANALYTIC HIERARCHY PROCESS

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ABSTRACT. Atmospheric environmental quality significantly influences the environment of people’s life and the development of modern society. Therefore, in this paper, we aim to accurately assess atmospheric environmental quality. Firstly, we propose and analyze two indicator systems for atmospheric environmental quality assessment, that is, 1) the standard air pollution index, and 2) an index system which covers different types of influencing factors related to air quality. In particular, the proposed index system is made up of seven parts, that is, 1) Climate and meteorology, 2) Economic and social development, 3) Industrial structure, 4) Energy consumption, 5) Industrial pollutant discharge, 6) The greening of the city, and 7) Environmental protection construction. Secondly, we propose a hybrid AHP-Fuzzy Comprehensive Evaluation Model to evaluate the atmospheric environmental quality. In the hybrid model, AHP is used to calculate the weight coefficient of the index system, and fuzzy comprehensive evaluation model is exploited to describe the vagueness of remark in the evaluation process. Finally, experimental results demonstrate that using the proposed index system, the hybrid AHP-Fuzzy comprehensive evaluation model is able to assess air quality more accurately than the modified API.

1. Introduction. With the rapid development of industrialization and urbanization, the city’s production and consumption have been expanded fast and fast [36]. As the advancement of urbanization process in the world, the coordination between provincial capital city’s economic development and its environment has been a crucial issue [27, 28]. Therefore, it leads the urban energy, transportation to increase significantly. Particularly, for the third-world countries, the energy structure is not reasonable, and coal is as the main types of fuel [41, 40]. Hence, the atmospheric environment pollution has been paid more attention [38]. Moreover, the repairable particulate matter, carbon monoxide, sulfur dioxide, nitrogen oxides in the air have speeded up the air pollution. Furthermore, air pollution may greatly influence our lives and threat modern society development [29, 19].

2010 Mathematics Subject Classification. Primary: 58F15, 58F17; Secondary: 53C35.
Key words and phrases. Atmospheric environmental quality, analytic hierarchy process, fuzzy comprehensive evaluation model, air pollution index, priority vector.

The first author is supported by the Natural Science Foundation of Kunming University of Science and Technology (Provincial talent training project) No. KKSY201508012, and the Science Fund Projects of Yunnan Provincial Education Department, No.2017ZZX160.
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Based on the above analysis, it can be observed that the environment of city becomes more and more serious, and it obviously affects the environment of people's life and the development among economy, society and environment [16, 6]. To efficiently manage and control the air pollution, we should assess air quality accurately. That is to say, it is of great importance to objectively and accurately make clear the current situation of air pollution in city and then forecast its development trend [15]. Furthermore, we should find a way to solve the problem of air pollution and propose an effective policy for the sustainable development.

In order to establish an automatic air quality monitoring system, we should construct an index system for air quality assessment in advance. If is of great importance to grasp the factors which influence the urban air quality and make clear the air quality varying trend timely and accurately [10, 8]. It has key theoretical significance and great value in urban development and construction, air pollution control, environmental management, and so on [7, 4].

The rest of the paper is organized as follows. Section 2 provides the literature review of the applications of AHP. In section 3, we provide the overview of the indicators for atmospheric environmental quality assessment. Section 4 proposes a novel Atmospheric environmental quality assess method based on AHP and Fuzzy Comprehensive Evaluation Model. To validate the effectiveness of the proposed algorithm, in section 5, a series of experiments are conducted. In the end, the conclusions are drawn in section 6.

2. Literature review. The analytic hierarchy process (denoted as AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. AHP has been successfully used in group decision making of many different areas, such as government management, business management, industry production, healthcare, modern education, and so on. In this section, we introduce the literature review about the application of AHP in various areas.

Zyoud et al. proposed an integrated multi-criteria decision making framework, in which the AHP model is utilized to prioritize water loss reduction options for a typical intermittent water supply network in Palestine. The AHP was exploited to model the decision issue into a hierarchy framework, and four groups of decision makers were assigned to make performance evaluate [45].

Zhang et al. exploited the AHP model to evaluate the urban agricultural landscape, which refers to both the earliest landscape that appeared and the most commonly distributed landscapes. Agricultural landscapes can be obtained increased attention from researchers, particularly, the one demonstrating on urban agricultural landscapes [43].

Zeraatkish et al. deployed analytic hierarchy process to select a priority for various goals which have been exploited in fishery optimal management in the Sea of Oman. In this work, the AHP is exploited to estimate the preferences (weight) of stakeholder groups for each of the objectives. This approach is belonged to a multi-criteria analysis system, which contains the inconsistent opinion of different groups involved in the management [42].

Wang et al. introduced the AHP to solve the problem of higher education management. In particular, a set of universal and effective evaluation index mechanism for the comprehensive evaluation of the system efficiency. In addition, a
comprehensive evaluation model for the system efficiency is used to develop an Internet Plus student affairs system [44].

Tan et al. proposed a systematic methodology for the multi-criteria evaluation of alternatives for the harvesting and drying processes. Particularly, this work utilized a fuzzy analytic hierarchy process, in which the pairwise comparison of the multiple criteria and alternatives are executed to prioritize the best harvesting and drying approach. Moreover, the proposed FAHP permits the degree of confidence of the expert to be quantified [39].

Sui et al. proposed an effective model to evaluate the shale fracability using the analytic hierarchy process (AHP) in terms of various effects on shale fracability. In addition, the fractal geometry is exploited to characterize the fracture degree of the shale [37].

Shi et al. proposed a medical cloud computing model using a hybrid analytic hierarchy process and RBF network. The authors constructed a security risk forecast model of cloud computing system and then utilize the MRHGA to perform the parallel evolutionary medical cloud computing Risk forecast approach [35].

In order to promote the capability of AHP in tackling different decision making issues, Ren et al. integrated the intuitionistic multiplicative information to AHP. The authors proved that the intuitionistic multiplicative weighted geometric aggregation operator has several features to ensure that the overall intuitionistic multiplicative preference relation is consistent only if all individual IMPRs are consistent as well [32].

In order to accurately evaluate the earthquake emergency plan implementation to accelerate the replenishment and the amendment of the earthquake emergency plan, Ren et al. proposed a novel approach for the effectiveness assessments of earthquake emergency plan implementation based on hesitant analytic hierarchy process [31].

Besides the above works, AHP has also been exploited in other application areas, such as Welder Selection Parameters estimation [25], Cultural heritage assessment [23], Organic Peroxides Instability Rating [22], Patient’s Priorities estimation [20], Decision making method of task arrangement [18], artner selection of international joint venture projects [14], optimal temperature selection of ethylene cracking furnaces [13], Fenton process optimization [5], Social benefits of the mine occupational health and safety management [3], Evaluating Defense Simulation Packages [2].

3. Overview of the indicators for atmospheric environmental quality assessment. In this section, we propose and discuss two indicator systems for atmospheric environmental quality assessment, which are 1) the standard air pollution index, and 2) our proposed index system. Afterwards, we test the performance of these two indicator systems in the experiment.

3.1. Overview of the Air Pollution Index. The Air Pollution Index (API) is a simple and generalized method to represent and calculate the air quality, and it is achieved from air pollution data. In China the API is replaced by an updated Air Quality Index [24, 9]. China’s Ministry of Environmental Protection is responsible for detect and forecast the quality of air pollution in China. The Air Pollution Index (API) level is based on the level of 6 atmospheric pollutants, including: 1) sulfur dioxide (SO2), 2) nitrogen dioxide (NO2), 3) suspended particulates smaller than 10 µm (PM10), 4) suspended particulates smaller than 2.5 µm (PM2.5), 5) carbon monoxide (CO), and 6) ozone (O3) [1, 21, 26].
The current API is computed through a linear interpolation of the reference scale values as follows.

\[ I_p = \frac{PI_h - PI_l}{BP_h - BP_l} \cdot (C_p - BP_l) + PI_l \]  

(1)

where \( I_p \) is the index of the air pollutant \( p \), \( C_p \) is the rounded concentration of \( p \), \( BP_h, BP_l \) refer to the break point which are larger or lower than \( C_p \), and \( PI_h, PI_l \) denote the API values which are related to \( BP_h, BP_l \) respectively.

To improve the performance of API, we combine the Shannon’s entropy function and standard API together to modify the standard API. The modified API is described as follows.

\[ API^* = \max \{ I_1, I_2, \ldots, I_n \} \cdot C_1 \cdot C_2 \]  

(2)

where \( I_1, I_2, \ldots, I_n \) are used to symbolize all pollutants which are saved in the monitoring point. \( C_1 \) refers to the background arithmetic mean index value of all types of pollutant, which is described as follows.

\[ C_1 = \frac{\sum_{j=1}^{n} Ave_d [I_j]}{Ave_y \sum_{j=1}^{n} Ave_d [I_j]} \]  

(3)

From the above equation, we can see that \( C_1 \) is designed to average all data in a year by adding the daily arithmetic averages or each index.

Furthermore, \( C_2 \) represents the background arithmetic mean entropy index, which is defined as follows.

\[ C_2 = \frac{Ave_y \{ Entropy_d [\max \{ I_1, I_2, \ldots, I_n \}] \}}{Entropy_{\max} [\max \{ I_1, I_2, \ldots, I_n \}] } \]  

(4)

\( C_2 \) is designed to integrate the yearly average and daily average entropy for each index. The proposed modified API indicator system can represent the influence of all pollutants.

3.2. Index system. Different from the Air Pollution Index, we try to propose an index system to assess air quality, and then compare these two various methods. After Investigating influencing factors about the atmospheric environmental quality assessment, we choose seven main aspects, such as Climate and meteorology, Economic and social development, Industrial structure, Energy consumption, Industrial pollutant discharge, The greening of the city, and Environmental protection construction. Framework of this index system is shown in Fig. 1.

4. The proposed method based on AHP. Analytic hierarchy process can obtain a priority of the weight for each alternative. The top level of the hierarchy refers to the goal of the decision issue. Then, the lower levels represent the tangible and intangible criteria and sub-criteria which contribute to the given goal [30, 33]. Afterwards, the bottom level is established by the alternatives to assess in terms of to the criteria.

In AHP, elements of a particular level are represented as \( X_1, X_2, \ldots, X_n \). Based on the relative evaluations calculated by a decision maker, the judgment matrix is
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Figure 1. Index system for atmospheric environmental quality assessment represented by the following equation.

\[
A = \begin{pmatrix}
    c_{11} & c_{12} & \cdots & c_{1n} \\
    c_{21} & c_{22} & \cdots & c_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    c_{n1} & c_{n2} & \cdots & c_{nn}
\end{pmatrix}
\]  (5)
where \( c_{ij} \cdot c_{ji} = 1 \).

Afterwards, the derivation of priorities at a given level is estimated by the judgment matrix. Therefore, the perfectly consistent case is represented as follows.

\[
A = \begin{pmatrix}
\frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\
\frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n}
\end{pmatrix}
\] (6)

where \( w = (w_1, \cdots, w_n) \) is satisfied.

Afterwards, the priority vector is calculated using the judgment matrix \( A \).

\[
A \times w = n \times w
\] (7)

\[
A \times w = \lambda_{\text{max}} \times w
\] (8)

where parameter \( \lambda_{\text{max}} \) is the largest eigenvalue of \( A \) and \( w \) denotes the weight vector. Next, the consistency index is computed as follows.

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\] (9)

Due to the consistency of the pairwise comparisons of criteria, the maximal principal eigenvalue \( \lambda_{\text{max}} \) of \( A \) is calculated as follows.

\[
\det (A - I \lambda) = 0
\] (10)

where \( I \) is a \( n \times n \) identity matrix, and the consistency ratio (CR) is represented as follows.

\[
CR = \frac{CI}{RI}
\] (11)

where \( RI \) is random index value.

Flowchart of analytic hierarchy process is shown in Fig. 2.

Based on the theory of the APH model, we propose a hybrid AHP-Fuzzy Comprehensive Evaluation Model to assess the atmospheric environmental quality [34, 17]. In the proposed hybrid model, AHP is able to estimate the weight coefficient of the index system, and fuzzy comprehensive evaluation [12, 11] approach can tackle the vagueness of remark in evaluation process. Firstly, we build a hierarchical evaluation index system by AHP, and then compute the weight for each layer indicator. Secondly we conduct the evaluations for the various levels of fuzzy comprehensive evaluation. In the end, the overall evaluation results can be obtained. The proposed hybrid AHP-Fuzzy Comprehensive Evaluation Model is made up of the following steps:

**Step 1.** Utilize AHP to analyze the atmospheric environmental quality assessment problem, and then construct the hierarchical framework of the comprehensive evaluation.

**Step 2.** Construct the evaluation factor \( U = \{u_1, u_2, \cdots, u_m\} \) and the remark set \( V = \{v_1, v_2, \cdots, v_t\} \).
If all judgments are consistent 

1. Construct the hierarchy of Atmospheric environmental quality assessment in a graph

2. Construct a pairwise comparison matrix

3. Compute the priority of each criterion

4. Determine whether the judgments of decision makers is consistent or not

If all judgments are consistent

N

Y

If all levels are compared

N

Y

(5) Rank the overall priority

Step 3. Compute weights of all factors.

Step 4. Construct the first layer fuzzy evaluation

Step 5. Establish a fuzzy evaluation matrix as follows.

\[ R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\
 r_{21} & r_{22} & \cdots & r_{2n} \\
 \vdots & \vdots & \ddots & \vdots \\
 r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \] (12)

where element \( r_{ij} \) (\( i = 1, 2, \cdots, m \); \( j = 1, 2, \cdots, n \)) represents the membership degree of the \( i^{th} \) element to the \( j^{th} \) evaluation level. Accordingly, \((r_{i1}, r_{i2}, \cdots, r_{in})\) is the fuzzy subset evaluation.

Step 6. Choose the appropriate fuzzy operator that generate \( W_k \) and \( R_k \), and then achieve the fuzzy comprehensive evaluation result vector as follows.

\[ B_k = W_k \circ R_k \] (13)
Step 7. Execute the secondary layer fuzzy evaluation, and then establish the total fuzzy evaluation matrix $R = (B_1, B_2, \ldots, B_n)^T$.

Step 8. Choose the appropriate fuzzy operator to compute the total fuzzy evaluation result vector $B = W \circ R$. After normalization, the fuzzy comprehensive evaluation result vector can be obtained.

Step 9. Obtain evaluation results. If $b_k = \max \{b_1, b_2, \ldots, b_t\}$, the remark of the total fuzzy comprehensive evaluation result is represented as $v_k$ in terms of the principle of the max membership degree.

5. Experiment. We choose five cities in China to test the proposed atmospheric environmental quality assessment method. Average diurnal variations for different types of pollutants are shown in Fig. 3.

Next, average yearly variations for different types of pollutants for different cities are given in Fig. 4.

The original data for the atmospheric environmental quality influencing factors are listed in Table. 1 as follows.

| Index | City 1 | City 2 | City 3 | City 4 | City 5 |
|-------|--------|--------|--------|--------|--------|
| X1    | 1562.3 | 1268.5 | 1324.5 | 1025.6 | 985.6  |
| X2    | 835.3  | 824.6  | 814.7  | 820.4  | 809.3  |
| X3    | 1896.7 | 2265.3 | 2859.1 | 3258.4 | 3896.4 |
| X4    | 4587.6 | 5247.4 | 5035.9 | 6254.6 | 8529.4 |
| X5    | 50.24  | 56.1   | 63.58  | 80.47  | 94.6   |
| X6    | 44.8   | 45.1   | 46.2   | 45.1   | 47.5   |
| X7    | 1258.7 | 1632.9 | 1845.1 | 1965.4 | 2154.8 |
| X8    | 2856.4 | 3021.6 | 3564.9 | 3458.2 | 3874.2 |
| X9    | 1045.9 | 1296.5 | 1358.4 | 1585.4 | 1478.7 |
| X10   | 2689.7 | 2897.4 | 3025.4 | 3024.6 | 3154.9 |
| X11   | 11.25  | 12.58  | 13.62  | 12.94  | 14.38  |
| X12   | 5.84   | 4.62   | 4.78   | 4.32   | 3.74   |
| X13   | 2.23   | 1.98   | 1.74   | 1.62   | 1.47   |
| X14   | 7.56   | 8.14   | 8.56   | 9.21   | 9.76   |
| X15   | 42589  | 52874  | 56987  | 62547  | 78451  |

Using the proposed AHP model, weight for each index in Table. 1 is listed in Fig. 5.

Based on the above index weight, we utilize hybrid AHP-Fuzzy Comprehensive Evaluation Model to estimate air quality for these five cities. To make performance comparison, expert opinion is used as the ground truth, and air quality evaluation
by modified API. After the process of normalization, atmospheric environmental quality assessment results for the above five cities are illustrated as follows.

From Fig. 6, we can see that compared with the modified API, the proposed method is much closer to the expert opinions by effectively analyzing the influence
Fig. 3 Average diurnal variations for different types of pollutants for different cities.

Figure 3. Average diurnal variations for different types of pollutants for different cities.
The proposed method can assess air quality more accurately than the modified API. Therefore, it can be concluded that the proposed index system and the Expert opinion are more reliable than the Modified API.
Based on the above index weight, we utilize hybrid AHP-Fuzzy Comprehensive Evaluation Model to estimate air quality for these five cities. To make performance comparison, expert opinion is used as the ground truth, and air quality evaluation by modified API. After the process of normalization, atmospheric environmental quality assessment results for the above five cities are illustrated as follows.

From Fig. 6, we can see that compared with the modified API, the proposed method is closer to the expert opinion. Therefore, it can be concluded that the proposed index system and the hybrid AHP-Fuzzy Comprehensive Evaluation Model can assess air quality more accurately than the modified API.

6. Conclusion. This paper proposed a novel method to assess the atmospheric environmental quality. Two indicator systems for atmospheric environmental quality assessment are proposed, and we want to compare the rationality of these two indicator systems. The main innovation of this paper lies in that we propose a hybrid AHP-Fuzzy Comprehensive Evaluation Model to evaluate the atmospheric environmental quality. Experimental results prove that the proposed method can achieve air quality assessment results with high accuracy.

In the future, we will extend the experimental dataset, and try to add some other evaluation factors in this work.

Acknowledgment. This study was supported by grants from the Yunnan Provincial Department of Education (China, Project No. 2015Z118, China. Project No. 2017ZZX160). The Yunnan Provincial Science and Technology Department (China, Project No. 2016FD059), and the Foundation of Kunming University of Science and Technology (China, Project No. KKSYSY201508012, China, Project No. KKSYSY201408044). The National Planning Office of Philosophy and Social Science (China, Project No. 14BJY029). National Natural Science Foundation of China (Project No. 71362023, Project No. 71762020).

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Received July 2017; revised January 2018.

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