Evaluation of Urban Air Quality Based on Entropy Weight Method

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Abstract. With the rapid development of China's economy and the continuous growth of population, environmental problems have become an important challenge to be solved urgently.In this study, entropy weight method is used to process the data in order to solve the common problem of multi-index evaluation of environmental problems. By calculating the information entropy between the indicators to determine the weights, avoid subjective errors, fully consider the relative importance of each indicator, and establish a mathematical model between the Air Quality index (AQI) and different pollutant concentrations.This paper describes in detail the selection of SO2, PM10, NO2, NO, O3, PM2.5 six indicators to evaluate the air quality status, and explains the source and characteristics of each indicator. Through data standardization and weight determination, the entropy weight method obtained the comprehensive score of the air quality of each city from 2013 to 2021, showing the air quality of different cities.Finally, the paper puts forward suggestions to improve air quality, including measures to reduce fossil fuel use, promote clean energy, and strengthen emission management and limits.

Keywords: Entropy Weight Method, Multi-index Evaluation, Air Pollution and Control, Air Quality Index (AQI).

1. Introduction

With the rapid economic development and continuous population growth, China is faced with urgent environmental problems that need to be addressed. These problems not only have a huge impact on people's health and quality of life, but also have caused great damage to the ecosystem and ecological balance. In recent years, the Chinese government has actively promoted the cause of environmental protection and achieved some results through a series of policies and measures. However, the problem of environmental pollution is still serious and needs further action to solve it.

Air pollution, in particular, has become one of the most prominent environmental problems in China. With the acceleration of urbanization and industrialization, harmful substances such as PM2.5 in the air in many cities exceed the standard, posing a serious threat to human health. Therefore, it has become crucial to establish a mathematical model of the relationship between the Air Quality Index (AQI) and the concentration of different pollutants. Such a model helps the government and the public to have a more comprehensive understanding of the state of air quality and take corresponding measures to improve air quality[1].

Worldwide, research on the relationship between air quality index and the concentration of various pollutants has become a hot topic in academia. Through a variety of angles and methods, a large number of domestic and foreign literature has been deeply analyzed.

Foreign scholars Horn Seth A and Dasgupta Purnendu K take an in-depth look at the history and analysis of the Air Quality Index (AQI)[2], introducing its development, especially how the US Environmental Protection Agency (EPA) has provided key information to the public over the past 45 years. They highlight the importance of AQI in unifying air quality standards across the country and serving as a template for other countries. They also discussed the dynamic framework of AQI and its relationship to national ambient air quality standards in the United States. The study by Mezoue Cyrille Adiang et al. focused on fine particulate matter concentration measurements and AQI estimates northeast of Douala, Cameroon, compensating for the lack of monitoring data in the region. They found that concentrations of PM10 and PM2.5 in the area exceeded World Health Organization standards, and AQI indicates that residents are exposed to high levels of air pollution[3]. The study by Jiang Zexi et al. focuses on the characteristics of ambient air quality in Shanghai and the proposed AQI model. They found that the synergistic effect between PM2.5, O3 and NO2 is enhanced in moderately polluted air, so they proposed a new multi-pollutant AQI model (NMAQI), which successfully classifies the observed data into different air quality levels, and improves the ability to assess the degree of urban ambient air pollution and reduce the risk of public exposure to highly polluted atmospheric environments[4]. These studies provide important information for us to understand and evaluate AQI in depth and provide insights and methods for improving air quality assessment. In 2021, Chinese scholars Wang Visiting, Zhao Wencheng and Jiang Shan proposed a multi-scale trend sample entropy to analyze the dynamic characteristics of AQI and pollutant concentration time series. The study found that the dynamic structure of Air quality index (AQI) is the closest to that of PM2.5, showing a similar evolution trend[5]. Through cluster analysis on different scales, suggestions for air pollution prevention and control are provided. The paper focuses on the dynamic characteristics of air quality. On the other hand, in their analysis of the change characteristics of air quality in 31 key Chinese cities from 2014 to 2018, Wang Fu-ming, Li Ming-yan, Zhang Meihang and Wang Hongwei found that the air quality in these cities has improved overall, with the main pollutants changing from PM2.5 and PM10 to O3. They analyzed the changes in air quality in each city in detail, including the increase in the proportion of non-polluted days. The study looked at the trend of air quality change in different cities and the factors that affect it[6].

This study deeply discusses the connotation of establishing a mathematical model of Air Quality Index (AQI) applicable to China and proposes an evaluation index system by integrating a large amount of literature. The system covers the concentration of pollutants such as PM2.5, PM10, O3, SO2, NO and NO2 and their impact on air quality. The entropy weight method is used to determine the weights of each index to ensure that the evaluation system is objective and scientific. A comprehensive assessment of air quality was carried out across the country, and the data of each city was selected, and the comprehensive score was obtained by linear weighted processing, reflecting the overall level of air quality in each city. Specific methods include selecting evaluation indicators and constructing evaluation index system to ensure systematic, scientific and practical. Entropy weight method avoids subjective errors, calculates weights through information entropy, and comprehensively considers the relative importance of each index. The steps include index collection, standardization, information entropy calculation, weight determination and consistency test. Finally, the comprehensive score is obtained by multiplying the weight with the index score, and the air quality level of each city is evaluated. In the whole research process, the concept of establishing AQI mathematical model was defined, the evaluation index system suitable for China was constructed, and the weight was determined by entropy weight method, and the comprehensive evaluation results of air quality in various cities were finally obtained.

2. Main content

2.1. Establishment of the model

The mathematical model of Air Quality Index (AQI) and the air quality of 10 best cities in China were established. Establishing a mathematical model of the Air Quality Index (AQI) can help the government and the public better understand the situation of air quality and take corresponding measures to improve air quality. The AQI mathematical model commonly used is the US Environmental Protection Agency's (EPA) mathematical model, which converts the concentrations of pollutants such as PM2.5, PM10, O3, SO2, NO and CO2 into equivalent concentrations respectively, and calculates AQI values based on these equivalent concentrations. AQI is divided into six grades according to national standards, from good to poor in order: excellent, good, light pollution, moderate pollution, heavy pollution, serious pollution. Taking the "Ambient Air Quality Index (AQI)

Technical Regulations (Trial)" implemented in 2013 as an example, the AQI calculation formula is: AQI = Max (IAQI1, IAQI2, IAQI3, IAQI4, IAQI5, IAQI6). Where, IAQI is the sub-index calculated by the relationship between the pollutant concentration and the corresponding pollutant concentration limit, and Max represents the maximum value in the six sub-indices. For this problem, the concentration of pollutants such as PM2.5, PM10, O3, SO2, NO and NO2 can be selected as the evaluation index. According to the influence of each index on AQI, the entropy weight method is used to determine the weight of each index, so as to determine the relative importance of each pollutant in the calculation of AQI.

The establishment of a reasonable evaluation index system is the premise of the study of question 1. Through the establishment of a scientific evaluation index system, it is conducive to more objectively measure the actual situation of the object, facilitate comparison and the pros and cons of the measurement scale, and facilitate scholars to carry out accurate evaluation. The entropy weight method is an objective method of empowerment. It calculates the information entropy among indicators, finds the weight of each indicator, assigns weight to each evaluation indicator and obtains the final comprehensive score. The use of entropy weight method to determine the weight effectively avoids the error brought by humans, and fully considers the relative importance of multiple indicators. The mathematical model of this paper is shown as follows:

$$V_j = \sum_{j=1}^{n} w_j y_{ij} \quad (i = 1,2,\ldots,n) \tag{1}$$

Where V_j represents the comprehensive score of agricultural modernization in year j, w_j represents the weight coefficient of index j, and y_{ij} represents the standardized data of the JTH index in year i.

2.2. The selection of indicators

In this paper, six indicators of SO2, PM10, NO, NO2, O3 and PM2.5 are selected for the evaluation of air quality. The details are as follows[7]:

(1) Sulfur dioxide is one of the earliest pollutants in the air to be concerned about, most of its sources are burning fossil fuels, ore smelting and other activities, easy to cause eye, respiratory system, cardiovascular and other diseases.

(2) PM10: PM10 refers to inhalable particles with a diameter of less than 10 microns, which is one of the main pollutants in the air, containing harmful dust, metal elements, bacteria, etc., which can cause respiratory diseases, cancer, and harm to the cardiovascular system.

(3) Nitrogen dioxide: mainly from the fuel combustion process, such as automobile exhaust, long-term exposure can cause respiratory system and cardiovascular system diseases, may also become a synergistic substance of photochemical reaction.

(4) Nitric oxide: it is one of the main emissions of fuel combustion, which will chemically react with other pollutants to produce harmful substances such as nitrogen dioxide.

(5) Ozone: is a photochemical pollutant, formed under high temperature, strong light and high oxygen concentration. Long-term exposure can cause respiratory diseases and immune system abnormalities.

(6) PM2.5: Refers to inhalable particulate matter less than 2.5 microns in diameter, a finer and more dangerous pollutant in air pollution that has been linked to cardiovascular and respiratory diseases and even cancer and is a precursor to chemicals such as ozone.

In general, the above six indicators are currently widely used air pollution indicators, the measurement method is simple, high reliability, can reflect the main pollutants in the air, have a greater impact on human health, is considered to be an important indicator of air quality assessment[8].

The notation and are illustrated in Table 1. The sources of air quality condition indicators are shown in Table 2.

Table.1. Symbol Description

X_1	CO2
X_2	SO2
X_3	O3
X_4	PM2.5
X_5	PM10
X_6	NO

Table.2. Sources of air quality status indicators

Indicators	Units	Sources	Properties
SO2	ug/m3	China Statistical Yearbook	Contrarian Indicators
PM10	ug/m3	China Statistical Yearbook	Contrarian Indicators
CO2	ug/m3	China Statistical Yearbook	Contrarian Indicators
CO	mg/m3	China Statistical Yearbook	Contrarian Indicators
O3	ug/m3	China Statistical Yearbook	Contrarian Indicators
PM2.5	ug/m3	China Statistical Yearbook	Contrarian Indicators

2.3. Solving the model

①Data standardization:
For positive indicators:

$$y_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (i = 1,2,\dots,n; j = 1,2,\dots,m) \tag{2}$$

For reverse indicators:

$$y_{ij} = \frac{\max\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (i = 1,2,\dots,n; j = 1,2,\dots,m) \tag{3}$$

② Determine the weight of each indicator:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} y_{ij}} \quad (i = 1,2,\dots,n; j = 1,2,\dots,m) \tag{4}$$

③ Entropy value of the jth indicator:

$$e_j = -(\ln m)^{-1} \sum_{i=1}^{m} P_{ij} \ln P_{ij}, \quad (i = 1,2,\dots,n; j = 1,2,\dots,m) \tag{5}$$

④ Coefficient of variation for the jth indicator:

$$g_j = 1 - e_j \quad (j = 1,2,\dots,m) \tag{6}$$

⑤ Weights of sub-indicators:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \quad (j = 1,2, \dots, m) \tag{7}$$

⑥ Composite score:

$$V_j = \sum_{j=1}^{n} w_j y_{ij} \quad (i = 1,2, \dots, n) \tag{8}$$

The calculation results are shown in Table 3.

Table 3 Comprehensive scores of air quality in 31 major cities

Serial Number	**City**	**Score**
1	Beijing	0.52463
2	Tianjin	0.59540
3	Shijiazhuang	0.87954
4	Taiyuan	0.76817
5	Hohhot	0.58992
6	Shenyang	0.66325
7	Changchun	0.40783
8	Harbin	0.44066
9	Shanghai	0.31450
10	Nanjing	0.44411
11	Hangzhou	0.38323
12	Hefei	0.36969
13	Fuzhou	0.11059
14	Nam Cheong	0.33361
15	Jinan	0.72918
16	Zhengzhou	0.66333
17	Wuhan	0.44515
18	Changsha	0.37021
19	Guangzhou	0.31347
20	Nanning	0.23152
21	Haikou	0.01056
22	Chungking	0.35130
23	Chengdu	0.45296
24	Guiyang	0.21520
25	Kunming	0.22884
26	Lhasa	0.14858
27	Xi 'an	0.62507
28	Lanzhou	0.62994
29	Sining	0.57315
30	Yinchuan	0.59122
31	Urumqi	0.56177

As can be seen from the above table, the air quality in Lhasa, Fuzhou and Haikou is good, while that in Taiyuan, Jinan and Shenyang is poor. Therefore, the government departments should strengthen supervision and formulate corresponding policies[9]. We should reduce the use of fossil fuels, promote clean energy, strengthen vehicle emission management and limitation, strengthen industrial emission management, and carry out nature conservation and management to improve air quality[10].

FIG. 1 shows the bar chart of air quality in each city.

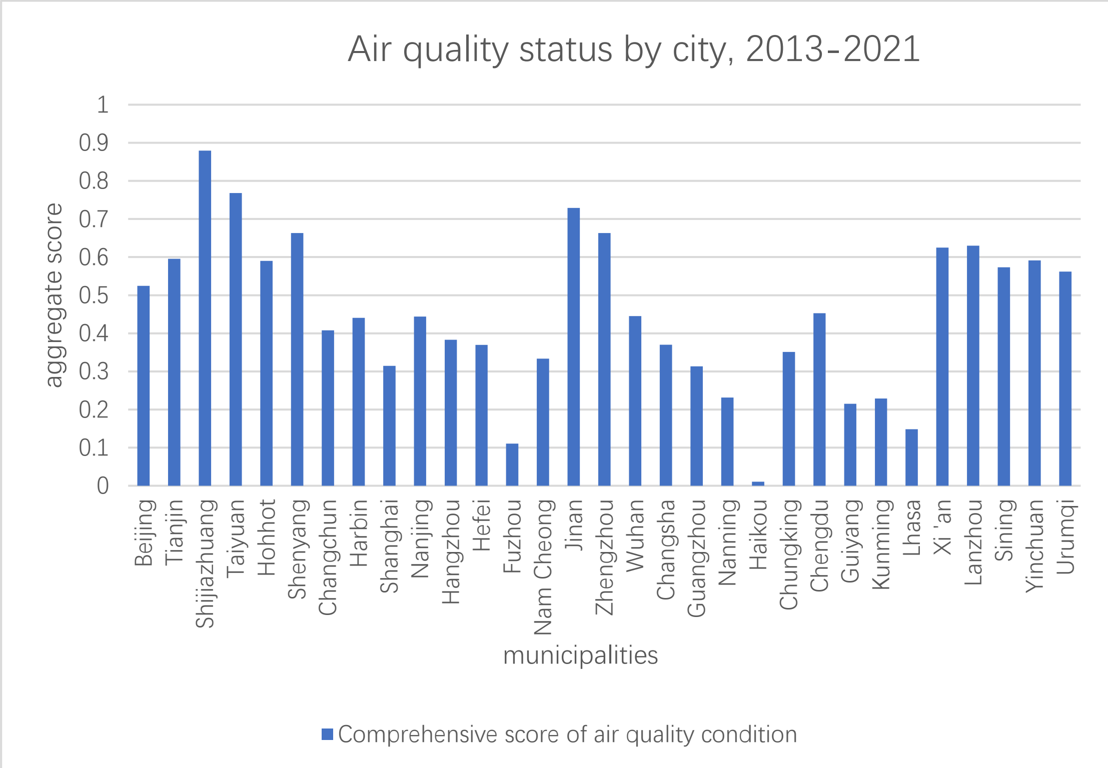

Figure 1 Urban air quality status from 2013 to 2021

3. Conclusions

In this paper, by using entropy weight method to process the data, the mathematical model of the relationship between Air Quality index (AQI) and different pollutant concentrations is established, so as to solve the common problem of multi-index evaluation in environmental problems. By evaluating the air quality status of six indicators such as SO2, PM10, NO2, NO, O3 and PM2.5, and determining the weight of each indicator, the air quality status of each city from 2013 to 2021 was comprehensively evaluated. At the end of the paper, suggestions were put forward to improve air quality, including measures to reduce fossil fuel use, promote clean energy, and strengthen emission management and limits. The study showed that the air quality in Lhasa, Fuzhou and Haikou was good, while the air quality in Taiyuan, Jinan and Shenyang was poor, suggesting that government departments strengthen supervision and formulate corresponding policies to improve air quality.

And this research shows the potential for a wide range of applications in the future. By establishing mathematical models, government departments and environmental protection agencies can effectively assess and monitor urban air quality, so as to formulate more accurate environmental protection policies and measures. By determining the weight of each pollutant index, air quality can be evaluated more accurately, and timely reference and decision support can be provided for relevant departments. In addition, the proposed suggestions for improving air quality, such as reducing the use of fossil fuels, promoting clean energy and strengthening emission management measures, provide important guidance and reference for future environmental protection work.

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