DOI: 10.23977/pree.2023.040116
ISSN 2616-2253 Vol. 4 Num. 1

Evaluation of light pollution risk level based on EWM-TOPSIS method

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Keywords: EWM- Topsis, Light pollution, Population density, Chongqing

Abstract: In this era, light pollution poses a great threat to people's health and safety. Based on the data of direct lighting, environmental performance and personnel performance of various districts and counties in Chongqing, seven indicators that may affect the size of light pollution are identified, and a model is established based on the EWM-Topsis method and the score is used as an indicator to determine the risk level of light pollution. The model was used to score the degree of light pollution in various districts and counties in Chongqing. Intervention strategies are proposed from the three aspects of law formulation, public action and industrial upgrading, and the specific actions for the implementation of each strategy are listed, and the impact that these actions may have on society is discussed. In addition, considering that population density accounts for the largest weight among the seven indicators, the sensitivity of the seven indicators is analyzed, and it is found that light pollution deepens as human accumulation deepens. Finally, the advantages and disadvantages of the model are discussed, and the areas where the model can be improved are analyzed.

1. Introduction

As an environmental issue, light pollution has attracted worldwide attention in recent years. With the acceleration of urbanization, the extensive use of artificial light sources and unreasonable lighting design have led to the continuous increase of night light level, which has brought great challenges to the night environment. In this context, light pollution risk assessment has become one of the important means to protect the natural dark environment at night.

In the existing literature, we can find that a series of light pollution evaluation methods and models already exist, such as the use of luminous flux, brightness, luminosity, color temperature and other indicators. However, these methods may have certain limitations in some cases, and it is difficult to comprehensively consider the multidimensional characteristics of light pollution, such as light intensity, spectral distribution, and spatiotemporal distribution. In addition, the existing methods also have a certain degree of subjectivity and uncertainty in the weight distribution and decision-making process, and lack a comprehensive and objective evaluation method, which brings certain difficulties to the work of decision makers and planners. The governments of many countries in the world have taken active measures to control light pollution and eliminated the negative effects of light pollution. In China, for example, the newly promulgated *Environmental Protection Law of the People's Republic of China* and the *Property Law of the People's Republic of China* restrict the use of light[1].

This paper aims to make up for these shortcomings and propose a light pollution evaluation model based on the EWM-TOPSIS method. The EWM-TOPSIS method combines the exponential weighted method (EWM) and the distance-based ranking method (Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which has high objectivity and comprehensiveness, and can better reflect the multidimensional characteristics and complexity of light pollution. By introducing the EWM-TOPSIS method, we will be able to more accurately assess the risk level of light pollution, provide stronger support to decision makers, and promote better management and control of light pollution problems.

2. Materials and methods

2.1 The source of the data

The article refers to the World Bank's WDI database, the International Statistical Yearbook 2019, the Model Whale website, and Wikipedia sources to obtain relevant data. The following countries were selected: United States, China, Japan, Germany, Netherlands, United Kingdom, France, Italy, Brazil, Canada, Russia, South Korea and Australia.

These data will provide us with a basis for further analysis and research on light pollution in these countries, and provide a scientific basis for the formulation of corresponding policies and measures. It is important to note that despite every effort to collect and integrate the available data, there may be certain limitations due to the limitations and incompleteness of the data.

In this paper, we dealt with missing data using two methods: deleting missing values and median interpolation.

Firstly, we used the method of deleting missing values. For samples or variables that contain missing values and are not mandatory, we will directly delete them. By removing missing values, we can ensure the integrity and accuracy of the analyzed samples.

Secondly, for samples or variables that are necessary but missing in the process, we adopted the median interpolation method. This interpolation method estimates missing values by using the median of other existing data. We calculated the median of each variable and used it to replace missing values.

By using these two methods, we can to some extent compensate for the impact of missing data and ensure the reliability of the analysis.

2.2 Based on EWM's Topsis method

The method used in the experiment is based on the Topsis evaluation model of the EWM (Entropy Weight Method). The model will score the areas that need to be evaluated in the subsequent process.

EWM-TOPSIS is based on two core principles: the empirically weighted method and the Topsis method. [2] The empirical weighting method is a method of weighting guidelines based on expert experience and knowledge, assigning different criteria different weights based on subjective judgments. The Topsis method is a multi-criteria decision-making method based on distance measurement, ranking and ranking by calculating the distance between the scheme to the ideal solution and the negative ideal solution.

EWM-TOPSIS can be applied to decision-making problems in various fields, such as enterprise performance evaluation, investment plan selection, product planning, etc. It can help decision makers assess alternatives more accurately and provide practical decision-making recommendations.

The calculation steps of EWM-TOPSIS mainly include the following stages: a. Determination of evaluation criteria and weights: The weights of each criterion are determined through expert judgment and subjective evaluation. b. Standardized assessment matrix: Transform raw assessment data into a standardized matrix. c. Calculation of positive and negative ideal solutions: Calculate the positive ideal solution and negative ideal solution of each criterion according to the standardized evaluation matrix. d. Calculate the distance between the scheme and the positive and negative ideal solution: By calculating the distance between the scheme and the positive and negative ideal solution, the evaluation value of each scheme is obtained. e. Rank and rank: Rank and rank alternatives based on assessed values.[3]

3. Model construction and solving

3.1 Construction of the EWM-TOPSIS model

Normalize the original input matrix$X$, transforming it into a non-negative space. This is necessary because subsequent calculations require all values to be positive or zero. The standardized formula used is:

$$z_{ij} = \frac{x_{ij} - \min\{x_{1j}, x_{2j}, \dots, x_{nj}\}}{\max\{x_{1j}, x_{2j}, \dots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \dots, x_{nj}\}} \tag{1}$$

z: the normalized matrix x: the original input matrix.

$\min\{X\}$: the smallest value in x $\max\{X\}$: the maximum value in X.

Next, calculate the proportion of each sample under each indicator. That is, the probability p_{ij} of the ith sample belonging to the jth indicator is calculated. A probability matrix, P, is constructed using these probabilities.

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \tag{2}$$

After the calculation of the proportion and probability, the information entropy value for each indicator is calculated. Information entropy is a measure of the uncertainty associated with a random variable. Here, it represents the extent to which each indicator contributes to the overall level of light pollution. Calculate the information entropy of each indicator to obtain its information utility value D:

$$d_{ij} = 1 - \left(-\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij})\right) \quad (j = 1,2, \dots, m) \tag{3}$$

Normalize D to obtain the entropy weight matrix W:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j \ (j=1,2,\dots,m)} \tag{4}$$

After the EWM obtains the weights of each indicator, topsis is used for evaluation

Regularize the primitive matrix. The formula for converting an intermediate indicator into a very large (beneficial) indicator is as follows.

$$\tilde{x}_i = 1 - \frac{|x_i - x_{best}|}{max\{|x_i - x_{best}|\}} \tag{5}$$

Normalize the regularization matrix to obtain the normalized matrix Y:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} {x_{ij}}^2}} \tag{6}$$

Define the maximum value Y^+ and the minimum value Y^- as follows:

$$Y^+ = \left(Y_1{}^+, Y_2{}^+, \dots, Y_m{}^+\right) = \begin{pmatrix} max\{y_{11}, y_{21}, \dots, y_{n1}\}, max\{y_{12}, y_{22}, \dots, y_{n2}\}, \dots, \\ max\{y_{1m}, y_{2m}, \dots, y_{nm}\} \end{pmatrix} \tag{7}$$

$$Y^- = \left(Y_1{}^-, Y_2{}^-, \dots, Y_m{}^-\right) = \begin{pmatrix} min\{y_{11}, y_{21}, \dots, y_{n1}\}, min\{y_{12}, y_{22}, \dots, y_{n2}\}, \dots, \\ min\{y_{1m}, y_{2m}, \dots, y_{nm}\} \end{pmatrix} \tag{8}$$

The distance of the i-th (i=1,2,...,n) evaluation object from the maximum and minimum values is defined as D_1^+ and D_2^+.

$$D_i{}^+ = \sqrt{\sum_{j=1}^{m} w_j \left(Y_j{}^+ - y_{ij}\right)^2} \tag{9}$$

Calculate the score S:

$$S_i = \frac{D_i{}^-}{D_i{}^+ + D_i{}^-} \tag{10}$$

According to the score and the actual situation, 5 partitions are divided to define the degree of light pollution in an area.

3.2 Establishment of standards

The purpose of this analysis is to understand and present the light pollution situation in different countries. The scores of 20 countries were obtained based on data from the training set. These scores were further analyzed and divided into different bands, which were then mapped to five levels of light pollution. This division helps to provide a more intuitive understanding of the level of light pollution in each country[4-6]. The severity of light pollution and the actual situation of each country were taken into consideration when dividing the scores into five levels: mild, moderate, severe, more severe, and extremely severe. This division can serve as a reference for the development of policies and measures. By dividing the scores into five levels, the level of light pollution in each country can be understood more intuitively, providing a basis for further research and policy formulation. The results of the model, solved using the score S and the actual situation, are summarized in Table 1.

Table 1: Light pollution level comparison table

Light pollution degree score	Light pollution level	Explanation
0.6754~0.8000	V	Light pollution is very severe
0.8000~0.8500	IV	Light pollution is severe
0.8500~0.9000	III	Light pollution is at a medium level
0.9000~0.9500	II	Light pollution is mild
0.9500~1.0000	I	Light pollution is very mild

4. Results and Analysis

4.1 Analysis of the results of the light pollution degree evaluation model

According to the collected data and the calculated index weights, the light pollution degree scores of 37 districts and counties in Chongqing are calculated, and the results are shown in the Figure 1.

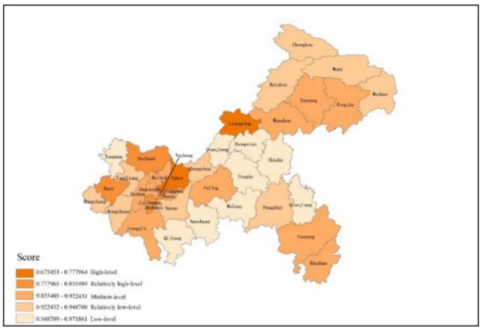

Figure 1: Scores of 38 districts and counties

Then, according to the established classification, the average score of each location is calculated separately and graded, and the results are as follows in Table 2.

Table 2: Scores and ratings for each position

Kind of Place	Score	Level
Protected land location	0.9435	II
Rural community	0.9251	II
Suburban community	0.8954	III
Urban community	0.8409	IV

From the Table 2, combined with the selected indicators, it can be found that in the four areas divided by the 37 districts and counties of Chongqing as the research object, in the densely populated, economically developed or pursuing rapid economic development of urban areas, usually the amount of lighting at night is large, the surface temperature rises, the health level of residents decreases correspondingly, etc. The calculated light pollution degree score is more likely to be lower, so that the degree of light pollution is judged to be more serious and above.

4.2 Sensitivity Analysis

According to the weight of each indicator in the previous model construction, the weight of each indicator that affects the score is calculated, and the weight of each indicator is as follows in the Table 3.

Table 3: Indicator weighting

Indicator Name	Weight Value
Rate of uniform temperature's change	0.069311
Population density	0.410030
GDP per capita	0.082399
Nighttime Light Index	0.183302
Eco-environmental quality score	0.0310607
Power consumption	0.108346
The number of people admitted to the emergency	0.115548

According to the model established above and the analysis of the problem, the above seven elements will have an impact on the light pollution score, and it is observed that the weight of population density is the largest, indicating that in real life, population density may be an important indicator that affects a reading of light pollution.

In the sample, the distribution range of population density is 54.7~28695.7, the span of this factor is relatively large, so it is not possible to simply let the value of this factor of population density fluctuate around the data in Yuzhong District and Chengkou County itself, and it is necessary to increase the span of the parameter according to the distribution interval of the large span. Therefore, five more suitable parameters for population density are specified M1=50, M2=500, M3=5000, M4=10000, M5=2000. This did not change the other 6 factors in Yuzhong District and Chengkou County, and a total of 10 results were obtained in this sensitivity analysis.

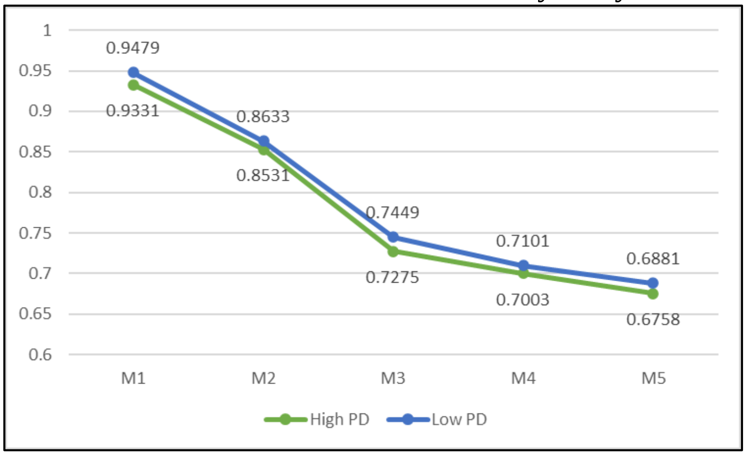

Figure 2: Sensitivity analysis results

It can be seen from the Figure 2 that the parameter of population density has a strong correlation with the score, and with the increase of population density, the light pollution fraction decreases sequentially, and the performance is more significant. This is consistent with the reality and with the assumption of the model.

At the same time, it can also be seen that the sensitivity of population density to light pollution fraction is very sensitive to population density below 5000, and when the population density continues to increase, although the light pollution score is also decreasing, but the degree of decline is not so large, that is, it is not so sensitive in this case. Combined with reality, it can be found that this result coincides with real life. Light pollution is obviously deepened with the gathering of human beings, and most of the serious places of light pollution in the world occur in cities in developed areas, but rarely occur in underdeveloped suburban rural areas. When the population density increases to a certain extent, due to the decline in the per capita sharing of public resources and the close saturation of public light, the amount of light required by people will also grow slowly.

5. Conclusion and discussion

5.1 Conclusion

According to the calculation results of the light pollution degree evaluation model, it can be concluded that in densely populated, economically developed, or urban areas pursuing rapid economic development, the calculated light pollution degree score is likely to be relatively low due to high night light illumination, rising surface temperature, and corresponding decline in residents' health levels. Therefore, the light pollution degree is judged to be more severe or above.

Through weight calculation, it can be seen that population density has the greatest impact on the score of light pollution among the known influencing factors. The sensitivity test on the influencing factor of population density verifies the rationality of the model. As the population density increases, the fraction of light pollution decreases sequentially and exhibits significant performance. Meanwhile, as the population density continues to increase above 5000, the degree of decrease in the score of light pollution gradually decreases. Analysis shows that the decrease in per capita share of public resources and the near saturation of public light lead to a slow increase in the amount of light people need.

Light pollution can have significant negative impacts on both natural and cultural aspects, such as affecting the growth cycle of animals and plants, increasing surface temperature, inducing human diseases and traffic accidents. This development pattern is clearly contradictory and not conducive to the sustainable and healthy development of cities. Dealing with the pollution problem is a long and arduous task. We must adhere to the principle of adapting measures to local conditions and the overall direction of national participation in pollution prevention and control, in order to scientifically and effectively solve a series of pollution prevention and control problems such as light pollution.

5.2 Research outlook

This paper introduces mathematical modeling, combines the topsis analysis method and entropy weight method, and visually presents the degree of light pollution in various regions in a relatively objective way.

However, the model does not fully include all the factors that affect light pollution, so the scope of application has certain limitations. At the same time, limited by the difficulty of data collection, the selection of seven indicators is based on a large number of assumptions, ignoring a certain number of details and more possibilities in reality, so that there is a certain deviation in the results. Finally, for the type of position and the selection of the most effective strategy corresponding to it, the processing method is more subjective, and the selected reference indicators are relatively simple. In the future, more index factors should be explored and the mathematical relationship between them should be explored, so as to make the selection of strategies more scientific and objective.

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