Research on Light Pollution Evaluation Using TOPSIS Model Based on Entropy Weight

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Abstract. Light is an indispensable lighting source in human life. From the initial fire light source to the later electric light, light provides human beings with the ability to see things in the dark, which greatly expands the time and scope of human activities. However, in recent years, light pollution has become a major problem for people**.** To quantify and evaluate the impact of light pollution, In order to solve this problem, this paper establishes a TOPSIS model based on entropy weight, and uses Arc GIS software to quantitatively analyze the visual light pollution map. Seven evaluation indexes are selected and quantified. Then, the weights of seven evaluation indexes are obtained by using the TOPSIS model based on entropy weight, and the light pollution evaluation of the selected cities is carried out. Finally, the comprehensive ranking of the light pollution degree of the five cities is obtained.Through this research, it is of great significance to protect human health, maintain ecological balance, promote astronomical observation and improve urban planning and lighting design.

Keywords: Light Pollution, TOPSIS Model, Entropy Weight Method.

1. Introduction

Studying the problem of light pollution is of great significance for protecting human health, maintaining ecological balance, promoting astronomical observations, and improving urban planning and lighting design. Risk assessment of light pollution is an important part of light pollution control [1]. Light pollution refers to the pollution of dry light on the environment, which is used to describe the excessive or bad use of artificial light. In the world, light pollution is generally divided into three categories, namely, white light pollution, artificial day pollution and color light pollution. Some phenomena we call light pollution include light intrusion, over-illumination, and light clutter, which may occur in various regions.

Light pollution assessment is a comprehensive process that aims to assess the impact of various light sources on human life, the natural environment and ecosystems. This evaluation involves not only scientific measurement and standard application but also social, cultural and economic aspects. With the development of society, the phenomenon of light pollution has become increasingly frequent in recent years, which has also caused more and more problems. Light pollution will darken the night sky, affect the brightness of the zenith, and also affect our health and safety. Excessive artificial light will damage our eyes, disrupt our circadian rhythm, and lead to a decline in sleep quality; The glare caused by artificial lights may also cause some motor vehicle accidents. Community officials or local groups can implement intervention strategies to reduce the negative impact of light pollution. However, artificial light has positive and negative effects and affects different locations in different ways. Therefore, the evaluation of the impact degree and potential impact of any intervention strategy must be targeted at specific locations [2-6].

At present, the research on light pollution lacks systematic quantitative evaluation, and the traditional evaluation methods lack the screening and quantification of indicators, such as CRITIC method and analytic hierarchy process, which have their defects respectively [7-9]. We use ArcGIS to quantify the screened indicators, and then use the TOPSIS model based on entropy weight to evaluate the light pollution problem and obtain an effective evaluation method.

2. The basic fundamental of TOPSIS model based on entropy weight

2.1. The structure of entropy weight method

Entropy weight method is a weight calculation method based on the principle of information entropy. According to the basic principles of information theory, information is a measure of the degree of order of the system, and entropy is a measure of the degree of disorder of the system. The smaller the entropy of entropy is, the more concentrated the information is, on the contrary, the more dispersed the information is. The entropy weight method determines the weight of each index by calculating the information entropy of each index and provides the basis for a multi-index comprehensive evaluation to achieve multi-index decision-making.

The calculation steps of the entropy weight method to calculate the weight are as follows:

(1) Standardized processing

$$\text{Positive indicators } X_{ij}=\frac{xij-minxij}{maxxij-minxij}\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{1}$$

$$\text{contrarian indicator } X_{ij}=\frac{maxxij-xij}{maxxij-minxij}\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{2}$$

(2) Calculation index proportion

$$P_{ij}=\frac{Xij}{\sum_{i=1}^{n} Xij}\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{3}$$

(3) Calculate indicator entropy value

$$Eij=-\frac{1}{\ln m}\left(\sum_{j=1}^{m} Pij \ln Pij\right)\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{4}$$

(4) Calculate the coefficient of variance

$$D_{ij}=1-E_{ij}\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{5}$$

(5) Calculate entropy weight

$$W_{ij}=\frac{Dj}{\sum_{j=1}^{m} Dj}\begin{pmatrix} i=1,2,\ldots,n \\ j=1,2,\ldots,m \end{pmatrix} \tag{6}$$

The calculation steps of the entropy weight method include data standardization, calculating the information entropy of each index, defining the entropy weight, and finally calculating the weight of each index. This method is an objective weighting method, which is very suitable for solving the optimal decision problem.

2.2. The structure of TOPSIS model

The TOPSIS model, known as Technique for Order Preference by Similarity to Ideal Solution, is a multi-attribute decision analysis method for evaluating and selecting the best solution or decision.

The basic idea of the TOPSIS model is to compare each candidate scheme with the ideal solution and determine the optimal scheme by calculating the similarity between each scheme and the ideal solution. The ideal solution is optimal, and each attribute value reaches the best value in each alternative. The negative ideal solution is the worst, and each attribute value reaches the worst value in each alternative.

The specific algorithm steps of the TOPSIS method are as follows:

(1) Obtain the canonical decision matrix by means of vector programming. Let the decision matrix $A=(a_{ij})m*n$ of the multi-attribute decision-making problem, the normalized decision matrix $B=(b_{ij})m*n$.

$$b_{ij}=a_{ij}/\sqrt{\sum_{i=1}^{m} {a_{ij}}^2}, i=1,2,\ldots,m; j=1,2,\ldots,n \tag{7}$$

(2) Construct weighted canonical matrix C=(c_{ij})m*n. Let the weight vector of each attribute given by the decision-maker be w=[w_1,w_2,…,w_n]T.

$$C_{ij} = w_{ij} * b_{ij}, i = 1,2, \dots, m; j = 1,2, \dots, n \tag{8}$$

(3) Determine the positive ideal solution C* and the negative ideal solution C0. Let the jth attribute value of the positive ideal solution C* be c_j*, and the jth attribute value of the negative ideal solution C0 be cj0.

$$c_{j*} = \begin{cases} max c_{ij}, j \ is \ benefit \ attribute, \\ min c_{ij}, j \ is \ cost \ attribute, \end{cases} \quad j = 1,2, \dots, n \tag{9}$$

$$c_{j0} = \begin{cases} min c_{ij}, j \ is \ benefit \ attribute, \\ max c_{ij}, j \ is \ cost \ attribute, \end{cases} \quad j = 1,2, \dots, n \tag{10}$$

(4) Calculate the distance of each scheme to the positive ideal solution and the negative ideal solution. The distance from the alternative di to the positive ideal solution is

$$s_{i*} = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_{j*})^2}, i = 1,2, \dots, m \tag{11}$$

The distance from the alternative di to the negative ideal solution is

$$s_{i0} = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_{j0})^2}, i = 1,2, \dots, m \tag{12}$$

(5) Calculate the ranking index value (ie comprehensive evaluation index) of each scheme.

$$f_{i*} = s_{i0}/(s_{i0} + s_{i*}), i = 1,2, \dots, m \tag{13}$$

(6) Arrange the pros and cons of the schemes according to fi* from large to small.

2.3. Selection and Calculation of Light Pollution Evaluation Index

1. Artificial light intensity

The two major sources of light pollution, artificial daytime and colored light pollution, almost all come from artificial light, which greatly increases the degree of light pollution in the night sky. Therefore, we first select the intensity of artificial light as the light pollution evaluation index.

Using "pseudo-invariant pixels" Methods The DMSP-OLS data was calibrated, and considering the consistency of time resolution between DMSP-OLS data and SNPP-VIIRS data, the missing data in the original monthly SNPP-VIIRS data was repaired before the annual SNPP-VIIRS data was synthesized. In addition, an improved DMSP-OLS-like dataset was calculated by further combining the calibrated DMSP-OLS data and the DMSP-OLS-like data converted from the SNPP-VIIRS data.

Open the processed 2021 China DMSP-OLS night light data in ArcMap, add the vector range surface data of the selected city area, perform mask extraction processing, and then load the administrative division data of each district and county in the selected city, and use regional analysis Tools for data connection and visualization.

In order to avoid the interference of natural light at night (such as moonlight, starlight, or aurora in high-latitude regions, etc., natural light reflected from the surface), we define the pixel gray value <10 as natural light, and the pixel gray value >10 as artificial light. Calculate the sum of the gray value of the pixel points in the city > 10, and calculate the sum of the gray value of all pixels and that is the artificial light intensity.

2. Zenith brightness[10]

Since the brightness of the sky gradually extends from the horizon to the zenith, the higher the brightness of the zenith, the more serious the urban light pollution. Therefore, the brightness of the zenith can be used as one of the important indicators for evaluating light pollution.

We adopt the Treanor model.

$$P = \frac{L(r)}{L_N} = (\frac{A}{r} + B/r^2) \cdot e^{(-kr)} \tag{14}$$

$$A = 1.80 \times 10^{-5} \cdot p \text{ (p is the population of the city)} \tag{15}$$

$$B = 13.6 \times 10^{-5} \cdot p \text{(p is the population of the city)} \tag{16}$$

$$k = 0.026 \tag{17}$$

Among them, P is the ratio of the brightness of the zenith to the brightness of the natural sky; L(r) is the brightness of the zenith; L_N is the brightness of the natural sky; r is the distance between the light source and the observation point of the light source (km); A, B are observation constants, proportional to the urban population. (Because P is the brightness ratio, so here we take the relative amount, that is, L_N is 1.)

3. Glare

Glare is the most common type of light pollution in outdoor lighting. It is uncomfortable for observers due to too bright objects in the field of view, or too large brightness contrast in space and time.

In the quantitative evaluation of glare in this paper, the unified glare index (UGR) formula recommended by CIE is adopted for the assessment of glare caused by artificial light; To assess daylight the Daylight Glare Probability (DGP) formula.

UGR calculation formula is:

$$UGR = 8 \log_{10}(\frac{0.25}{L_b}) \sum_{i=1}^{n} \frac{L_i^2 \times wi}{Pi} \tag{18}$$

among them: L_b is the background brightness (unit cd/m2); L_i is the brightness of the i-th glare source (unit cd/m2); w_i is the solid angle of the i-th glare source; P_i is the position index of the i-th glare source .

The calculation formula of DGP is:

$$DGP = 5.87 \times 10^{-5} Ev + 9.81 \times 10^{-2} \log\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 w_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16 \tag{19}$$

among them, E_v is the vertical illuminance of the human eye (unit lux), L_s is the brightness of the glare source (unit cd/m2), a_s is the solid angle of the glare source, and P is the position index of the glare source.

4. The level of economic development

Urban areas are some of the most light-polluted places on Earth. The improvement of people's living standards and the increase in per capita consumption level have increased the pressure on the light environment and caused light pollution. From the Northeast Corridor from Boston to Washington, D.C., from London to Liverpool, to Beijing, Hong Kong, and Cairo, Egypt, it is difficult for people to see the Milky Way at night due to light pollution.As shown in Figure1, the level of social and economic development can be used as one of the evaluation indicators of light pollution, and we use GDP as the evaluation indicator of the level of social and economic development.

5. Population

As the population increases, the demand for resources will inevitably increase, which will also have an impact on the light environment. In densely populated areas, the intensity of artificial light will generally increase, and the corresponding light pollution will increase, such as Western Europe, the northeastern United States, and Shanghai and Sichuan in China. So we choose population as one of the indicators of light pollution.

Figure 1 China City GDP in 2021 (trillion yuan)

6. Climate

Sunlight exposure is the most basic factor in the formation of a local climate. The thermal energy of a beam of sunlight is fixed. When the sunlight hits the earth's surface vertically, the light is most concentrated, the surface is heated more, and the temperature of the climate becomes higher; When the light is concentrated, it may cause white light pollution, so here we choose climate as one of the evaluation indicators of light pollution from the perspective of natural light.

According to the relationship between climate and light, we choose the annual light time in different regions as the climate evaluation index.

7. Spatial Range Average Light Intensity

There is a certain degree of distinction between the average light intensity in the spatial range and the artificial light intensity. The calculation formula is:

$$\frac{Luminous\ intensity}{The\ total\ area} \tag{20}$$

3. Results

3.1. Analysis of the results of TOPSIS model based on entropy weight

We use the entropy weight method to deal with the seven indicators of artificial light intensity, Zenith Brightness, glare, Economic development level, Population, climate, and Average light intensity over the spatial extent. Based on five different cities, the weights of the seven evaluation indicators are obtained.

Figure 2 below is a schematic diagram of the lighting effect we have drawn.

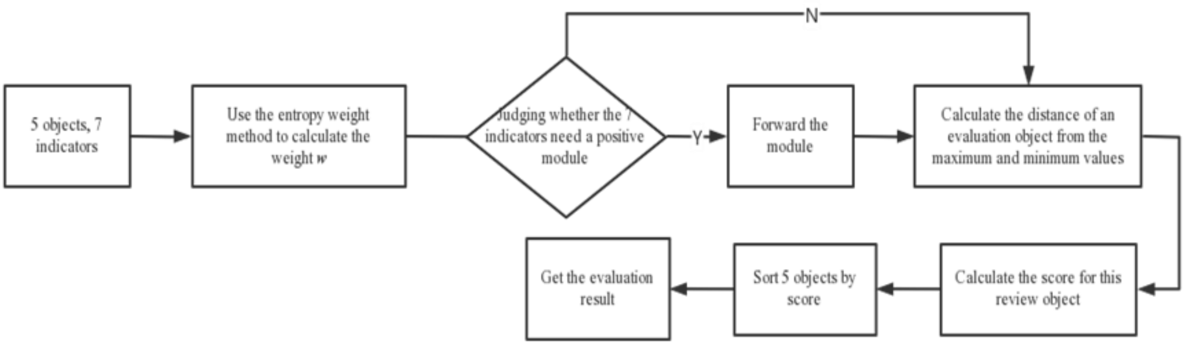

Figure 2 Schematic diagram of lighting effects

Table 1 Light Pollution Index System Data

City	artificial light intensity	Zenith Brightness	glare	Economic development level (trillion yuan)	Population (10,000 people)	climate (hours)	Average light intensity over the spatial extent
Shanghai	0.91876619	2.217158796	3.8	4.47	2489.4	1649.5	1.169856951
Beijing	0.768455199	0.822749836	5	4.16	2188.6	2667.2	0.448189397
Lhasa	0.006316163	0.015015742	6.7	3.24	1768.2	1608	0.014189001
Guangzhou	0.88251673	2.1244612	3.52	2.88	1881.1	1609.2	0.94507129
Chongqing	0.689850953	0.081950341	2.77	2.91	3213.3	961.1	0.052360076

Through Table 1, the calculation weights of artificial light intensity, zenith brightness, glare, economic development level, population, climate and spatial range average light intensity are calculated through the entropy weight method model as follows:

[0.09068247 0.21098113 0.16467623 0.09635267 0.09661156 0.13570024 0.20499571]

We substitute the weight into the TOPSIS model to analyze the five cities of Shanghai (As shown in Fig.3), Guangzhou (As shown in Fig.4), Chongqing (As shown in Fig.5), Lhasa (As shown in Fig.6) and Beijing (As shown in Fig.7) and get the final ranking of light pollution.

Table 2 Distance value and comprehensive value index

City	s0	s*	Comprehensive evaluation index f*
Shanghai	0.329444884	0.141197674	0.696044176
Beijing	0.233635846	0.200025035	0.542449312
Lhasa	0.145572738	0.337457103	0.332024721
Guangzhou	0.227542526	0.275504422	0.631191873
Chongqing	0.168911057	0.343428023	0.271893199

Figure 3 Comparison chart before and after treatment in Shanghai

According to the comprehensive index values in Table 2, we can conclude that the order of light pollution from strong to weak is Shanghai, Beijing, Guangzhou, Chongqing, and Lhasa. The following are the comparative analysis charts of Shanghai, Guangzhou, Chongqing and Lhasa before and after data processing.

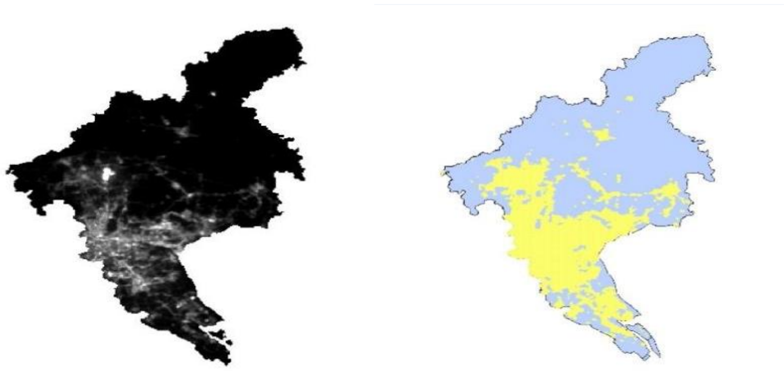

Figure 4 Comparison chart before and after treatment in Guangzhou

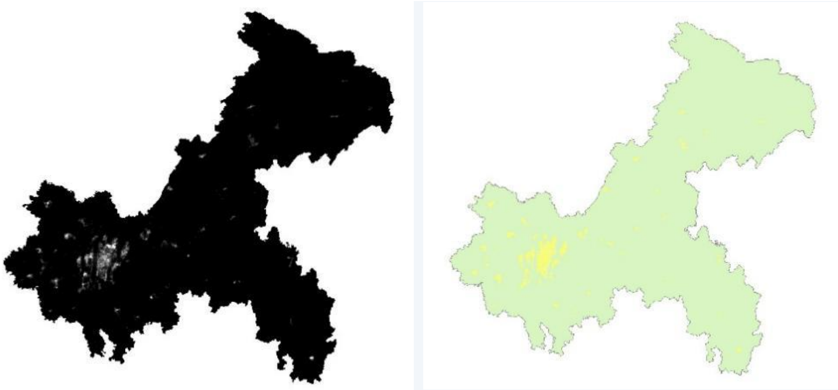

Figure 5 Comparison chart of Chongqing before and after treatment

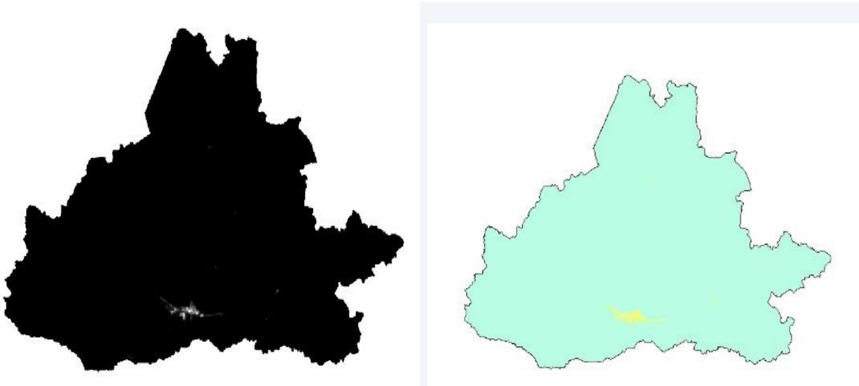

Figure 6 Comparison chart before and after Lhasa treatment

3.2. Analysis of light pollution in Beijing Based on the TOPSIS model of entropy weight

We still use the entropy weight method and the TOPSIS model. However, the indicator system and data have changed, which will be explained below.

Since the latitudes of the four different types of locations have little difference, and the outdoor light has little difference, the influence of glare and climate on light pollution is ignored.

On this basis, the brightness of the four areas in Beijing is divided, and each area must be illuminated within a certain period. What we need to calculate is the impact of excessive illumination. Therefore, according to the difference in data in the four regions, based on the model in the first question, the intensity of light pollution in each region can be calculated respectively, and then the impact of light that should be reduced should be reduced accordingly. Right now:

$$\beta_{actual} = \beta_{total} - \alpha_i \tag{21}$$

Among them, β_{total} represents the light pollution actually calculated, β_{actual} represents the actual risk of light pollution in the area, and α_i represents the light pollution that should be produced.

Table 3 Evaluation index data of four regions

area	artificial light intensity	Zenith Brightness	Economic development level (trillion yuan)	Economic development level (trillion yuan)	Economic development l evel (trillion yuan)
Yanqing District	0.030814577	1.66846E-05	204.7	34.6	4.51151711
Daxing District	0.318451613	0.00017459	1461.8	199.5	38.28375844
Changping District	0.153051083	0.000157577	1287	227	16.70919636
Chaoyang District	0.933638444	0.000596562	7911.2	344.9	98.0880853

We use the entropy weight method to process the five indicators of artificial light intensity, zenith brightness, economic development level (trillion yuan), economic development level (trillion yuan), economic development level (trillion yuan), and economic development level (trillion yuan). Based on the four regions of Beijing, the weights of the indicators are obtained:

[0.21479507 0.19048818 0.25500085 0.12183765 0.21787826]

Therefore, the light pollution measurement results from strong to weak are Chaoyang District, Daxing District, Changping District, and Yanqing District. (Because we included the excess light intensity, the result is a bit different.) Below we draw the corresponding regional GIS map for impact assessment.

Table 4 Distance value and comprehensive value index

area	s0	s*	Comprehensive evaluation index f*
Yanqing District	0	0.338987966	0
Daxing District	0.130517032	0.221045058	0.37124888
Changping District	0.13022098	0.24159854	0.350226314
Chaoyang District	0.338987966	0	1

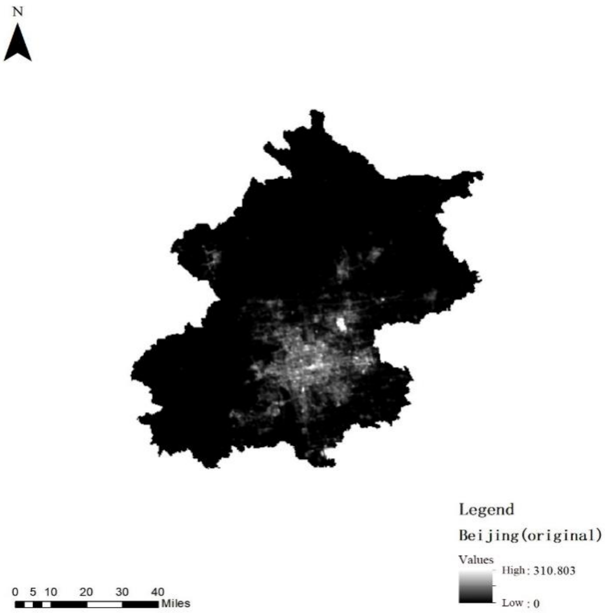

Figure 7 Beijing Regional GIS map before processing

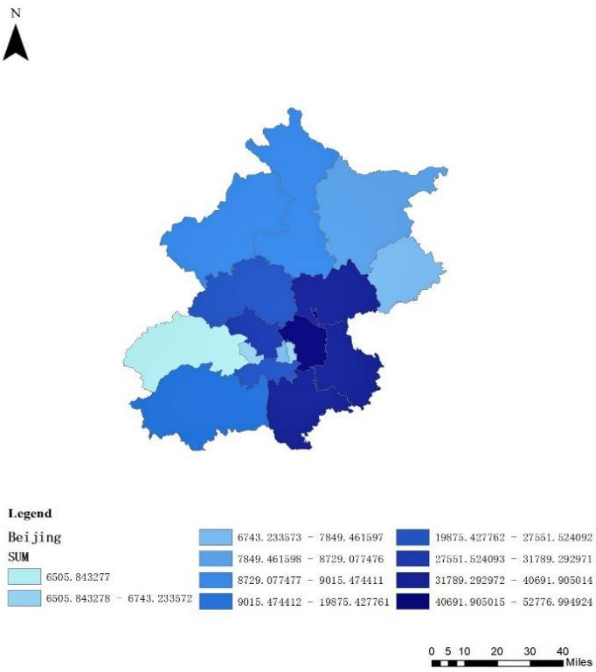

Figure 8 Beijing Regional GIS map after processing

4. Conclusions and outlooks

The evaluation of light pollution is a complex and important issue, that involves many aspects of the human living environment, health and natural ecology. Light pollution assessment mainly focuses on the negative effects of light on the environment and human life, including visual interference, biological clock disturbance, energy consumption and ecological environment damage. The classical evaluation method lacks the process of screening and quantifying the evaluation indicators, which affects the accuracy of the evaluation results. In this paper, the TOPSIS model based on entropy weight is used to construct the light pollution evaluation model. The experimental results show that the TOPSIS model based on entropy weight has good evaluation accuracy, can effectively analyze the problem of light pollution, and has certain practical application value.

This paper mainly discusses the TOPSIS model based on entropy weight to study the problem of light pollution. Due to technical problems and the limited ability of the author, the conclusions obtained are limited, and the research on the evaluation of light pollution is not deep enough. There are the following problems: The calculation formula is simplified when quantitative analysis is performed for quantitative analysis, and some conditions are ignored, which has a certain impact on the model results. TOPSIS model can only reflect the relative closeness within each evaluation object, and it cannot reflect the relative approach of the best solution to the ideal. The sensitivity is not high.

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