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Study on the risk level assessment of light pollution based on entropy power method

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Abstract: *As the harm of light pollution to human life and ecological systems becomes increasingly severe, the control of light pollution has attracted more and more attention. To accurately measure the risk level of light pollution, an evaluation model was established. Firstly, four indicators that affect the degree of light pollution were identified, and a topsis model based on entropy weight method was used to calculate the scores of 9 cities for ranking and comparison with the actual rankings. The final result showed that the two rankings were close, indicating that the evaluation model is reasonable and the weights of the four indicators are as follows: electricity consumption: 0.2982, vegetation coverage rate: 0.1903, population: 0.3150, gross domestic product: 0.1964.*

Keywords: *Topsis, Entropy weight method, Light pollution*

1. Introduction

With the rapid development of human society's productivity, especially since the Industrial Revolution, the rapid development of science and technology has brought tremendous material wealth to human society. However, at the same time, the resulting environmental problems have become increasingly serious, making environmental pollution a hot topic of global concern in recent years[1-2]. Environmental problems refer to environmental damage and changes in environmental quality caused by natural changes or human activities, as well as the adverse effects on human survival and development caused by these changes[3]. In fact, since the beginning of human civilization, environmental pollution has been a difficult social problem to solve. Especially in modern times, the development of science and technology has brought many new forms of environmental pollution[4-5]. Any excessive or improper use of artificial light gradually affects our lives and changes the environment on which we depend[6]. Some phenomena known as light pollution include light intrusion, excessive illumination, and light clutter. Light pollution, a seemingly unfamiliar term for many people, has actually become a new type of environmental pollution that is increasingly invading daily life. Light pollution not only obscures brilliant starlight, but also increases energy consumption, harms human physical and mental health, creates traffic safety hazards, and subverts the natural growth laws of organisms, destroying ecological balance. Therefore, this article is willing to establish a rating system to evaluate the level of light pollution risk at a given location[7-8].

2. The topsis model based on the entropy weight method

2.1 The Foundation of Model

Table 1: Indicators and Indicator Types

Lever 1 indicators	Secondery indicators	Indicator type
environment	vegetation coverage rate	Very large Indicator
Urban performance	gross domestic product	Very small Indicator
	electricity consumption	Very small Indicator
	population	Very small Indicator

After reviewing relevant literature, we have established the following five indicators that can affect the level of light pollution in an area[9-10]. Indicators and Indicator Types are shown in table 1.

2.1.1 Model Establishment

The specific modeling process is as follows:

Step 1: First, the original data matrix is normalized to a uniform indicator type and subjected to forward normalization to obtain a normalized matrix."

(1)Maximal-type indicators remain invariant.

(2)Transforming minimal-type indicators into maximal-type indicators through $\max - y$ transformation.

Step 2: Quantification of light pollution levels in 9 cities was carried out using a system based on four evaluation indicators. The normalized matrix of each of the 4 indicators corresponding to the 9 cities is as follows:

$$Y = \begin{bmatrix} y_{1,1} & y_{1,2} & \cdots & y_{9,4} \\ y_{2,1} & y_{2,2} & \cdots & y_{9,4} \\ \vdots & \vdots & \ddots & \vdots \\ y_{9,1} & y_{9,2} & \cdots & y_{9,4} \end{bmatrix} \tag{1}$$

The normalized matrix is further standardized, and the resulting standardized matrix is denoted as M . Each element of M is:

$$m_{pq} = \frac{y_{pq}}{\sqrt{\sum_{p=1}^{9} {y^2}_{pq}}} \tag{2}$$

To judge whether there is a negative number in the matrix M , if so, it is necessary to use another normalization method for Y to standardize the matrix $\widetilde{M}$ once and obtain the matrix. The normalization formula is as follows:

$$\widetilde{m}_{pq} = \frac{y_{pq} - \min\{y_{1,q}, y_{2,q}, \cdots y_{9,q}\}}{\max\{y_{1,q}, y_{2,q}, \cdots, y_{9,q}\} - \min\{y_{1,q}, y_{2,q}, \cdots y_{9,q}\}} \tag{3}$$

At present, there are 9 objects to be evaluated and 4 evaluation indicators, and the non-negative matrix is obtained after processing in the previous step:

$$\widetilde{M} = \begin{bmatrix} \widetilde{m}_{1,1} & \widetilde{m}_{1,2} & \cdots & \widetilde{m}_{1,4} \\ \widetilde{m}_{2,1} & \widetilde{m}_{2,2} & \cdots & \widetilde{m}_{2,4} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{m}_{9,5} & \widetilde{m}_{9,5} & \cdots & \widetilde{m}_{9,4} \end{bmatrix} \tag{4}$$

Calculate the probability matrix, where each element in W is calculated by the following formula:

$$w_{pq} = -\frac{\widetilde{m}_{pq}}{\sum_{p=1}^{9} \widetilde{m}_{pq}} \tag{5}$$

Easy to verify:: $\sum_{p=1}^{n} w_{pq} = 1$, the sum of the probabilities corresponding to each index is guaranteed to be 1.

For the index ranked p, the formula for calculating its information entropy is:

$$e_j = -\frac{1}{\ln n}\sum_{p=1}^{9} w_{pq}\ln(w_{pq}) \tag{6}$$

Define: $d_q = 1 - e_p$, the larger the information utility value, the more information it corresponds to. By normalizing the information utility value, we can get the entropy weight of each indicator:

$$W_p = \frac{d_p}{\sum_{j=1}^{m} d_p}(j=1,2,\cdots,m) \tag{7}$$

Thus, the weights of each indicator are shown in the table 2:

Table 2: Index Weight

Secondery indicators	vegetation coverage	gross domestic product	electricity consumption	population
index weight	0.1903	0.1964	0.2982	0.3150

Step 3: To evaluate and rank multiple options, first identify the best and worst options among them. Then, calculate the distances between each evaluation object and the best and worst options, obtaining the relative closeness of each evaluation object to the best option. This serves as the basis for evaluating the quality of the options. After weighting the evaluation criteria, calculate the score and normalize it.

$$Z = \begin{bmatrix} z_{1,1} & z_{1,2} & \cdots & z_{1,4} \\ z_{2,1} & z_{2,2} & \cdots & z_{2,4} \\ \vdots & \vdots & \ddots & \vdots \\ z_{9,1} & z_{9,2} & \cdots & z_{9,4} \end{bmatrix} \tag{8}$$

Define maximum:

$$\begin{aligned} Z^+ &= (Z_1^+, Z_2^+, \cdots, Z_m^+) \\ &= (\max\{z_{11}, z_{21,} \cdots, z_{n1}\}, \max\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, \max\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) \end{aligned} \tag{9}$$

Defined minimum:

$$\begin{aligned} Z^- &= (Z_1^-, Z_2^-, \cdots, Z_m^-) \\ &= (\min\{z_{11}, z_{21,} \cdots, z_{n1}\}, \min\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, \min\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) \end{aligned} \tag{10}$$

Define the distance between the ith ($i=1,2,\cdots n$) evaluation object and the maximum value

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\omega_j(Z_j^+ - z_{ij})^2} \tag{11}$$

Define the distance between the ith ($i=1,2,\cdots n$) evaluation object and the minimum value

$$D_i^- = \sqrt{\sum_{j=1}^{m}\omega_j(Z_j^- - z_{ij})^2} \tag{12}$$

Then, we can calculate the unnormalized score of the ith ($i=1,2,\cdots n$) evaluation object:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{13}$$

The result can be obtained by normalization.

3. Results

After the above steps, the development index of modern service industry in each region and its ranking are calculated, as shown in Table 3.

Table 3: Light Pollution Ranking of Urbans

Urban	BeiJing	ShangHai	JiangShu	ZheJiang	TianJiang	HuBei
Light Pollution Ranking	1	2	3	4	5	6
Urban	HeNan	ShanDong	FuJian			
Light Pollution Ranking	7	8	9			

Luojia 1 can directly obtain remote sensing image data of the earth surface. According to the remote sensing data of the satellite, the radiation brightness ranking and value of ten regions can be obtained, and the light pollution situation of ten regions can be directly reflected. The color map in the lower right corner represents the degree of light pollution, and the degree of pollution decreases gradually from dark to light. Intuitive map of China's radiance is shown in figure 1.

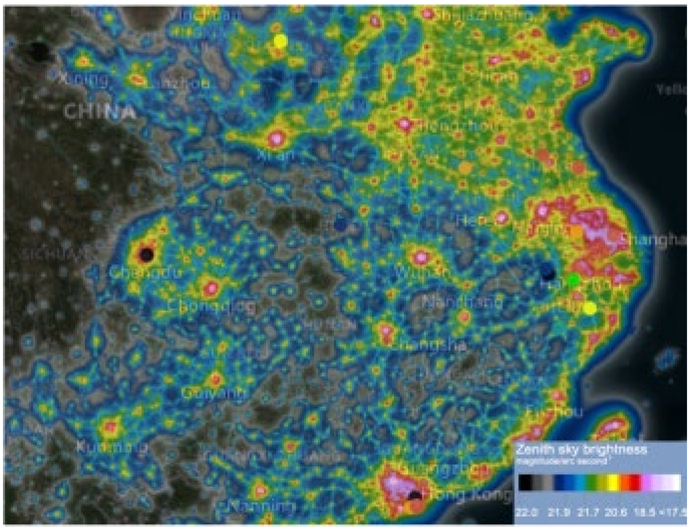

Figure 1: Intuitive map of China's radiance

The radiation brightness conversion formula of Luojia No. 1 product is as follows:

$$L = DN^{3/2} \cdot 10^{-10} \tag{14}$$

In the formula, L is the radiation brightness value after absolute radiation correction, and the unit is $W/(m^2 \cdot sr \cdot \mu m)$, which is the gray degree of the image. The radiation brightness values and rankings of ten cities including Shanghai are shown in the following table 4.

Table 4: The urban's radiance value and ranking

Urban	BeiJing	ShangHai	ZheJiang	TianJiang	JiangShu
Radiance value	33.4	30.9	23.3	22.2	21.6
ranking	1	2	3	4	5
Urban	HeNan	HuBei	ShanDong	FuJian	
Radiance value	20.02	19.5	14.85	9.46	
ranking	6	7	8	9	

Comparison of the rankings of urban radiation brightness values and light pollution shows that there may be some discrepancies between the results obtained from the code and the actual results when using the TOPSIS method based on entropy weight to determine the ranking of light pollution levels for the 9 cities. For instance, JiangShu ranks 5th in radiation brightness but 3th in light pollution level. The reasons for this may be as follows:

Firstly, the local government in JiangShu strictly implements environmental protection policies and actively responds to climate change, while also strictly controlling excessive electricity consumption (EC). These measures can all affect the local light pollution level.

Secondly, the actual level of light pollution should be influenced by many different factors, while the model is relatively ideal and only considers 4 indicators, ignoring factors such as light radiation levels, the number of modern buildings with LED screens in the area, or weakly correlated factors such as local temperature and geographic location.

4. Conclusions

As the harm of light pollution to human life and ecological systems becomes increasingly severe, the control of light pollution has attracted more and more attention. This article mainly studies the evaluation methods for the degree of light pollution.To solve this question, an evaluation model was established. Firstly, four indicators that affect the degree of light pollution were identified, and a topsis model based on entropy weight method was used to calculate the scores of 9 cities for ranking and comparison with the actual rankings. The final result showed that the two rankings were close, indicating that the evaluation model is reasonable and the weights of the four indicators are as follows: electricity consumption (EC): 0.2982, vegetation coverage(VC) rate: 0.1903, population(PO): 0.3150, and gross domestic product(GDP): 0.1964.

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