

A study of light pollution based on TOPSIS model

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Abstract. Light pollution is a growing environmental problem that has a significant negative impact on humans and wildlife. In order to cope with this problem, a light pollution risk assessment model is developed in this paper. This model is built by the TOPSIS model and coefficient of variation method, by carefully selecting evaluation indicators and using statistical methods to determine their weights. After the solution, it was found that the distribution density of light pollution sources, population density, and biodiversity has the greatest influence on light pollution. To evaluate the effectiveness of the model, this paper applies it to 30 cities in China. Finally, it was found that the highest light pollution levels were found in suburban and urban areas, while the lowest light pollution levels were found in protected areas. However, in Inner Mongolia, the risk of light pollution was higher in rural areas than in urban and suburban areas. This finding emphasizes the importance of considering regional differences when developing mitigation strategies. Based on the findings of this paper, it is recommended that the density of light pollution sources be adjusted to mitigate its impact while focusing on urban and suburban areas. Overall, the light pollution risk assessment model developed in this paper is a valuable tool for policymakers and researchers to better understand the impacts of light pollution and develop effective mitigation strategies. Finally, this paper also conducts model extensions and evaluations.

Keywords: Light Pollution, TOPSIS model, coefficient of variation method

1. Introduction

Unlike common pollution such as waste water and waste residue, light pollution is a new type of environmental pollution source. Light pollution not only wastes many available resources but also has an impact on human physiological and psychological health. According to statistics, light pollution in every country is growing year by year, and the trend is getting more and more serious. More than 90% of light pollution comes from artificial light sources, which will have a great impact on people's lives. The problem in China is not very serious, but as a large population country, the harm of light pollution is obvious and is increasing and spreading^[1]. Therefore, a better understanding of the health threats induced by light pollution can contribute to risk assessment and better regulation of artificial lighting, leading to a healthy lighting environment^[2].

There are many examples of studies on light pollution, and some researchers have found through a review of light pollution data analysis that a significant number of studies have focused on ground-based observations at the expense of data analysis. And data analysis, as an integral part of efforts to understand light pollution, needs to be used effectively by all stakeholders in the pursuit of sustainable development^[3]. For data processing, machine learning is mostly an effective approach in many cases, for example, Velasque M, Denton J A, and Briffa M^[4] used a Bayesian mixture model to estimate mean behavioral changes as well as inter- and intra-individual bilevel responses to laboratory light when studying the effects of constant light on the personality traits and metabolism of European hermit crabs variation. The experimental results showed that light had no effect on the consistency of individual behavior, while boldness was related to light pollution risk levels. Li Jiayi, Xu Yongming, Cui Wei Ping, Wu Yu Yang, Wang Jing, Su Bo Yang, and Ji Meng^[5] monitored nocturnal light pollution in Nanjing based on Liaojia 1 night light remote sensing imagery. The nighttime pollution distribution in Nanjing was monitored based on the nighttime remote sensing images of LuoJia-1 and obtained after the field study and the calculation of various empirical models. The results showed that the areas with serious light pollution were mainly concentrated in the main urban area and decreased from the main urban area to the surrounding area, while the light pollution level in the suburban areas

was relatively weak. Hao Qing li^[6] explored the multidimensional real measurement and remote sensing digital cooperative observation of the nighttime light environment, constructed a spatial light environment model, and analyzed the light environment distribution characteristics of different types of areas in order to achieve the prevention and control of light pollution. Lei Qing Hua^[7] built an experimental environment for a curved immersive projection system to solve the "light pollution" problem in the immersive projection system, studied the basic principles of the light pollution phenomenon, and proposed a light pollution compensation algorithm for the curved projection system. After the model is built, we also need to evaluate the results to test the model, which makes it more important to define a general index that can be used to describe light pollution^[8]. Li Xue-ting, Liu Bu Yun, and Jin Jie^[9] introduced the hazards of light pollution from glass curtain walls, analyzed the influencing factors of light pollution from glass curtain walls, and proposed several specific measures to prevent light pollution. Zhou Zu Tong^[10] drew on the experience of foreign legislation to prevent and control light pollution, and combined with the actual situation in China, proposed a strategy to formulate the Light Pollution Prevention and Control Law. In this paper, thirty major cities in China are selected, and then four sub-districts in the cities are selected to measure the light pollution risk level with a light pollution score; the higher the score of an area, the higher its light pollution risk level. In terms of method selection, this paper differs from the machine learning approach and instead uses the traditional evaluation model approach to calculate the light pollution score of an area and measure the light pollution risk level of the area.

2. Model development and solution

2.1. Establishment of evaluation index system

In this paper, through the collection of satellite data of Luojia-1, we have selected the more representative indicators and established an index system to evaluate light pollution. The specific results are shown in Table 1.

Table 1. Evaluation Indicators

First Grade Index	Symbol Station	Second Grade Index	Symbol Notation	Effect	Weight
Light pollution source	X_1	1. Light intensity	X_{11}	+	0.104
		2.Light pollution source distribution density	X_{12}	+	0.198
Environmen-tal factors	X_2	3.Co ₂ concentration	X_{21}	+	0.112
		4.Bio-diversity	X_{22}	-	0.181
		5.Area	X_{23}	+	0.042
Socio- economic factors	X_3	6.Greening coverage	X_{24}	-	0.05
		7.Population density	X_{31}	+	0.184
		8.GDP	X_{32}	+	0.125

2.2. Correlation Analysis

In order to exclude the influence of too high a correlation between model indicators on the final results of the model, correlation analysis was also performed on the selected indicators in this paper, and the correlation results are presented in Figure 1.



Figure 1. Correlation analysis chart of various indicators

2.3. Model building

The main method used in this paper is the TOPSIS method combined with the coefficient of variation method. Based on the index system already established above, eight evaluation indicators (all normalized) were identified, which are known to constitute the normalization matrix.

$$\begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{18} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{28} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{i8} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{m8} \end{pmatrix} \quad (1)$$

2.3.1 Coefficient of variation method

- (1) Calculate the mean and variance of indicators from the forwarding matrix.

$$\bar{x}_i = \frac{1}{n} \sum_{j=1}^n a_{ij}, s_i^2 = \frac{1}{n-1} \sum_{j=1}^n \left(a_{ij} - \bar{x}_i \right)^2 \quad (2)$$

- (2) Let $v_i = \frac{s_i}{|\bar{x}_i|}$, then the normalized is the weight of each indicator, that is

$$\omega_i = \frac{v_i}{\sum v_i} \quad (3)$$

From this, we can derive the weights of each indicator $(\omega_1 \dots \omega_8)$.

2.3.2 TOPSIS method

Step1. The polarity and extreme value of evaluation indexes are processed to obtain the normalized matrix A.

Light intensity, light pollution source distribution density, regional area, CO2 concentration, population density, and GDP belong to extremely large sizes, and green coverage and biodiversity belong to extremely small sizes. The evaluation indexes are subjected to extreme value processing, while the polarity processing is performed afterward to obtain the normalized matrix A of the evaluation indexes.

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad (4)$$

Step2. Construct the weighted norm matrix Z

The weight vector was obtained based on the coefficient of variation method.

$$\omega = \{\omega_1, \omega_2, \dots, \omega_8\} \quad (5)$$

$$z_{ij} = \omega_j \cdot a_{ij}$$

Step3. Determine the positive ideal solution and negative ideal solution

Let the positive ideal solution be, and the negative ideal solution be, then the comprehensive evaluation value is

$$D_i^+ = \sqrt{\sum_{j=1}^m (z_j^+ - z_{ij})^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^m (z_j^- - z_{ij})^2} \quad (7)$$

At this point, the greater the various indicators, the closer the state of the evaluated area is to the negative ideal value, and the greater the comprehensive evaluation value obtained, that is, the higher the level of light pollution risk in this area, and vice versa, the lower.

2.4. Solving of the model

2.4.1 Data Analysis

In the solution of the model, this paper adopts the method of TOPSIS combined with the coefficient of variation, first using the coefficient of variation to determine the weights of indicators, and then using the TOPSIS method to determine the risk of light pollution.

With the help of the China Bureau of Statistics and satellite remote sensing data, thirty cities in China are selected in this paper and substituted into the model developed above to obtain the scores of each of the thirty cities. The results of the scores are shown in Figure 2.

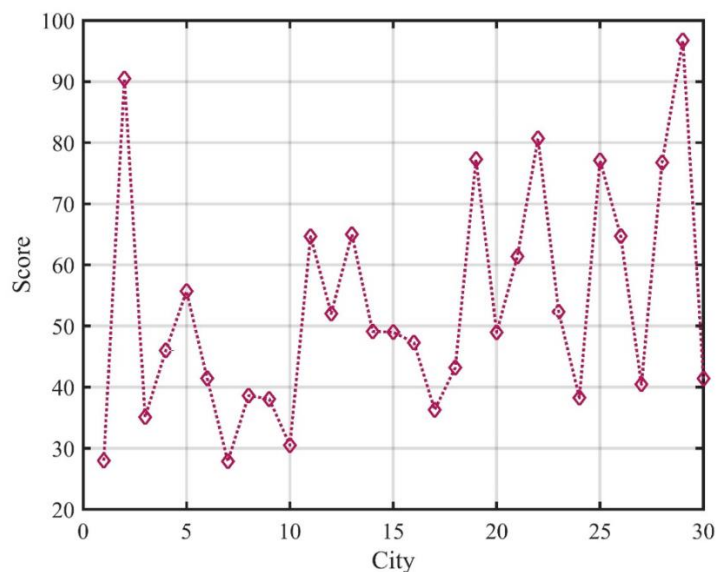


Figure 2. Data Analysis

From the above figure, it can be seen that for cities in different regions, their light pollution risk levels show significant differences, thus the validity of the model can be verified. Besides, after calculating the weights, we get the light pollution source distribution density of 0.198, the population density of 0.184, and the biodiversity of 0.181, which have a greater impact on the light environment.

3. Case study

According to the "Tianjin residential area night light pollution evaluation system" [1] literature, the residential environment is evaluated in layers and levels and tested, we are now four levels of the atmosphere throughout the country according to the economic level, from each level to select a city, the city's "protected land" "rural" "suburban" "urban" light pollution degree analysis, the results are shown in Figure 3.

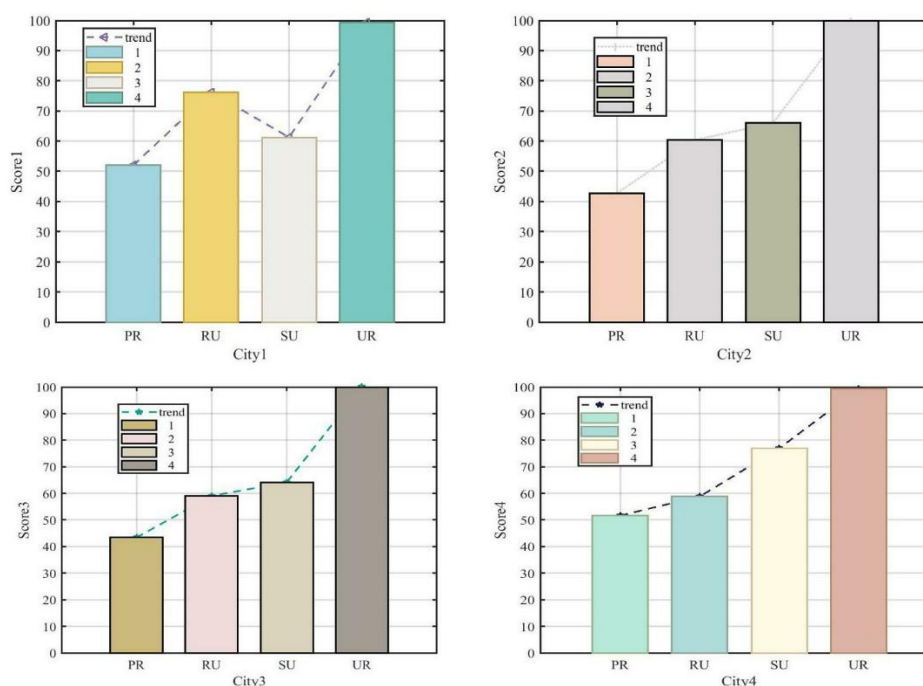


Figure 3. Results of light pollution risk levels in four areas of four cities

As can be seen from Figure 6, the comparison of light pollution risk in most cities is: "protected land" < "rural communities" < "suburban communities" < "urban communities", but in

City1"protected land" "rural communities" "suburban communities" "This indicates that the risk level of light pollution in rural communities sometimes exceeds the risk level in suburban communities. This reflects the fact that remote areas may also have higher levels of light pollution risk.

4. Conclusions

The main method used in this paper is TOPSIS combined with the coefficient of variation to determine the risk level of light pollution in different regions. Firstly, the data of indicators in thirty major cities in China were selected and substituted into the above method, and after calculating the weights, we got the light pollution source distribution density of 0.198, the population density of 0.184, and biodiversity of 0.181, which have a high impact on the light environment. Then four different areas in four of the cities were selected: protected locations, rural communities, suburban communities, and urban communities. Finally, it was calculated that by and large, the protected location had the lowest level of light pollution risk and the urban community had the highest level of light pollution risk, which indicates that the level of light pollution risk is highly related to the level of development of an area, and the country can focus on these areas when solving the light pollution problem. However, in Inner Mongolia, the results of higher light pollution risk levels in rural communities than in suburban communities were obtained, which indicates that light pollution in less developed areas cannot be ignored. This paper proposes a model for solving a problem using the coefficient of variation and TOPSIS methods. The model offers several advantages, such as transforming qualitative analysis into quantitative analysis, considering more factors that influence light pollution, and providing precise and practical results. However, the model has limitations in reflecting the gap with the ideal environment and being limited by space and data collection. Therefore, to extend the model to other places, indicators may need to be added or deleted.

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