# Research on Comprehensive Evaluation Model of Light Pollution Based on Entropy Weight Method

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**Abstract.** With the development of urbanization, light pollution has become a serious problem that needs the public to pay attention. In this paper, the factors that affect the degree of light pollution are summarized. As a result, 9 evaluation indicators are selected, and the entropy weight method is used to objectively weigh the selected indicators. Among them, the impact range of curtain walls and the lightness of LED screens occupy the largest weight. Then, by introducing the degree of coordinated development and considering the interaction among various indexes, a widely applicable evaluation model of light pollution degree was established. The model is used to evaluate the degree of light pollution in different regions while Beijing was used as an instance in this paper. It is found that the economic development level of the region is positively correlated with the degree of light pollution. Aiming at the increasingly serious problem of light pollution in the world, the model established in this paper not only provides a new idea for evaluating the degree of light pollution in each region but also defines the level of light pollution, which is helpful to solve the problem of light pollution on a global scale.

**Keywords:** Light Pollution, Entropy Weighted Method, Comprehensive Evaluation Model.

## 1. Introduction

Light pollution, also known as "visual pollution", is a new kind of environmental pollution after the four major environmental pollutants, and will have a great impact on people's vision, sleep cycle, and so on. Therefore, as early as the 1990s, relevant scholars put forward light pollution and the detection and protection of the night sky. With the development of urbanization, various forms of light pollution and the rating of local light pollution have become the first step to controlling and alleviating light pollution.

At present, there are relevant studies on the evaluation system of light pollution in China, but they are different in the selection of evaluation indicators and measurement methods.

For example, through field investigation, experimental simulation, and neural network simulation, Liu Ming[1] [2]et al. established an evaluation research system for urban lighting light pollution. Six evaluation indexes and seven technical monitoring indexes were adopted to comprehensively evaluate and analyze the degree of urban light pollution. To quantify the extent of light pollution, Yali Katz et al. used a sky quality meter and compared it with EROS-B images to analyze the correlation between the two[3].

Based on the seriousness of light pollution and the differences and similarities between the comprehensive evaluation indexes and prediction analysis models of light pollution by many scholars, nine indexes including glass curtain wall, visibility, average sunshine duration, and LED lighting in cities are selected as the basis of the model establishment from five levels including residents and buildings, and a comprehensive evaluation model of light pollution based on entropy weight method is established. The model can be consistent in most areas.

## 2. Literature review

With the rapid development of the global economy and the promotion of urbanization, the problem of light pollution is becoming more and more serious. However, the current evaluation system for

light pollution is not complete, and there is no unified standard. Therefore, it is necessary to establish a widely applicable light pollution evaluation system.

To solve this problem, many scholars have done relevant research on the evaluation model of light pollution. Ying et al (2021). [4], through the recognition method of deep learning, selected indicators such as the area and brightness of the light source carried out a multi-level analysis of the light pollution data of a fixed area and established a light pollution evaluation model for glass curtain walls. Chen (2020) [5] et al. established a comprehensive evaluation model to evaluate the water environment of the Three Gorges Reservoir by optimizing the fuzzy evaluation method and adjusting the weights of evaluation indicators by using the analytic Hierarchy Process (AHP) -entropy weight method, which provided a new idea for us to establish the evaluation model of light pollution. Tong (2022) [6] et al. selected the vertical and horizontal illuminance of street lamps as the evaluation index of the spatial impact of light pollution and predicted the impact of the change of lighting mode on the overall light pollution level. Li (2022) [7] et al. established a variety of empirical models to calculate nighttime environmental illumination based on remote sensing influence data of Luojia No. 1, which provided scientific guidance for the accurate detection of light pollution.

## 3. Data selection and processing

Based on theoretical analysis and combined with data availability, we identified the following indicators and processing methods.

Five aspects need to be considered, namely commercial activity, transportation activity, construction light pollution, light pollution in residential zones, and natural factors. Meanwhile, we choose nine indicators to comprehensively. This is shown in the following table 1.

**Table.1.** Selection of indicators

| Indicator | Symbol |
|---|---|
| The reflectivity of glass curtain wall | $X_1$ |
| Impact range of curtain wall | $X_2$ |
| Important Illumination Factor | $X_3$ |
| Average illumination on the pavement | $X_4$ |
| Average road brightness | $X_5$ |
| The brightness of advertising light box | $X_6$ |
| The brightness of LED screens | $X_7$ |
| Visibility | $X_8$ |
| Mean Light Duration | $X_9$ |

Commercial activity can produce light pollution by using tons of LED lights, and billboards. According to the data, a concert with an idol requires millions of support lights and lots of LED lights[8], which can make contributions to light pollution, thus commercial activity is an important aspect we should consider. We use 2 indicators, which include the brightness of the advertising lightbox and LED screens, to illustrate the location's light pollution caused by commercial activity.

Transportation is also a factor in light pollution. Pavement illumination uniformity is one of the road lighting evaluation indexes, which refers to the ratio of minimum illumination to average illumination on the pavement. Furthermore, Average road brightness can also reflect the situation of road brightness. We choose these two indicators because of their availability, as well as representativeness.

During the process of urbanization, the construction of buildings can also lead to lots of light pollution, especially through the glass reflection. Thus, we use the reflectivity of glass curtain walls[9]and the impact range of curtain wall light pollution to indicate this factor comprehensively.

However, the most general light pollution is produced in our residential zones, our daily lives are filled with light and illumination. Important illumination factors can represent the different extents of brightness in our daily life, hence we combine this indicator in our model[10].

As for the natural indicators, several important indexes can directly have an impact on the locations' level of light pollution (visibility, mean sunshine duration, and so on). Because of the different sunshine duration, every area would use the night light a different times. Meanwhile, lower visibility of air may lead to serious light pollution.

## 4. Entropy Weight Method

### 4.1. Establish a raw data matrix

After collecting the data from various indicators, a spatial matrix S is established, which consists of n regions and m indicators.

$$C = \left[C_{ij}\right]_{n\times m}, i = 1.2.3\cdots n, j = 1,2,3\cdots m \tag{1}$$

### 4.2. Dimensionless

Before the operation, the data is dimensionless according to the range method to make it have a unified standard. First, the maximum and minimum values of various indicators are differentiated to obtain the difference. Second, let each indicator differ from the corresponding minimum value, and then divide by the calculated difference.

If the indicator is positive, use the following formula for dimensionless processing:

$$X'_{ij} = \frac{c_{ij}-min(c_j)}{max(c_j)-min(c_j)} \tag{2}$$

If the indicator is negative, the following formula is used for dimensionless processing:

$$X'_{ij} = \frac{max(c_j)-c_{ij}}{max(c_j)-min(c_j)} \tag{3}$$

Among them, $X_{ij}$ is the original data corresponding to the $j^{th}$ index in the $i^{th}$ region, and $X'_{ij}$ is the result of dimensionless processing of the data corresponding to the $j^{th}$ index of the $i^{th}$ region. $max(C_j)$ and $min(C_j)$ are the maximum and minimum values in the corresponding data of various indicators, respectively.

### 4.3. Determine metric weights

The entropy weight method is a method to objectively assign weight to the index system by using known data in statistics. Its principle is that the smaller the variation degree of the index, the less information reflected, and the lower the corresponding weight value. In this method, according to the dispersion degree of the data of each index, the entropy weight of each index is calculated by using the information entropy, and then the entropy weight is modified to a certain extent, so as to obtain a relatively objective index weight.

This paper uses the entropy weight method to determine the weight and uses the information entropy to calculate the entropy weight of each index according to the discreteness of each index data, which is an objective empowerment method and will not be affected by subjective factors. The specific steps are as follows.

Calculate the ratio of the indicator value to the indicator sum ($Y_{ij}$)

$$Y_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}}, 0 \le Y_{ij} \le 1 \tag{4}$$

Solve for the entropy value of the $j^{th}$ indicator($e_j$)

$$e_j = -\frac{1}{ln(m)}\sum_{i=1}^{m}\left(Y_{ij} \times ln\left(Y_{ij}\right)\right) \tag{5}$$

Calculate the value of indicator j ($d_j$)

Because the smaller the entropy value, the greater the difference between indicators, the calculated $e_j$ needs to be processed to obtain the $j^{th}$ index value $d_j$

$$d_j = 1 - e_j \tag{6}$$

Calculate the weight of each indicator

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{7}$$

Using the above formula, the weights corresponding to the 9 indicators can be obtained through MATLAB calculation, this is shown in Table 2.

**Table.2.** Entropy Weight of Each Indicator

| Indicator | Symbol | Weight |
|---|---|---|
| The reflectivity of glass curtain wall | $X_1$ | 0.128 |
| Impact range of curtain wall | $X_2$ | 0.152 |
| Important Illumination Factor | $X_3$ | 0.142 |
| Average illumination on the pavement | $X_4$ | 0.073 |
| Average road brightness | $X_5$ | 0.077 |
| Brightness of advertising lightbox | $X_6$ | 0.142 |
| Brightness of LED screens | $X_7$ | 0.208 |
| Visibility | $X_8$ | 0.017 |
| Mean Light Duration | $X_9$ | 0.061 |

## 5. Synthetical Model Establishment

### 5.1. Analyze the coordinated development relationship between various indicators

The composite index that defines the glass reflection of the building exterior wall is $\{a_1, a_2, \cdots a_m\}$. The comprehensive evaluation index of residential areas is $\{b_1, b_2, \cdots b_n\}$.

The comprehensive evaluation index of the road area is $\{c_1, c_2, \cdots c_p\}$. The overall evalua tion index of the commercial areas is $\{d_1, d_2, \cdots d_q\}$.The comprehensive evaluation index of natural environment is $\{z_1, z_2, \cdots z_r\}$.

Overall, the evaluation function can be illustrated as followed

$$f(a) = \sum_{i=1}^{m} w_i \times a_i' \tag{8}$$

$$f(a) = \sum_{i=1}^{m} w_i \times a_i' \tag{9}$$

$$h(c) = \sum_{k=1}^{p} w_k \times c_k' \tag{10}$$

$$g(d) = \sum_{l=1}^{q} w_l \times d_l' \tag{11}$$

$$S(e) = \sum_{t=1}^{r} w_t \times e_t' \tag{12}$$

### 5.2. Calculate the coordination degree of the model

Firstly, we use **C** to define the coordination degree, so that we can ensure that the coordination degree derived from the established model is hierarchical.

$$C = \Big\{f(a) \cdot y(b) \cdot h(c) \cdot g(d) \cdot S(e) \cdot \left[\left(f(a) + y(b) + h(c) + g(d) + S(e)\right)/3\right]^{-5}\Big\}^{\gamma} \tag{13}$$

C is the value of the coordination degree between the indicators, and the value range is [0,1], $\boldsymbol{\gamma}$ is the coordination degree. Its value is equal to the number of subsystems studying the coordination relationship.

### 5.3. Establish a coordinated development degree

Due to the complex coordination relationship between multiple subsystems, the degree of coordination cannot reflect the regional light pollution level in some cases, so it is necessary to establish an indicator that can measure the degree of development, that is, the degree of coordinated development, and the calculation formula is as follows.

$$T = \alpha f(a) + \beta y(b) + \gamma h(c) + \delta g(d) + \varepsilon S(e) \tag{14}$$

$$S = \sqrt{CT} \tag{15}$$

Because the five subsystems have similar effects on the evaluation of light pollution levels, so $\alpha = \beta = \gamma = \delta = \varepsilon = 1/5$, S is the degree of coordinated development, the value range is [0,1].

## 6. Result

Use Beijing as an example, the result of Beijing is followed(Table. 3.):

**Table.3.** Sample Result

| Area | S | Rank |
|---|---|---|
| Central City | 0.9914 | 1 |
| Suburb of the city | 0.3019 | 2 |
| Countryside around Beijing | 0.1856 | 3 |
| Protected Land | 0 | 4 |

Our model can be visualized by the map, here is whole result of China:

Firstly we found that economic development may be the most relevant factor affecting the level of light pollution. Areas like the Chaoyang district of Beijing, and the Pudong districts of Shanghai, which have the highest GDP of the city, are more probably leads to serious problems.

Of the 9 indicators we selected according to the data, the construction of curtain n walls and the light pollution from the LED screens are the two indicators have that the most weight.

With the construction of the high building and the installation of LED screens in the city, will cause more light pollution.

### 6.1. Analysis of Result

We set a synthetical evaluation model and use 5 different extents to show the light pollution level according to **S** (Table.4.).

**Table.4.** Evaluation Criterion

| Level | Excellent | Good | Moderate | Poor | Very Poor |
|---|---|---|---|---|---|
| Value of **S** | 0-0.2 | 0.2-0.4 | 0.4-0.6 | 0.6-0.8 | 0.8-1 |

The ranking results make full use of the original data information, which can quantitatively reflect the advantages and disadvantages of different evaluation units, which is more intuitive and reliable. The obtained relative proximity S value is from the range of [0,1], the closer the value is to 1, the higher the degree of the evaluation unit close to the optimal level, and conversely, the closer the value is to 0, the lower or closer the evaluation unit is to the optimal level.

Through the above analysis and calculation, the above result table is obtained, from the table, it can be seen that the proximity value of urban areas is 0.9914, the closest to 1, indicating that the degree of light pollution in this area is the most serious among the four regions, followed by urban

suburbs, 0.3019, and the proximity of rural areas is 0.1856, second only to the protected land area with the lowest proximity value, its proximity is 0, indicating that the degree of light pollution in this area is the lightest.

## 7. Conclusion

Based on the satellite data, a comprehensive evaluation model of each region is established by using the entropy weight method to compare the degree of light pollution in and around Beijing. Meanwhile, the model is used to test the four regions. The model is mainly based on 9 indicators including 5 levels, such as architecture and nature aspects, and makes comprehensive evaluation with weighted data. Among the four types of areas, including city central, suburb of the city, rural area of Beijing and protected land, protected has the best degree of light pollution, while the city center has the highest degree of light pollution due to glass curtain wall, building reflection and other reasons. For these four types of areas with different degrees of light pollution, it is necessary to take different measures.

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