# Research on light pollution level based on comprehensive evaluation —— A case study of Beijing

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**Abstract.** With the excessive use of artificial light, light pollution has become an increasingly serious problem. In order to accurately measure the level of light pollution in a certain region, this paper randomly selects 28 provinces in China as objects, and chooses the radiant luminance value L, the sky brightness, the glare value URG, the exposed area S, the GDP of gross domestic product and the number of inhabitants P as the indicators to measure the level of light pollution. Subsequently, using the Luo Jia 1 satellite and related databases, the indicators were weighted by entropy weighting method based on the TOPSIS model to obtain the corresponding scores of the 28 regions, and the normalised scores were recorded as the light pollution index. Finally, taking Beijing as an example, four types of areas were selected, relevant indicator data were collected, and the established TOPSIS model was used to obtain the value of the light pollution index and determine the light pollution level of these four types of areas.

**Keywords:** TOPSIS model; Light pollution index; EWM.

## 1. Introduction

With rapid socio-economic development, the widespread use of artificial light has brought people convenience but also negative effects - light pollution [1].Light pollution is a phenomenon in which excessive light radiation has an adverse effect on the human living and production environment. Some areas already suffer from severe light pollution. Studies have shown that light pollution interferes with the biological clock of humans, affects the natural life patterns of plants and animals, and causes a great waste of energy. It is therefore particularly important to manage and remedy light pollution. Johannes Puschnig, Stefan Wallner, Axel Schwope, Magnus Näslund, and their colleagues demonstrated a quantitative approach to assessing light pollution using night sky brightness (NSB) measurements obtained from sky quality meters (SQMs) and a rich set of atmospheric data. Their study utilizes a valuable dataset covering an extended period (4 to 10 years) and encompasses different types of locations. However, the study heavily relies on various assumptions and corrections, such as the SQM aging correction method and the use of an atmospheric model. These assumptions might introduce uncertainties into the findings [2].Linrui Ji, Xin Ai, Chenou Wang, Xinxin Jiang proposed a light pollution risk rating model. The advantage of this model is that by analyzing the factors of light pollution from multiple angles, applying the multi-linear evaluation method and the least square method to estimate the parameters, and combining the entropy weight method to determine the weight of the relevant parameters, so as to help people to understand and evaluate the light pollution level in different regions or cities more comprehensively. However, the model still has challenges in parameter estimation and regional differences [3].Lanyu Jin, Yangyang Qin, Tianwei Ma studied the light pollution risk level based on satellite remote sensing image data, and proposed the RIM model. The advantage of this model is that the satellite remote sensing image data combined with the double difference robust regression algorithm is used to establish a comprehensive RIM model, which helps to understand and evaluate the light pollution risk more comprehensively. In addition, the results of the model are visualized using Matlab, which helps researchers and decision makers to more easily understand and interpret the output of the model. However, this model may require considerable computational cost for large-scale data processing, and there are defects in model complexity and computational cost [4].

This paper addresses these challenges by synthesising the factors influencing light pollution and proposing indicators to measure its level of risk. In addition, the paper categorises areas into four different classifications: protected areas, rural communities, suburban communities and urban communities. By implementing the identified indicators, the study interprets and analyses each classification. The study used a random selection of 28 Chinese provinces to apply the proposed methodology, and further validated it using Beijing as an example. The results of the study proved the accuracy and reliability of the model, revealing different levels of light pollution in different regions. This study contributes to the understanding and management of light pollution and provides valuable insights for environmental planning and conservation efforts.

## 2. Light Pollution Level Model

### 2.1. Selection of indicators

The Light Pollution Index (LPI) is used to assess the level of light pollution risk in an area, which is influenced by artificial light intensity, sky brightness, glare, economic level and population size.

Artificial Light Intensity: This factor reflects the intensity of outdoor artificial light in the area.

Sky Brightness: This factor measures the brightness of the night sky. Sky brightness is affected by artificial light sources as well as scattered light from natural sources such as the moon and stars.

Glare: This factor measures light that is scattered or reflected by the atmosphere or the ground and can cause visual discomfort or damage.

Spatial extent: This factor reflects the size of the area of light pollution.

Economic level: This factor measures the level of economic development within the region and can indirectly reflect the amount of light pollution.

Population size: This factor measures the number of people in the area. Densely populated areas are usually more light polluted and are therefore an important indicator of the amount of light pollution.

Radiance values are expressed in ($L$), sky brightness ($L_0$), glare in glare value ($UGR$), spatial extent in area ($S$), economic level in gross domestic product ($GDP$) and population size in number of inhabitants ($P$).

Based on the Porters dark sky classification, we have divided the sky brightness ($L_0$) into nine levels. 1-3 are the darkest, 4-6 are darker and 7-9 are brighter. The higher the sky brightness the brighter it is.

### 2.2. Data Description

In order to determine light pollution levels, we need to collect and process some data on light pollution. We have collected and collated reliable and relevant data for 28 randomly selected Chinese provinces, combined with the above-mentioned indicators, using time as the axis. The countries are listed in columns and the indicators in rows. Due to the sheer volume of data, they are not given here.

Among them, the data of radiation brightness values are mainly obtained by analyzing satellite images. With the development of remote sensing technology, remote sensing is gradually becoming an effective means of monitoring light pollution with its advantage of simultaneous observation over a large area[5].Therefore in this model we collect the highly accurate LJ-01 Luojia-1 night light data, which provides 130 m resolution night light remote sensing images[6].

The LJ 1-01 night-light remote sensing image was imaged at 22:00 on 18 February 2023, with a spatial resolution of 130 m, an imaging band range of 480-800 nm, and an amplitude of 260 km [7]. The Luojia 1 data contains a TIF file and an xml file, where the TIFF records the image information and the xml file records the Meta information. This file has already been geometrically corrected by the system and no geometric processing is required. Next, we use the radiometric calibration equation to radiometrically calibrate the LJ 1-01 night-light remote sensing image, using equation (1) to transform the grey scale value to the radiometric brightness. Where L is the radiometric luminance value in lx and DN is the grey scale value of the image.

$$L = DN^{\frac{3}{2}} \cdot 10^{-10} \tag{1}$$

We define the glare value (UGR) as equation (2), where $\omega$ is the average building reflectance and $\theta$ is the percentage of building coverage. The corresponding data are collected separately to obtain the glare values for different areas [8].

$$UGR = \omega\left(1-\theta\right) \tag{2}$$

Other data sources are shown in Table 1

**Table.1.** Data source collation.

| Database Names | Database Websites Data |
|---|---|
| China Statistical Yearbook | http://www.stats.gov.cn/ |
| UN Data | http://data.un.org/ |

### 2.3. Definition of light pollution index

We used the TOPSIS model as the basis, combined with the entropy weighting method, and then further processed the scores.

TOPSIS is a widely used comprehensive evaluation method. It makes full use of the data and the results accurately reflect the gaps between objects [9].

#### 2.3.1. Data normalization

Firstly, after collecting and collating the data, we have to normalise the raw data i.e. convert all the indicator data types into very large indicators. The six indicators we have selected are all very large indicators, i.e. the larger the value the better. Therefore, the normalisation matrix $X$ is obtained as follows.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{3}$$

Where $n$ is the number of different regions, i.e. $n = 28$, and $m$ is the number of indicators, i.e. $m = 6$. Where $x_{ij}\left(i = 1, 2, \cdots, n, j = 1, 2, \cdots, m\right)$ denotes the $i$th positive indicatorised value for the $j$th region.

In order to eliminate the influence of different indicator magnitudes, we normalise the normalised matrix. The standardised matrix is $Z$.

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{bmatrix} \tag{4}$$

Each element in $Z$ is calculated as follows.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{5}$$

Where $z_{ij}\left(i=1,2,\cdots,n,\ j=1,2,\cdots,m\right)$ denotes the standardised value of the $i$ th index for the $j$ th country.

### 2.3.2. Determination of index weights

The entropy weighting method was used to determine the weights of each indicator.

The entropy method is an objective weighting method. It is based on the principle that the less variation an indicator has, the less information it reflects and the lower its corresponding weight should be.

The calculation leads us to the conclusion that the normalised matrix $Z$ has no negative numbers, so no processing is required.

Next we calculate the probability matrix $P$ , where each element $p_{ij}$ in $P$ is calculated as follows.

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

For indicator $j$ , the formula for calculating its information entropy $e_j$ is as follows.

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln\left(p_{ij}\right)\left(j=1,2,\cdots,m\right) \tag{7}$$

For indicator $j$ , the formula for calculating its information utility value $d_j$ is as follows.

$$d_j = 1 - e_j \tag{8}$$

By normalizing the information utility values, we are able to obtain the entropy weight $W$ for each indicator. The formula is as follows.

$$W_j = \frac{d_j}{\sum_{j=1}^{m} d_j}\left(j=1,2,\cdots,m\right) \tag{9}$$

### 2.3.3. Score calculation

(1) First define the maximum value.

$$Z^{+} = \left(Z_1^{+}, Z_2^{+}, \cdots, Z_m^{+}\right) = \left(\max\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \cdots, \max\left\{z_{1m}, z_{2m}, \cdots, z_{nm}\right\}\right) \tag{10}$$

(2) Followed by the minimum value.

$$Z^{-} = \left(Z_1^{-}, Z_2^{-}, \cdots, Z_m^{-}\right) = \left(\max\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \cdots, \max\left\{z_{1m}, z_{2m}, \cdots, z_{nm}\right\}\right) \tag{11}$$

(3) Define the distance of the $i\left(i=1,2,\cdots,n\right)$th evaluation object from the maximum value to be $D_i^{+}$ .

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

(4) Define the distance of the $i\left(i = 1, 2, \cdots, n\right)$th evaluation object from the minimum value as $D_i^-$.

$$D_i^- = \sqrt{\sum_{j=1}^{m} \omega_j \left(Z_j^- - z_{ij}\right)^2} \tag{13}$$

(5) Defining the unnormalized score $S_i$, we can calculate the unnormalized score of the $i\left(i = 1, 2, \cdots, n\right)$th evaluation object:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{14}$$

The unnormalised scores are then normalised and the scores are normalised by $S_i = S_i / \sum_{i=1}^{28} S_i$ such that $\sum_{i=1}^{28} S_i = 1$.

$\widetilde{S}_i$ Is the light pollution index (LPI) corresponding to the $i$th evaluation object. Using the above model we can obtain the LPI for 28 regions in China, as shown in Figure 1, we can see that Tibet has the smallest LPI value and Shanghai has the largest LPI value. The LPI in Tibet, Inner Mongolia, Xinjiang and Qinghai is less than 0.2, the LPI in Gansu, Ningxia, Guangxi and Heilongjiang is less than 0.5, the LPI in Beijing, Shanghai, Guangzhou, Hong Kong and Macau is greater than 0.8, and the LPI in the rest of the regions is between 0.5 and 0.8. We can see that the larger the LPI value, the higher the light pollution level.

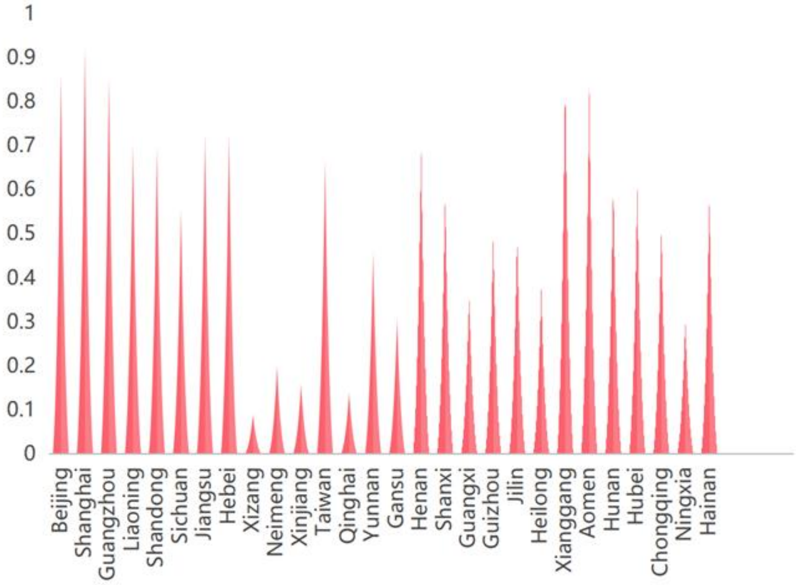

**Figure 1.** LPI in selected areas of China.

## 2.4. Grading of light pollution levels

With reference to the above LPI and light pollution map for some regions in China, we classify the light pollution risk level below (Table 2). When the LPI of a location is less than 0.2, it is considered no light pollution; when the LPI of a location is greater than or equal to 0.2 and less than 0.5, it is considered light pollution; when the LPI of a location is greater than or equal to 0.5 and less than 0.8, it is considered moderate light pollution; when the LPI of a location is greater than or equal to 0.8, it is considered heavy light pollution.

**Table 2.** Classification standards for light pollution of different grades.

| Level | Light pollution level | LPI |
|---|---|---|
| Level 0 | No light pollution | <0.2 |
| Level 1 | Mild light pollution | [0.2,0.5) |
| Level 2 | Moderate light pollution | [05,0.8) |
| Level 3 | Severe light pollution | [0.8,1] |

## 3. Apply LPI model on four types of locations

In different regions we applied the light pollution rating model described above, determined the values of the five influencing factors and calculated the light pollution index to determine the light pollution rating separately [10]. The source of the data here is the Beijing Regional Statistical Yearbook published by the Beijing Bureau of Statistics.

### 3.1. Protected land location

Protected land includes nature reserves, national co-related and areas of outstanding natural beauty that are dark areas. Below this text have used the Beijing Songshan National Nature Reserve as an example to determine the level of light pollution. The values for each indicator for this reserve are shown in the table 3.

**Table 3.** Beijing Songshan National Nature Reserve Values by Indicator

| L | L0 | URG | P | GDP | S |
|---|---|---|---|---|---|
| $0.75\,lx$ | Level 2 | 0.0975 | $10^4$ | $1.8\times10^9\,yuan$ | $4761\,hm^2$ |

Substituting these values into the model above gives the Light Pollution Index, $LPI = 0.078$, a light pollution rating of no light pollution.

Beijing Songshan Nature Reserve consists of two core reserves, two buffer strips and an experimental area, only the experimental area has a long history of relatively high human activity. Therefore the nature reserve has a low floor area occupation rate, low population density and a better ecological environment; at the same time this area is far away from the city centre, there are no large commercial areas and the illumination level is extremely low at night, therefore the light pollution level is no light pollution.

### 3.2. Rural community

The countryside includes the outer areas of the city and rural residential areas, which are areas of low brightness. Below this text use the Yanqing district of Beijing as an example to determine the level of light pollution. The values of each indicator for this area are as follow table 4.

**Table 4.** Values of indicators in Yanqing District, Beijing

| L | L0 | URG | P | GDP | S |
|---|---|---|---|---|---|
| $4.786\,lx$ | Level 5 | 0.2079 | $3.57\times10^6$ | $1.956\times10^{10}\,yuan$ | $10041.4\,hm^2$ |

Substituting these values into the model above gives the Light Pollution Index, $LPI = 0.364$, a light pollution rating of light pollution.

The Yanqing district is the furthest district from the centre of Beijing, with less convenient transportation, less economic development, fewer large commercial areas and lower illumination at night, and a sparsely populated, more developed tourism industry with a good ecological environment. Therefore, the light pollution level in this area is light.

### 3.3. Suburban community

Suburban areas include suburban residential areas as well as urban residential areas, which are areas of medium brightness. Below this text use the Shunyi District of Beijing as an example to determine the light pollution level. The values for each indicator in this area are as table 5.

**Table 5.** Value of indicators in Shunyi District, Beijing

| L | L0 | URG | P | GDP | S |
|---|---|---|---|---|---|
| $8.97\,lx$ | Level 7 | 0.2079 | $1.228\times10^{7}$ | $1.993\times10^{11}\,yuan$ | $28698.2\,hm^{2}$ |

Substituting these values into the model above gives the Light Pollution Index, $LPI = 0.67$ , a light pollution rating of moderate light pollution.

Beijing Shunyi District belongs to the suburban area, a large area, the economy is more developed, and more attention to environmental protection and greening, the green planting rate is relatively high. There are many large shopping malls in this area, and the traffic layout is relatively tight, so commercial lighting and landscape lighting cause high illumination at night. Therefore, this area is moderate light pollution.

### 3.4. Urban community

Urban areas include urban commercial areas with activity functions at night, industrial areas, mixed residential areas and urban commercial areas with highly activity-rich functions at night, mixed commercial and residential areas, which are high brightness areas. Below this text use the Haidian District of Beijing as an example to determine the light pollution level. The values for each indicator in this area are as table 6.

**Table 6.** Value of indicators in Shunyi District, Beijing.

| L | L0 | URG | P | GDP | S |
|---|---|---|---|---|---|
| $19.87\,lx$ | Level 9 | 0.2555 | $3.237\times10^{7}$ | $7.369\times10^{11}\,yuan$ | $24334.1\,hm^{2}$ |

Substituting these values into the model above gives the Light Pollution Index, $LPI = 0.89$, a light pollution rating of severe light pollution.

Haidian District is located in the centre of Beijing, with the highest economic development rate for many years, a tight traffic layout, a dense population and a large commercial area. This is why the area is heavily light polluted.

## 4. Conclusion

With the excessive use of artificial light, light pollution is a growing problem. In this paper, we first define a light pollution index, develop an evaluation model for the degree of light pollution, determine the risk level of light pollution, and then classify light pollution into four classes.We first determined the measurement method of light pollution levels. We randomly selected 28 provinces in China as objects, and selected radiation brightness value L, sky brightness $L_0$, glare value URG, exposed area S, gross domestic product GDP and number of inhabitants P as indicators to measure the level of light pollution. Next, after collecting and collating the data using the Luojia-1 satellite and related databases, we used the TOPSIS model as the basis and weighted the indicators using the entropy weighting method to obtain the corresponding scores of the 28 regions and normalized them, and recorded the normalized scores as the light pollution index. Finally, we combined the light pollution map with the light pollution index to classify light pollution into four classes and gave the corresponding light pollution index intervals.

For four different types of areas, we took Beijing as an example and selected each of these four different types of areas in Beijing to collect data on relevant indicators and use the established TOPSIS model to obtain the value of the light pollution index and then determine the light pollution level. We found that the light pollution level of Beijing Songshan National Nature Reserve is no light pollution, the light pollution level of Beijing Yanqing District is light light light pollution, Beijing Shunyi District is moderate light pollution, and Beijing Haidian District is heavy light pollution. This verifies the accuracy and reasonableness of the model, and finally we interpret and analyse the results obtained in terms of traffic, humanities, life and geography.

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