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# *Ways to Improve the Environment and Reduce Light Pollution*

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***Keywords:*** Light pollution, EWM, CVM, LPI, Prevention and Treatment

***Abstract:*** Light pollution was introduced by astronomers in the 1930s. Light pollution is the excessive or improper use of artificial light. With the continuous development of industrialization and urbanization, light pollution is becoming more and more serious, which has adverse effects on human health, plant growth cycle, animal and other aspects. This paper presents a light pollution index (LPI) model to assess the impact of light pollution on human health and the environment. The model is based on a series of indicators such as light flux, electricity consumption and green space management. The model was tested and applied at different sites to assess its validity. Intervention strategies such as green space management, light flow management and electricity consumption management are proposed to reduce light pollution. The effects of the intervention are analyzed, and the advantages and disadvantages of the model are discussed. Future work includes extending the model to other regions and improving its accuracy.

## 1. Introduction

### 1.1 Problem Background

The problem of light pollution is becoming increasingly unnoticeable. To address this issue, we need to develop a metric to measure the light pollution risk level and to develop and implement appropriate intervention strategies to mitigate the negative effects of light pollution.

### 1.2 Restatement of the Problem

In order to mitigate the negative effects of light pollution, we need to identify the influencing factors of light pollution and find effective intervention strategies based on them. We need to do as follows:

Task1. We need to find indicators of light pollution.A metric is then constructed to assess the level of light pollution risk at a site.

Task2. Relevant personnel may apply the metric to a protected land location, a rural community, a suburban community, and an urban community to assess the risk level of light pollution in different areas.

Task3. Based on the above studies, we need to propose three intervention strategies and their specific actions, and explore where these actions have had an impact on mitigating the side effects of light pollution.

Task4. It can select the actual sites and combine with the constructed metric to determine the intervention strategy with optimal benefits.

### 1.3 Our work & Model Overview

Our work & Model Overview, as shown in Figure 1.

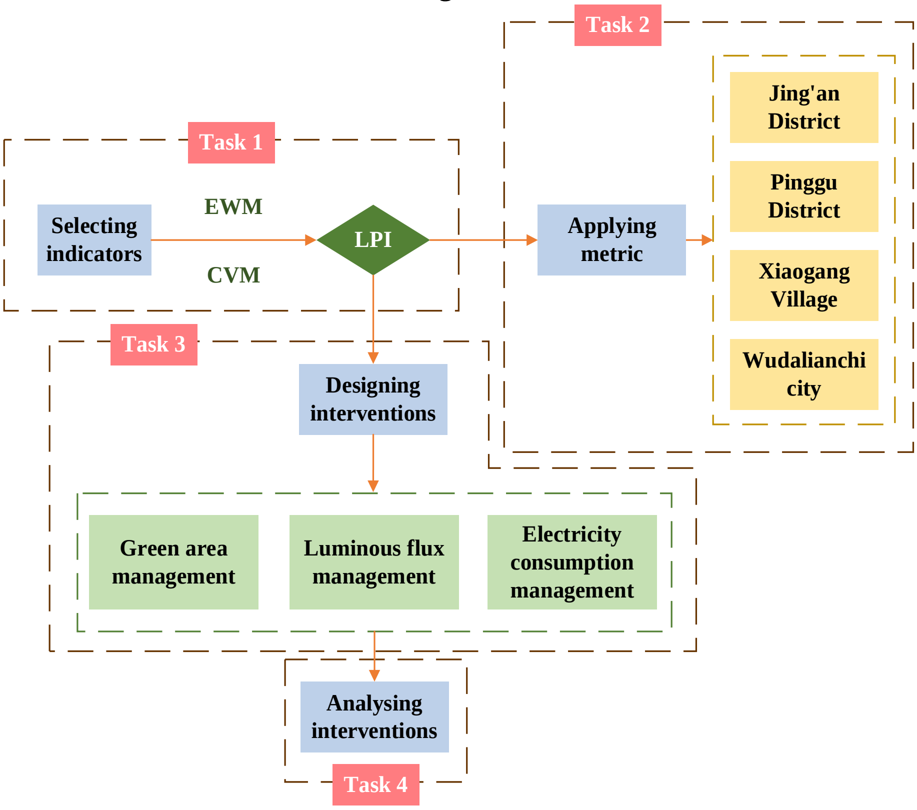


Figure 1: Framework of our study

## 2. Assumptions

In order to simplify the problem and to facilitate our simulation of living conditions under realistic prevailing conditions, we have made the following basic assumptions. Each assumption is reasonable.

(1) The data source is reliable.

(2) The world political landscape and economic situation will not change dramatically in recent years.

(3) Ignore the impact of large-scale natural disasters because it is very rare.

(4) The areas we have selected will not change in nature in recent years. For example, from rural community development to urban community, protected land is no longer protected.

(5) Governments in each country or region have a positive attitude toward light pollution control and are willing to cooperate with the intervention strategies we propose.

## 3. Notations

We list the symbols and notations used in this paper in Table 1.

Table 1: Notations

| Symbols | Definition |
|---|---|
| EWM | Entropy weight method |
| EI | Economy index |
| SI | Society index |
| ESI | Ecosystem sustainability index |
| LI | Light index |
| LPI | Light pollution index |
| CVM | The coefficient of variation method |
| NTL | International nighttime light |
| DN | Digital number |

## 4. LPI model building

### 4.1 Indicator description

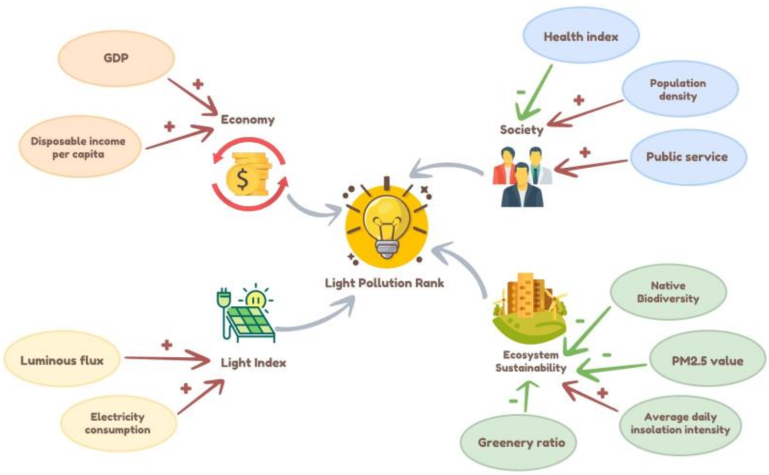


Figure 2: Light pollution risk rank evaluation index. (Symbol '+' means that for the indicator, bigger is better. Similarly, symbol '-' means smaller is better.)

(1) Economy index, as shown in Figure 2:

a) Gross Domestic Product X1 (yuan). GDP is the final result of production activities of all resident units in a country (or region) during a certain period of time. Its higher value means that the more developed the local economy is, the more light pollution is produced.

b) Disposable income per capita X2 (yuan/people). Disposable income per capita is the balance of personal income after deducting taxes and fees payable. Higher income levels mean that the local economy is more developed and more likely to produce light pollution.

(2) Society index:

a) Heath index X3. The healthier the people are, the less the diseases are, the less sensitive to influences of light pollution change.

b) Population density X4 (people/km2). Population density is the number of people per unit of land area. Higher density means that the site requires more lighting facilities, so the level of light pollution is higher.

c) Public service X5. Public service refers to the performance of legal duties by government departments to provide assistance or handle relevant affairs for citizens and legal persons upon their request. The better the public service, the more service facilities are required, and therefore the more light pollution is generated.

(3) Ecosystem sustainability index:

a) Native Biodiversity X6. Biodiversity is the sum of the ecological complex formed by organisms and the environment and the various ecological processes associated with it. The better the biodiversity, the lower the level of light pollution.

b) PM2.5 value X7 (μg/m3). PM2.5 value is the concentration of drifting dust with a diameter less than or equal to 2.5 μm in the ambient air. Higher PM2.5 value means lower visibility and therefore lower light pollution level.[1]

c) Average daily insolation intensity X8 (W/m2). The average daily insolation intensity is the amount of solar radiation power received per unit area per day. This number means that the higher the sunlight intensity, the higher the light pollution level.[2]

d) Greenery ratio X9. Greenery ratio is the ratio of green land area to total land area. The higher the greenery ratio, the more light it can absorb, so the light pollution level is lower.

(4) Light index

a) Luminous flux X10 (lm/W). Luminous flux refers to the radiant power that can be felt by the human eye. The greater the luminous flux means the more serious the degree of light pollution.

b) Electricity consumption X11 (kW ·h). Electricity consumption is the amount of active electrical energy consumed by the object using electricity. This number means that the higher the electricity consumption, the higher the level of light pollution.

## 4.2 Weight of indicators

(1) Entropy weight method

In this section, based on the evaluation indicators defined above, we further determined the weights of these ten indicators, thus forming a combination of the main indicators.

Firstly, for some cities with missing certain indicators, we fill them by finding the mean value of the corresponding indicators for cities with the same city hierarchy. Further, the entropy weighting method (EWM) is applied to eliminate data incommensurability due to inconsistent data dimensions, based on the attribute types of the original indicators, using the standard 0-1 transformation and the given optimal interval method for dimensionless, normalization and deflating. Thus, it is convenient to judge the merit of evaluation indicators directly from the values, and facilitates the evaluation of multi-attribute decision making.

These 11 indicators of $X_1, X_2, \cdots, X_{11}$, where $X_i = \{x_{i1}, x_{i2}, \cdots, x_{in}\}$, describe the factors influencing the risk level of light pollution. Among them, $X_1, X_2, X_4, X_5, X_8$ and $X_{11}$ is proportional to the value of the index, while $X_3, X_6, X_7$ and $X_9$ decrease with the increase of the value of the index. Thus, we have

$$\begin{cases} y_{ij} = \dfrac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \\ y_{ij} = \dfrac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \end{cases} \quad j = 1, 2, \cdots, n \tag{1}$$

where $y_{ij}$ is the standardized value of each evaluation indicator of each size, $\max(x_i)$ and

$\min(x_i)$ are the maximum and minimum value of the evaluation indicator $X_i$. After data standardization, we can use $y_{ij}$ instead of $x_{ij}$ to describe ecosystem services, and then we have:

$$q_i = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}} \tag{2}$$

According to the concept of self-information and entropy in information theory, the information entropy $e_i$ of each evaluation index can be calculated, and thus:

$$e_i = -\ln(n)^{-1}\sum_{j=1}^{n} q_{ij}\ln(q_{ij}) \tag{3}$$

Based on the information entropy, we will further calculate the weight of each evaluation indicator we defined before.

$$w_i = \frac{1-e_i}{k-\sum_i e_i} \quad i = 1, 2, \cdots, k \tag{4}$$

Furthermore, four comprehensive evaluation indicators of economy, society, ecosystem sustainability and light index are obtained. This article will be abbreviated as E, S, ES and LI based on the weight of these calculations, we have:

$$\begin{cases} EI_j = w_1 y_{1j} + w_2 y_{2j} \\ SI_j = w_3 y_{3j} + w_4 y_{4j} + w_5 y_{5j} \\ ESI_j = w_6 y_{6j} + w_7 y_{7j} + w_8 y_{8j} + w_9 y_{9j} \\ LI_j = w_{10} y_{10j} + w_{11} y_{11j} \end{cases} \tag{5}$$

where $EI_j, SI_j, ESI_j$ and $LI_j$ represent the secondary indicators of the size of j. The weights of these indexes are determined by EWM and the expression of these indexes are finally described.

(2) Coefficient of variation method

After representing 10 indicators as four comprehensive variables, we need to further aggregate the four indicators into a comprehensive indicator to directly assess the light pollution risk level, providing a basis for effective intervention strategies to combat light pollution.[3]

The coefficient of variation method (CVM) is a method of directly using the information contained in each indicator and calculating the weight of the indicator by calculation. Considering the difference between the units and the mean of the four comprehensive indicators, the standard deviation cannot be used to compare the degree of variation, but the ratio of the standard deviation to the mean is used to compare. The equation for each exponent can be expressed as:

$$C.V_i = \frac{\sigma_i}{\bar{x}_i} \quad i = 1, 2, 3, 4 \tag{6}$$

Subsequently, on the basis of those calculated weights, we can derive the light pollution index, which is abbreviated as LPI.

$$LPI = (W_1 \times EI + W_2 \times SI + W_3 \times ESI + W_4 \times LI) \times 100 \tag{7}$$

Since the specific value of those indicators have been given in Table 2, hence we can calculate the LPI of our selected projects. As can be seen from Table 2 below, for the 11 evaluation indicators, the weight difference between them is not big, which is generally around 0.1. Disposable income per capita has the largest weight of 0.1207. For the four comprehensive indicators, economy ranks the first with the weight of 0.4048 in our final criterion, with ecosystem sustainability following behind, while society ranks the third and light index is at the bottom.[4]

Table 2: Weight values of the indicators

<table>
<tr><th>Indicators(I)</th><th>Indicators(II)</th><th>Weights</th><th>Indicators(III)</th><th>Weights</th></tr>
<tr><td rowspan="11">Light pollution index</td><td rowspan="2">Economy</td><td rowspan="2">0.4048</td><td>GDP</td><td>0.1060</td></tr>
<tr><td>Disposable income per capita</td><td>0.1207</td></tr>
<tr><td rowspan="3">Society</td><td rowspan="3">0.1145</td><td>Heath index</td><td>0.0582</td></tr>
<tr><td>Population density</td><td>0.1128</td></tr>
<tr><td>Public service</td><td>0.0933</td></tr>
<tr><td rowspan="2">Light index</td><td rowspan="2">0.3293</td><td>Luminous flux</td><td>0.0884</td></tr>
<tr><td>Electricity consumption</td><td>0.0832</td></tr>
<tr><td rowspan="4">Ecosystem sustainability</td><td rowspan="4">0.1514</td><td>Native Biodiversity</td><td>0.0787</td></tr>
<tr><td>PM2.5 value</td><td>0.0500</td></tr>
<tr><td>Average daily insolation intensity</td><td>0.0954</td></tr>
<tr><td>Greenery ratio</td><td>0.1133</td></tr>
</table>

### 4.3 Test LPI

After building the basic model LPI, we will test it. We selected 20 locations with different levels. We analyze the results of LPI calculations and set thresholds based on the relevant reports:

$$Risk\ rank = \begin{cases} High & if\ \ LPI \geq 120 \\ Medium & if\ \ 40 \leq \mathrm{LPI} < 120 \\ Low & if\ \ 0 \leq LPI < 40 \end{cases} \tag{8}$$

## 5. Application of the model in different locations

In this session, four sites were selected to represent protected land location, rural communities, suburban communities and urban communities to measure the level of light pollution risk in different areas. The selected areas are as follows:

Protected land location--Wudalianchi city. Wudalianchi city is located in Heilongjiang Province, China, with a total area of 1069km2, of which 1009.77km2 is protected from development due to its natural importance. Therefore, we used the data of this city to represent the risk level of light pollution in the protected area.

Rural communities--Xiaogang Village. Xiaogang Village is a rural village located in Anhui Province, China, with a resident population of 4,173 people. The population density is very undense, so it is used as a representative of rural communities.

Suburban communities--Pinggu District. Pinggu District is a distant suburb located in the northeastern part of Beijing, China, with a resident population of 457,000. The population is moderately dense, so it is used as a representative of suburban communities.

Urban communities--Jing'an District. Jing'an District is located in the middle of the central city of Central Shanghai, with a resident population of 975,700. The population density is very concentrated, so it is used as a representative of urban communities.

Because we are only comparing between regions, all data for the four regions are from the same time period of September 2011 to February 2023. Substituting the data of each indicator for the four selected regions into the LPI calculation formula, the corresponding results were obtained as follows:

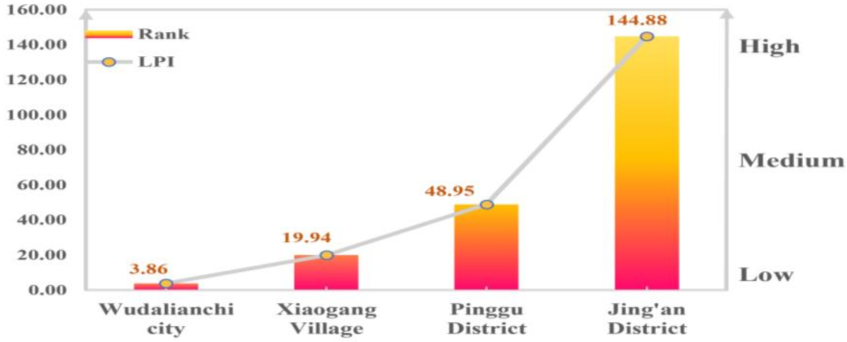


Figure 3: Comparison of LPI original ranking and risk level valuation indicators

As can be seen from Figure 3, the four areas with the highest level of light pollution risk from the bottom are Jing'an District, Pinggu District, Xiaogang Village and Wudalianchi City. This means that urban communities have the most severe light pollution, followed by suburban communities, rural communities are third, and protected lands have the least light pollution.

The high risk to urban communities may be due to the increase in outdoor lighting as a result of urbanization and the development of transportation networks. As urban development moves to the periphery, a significant portion of the suburban areas that were originally on the edge of the city have become or are becoming busy urban areas. The need for commercial and urban "image" has led to the expansion of "brightening projects", with similarly high risks of light pollution[5]. Rural areas are relatively less affected by light pollution due to their relatively slow development. Protected lands are protected from development and receive special ecological protection due to their special characteristics, and therefore have the lowest level of light pollution risk.

The main data sources in the domestic and international nighttime light (NTL) index include DMSP/OLS images, nighttime light remote sensing data acquired by Soumi-NPP satellite, and nighttime light data acquired by the domestic remote sensing satellite "Luojia-1"[6]. NTL shows its average light intensity by digital value (DN) value.

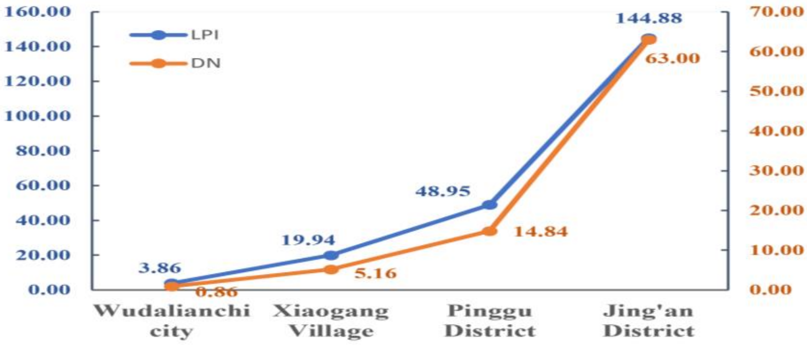


Figure 4: Comparison of four locations LPI and DN

The image DN values[7] from the Figure 4 can be obtained from the NTL index of four areas from the highest to the lowest: Jing'an District, Pinggu District, Xiaogang Village and Wudalianchi City. It can be found that the results calculated by our model are consistent with the nighttime lighting index, which can prove the validity of the model.

## 6. Intervention strategies

### 6.1 Intervention 1: Green area management

(1) Specific actions

First, we can increase the area of flat greenery. Planting more trees and grass in the inner city to reduce reflection and diffuse reflection from the urban surface and to increase reflection and scattering of natural light. It can significantly reduce white bright pollution.

Second, we can add three-dimensional greening facilities. The current smooth, reflective surfaces of buildings can be replaced with "eco-walls". It is the use of nature's green plants to build a wall. This wall has the function of greening and beautifying the city, and reducing light pollution. Some low-rise buildings can also be planted with "creeper" type of plants to reduce the reflection of sunlight[8].

(2) Potential Impact

Excessive greenery may crowd out some roads or housing areas. Above a certain value, the effectiveness of the greenery ratio will be reduced[9]. The threshold of greening rate needs to be controlled during the implementation of intervention 1.

### 6.2 Intervention 2: Luminous flux management

(1) Specific actions

First, we can use low-reflectivity building materials. We need to use materials with low reflectivity for building facades, and popularize new matte facade materials. Relevant department limit or reduce the number of buildings with glass curtain walls and avoid residential areas as much as possible. We need to reduce the area of glass curtain walls in existing high-rise buildings as much as possible and avoid the reflection of sunlight into residential areas.

Second, we should make improvements to the lamps. Priority is given to choose a small beam divergence angle and environmentally friendly energy-saving lamps and lanterns. The use of lamps and lanterns with a spacer or shade and other measures to reduce the generation of light pollution. Black lights, rotating lights, fluorescent lights and flashing colored light sources should be managed scientifically and strictly controlled to reduce the use of high-powered strong light sources.

Third, additional shading equipment. We can avoid color light pollution by adding blackout curtains, blinds and so on. In the area where the color light pollution is serious, we can set up a shading shed to reduce the pollution.

Fourth, we should increase the roughness of the ground. According to the principle of rough disintegration of light, we can appropriately increase the roughness of the ground by changing the land surface material, in order to reduce the degree of reflection of the object surface.

(2) Potential impact

Low luminous flux may result in low neighborhood visibility at night, leading to increased crime rates. Intervention 2 can be implemented in conjunction with nighttime security patrol measures.

### 6.3 Intervention 3: Electricity consumption management

(1) Specific actions

First, government departments should control the electricity consumption of business and functional buildings. The government should set relevant regulations to limit the electricity consumption of buildings such as hospital ward buildings, hotel rooms and commercial buildings. And they can reduce the frequency of the use of promotional light boxes.

Second, government departments should pay attention to the management of electricity consumption in residential areas. Government departments should reinforce the publicity of light pollution hazards and encourage residents to reduce unnecessary lighting.

Third, government departments should strengthen the development of energy-efficient industries. The government can incentivize investments that are conducive to reducing electricity consumption through credit incentives and government subsidies. And government departments should give economic incentives for the development and promotion of energy-efficient technologies[10].

(2) Potential effects

The control of electricity consumption may cause inconvenience to people's life and some business and functional buildings. Therefore, more rational and effective planning is needed to coordinate electricity consumption.

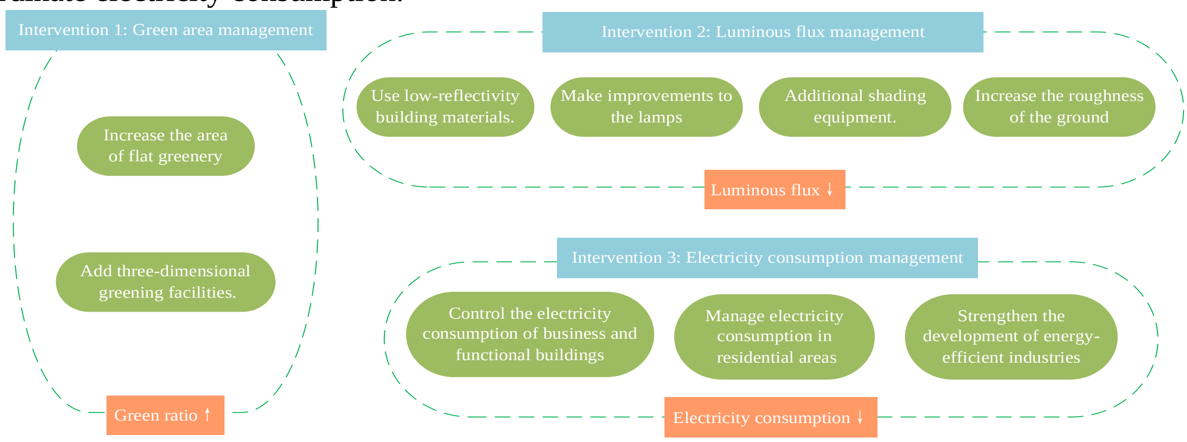


Figure 5: The effect of three strategies on light pollution indicators

As seen in Figure 5, intervention 1 mitigates LPI by increasing the greenery rate. Intervention 2 mitigates LPI by reducing light flux. Intervention 3 mitigates LPI by reducing electricity consumption.

## 7. Effects of intervention

In this session, we selected the average LPI from September 2011 to February 2023 for two locations, Jing'an District and Pinggu District, to simulate the implementation of three intervention strategies. The effects of the interventions are shown in Figure 6:

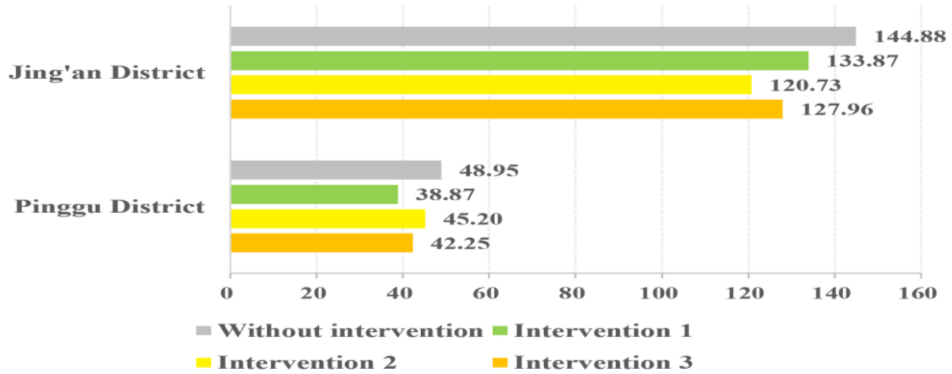


Figure 6: LPI analysis for two locations affected by the intervention strategies

As seen in Figure 6, the most effective intervention for the Jing'an District is Intervention 2: luminous flux management.With the effective impact of our Intervention 2, the LPI value at the location decreased from 144.88 before the intervention to 120.73, which is very close to the medium tipping point of 120 for our risk level threshold.

The most effective intervention for the Pinggu district is intervention 1: green area management. Its LPI value is 48.95 when no intervention is implemented, which means that its light pollution is at medium risk. The LPI value was reduced to 38.87 after the implementation of intervention 1. The risk level was directly reduced from medium risk to low risk.

Jing'an District is in the central city. Its available green area is small, and the dense commercial buildings, office buildings and residential areas are not conducive to the control of electricity consumption, so the most effective measure is to reduce the amount of luminous flux. The Pinggu District is in the far suburbs, and the luminous flux and electricity consumption are basically in line with the needs of normal life, so there is little room for reduction. In contrast, the land available for greening makes increasing the greening rate the most effective measure. Therefore, our most effective intervention strategy matches with the actual location characteristics.

## 8. Sensitive Analysis

We selected four indicators in ES Pinggu district: greenery rate, average daily insolation intensity, PM2.5 value and native biodiversity to do sensitivity analysis on the model. Their initial values were 52, 151, 533, and 71 in that order. 5% continuous up and down fluctuations were made for these variables. This paper plots these four indicators according to LPI:

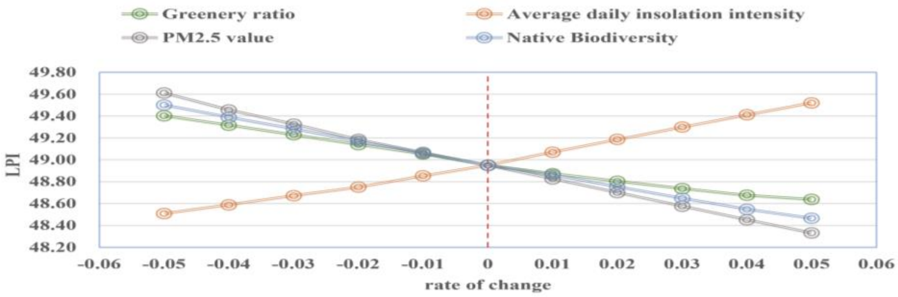


Figure 7: Sensitive analysis of percentage change of four indicators using LPI model of Pinggu district

As can be seen from Figure 7, for positive indicators, the LPI value increases as the ratio rises. For the negative indicators, the LPI value decreases when the ratio increases. Among them, it can be seen from the slope that LPI is the most sensitive to PM2.5 indicator and the least sensitive to the greenery rate indicator. Overall, the value of LPI changes less with the fluctuation of the change ratio, so our model can effectively solve the problem within a certain range.

## 9. Strengths and Weakness

### 9.1 Strengths

We use the EWM and the CVM to determine the weight of light pollution indicators, avoiding the negative effects of a single method. The results of LPI matches the ranks of selected countries from DN well, which indicates our model is reasonable and effective.Experienced studies show that, our model can be adapted to different locations for effective analysis on light pollution risk level.We employ 11 indicators of 4 fields in the LPI model to measure the risk level of an area. In this way the LPI model is able to avoid abrupt influence of a single indicator, and the results are more integrated.

## 9.2 Weaknesses

Due to the limited search data, the indicators used cannot completely describe the actual light pollution risk level, which may reduce the accuracy of our model.In our model, due to time constraints, we just choose the average light pollution index to confirm the effectiveness of the intervention strategies. Thus, there will be some deviation.We argue that all the countries react positively to light pollution, neglecting those passive countries, which may exert on our intervention model.

## 10. Conclusion

In this paper, we construct a risk ranking evaluation system to represent the light pollution risk level of a certain area by the LPI. We substitute the relevant data of Jing'an district, Pinggu district, Xiaogang village and Wudalianchi city into the model, and calculate that the risk level of light pollution is the highest in the urban community represented by Jing'an district and the risk level of light pollution is the lowest in the protected land represented by Wudalianchi city. The robustness of our model was demonstrated by comparing the DN values of NTL in the four locations with the model calculation results. In order to better promote the awareness of light pollution, we produced a flyer to promote luminous flux management measures in Jing'an district, in order to motivate people to work together to reduce light pollution.

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