Research on Comprehensive Evaluation Model Based on AHP-EWM

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Abstract: Light pollution is becoming more and more serious due to the indiscriminate use of light by human beings. Light pollution is an inevitable negative impact in the process of urban development, and the degree of urban development is often inherently linked to the severity of pollution. This paper establishes a risk assessment model for light pollution using the entropy weight method and analytic hierarchy process to provide effective policy interventions for light pollution prevention and control. According to our research results, the higher the LPS (Light Pollution Score) value, the more severe the light pollution in the area. Through the calculation of our model, this paper eventually got the assessment scores of China's Greater Khingan Mountains, PUMA Township in Nevada, the suburb of St. Louis in Missouri, and Chinatown in San Francisco are 5.18475, 7.58404, 6.44596 and 14.50219, respectively.

Keywords: Light pollution assessment model, Intervention strategy, Entropy weight-Analytic hierarchy process, Analysis of regression.

1. Introduction

1.1. Background

Light pollution has become the fifth major form of pollution following air pollution, water pollution, noise pollution, and solid waste pollution as a result of the development of industrialization and urbanization in the society [1]. Currently, more than 80% of the global population lives in light pollution at night [2]. Excessive light pollution alters the natural light cycle of cities and disrupts people's daily routines.

1.2. Literature review

Chinese scholar Liu Ming studied the potential effects of urban nighttime light pollution on animal behavior [3]. He pointed out that urban nighttime light pollution could lead to abnormal behavior in animals. In addition, domestic scholars mainly Cao Min proposed the proposition of "toxicological mechanism of light pollution through circadian rhythm destruction"[4]. In terms of foreign studies on light pollution, scholars, mainly Pauwels J, put forward that artificial light at night affected the conservation of biodiversity, especially the most vulnerable species that existed in semi-natural areas [5]. According to the above research status, reducing light pollution not only provides a guarantee for the construction of a harmonious and safe human society, but also protects many animals in nature.

Light pollution has a widespread impact on human life, and to promote the development of a healthy lighting environment, it is necessary to understand the benefits and drawbacks of current light pollution. In addition, how to judge the risk level of light pollution in a given area?

1.3. Our work

In this paper, indicators are selected based on the benefits and drawbacks of light pollution on human beings. Using these indicators, a model for evaluating light pollution is established to

determine the level of risk in a given location. The entropy weight method and analytic hierarchy process are combined to establish the light pollution evaluation model. Then, the weights of each indicator are calculated to determine the level of light pollution risk in a specific location, thus obtaining research value.

2. Preliminary

This paper uses the analytic hierarchy process and entropy weight method to establish a model for evaluating light pollution.

2.1. Analytic Hierarchy Process method

The Analytic Hierarchy Process (AHP) is a method for organizing and analyzing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then. It contains three parts: the ultimate goal or problem you're trying to solve, all of the possible solutions, called alternatives, and the criteria you will judge the alternatives on. AHP provides a rational framework for a needed decision by quantifying its criteria and alternative options, and for relating those elements to the overall goal.

Entropy weight method: The entropy weight method (EWM) is an important information weight model that has been extensively studied and practiced [6, 7]. Compared with various subjective weighting models, the biggest advantage of the EWM is the avoidance of the interference of human factors on the weight of indicators, thus enhancing the objectivity of the comprehensive evaluation results [8, 9]. Therefore, the EWM has been widely used in decision-making in recent years [10–12].

2.2. Notation

The symbols used in this paper are shown in table 1 below.

Table 1. Symbol

Symbol	Definition
$(X_{ij})'$	Data matrix element of index forward transformation
r_{ij}	Standardized data matrix elements
R	Data matrix
r_j	Index
E_j	Information entropy
w_{ij}	Weight vector
λmax	The largest eigenvalue
CI	Coincidence indicator
RI	Average random consistency index
CR	Consistency ratio
ω_i	Weight vector
k	Eigenvector
LPS	Light Pollution Score

3. Model Establishment

With people's colorful night life come into being, a variety of night lighting equipment was following. Therefore, the generation of light pollution and its hazards is inevitable. Studies have shown that the faster the urbanization process, the worse the light pollution is. This paper addresses the question of the level of light pollution risk at a site from two perspectives. On the one hand, considering that light pollution will cause certain harm to human beings and nature, the specific harm to human beings is: cancer risk, sleep quality decline, depression, etc [13]. The specific harm to the nature is greenhouse effect, changes in the number of birds, plant growth cycle disorder, etc. But

everything has two sides, both advantages and disadvantages. On the other hand, light pollution has some benefits in other aspects, including social benefits (reducing crime rate and enriching human night life), economic benefits (increasing GDP in locations and improving work efficiency) shown in Figure 1.

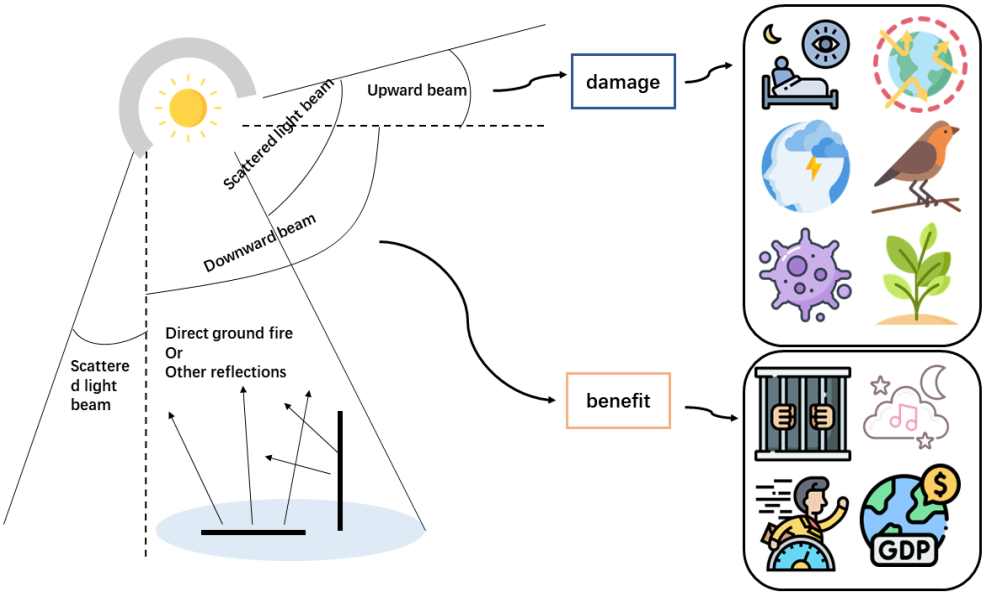


Figure 1. Harms and benefits from light pollution

This paper uses Analytic Hierarchy Process method to establish two indexes--criterion layer and sub-criterion layer by analyzing the disadvantages and benefits of light pollution. The secondary indicators are human, natural, social and economic. The tertiary indicators are cancer risk, incidence of depression, sleep proportion, greenhouse effect, number of birds, happiness index, crime rate, and GDP, as shown in Figure 2. This paper utilizes the entropy weight method to determine the weight of the three-tier index since the Analytic Hierarchy Process method is highly subjective. The combination of the two makes our final results more credible and convincing.

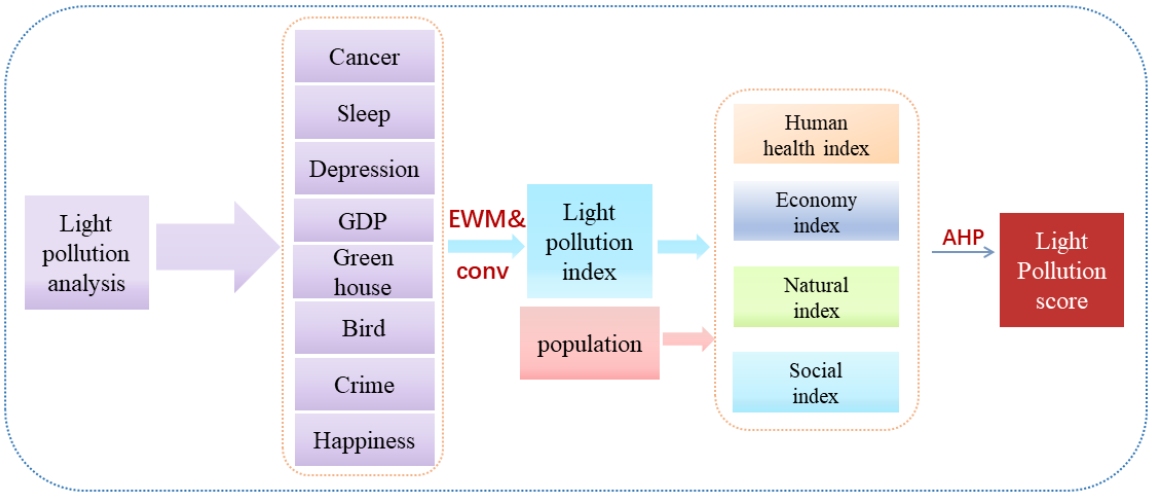


Figure 2. Hierarchy diagram

4. Model Solving

First of all, this paper sourced relevant data on cancer risk, depression rate, sleep proportion, greenhouse effect, bird population, happiness index, crime rate, GDP from Our World in Data website [3]. Then, this paper normalizes the indicators based on the type of criteria, that is, smaller values are better.

$$x_{ij}^{'} = \max(x_{ij}) - x_{ij} \tag{1}$$

Then, this paper standardizes the data. Because each indicator is of different orders of magnitude, this paper need to translate them into the same range before comparing them. The paper uses the normalization method with the maximum minimum value, sets the standardized data matrix element is r_{ij}, and after the index is forward, the data matrix element is $(X_{ij})'$.

$$r_{ij} = \frac{x_{ij}^{'} - \min(x_{j}^{'})}{\max(x_{j}^{'}) - \min(x_{j}^{'})} \tag{2}$$

Next, the paper constitutes the data matrix $R = (r_{ij})_{m*n}$, and then the index r_j information entropy E_j is:

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{3}$$

Including

$$p_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \tag{4}$$

The normalized lowest interval can start at 0.002 in order to avoid calculation errors in the occurrence of P_{ij} zero elements. If the information entropy E_j of an index is smaller, the greater the variation of the index value, and the greater the information provided, it can be considered that the index plays a greater role in the comprehensive evaluation. Finally, the three-level index weights are calculated.

$$w_{ij} = \frac{(1 - E_j)}{\sum_{j=1}^{n}(1 - E_j)} \tag{5}$$

The results calculated are shown in table 2:

Table 2. Three-level index weight

Cancer risk	Prevalence of depression	Sleep proportion	Greenhouse effect
0.1261	0.1328	0.0887	0.2178
Bird number	Happiness index	Crime rate	GDP
0.0980	0.0733	0.0701	0.1930

Then, the paper constructs a judgment matrix for the criteria layer in the goal layer, taking into consideration both the importance and characteristics of the matrix. In order to determine the weights between the factors at each level, this paper tries to improve the accuracy of the scale. Instead of comparing all the factors together, the paper compares the pairs to each other. This paper uses relative scale to minimize the difficulty of comparing different factors with each other. As shown in Table 3 below.

Table 3. The scale of the judgment matrix

Scale	**Implication**
1	Two factors have the same importance
3	Compared to the two factors, one factor is slightly more important than the other factor
5	Compared with the two factors, one factor is significantly more important than the other factor
7	Compared to the two factors, one factor is strongly more important than the other factor
9	Compared with the two factors, one factor is extremely more important than the other factor
2、4、6、8	The median value of the two adjacent judgments
reciprocal value	If the scale is 3 compared to A and B, then B is 1 / 3 compared to A

The **characters** of judgment matrix are as followed (where *i* represents row and *j* represents column)

1. The meaning of a_{ij} is the importance of *i* compared to the index *j*.

2. When $i = j$, two indexes of equal importance are denoted as 1.

3. When $a_j > 0$ and $a_{ij} \times a_{ji} = 1$**,** the matrix satisfying this condition is a positive reciprocal matrix. As shown in Table 4 below.

Table 4. Judgment Matrix

Light pollution	Human beings	Environment	Society	Economy
Human beings	1	2	4	6
Environment	1/2	1	2	3
Society	1/4	1/2	1	3/2
Economy	1/6	1/3	2/3	1

Then **the** paper performs the consistency test on the judgment matrix. In the first step, calculate the maximum feature root λ_{max}:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{w_i} \tag{6}$$

In the **second** step, calculate the consistency index *CI:*

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

In the third **step**, find the corresponding average random consistency index *RI***.** As shown in Table 5 below.

Table 5. *RI* indicators

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	**0**	**0**	**0.52**	**0.89**	**1.12**	**1.26**	**1.36**	**1.41**	**1.46**	**1.49**

In the **fourth** step, calculate the consistency proportion *CR*:

$$CR = \frac{CI}{RI} \tag{8}$$

Finally, we conclude that $CR < 0.1$, the consistency of the matrix is acceptable.

Then the **paper** finds the weights according to the arithmetic average method, geometric average method and eigenvalue method.

1. Arithmetic average method

First, the judgment matrix is normalized by columns, and each element is divided by the sum of the **columns**. Then, add the normalized columns and find the sum of each line. Finally, the w- eight vector is obtained by dividing each element in the resulting vector by n.

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}, (i = 1, 2, \ \dots, n) \tag{9}$$

2. Geometric average method

First, multiply the elements of A by rows to obtain a new column vector. Then, open each component of the new vector in the n order. Finally, the weight vector is obtained by normalizing the column vector.

$$\omega_i = \frac{(\prod_{j=1}^{n}a_{ij})^{\frac{1}{n}}}{\sum_{k=1}^{n}(\prod_{j=1}^{n}a_{kj})^{\frac{1}{n}}}, (i = 1, 2, \ \dots, n) \tag{10}$$

3. Eigenvalue method

From the lemma, the consensus matrix has an eigenvalue of n and the remaining eigenvalues of 0. Therefore, when the eigenvalue is n, the corresponding eigenvector is exactly:

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}, (i = 1, 2, \ \dots, n) \tag{11}$$

Then we can directly normalize the eigenvector to obtain the eigenvector.

$$k = \left[\frac{1}{a_{11}}, \frac{1}{a_{12}}, \ \dots, \frac{1}{a_{1n}}\right]^T (k \neq 0) \tag{12}$$

Next, this paper obtains the weight vector by normalize the feature vector. Finally, the paper uses calculate the average of the three methods and the results of the second-level index weights are shown in table 6.

Table 6. Secondary index weight

Human beings	Environment	Society	Economy
0.50977	0.24369	0.18908	0.17708

Three regions in the United States and one region in China are selected, namely Greater Khingan Mountains in China, PUMA Township in Nevada, the suburb of St. Louis in Missouri, and Chinatown in San Francisco. Then, according to the Light Pollution Assessment Model, we calculated the assessment scores of the four regions, which are 5.18475, 7.58404, 6.44596 and 14.50219.

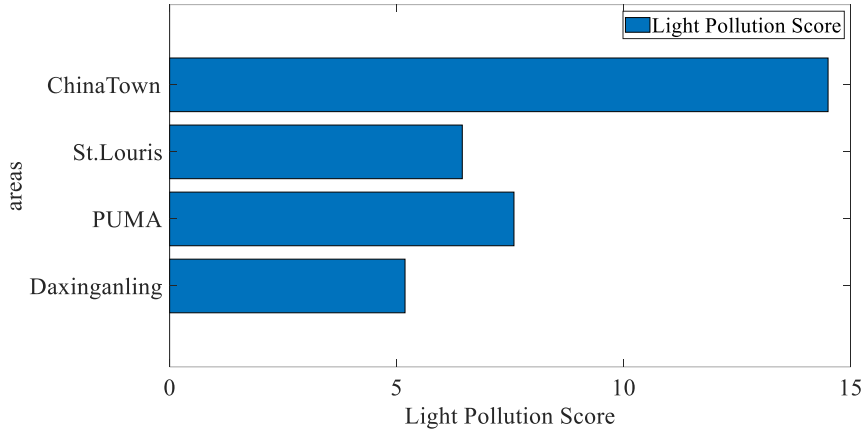


Figure 3. Evaluation points of the four regions

The Light Pollution Score is shown in above figure 3.

5. Conclusions

The light pollution risk level of a certain area can be evaluated by the Light Pollution Assessment Model this paper has established. What's more, the area with more severe light pollution has the higher scores. Studies show that light pollution not only has negative impacts, but also some positive impacts in certain aspects. The impacts of light pollution on people: increase the risk of cancer, increase the incidence of depression, interfere with normal work and rest, etc. Impacts on nature: increasing the greenhouse effect, reducing the number of birds and insects, disrupting the life cycle of plants, etc. The impacts on socio-economic aspects include enriching nightlife, reducing crime rate, increasing GDP, and improving work efficiency.

Therefore, four regions are selected for evaluation to verify the feasibility of the model: the Daxing'an Mountains in China, the town of Beatty in Nevada, the suburbs of St. Louis in Missouri, and San Francisco's Chinatown in the United States. Using the light pollution evaluation model, the evaluation scores for the four regions were 5.18475, 7.58404, 6.44596, and 14.50219, respectively. The data show that Chinatown has the most severe light pollution. While there have been some studies on light pollution, there are still many issues that require further research. For example, the long-term impact of light pollution on human health, the prevention and control of light pollution, and the relationship between light pollution and other environmental issues all require more in-depth research.

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