Light pollution risk level assessment based on Delphi method and analytic hierarchy process

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Abstract. Aiming at the light pollution phenomenon, this paper establishes the light pollution risk level evaluation model. First, the assessment indexes were screened and modified by Delphi's method. Then, on the basis of this assessment system, the assessment model of light pollution risk level was established based on the analytic hierarchy process (AHP) . Finally, the light pollution risk index was defined in the way of weighted summation of each index.

Keywords: the Delphi method, AHP, light pollution.

1. Introduction

Light pollution refers to the propagation of light signals in the atmosphere, which can affect human vision, hearing, psychological perception and physiological functions, and cause environmental pollution. [1][2][3] In recent years, with the development of the times and the process of urban modernization, light pollution has been intensifying, causing more and more serious impacts on human health, wildlife, plants and ecological environment, and the study of light pollution has become a global hot issue. In this context, the study of light pollution has become particularly important.

In this paper, an evaluation model is developed to assess the risk level of light pollution in an area. The results of this paper have important implications for determining the light pollution level class.

2. Data preprocessing

(1) Data collection

We collected data on four indicators: total light intensity at night, average daily light hours, percentage of total area covered by nighttime light, and biodiversity in Beijing, China.

(2) Data cleaning

In our sample data, we excluded the samples with indicator data below zero because the data of these indicators were statistically significant only when they were above zero.

(3) Data normalization

We need to normalize the data, and we defined a min-max function to transform the data.

$$Data\ after\ normalisation = \frac{Original\ data - Minimal\ values}{Maximum\ value - Minimal\ values}$$

In addition, since total light intensity at night, average daily light hours, and percentage of total area covered by nighttime light were positively correlated with light pollution risk level, while biodiversity indicator was negatively correlated with light pollution risk level, we need to normalize the biodiversity data with the following equation.

$$Data\ after\ forwarding = 1 - Data\ before\ forwarding$$

3. light pollution risk level evaluation model

3.1. The construction of light pollution risk assessment indicator system

Through the literature research, combined with the special and complicated nature of establishing the indicator system of light pollution risk level evaluation, this paper mainly uses the expert questionnaire method to construct the indicator system of light pollution risk level evaluation.[4][5][6]

First is the establishment of initial indicators. By referring to relevant literature and the opinions of experienced scholars, a framework of light pollution risk assessment indicator system is initially established, as shown in table 1.

Table 1 summary table of evaluation indicators

objective	primary evaluation indicators	secondary evaluation indicators
evaluation of the risk level of light pollution	evaluation indicators on the causes of light pollution	population
		road mileage
		motor vehicle occupancy rate
		urbanization rate
		industrial electricity consumption
		commercial electricity consumption
		residential electricity consumption
		GDP level
		rate of low quality people
		coverage rate of urban vegetation
		the proportion of three major industries
		number of street lights
	evaluation indicators on light pollution impact	proportion of organisms whose growth rate was affected
		rate of organisms whose migration patterns were affected
		incidence rate of traffic accidents
		rate of humans whose biological clocks were affected
		rate of crime
	evaluation indicators on light sources	average daily light hours
		percentage of total area covered by nighttime light
		total light intensity at night

Second is indicator screening, the Delphi method was applied to determine the final indicators through three rounds of consultation. The feedback from experts in each round needs to be summarized and analyzed to form the next round of questionnaire, and then further judged and supplemented by risk assessment experts. The importance of the indicators is divided into five levels: importance, relative importance, average importance, secondary importance and non-importance, which are 5,4,3,2 and 1 points respectively. Experts were asked to“Mark” the importance of their choice, based on their experience and understanding of the subject. If experts feel that certain indicators need to be adjusted, they can add additional explanations in the comments section.

First round of consultation

The first round of indicator screening experts gave the following opinion: Although indicators such as GDP, population and road mileage greatly influence the level of light pollution risk, since the light pollution caused by them can be measured by light hours, light intensity and light range, these indicators can be eliminated and the above three indicators can summarize the impact caused by factors such as GDP.

Second round of consultation

The indicators with mean values less than 3 in the first round of consultation were deleted and the second round of consultation was conducted, in the second round of consultation, experts gave the opinion that it is more general to change “rate of organisms whose migration patterns were affected” to biodiversity, and that light pollution caused by urbanization rate and commercial electricity

consumption can be eliminated because it can be measured by light time, light intensity, and light range.

Third round of consultation

The data with the mean less than 3 in the second round were deleted, and the biological migration indicator was replaced with biodiversity for the third round of solicitation, from the results of the third round of consultation, it can be seen that there is a convergence of expert opinions and there are no indicators that need to be eliminated, so all indicators are retained as the final indicator evaluation system.

Explanation of indicators

- total light intensity at night: high level of light intensity usually indicates that light pollution will be more serious. For example, harsh glare at night, glass curtain wall, dazzling light, will constitute a serious light pollution phenomenon, which will seriously lead to traffic accidents. Through three rounds of expert solicitation results, this indicator is also one of the four evaluation indicators, the largest weight.[7]
- average daily light hours: the longer the light hours, the more serious light pollution, too long light hours will affect the biological rhythm, such as affecting the normal biological clock, and then affect the mental state and psychological health of people.
- percentage of total area covered by nighttime light: the larger the percentage of light area at night, the more light pollution may endanger the area.[8]
- biodiversity: Light pollution has an impact on the migration, growth and reproduction of wildlife, birds and insects, so we need to consider the changes in biodiversity at a particular site to assess the level of light pollution.

3.2. Establishment of light pollution risk level evaluation model

This paper constructs the evaluation model of light pollution risk level based on the Analytic Hierarchy Process.[9][10]

3.2.1. Construction of the hierarchy

Using the four evaluation indicators obtained above and based on analytic hierarchy process , the hierarchical structure is established in figure 1.

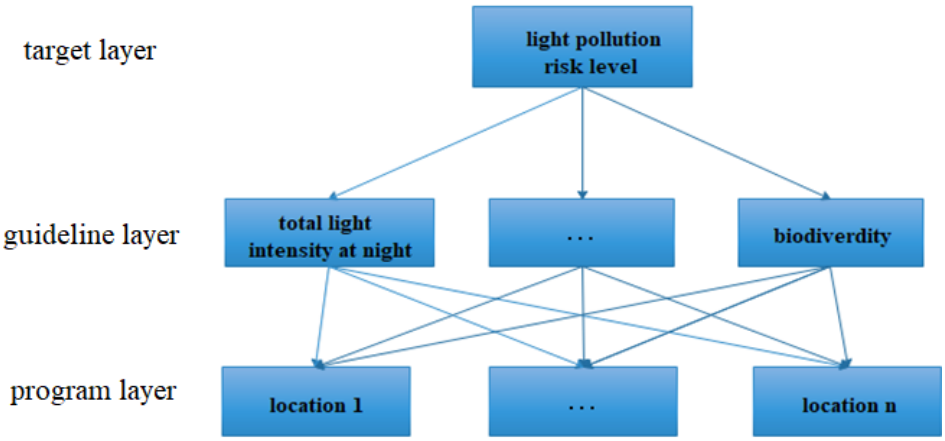


Figure 1 the hierarchical structure diagram

Target layer: light pollution risk level

Guideline layer:

1.total light intensity at night

2. average daily light hours

3.percentage of total area covered by nighttime light

4.biodiverdity

Program layer:

location1 to location n

3.2.2. Constructing the judgment matrix

After integrating the expert opinions and giving the indicator layer scoring, the light pollution risk level evaluation matrix was constructed. Pairwise comparisons using the 1-9 scaling method were used to quantify the model by constructing a two-by-two comparison judgment matrix, which finally yielded.

The judgment matrix of the guideline layer B_i to the target layer B is as follows.

$$B = \begin{pmatrix} 1 & \frac{5}{4} & \frac{5}{4} & 2 \\ \frac{4}{5} & 1 & 1 & \frac{5}{4} \\ \frac{4}{5} & 1 & 1 & \frac{5}{4} \\ \frac{1}{2} & \frac{4}{5} & \frac{4}{5} & 1 \end{pmatrix}$$

3.2.3. Consistency test of judgment matrix

All judgment matrices are normalized and calculated with the help of MATLAB programming to obtain the eigenvectors, W_B where i=1,2,3,4, and the maximum eigenvalue λ_{max}.

When calculating the weights. In order to ensure the robustness of the results, three methods are used in this paper: arithmetic average method, geometric average method, and eigenvalue method, and the average value is calculated after the weights are derived respectively.

Then according to the obtained eigenvalues according to formula (1) and formula (2) for consistency test. (CI represents the consistency of the judgment matrix, the closer the value of CI is to 0, the higher the consistency of the judgment matrix; CR represents the consistency ratio, the consistency ratio is less than 0.1, then the consistency test is passed. CI is the random consistency index, the specific value is shown in Table 2, where n represents the order of the judgment matrix.)

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

$$CR = \frac{CI}{RI} \tag{2}$$

Table 2 Table of random consistency index RI values

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The final calculation results are organized in Table 3 below.

Table 3 Results of consistency tests and weights

Indicator weights obtained by arithmetic averaging method	Indicator weights obtained by geometric averaging method	Indicator weights obtained by Eigenvalue method	Average of the weights of the three indicators	*CI*	*CR*	Whether the consistency test is passed
0.3259	0.3257	0.3261	0.3259	0.0025	0.0029	yes
0.2448	0.2450	0.2448	0.244867			
0.2448	0.2450	0.2448	0.244867			
0.1845	0.1843	0.1844	0.1844			

3.3. Definition of light pollution risk level index

3.3.1. Calculation of the initial score for each indicator

After cleaning and normalizing all the collected data, each indicator evaluation score will be calculated on a scale of 100 out of 100.

For positive indicators, Each data of the indicator was first calculated according to formula (3), and then the results were averaged to obtain the initial score of each indicator, and for negative indicators, each data of the indicator was first calculated according to equation (4), and then the results were averaged to obtain the initial score of each indicator. (It is easy to know that biodiversity is a negative indicator.)

where the p_i represents the value after data processing of the positive indicator and the n represents the value after data processing of the negative indicator. p_{l_i} represents the initial score of each positive indicator, n_l represents the initial score of the negative indicator.

$$p_{l_i} = p_i * 100 \tag{3}$$

$$n_l = n * 100 \tag{4}$$

3.3.2. Calculation of the final score for each indicator

Then, calculate the score of each indicator based on the obtained weight matrix. initial score of each indicator multiplied by the weight is the final score of the indicator.

3.3.3. Definition of light pollution risk index and classification of light pollution risk level

Let the initial scores obtained in 1 be s_i. Define the light pollution risk index according to Equation (5) as the final light pollution level evaluation index.

$$\text{Index} = \sum_{i=1}^{4} w_i s_i \tag{5}$$

It is easy to know that the final score interval ranges from 0 to 100, and we classify areas with light pollution risk index between 0 and 20 as lower risk areas, between 20 and 40 as low risk areas, between 40 and 60 as medium risk areas, between 60 and 80 as high risk areas, and between 80 and 100 as higher risk areas.

Table 4 shows how the risk level is classified.

Table 4 Criteria for risk level classification

index	0-20	20-40	40-60	60-80	80-100
Risk Level	Lower light pollution(I)	Low light pollution(II)	Medium light pollution(III)	High light pollution (IV)	Higher light pollution(V)

4. Conclusion

In this paper, the assessment model of light pollution risk level is established based on Delphi method and analytic hierarchy process (AHP) , which provides model support for the identification of urban light pollution risk level. This paper first constructs the evaluation index system by Delphi method, then calculates the weight of each index by compiling the code and analyzing the hierarchical process, and uses Excel to count the scores of each evaluation index of each city, the light pollution risk index was defined as an index to evaluate the level of light pollution. The light pollution risk index is calculated by summing the scores of each index and multiplying them by 100. Finally, the city is divided into five grades according to the range of the light pollution risk index.

The Delphi method is adopted for the determination of indicators, which avoids the problems of incorrect and incomplete selection of indicators caused by the lack of professional knowledge. When calculating weights using hierarchical analysis, three methods (arithmetic average method, geometric average method, and eigenvalue method) are used to calculate weights and finally take the average, which solves the deviation of results caused by the traditional method of calculating weights by only

one method and ensures the robustness of results, and then calculates the scores of each solution according to the obtained weight matrix for ranking and comprehensive analysis, which results in more compre-hensive and effective conclusions. But this method can not avoid the subjectivity of AHP, the index system still needs to be further improved.

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