Light pollution assessment based on linear weight scoring function

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Abstract. In recent years, with the rapid development of big cities, light pollution is everywhere, which causes people to think. Balancing the benefits of artificial light and the negative effects of light pollution is an increasingly thorny issue. More and more environmentalists are calling for the cessation of extensive night lighting and nightlife to reduce the harm caused by light pollution. This paper establishes a risk level assessment model for light pollution and proposes three options for dealing with the phenomenon.Considering that the impact of light pollution involves all aspects of people's lives, six indicators, namely GDP, population density, percentage of arable land, energy consumption, percentage of population living under artificial brightness higher than natural brightness, and crime rate, were selected from economic, ecological, and social aspects to determine the risk level of light pollution. Hierarchical analysis and entropy weight were combined to obtain the combined weights. A linear weight scoring function r was constructed to determine the local light pollution level.In response to the formation factors of light pollution, three strategies are proposed to control light pollution in terms of luminaire types, lighting patterns and government management intervention and guidance. Among the types of lamps and lanterns, it is recommended to promote truncated lamps. In addition, reducing the commercial use of LED lighting is also a necessary solution. In terms of lighting patterns, two different lighting patterns are proposed, reducing the use of floodlighting and using less special lighting to minimize light pollution caused by improper lighting patterns. Finally, stand for the government to increase the management mode and optimize the city's lighting hours.

Keywords: risk level assessment model for light pollution, strategies for light pollution control, the combined weight.

1. Introduction

1.1. Problem Background

Light pollution, the problem caused by the excessive use of lighting system, due to the coverage of lights in the city and outside the night sky stars disappear, and even destroy the ecological balance. [1]There are many causes of light pollution, mainly from inefficient or unnecessary artificial light sources. The main light pollution problems can be divided into five categories: light invasion, light over-illumination, glare, sky glow, and clutter light.

Light pollution also causes a lot of problems such as reduced safety, studies have shown that adequate light reduces crime but misdirected lighting does the opposite; It can affect human health. [2]Studies have shown that exposure to excessive light at night can affect melatonin production, cause myopia, and affect mood loss. The destruction of the night sky scene, the Milky Way or starry sky can not be observed, seriously damaged the astronomy enthusiasts and people's humanistic and scientific literacy; Waste of energy, which occurs when more light is generated than is needed or when the light does not reach the intended target.

Even though light pollution is such a serious problem, there are still differences in the definition of responsibility and scale, requiring repeated negotiations between different groups, and the economic development of modern industrial societies is very dependent on lighting systems.[3] Even the authorities have to be flexible to limit the amount of light that exceeds the standard to legal limits.

There is no concrete way to solve the problem of traditional pollution. Only social progress and the change of people's living habits can mitigate its negative effects.

1.2. our work

As shown in figure 1 below, the evaluation model of light pollution risk level was constructed. Based on the impact of light pollution on economy, ecology and society, six indicators were selected to determine the risk level of light pollution, including GDP, population density, percentage of arable land, energy consumption, proportion of people living under the sky with artificial brightness higher than natural brightness, and crime rate. Combined with AHP and entropy weight, the combined weight was obtained. The linear weight scoring function r was constructed to determine the local light pollution level.

We propose three prevention and control strategies of light pollution, and give specific actions of these three strategies. Considering the impact of each strategy after implementation, intervention and guidance are carried out from three aspects: lamp type, lighting intensity and government management, and the results of each prevention and control strategy are obtained.

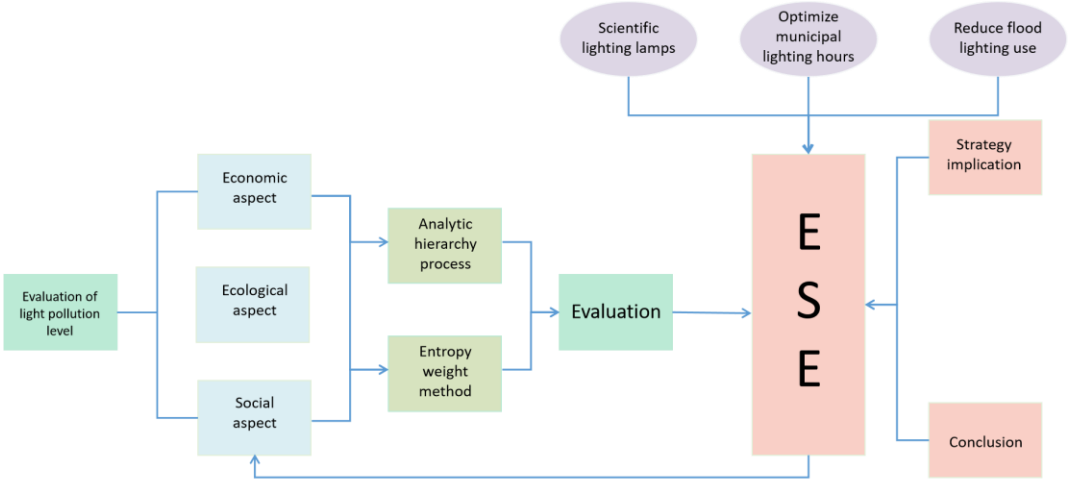


Figure 1. structure of our paper

2. Light pollution risk level evaluation model

2.1. The construction of index system

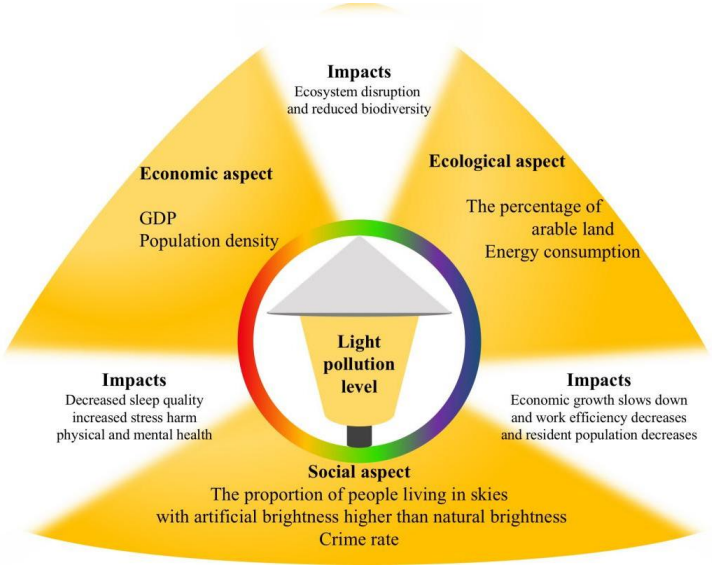


Figure 2. Schematic diagram of evaluation index of light pollution risk level

When assessing the level of light pollution, three influencing factors from economic, ecological and social aspects are considered(shown in figure 2). On the economic side, GDP and population density are taken account. The percentage of arable land and energy consumption correspond ecology. Social side is related to the percentage of people who live under skies that are brighter than natural and the crime rate.

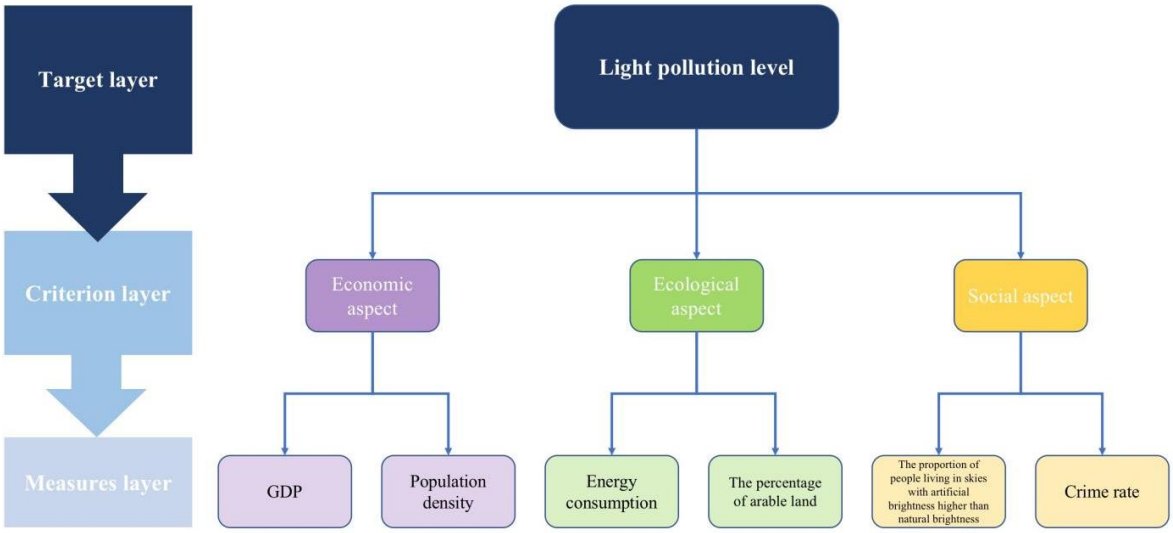


Figure 3. Model hierarchical structure diagram

Table 1. Evaluation index system of light pollution risk level

Target layer	System layer	Index layer
Light pollution level(A)	Economic aspect(B1)	GDP(C1)
		Population density(C2)
	Ecological aspect(B2)	The percentage of arable land(C3)
		Energy consumption(C4)
	Social aspect(B3)	The proportion of people living under skies with artificial brightness higher than natural brightness(C5)
		Crime rate(C6)

At the general level, the higher the GDP, the developed economy of the region, the price of a prosperous city is sufficient artificial light, mainly reflected in the night, the city nightlife lights up the whole sky, just like in the day. When the GDP level of a country is low, the degree of light pollution is relatively light. With the increase of GDP of a country, the degree of light pollution increases from low to high, and the degree of environmental deterioration worsens with the economic growth. In fact, increases in light pollution can be correlated with increases in gross domestic product. As the GDP of countries in South America, Africa and Asia has soared, so has the use of artificial lighting. But following earlier researchers (Grossman and Krueger, 1995; Harbaugh, et al, 2002), The possibility of a possible inverted u-shaped relationship between GDP and light pollution was considered. For some other pollutants, economic development tends to first increase pollution and then eventually decrease it as the economy continues to grow. The inverted u-shaped curve is often referred to as the "environmental Kuznets curve" (EKC) because of its similarity to the economic inequality function first proposed by Kuznets (1955)[4].

Consider GDP and consider the possible Kuznets relationship,Unfortunately, the lack of comparable economic data in many countries greatly limits our possible explanatory variables. However, some basic variables are included that indicate the resources and economic structure of a country. These variables include arable land and energy production. It’s feasible to use the percentage

of arable land to capture the impact of a national geographic. For example, a country with a lot of desert or mountains (less arable land) tends to have less light pollution. Abundant energy can make lighting cheaper. In addition, natural gas flares from oil Wells and refineries directly increase light pollution.[5] Light pollution is more serious in countries or regions with less cultivated land.As shown in figure 3 and table 1.

The higher the population density, the more serious the light pollution phenomenon.

2.2. The establishment of evaluation model

Combine the analytic hierarchy process and entropy weight method to determine the combined weight.

- **Analytic Hierarchy Process**

For each index of the same level, the index of the upper level is used as the criterion for pairwise comparison, the judgment matrix of pairwise comparison is constructed, and the consistency test is carried out to determine the index weight W_{1i}. Matrix, and then use the weight values of all subordinate indicators at the same level and the weights of all indicators at the upper level to calculate the weight values of all indicators at this level to the highest level, and finally get the comprehensive weight of light pollution level.

- **Entropy Weight Method**

The more information you have, the more important it is to make decisions. When the values of evaluation objects differ greatly in an index, the entropy value is small, indicating that the index provides a large amount of information, and the weight of the index should also be large. Information entropy theory can be used to evaluate the orderliness and utility of each index, that is, the weight of each evaluation index is determined by the judgment matrix composed of evaluation index values.

With m evaluation objects and n evaluation indexes, r_{ij} is the original data of the i item of the j index, and its initial matrix $R=(r_{ij})_{m\times n}$,

Statistical data are selected according to the evaluation index system, and an initial matrix is constructed. There are m evaluation objects and n evaluation indexes. r_{ij} is the original data of the i item of the j index, and its initial matrix R is as follows:

$$R=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & r_{ij} & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}_{m\times n} \tag{1}$$

If j is a benefit type indicator, treated according to formula (2); if j is a cost-based index, treated according to formula (3):

$$a_{ij}=r_{ij}/r_j^{\max} \tag{2}$$

$$a_{ij}=r_j^{\min}/r_{ij} \tag{3}$$

The entropy of the i_{th} index is defined as:

$$H_i=-k\sum_{j=1}^{n} f_{ij}\ln f_{ij}\,(i=1,2,3,\cdots,m;\ j=1,2,3,\cdots,n) \tag{4}$$

Where, $f_{ij} = f_{ij} / \sum_{j=1}^{n} r_{ij}$,k=1/ln$n$,when f_{ij}=lnf_{ij}=0.f_{ij} is the proportion of the j_{th} evaluation object in the i_{th} index; n is the number of evaluation objects; H_i is the entropy of the i_{th} index.

After the entropy of the i_{th} index is defined, the entropy weight of the i_{th} index is defined as:

$$w_{2i} = \frac{1 - H_i}{n - \sum_{i=1}^{m} H_i} \tag{5}$$

Where, $0 \le w_{2i} \le 1$, $\sum_{i=1}^{m} H_i = 1$. H_i is the entropy of the i_{th} index; m is the number of evaluation indexes, and w_{2i} is the entropy weight of the i_{th} index.

The minimum relative information entropy determines the combination weight:

The combined weight W_i can be obtained from the subjective weight W_{1i} and objective weight of the comprehensive index W_{2i}, W_{1i} and W_{2i} should be as close as possible. According to the principle of minimum relative information entropy, the Lagrange multiplier method is used to optimize the combined weight formula[6]:

$$w_i = \frac{(w_{1i} w_{2i})^{0.5}}{\sum_{i=1}^{m} (w_{1i} w_{2i})^{0.5}} \tag{6}$$

Through the above steps, the weights of each index in the light pollution level evaluation model system under different methods can be determined. When comprehensively evaluating the light pollution level of the four regions, the weight of the group method is used to evaluate, and the index weight of the system layer is obtained by adding the weights of the index layers. When the quality of the index of the system layer is evaluated separately, the evaluation system only contains the system layer and the index layer, but does not contain the target layer. The index weight of the index layer can be obtained by calculating the ratio of the weight of the original index layer to that of the corresponding system layer (Table 2).

Table 2. Weights of evaluation indicators determined by different methods

Criteria Layer	Weight(combination)	Index Layer	Weight		
			AHP	Entropy method	Combination
B1	0.3913	C1	0.1977	0.2678	0.2460
		C2	0.0912	0.2027	0.1453
B2	0.2953	C3	0.1224	0.0921	0.1135
		C4	0.1246	0.2321	0.1817
B3	0.3134	C5	0.3949	0.1172	0.2300
		C6	0.0692	0.0881	0.0835

Among them, the data obtained from the weight calculation of analytic hierarchy process come from the six indexes and the terms of light pollution in Google search, as follows. Light pollution and GDP had 85,700,000 entries, light pollution and population density 37,800,000 entries, light pollution and arable land 59,800,000 entries, light pollution and energy consumption 61,000,000 entries, and light pollution and crime rate 20.200,000 entries. Since C5 index is set by our research, there are few articles about light pollution on the Internet.

The evaluation value of the light pollution level in each region can be obtained by synthesizing the index combination weight w_i and the non-dimensionalized value y_i of the index in each region.

$$z_i = \sum_{i=1}^{m} w_i y_i (i = 1, 2, 3, \cdots, m) \quad (7)$$

Where z_i represents **the light pollution level, and the higher the value, the more serious the light pollution phenomenon.**

3. Development of light pollution response strategies

3.1. Adopt scientific lighting fixtures

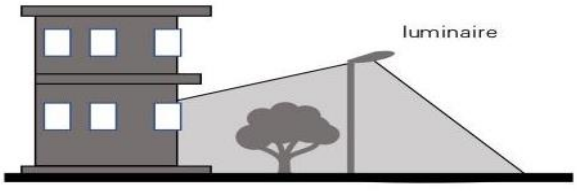
Lighting fixtures are the source of light pollution control[7], it is also the main cause of light pollution in the lighting process. A more scientific lighting fixture is characterized by basic preventive measures such as anti-glare and anti-spill light. In the current lighting purchase market, if a light fixture with preventive measures against light pollution prices will be relatively high; if the lighting products are relatively inexpensive, the use of a fairly wide range, but most of the lighting manufacturers have insufficient design capabilities, and little consideration of anti-light pollution.

3.1.1 Use of cut-off type lamps

Cut-off type lamps and lanterns are defined as: "the maximum light intensity direction of the lamps and lanterns downward vertical angle between 0-65 °, 90 ° angle and 80 ° angle direction of the light intensity of the maximum allowable value of 10cd / 1000lm and 30cd / 10001m lamps and lanterns. And regardless of the size of the light source luminous flux, the maximum value of its light intensity in the direction of 90 ° angle shall not exceed 1000cd.[8]The use of traffic road luminaires is huge, they are an integral part of people's normal night travel, so any change to this structure has a great impact on a city. Some data show that the use of cut-off luminaires has a huge effect on the prevention of light pollution. In Australia, there are data on cut-off and semi-cut-off luminaires, and the data show that cut-off luminaires are more effective.[9]As shown in figure 4,5 and table 3.

Table 3. Percentage of light reflected from cut-off and semi-cut-off streetlights to the sky

Luminaire type	Installation distance(s/h)	Uplighting(%)	Uplighting(%)
Truncated type	3	0	67
Semi-truncated light type	5	3	67



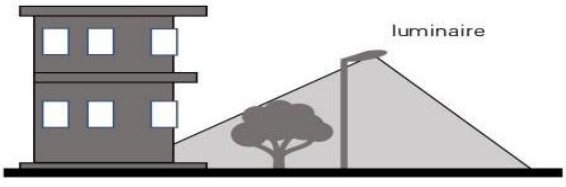


Figure 4. General Lighting **Figure 5.** Optimized design of cut-off type luminaire

Light cut-off data[10] has many uses, from the level of prevention of light pollution, light cut-off properties should be penetrated into most types of lighting. In the city for planning road lighting and life lighting plan, should be reasonable division of the light cut-off properties of lamps and lanterns, conducive to the later government for lighting intervention and lighting selection constraints.

3.2. Adopt reasonable lighting method

City night light pollution by a combination of different night lighting, for different scenes and different objects, use different lighting methods to maximize the reduction of light pollution behavior caused by inappropriate lighting.

3.2.1 Reduce the use of floodlighting

In general, floodlighting is one of the most common lighting methods, so most of the pollution caused by light trespass in residential areas, the culprit is floodlighting. Building codes clearly state that floodlighting is not suitable for residential buildings.

3.2.2 Use less special lighting

At present, the application and development of fiber optics, laser, especially computer control technology and other high-tech in the lighting engineering There are more and more beautiful and special night scenes. Shanghai's Oriental Pearl TV Tower sphere has 360 nodes, each node inside the use of fiber optic ends, forming a bright point of light, these nodes in accordance with computer requirements can make a variety of color change, shape, light and dark and other fantastical lighting effects. However, special lighting should not be used in large quantities, otherwise it will destroy the overall lighting effect of the city.

3.3. Increase government management efforts

Increase urban management In the process of urban development, it is necessary to strengthen the management of lighting tools as well as the construction aspects of the building. Without strict management, the requirements of the building will decline, which will also affect the quality of urban development and the living experience of the people, and will even destroy the living environment of human beings, animals and plants and reduce the living space. At the same time, the development of appropriate standards and regulations is also an important management approach in the stage of preventing light pollution.

3.3.1 Optimize municipal lighting hours

Night light pollution in addition to the illumination of lighting fixtures and lighting methods, but also closely related to the irradiation time, even if the level of light pollution is even greater, if the source stopped working, then the corresponding pollution disappeared, which means that light pollution is not only related to the brightness of the lamps and lanterns, but also related to the irradiation time.

Therefore, reasonable control of irradiation time, when needed to open the lamps and lanterns, when not needed to close, which is a kind of both energy saving and environmental protection can effectively reduce light pollution initiatives, in fact, the city's night lighting after late at night do not need to open all.

4. Conclusions

Focusing on the difficulty of determining the influencing factors of light pollution, the light pollution level evaluation model in this paper takes into account the comprehensiveness of the parameters, and creatively introduces the variable of the proportion of the population living under the sky with artificial brightness higher than the natural brightness in addition to the economic and environmental variables, while taking into account the influence of light pollution at all levels, and determines its weights by the method of subjective and objective factors, and the weights are more accurate. Provide a kind of reference for the current measurement of light pollution level.

Aiming at the current status quo of the increasingly serious light pollution in the world, this article proposed relevant governance measures from three aspects, namely, the types of lamps and lanterns,

lighting patterns, and the intervention and guidance of governmental management respectively, in an effort to realize the new situation of prevention-oriented, prevention and control combined, and to avoid as early as possible taking the old road of development first and governance later.

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