Study on the Risk Level of Regional Light Pollution Based on the EWM-TOPSIS Model —— A Case Study of China

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Abstract. In recent years, the rapid development of industrialisation has led to serious light pollution problems . In order to measure the degree of regional light pollution, firstly, this paper divides light pollution into three parts: ecological light pollution (Eco), daylight pollution (Dai) and decorative light pollution (Dec), selects nine secondary indicators, assigns a value to each indicator using the entropy weight method (EWM), and the three main indicators are 0.2484, 0.3569 and 0.3947, and combines with the tosis to establish a comprehensive evaluation model. In addition, considering the importance of necessary light, we added three metrics to the original metrics to optimise the model to ensure better safety and comfort.Finally, Applying the model to four specific areas, namely urban, rural, suburban and protected areas, to measure the specific pollution level of the region. Domestic research on light pollution is mainly qualitative research, this paper comprehensively considers the necessity of appropriate amount of light and the harm of excessive light, and proposes a comprehensive evaluation model of light pollution based on the entropy weight method to quantitatively analyse the degree of light pollution. This paper provides a new perspective for light pollution prevention and control.

Keywords: light pollution model, EWM, Topsis.

1. Introduction

Light pollution can be defined as excessive or poor use of artificial light, including light clutter, over-illumination and light trespass[1].With industrialization and urbanization, the phenomenon of light pollution in city construction has appeared more and more, which has a negative impact on the environment, ecology, and human health.

In order to measure the degree of regional light pollution,Hao carried out regional light environment testing and comparative study of the current status of light pollution in various regions by adopting the centre distribution method[2].Feng derives the common features of urban lighting light pollution evolution through the quantitative analysis method of VIIRS satellite images based on R language[3].Using the luminance contrast and glare value under light pollution environment, Zhou proposes a comprehensive evaluation model of night-time light pollution based on colour CCD camera and image processing technology to evaluate the degree of light pollution in navigable waters.[4].Qin selected fourteen indexes to establish a comprehensive evaluation index system of the quality of the light environment by using the hierarchical analysis method and the comprehensive index evaluation method to evaluate the quality of the light environment in the typical area[5].At present, the domestic research on light pollution is mainly qualitative research, and the quantitative research on light pollution is very little.This paper adopts the TOPSIS model based on entropy weighting method to quantify the degree of regional light pollution from multiple perspectives, and proposes a complete comprehensive evaluation system.

2. Light Pollution Model

2.1. Definition of light pollution

Light pollution is used to describe any excessive or poor use of artificial light.Light pollution alters the behavior, physiological functions and biological rhythms of individual organisms, and may threaten the balance of ecosystems in the long run.Furthermore, light pollution will have an impact on the sky, human life and health. Figure.1 briefly categorises the various effects of light pollution.

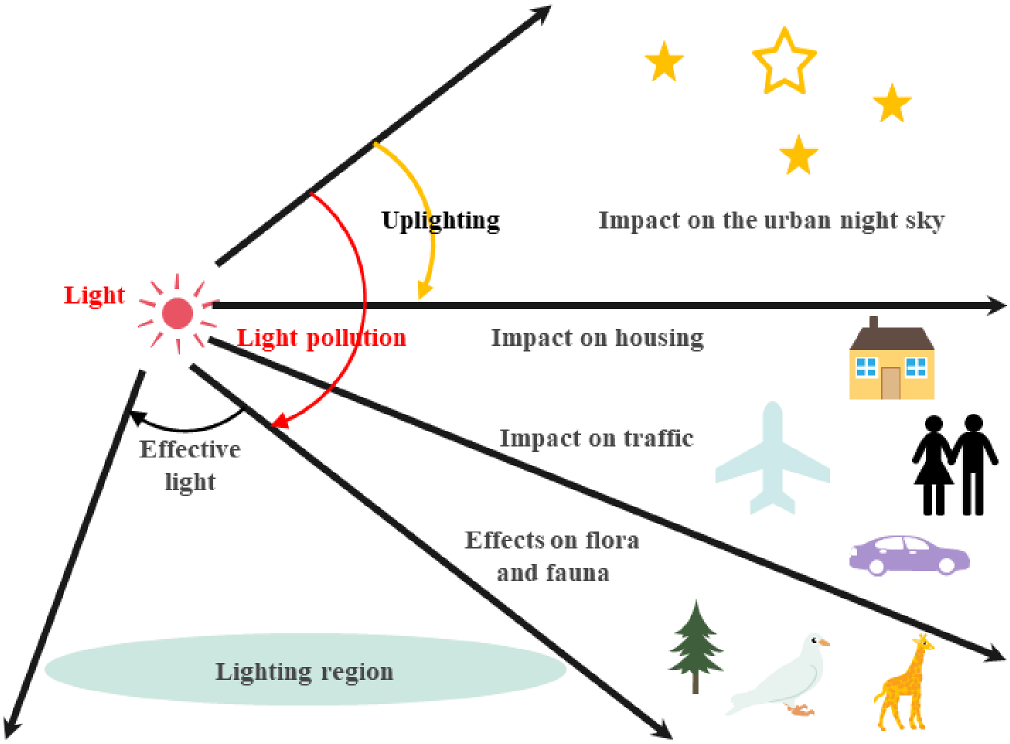

Figure 1. Light pollution impact distribution

2.2. Light Pollution Index

The evaluation of light pollution risk level is an important part of reducing light pollution.Light pollution risk level mainly consider artificial light and natural Light, which includes three aspects: ecological light pollution, daily light pollution and decorative light pollution.

At the same time, among the factors that produce light pollution also include environmental and socio-economic drivers, and for light pollution it will have environmental and socio-economic results.Therefore, when we analyze the environmental and socio-economic factors of light pollution, we should consider the interaction between the various parts of the light pollution and determine the proportion of each part.

Thus, an evaluation system consisting of ecological light pollution, living light pollution and decorative light pollution is established.Figure.2 shows the specific components of the evaluation system.

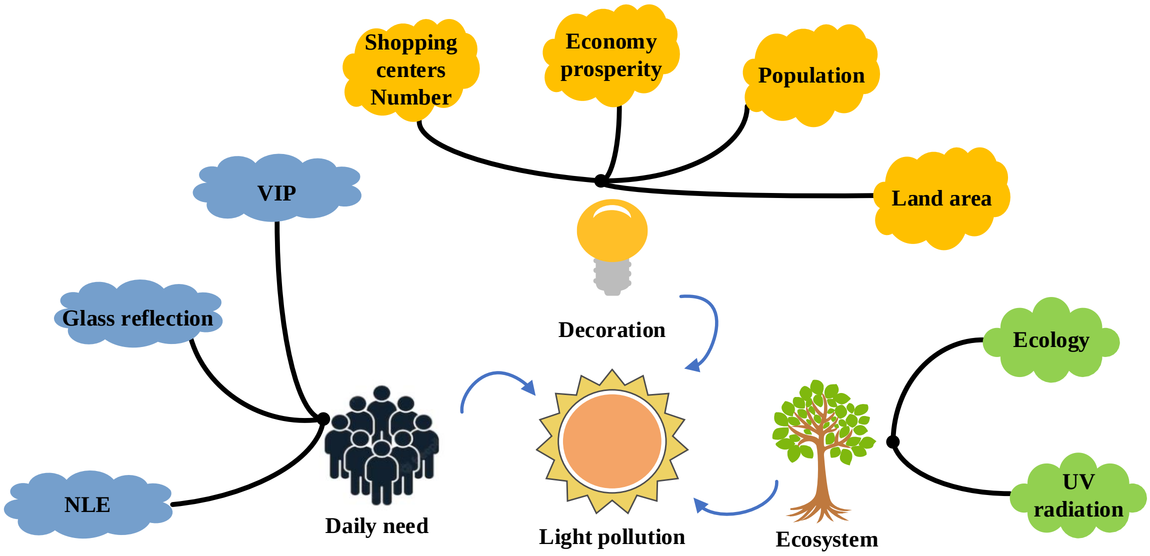

Figure 2. Light pollution index

2.2.1 Ecological light pollution

Ecological light pollution refers to effects of light on the ecosystem including flora and fauna ,among it we mainly consider ultraviolet radiation pollution and light invasion to the ecological environment.

(1) Ultraviolet radiation pollution(UVR)

Ultraviolet radiation pollution refers to the radiation of excessive ultraviolet light that can cause adverse effects on human health, human life and working environment[6].We determine UV radiation pollution by considering **the range of radiation from light to an area** and the duration of radiation.

(2) Ecological environment(EcE)

Ecological environment refers to vegetation cover and biodiversity in the region.Light pollution may affect the circadian rhythms of plants and animals.We evaluate the regional ecological environment by **the amount of vegetation cover and ecological indicators** of the region.Since light radiation affects the ecosystem, the less light radiation, the less ecosystem environment.

2.2.2 Daily light pollution

Daily light pollution refers to the light pollution produced by people's daily life in general, including the reflection of glass buildings, the lights of vehicles at night, and street lights at night.

(1) Glass reflection(GR)

Glass reflection means reflected glare that occurs when light hits the glass surface due to the specular reflection of the glass.Reflected glare can damage people's retina and indirectly lead to some traffic accidents[7].Considering that glass reflection mainly exists in buildings, we use **the number and footprint of urban building clusters** to assess the amount of light reflected from architectural glass. Figures 3 and 4 briefly illustrate the principles of glass reflection and glare formation.

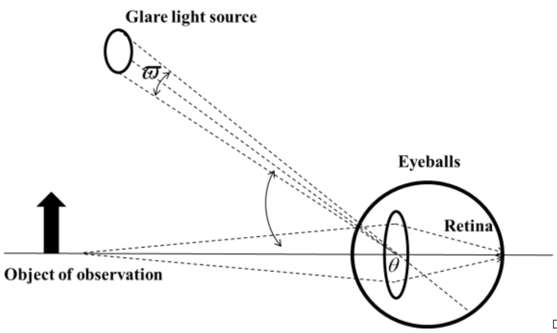

Figure 3. Glare formation [8]

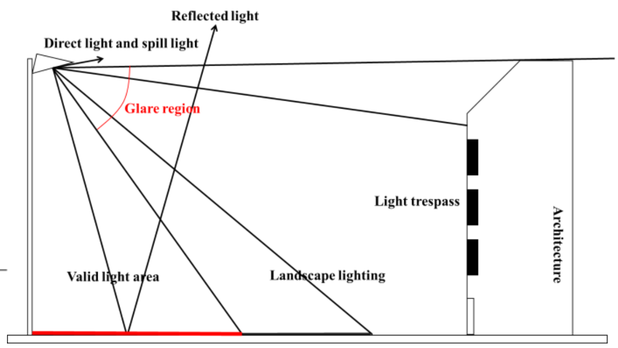

Figure 4. Glare pollution range

(2) Vehicle light pollution(VIP)

Vehicle light pollution refers to high-intensity lights for night that may affect the vision of drivers or pedestrians and cause traffic accidents.We assess traffic light pollution by **the number of vehicles** in each region.

(3) Nighttime lighting equipment(NLE)

Nighttime lighting equipment refers to lighting equipment such as street lights at night, which have impact on human sleep depth.Since night lighting mainly relies on street lights, **the number of street lights** in the area as the main night light pollution evaluation index.

2.2.3 decorative light pollution

Decorative light pollution refers to the use of lights as decoration, including shops decorated with colored lights, neon lights, etc.The number of decorative lights is usually related to the prosperity of the city, including economic prosperity, population density, and the number of shopping centers.

(1) Economic prosperity(EcP)

Generally speaking, the higher the economic prosperity of the city, the more entertainment facilities are equipped, which causes more serious decorative light pollution.**GDP** is used to measure a city's economic prosperity.

(2) Population density(PoD)

Population density refers to the ratio of population to land area.Regional population density is closely related to commercial prosperity, so we collect the **population(Pop)** and **available land area(LA)** of each region as evaluation indicators.

(3) Shopping center number(SCN)

Large shopping malls in cities make extensive use of decorative colored lights, and the more large shopping malls there are in a region, the more serious the decorative light pollution is.Therefore, we use **the number of large shopping malls** in each region as an evaluation indicator.

2.3. Establishment of the Basic Light Pollution Model

2.3.1 Entropy weight method

For a certain indicator, the entropy value can be used to determine the dispersion degree of a certain indicator.The smaller the entropy value of its information, the greater the dispersion degree of the indicator, and the greater the influence of the indicator on the comprehensive evaluation.therefore, the entropy weight method can be used to calculate the weights of each indicator, which provides the basis for the comprehensive evaluation of multiple indicators.The calculation process is as follows:

Step1: Data standardization.Assuming the original sample data matrix $A=\left(a_{ij}\right)_{m\times n}$, Standardized sample data matrix $B=\left(b_{ij}\right)_{m\times n}$:

$$b_{ij}=a_{ij}/\sqrt{\sum_{i=1}^{m}b_{ij}^{2}},i=1,2,...,m;\ j=1,2,...,n \tag{1}$$

Step2: Calculate the probability matrix P ,each element p_{ij} in P is calculated as follows

$$p_{ij}=\frac{b_{ij}}{\sum_{i=1}^{m}b_{ij}} \tag{2}$$

Step3: Calculate the proportion of the ith sample of the jth index:

$$e_{j}=-\frac{1}{\ln m}\sum_{i=1}^{m}p_{ij}\ln\left(p_{ij}\right)\quad ,j=1,2,...,n \tag{3}$$

Step4: The entropy weight required for each indicator is obtained by the derived formula:

$$W_j = \frac{1 - e_j}{n - \sum_{j=1}^{n} e_j} \tag{4}$$

Step5: Calculate the score of the sample ith, marked as S_i:

$$S_i = \sum_{j=1}^{n} a_{ij} w_j \tag{5}$$

Step6: Weights of sub-indicators derived usg method

$$\begin{cases} Eco = w_1 UVR + w_2 EcE \\ Dai = w_3 GR + w_4 VIP + w_5 NLE \\ Dec = w_6 SCN + w_7 EcP + w_8 Pop + w_9 LA \end{cases} \tag{6}$$

Step7: Calculate the entropy weights of the main indicators:

$$W_j = \frac{1 - S_i}{n - \sum_{j=1}^{n} S_i} \tag{7}$$

Subsequently, the weights of three comprehensive evaluation indicators can be calculated by EWM: ecological light pollution, daily light pollution and decorative light pollution. The calculated weight index results are shown in the Table 1 below:

Table 1. Weight of indicators

Indicator(I)	**Indicators(II)**	**Weights**	**Indicators(III)**	**Weights**
Light pollution Index	Ecological light pollution (Eco)	0.2484	Ultraviolet radiation pollution	0.1357
			Ecological environment	0.8643
	Daily light pollution (Dai)	0.3569	Glass reflection	0.3266
			Vehicle light pollution	0.1751
			Nighttime lighting equipment	0.4983
	Decorative light pollution (Dec)	0.3947	Shopping centers Number	0.4129
			Economy prosperity	0.2811
			Population	0.1424
			Land area	0.1636

2.3.2 TOPSIS Method

TOPSIS method, also known as the ideal solution method, is an effective multi-indicator evaluation method.This method constructs positive and negative ideal solutions to the evaluation problem and calculate the relative closeness of each solution to the ideal solution to rank the solutions so that the best solution is selected.

Step1: Standardized Decision Matrix $B = (b_{ij})_{m \times n}$

$$b_{ij} = a_{ij} / \sqrt{\sum_{i=1}^{m} b_{ij}^2}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{8}$$

Step2: Constructing a weighted standardized decision matrix $C = (c_{ij})_{m \times n}$, According to the entropy weight method the weight vector of each attribute is $w = [w_1, w_2, \ldots, w_n]^{\mathrm{T}}$,so

$$c_{ij} = w_j \cdot b_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{9}$$

Step3: Determine the positive ideal solution C^* and the negative ideal solution C^0 。Let the value of the j th attribute of the positive ideal C^* solution be c_j^*, and the value of the j th attribute of the negative ideal C^0 solution be c_j^0, then

$$\text{Positive ideal solution } c_j^* = \begin{cases} \max\limits_i c_{ij}, j \text{ is a benefit attribute,} \\ \min\limits_i c_{ij}, j \text{ is a cost attribute,} \end{cases} j = 1, 2, ..., n \tag{10}$$

$$\text{Negative ideal solution } c_j^0 = \begin{cases} \max\limits_i c_{ij}, j \text{ is a benefit attribute,} \\ \min\limits_i c_{ij}, j \text{ is a cost attribute,} \end{cases} j = 1, 2, ..., n \tag{11}$$

Step4: Calculate the distance from each solution to the positive ideal solution and the negative ideal solution.The distance of the alternative solution d_i to the positive ideal solution is as follows.

$$s_i^* = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_j^*)^2}, i = 1, 2, ..., m \tag{12}$$

The distance of the alternative solution d_i to the negative ideal solution is

$$s_i^0 = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_j^0)^2}, i = 1, 2, ..., m \tag{13}$$

Step5: Calculate the value of the ranking index for each program

$$LPI_i = s_i^0 / (s_i^0 + s_i^*), i = 1, 2, ..., m \tag{14}$$

Step6: Order the options in descending order of merit by LPI_i .

2.4. Optimization for Security and Comfort

In the previous model we only discussed the negative effects of light and ignored the positive effects of light.Considering that lower lit streets may lead to increased crime and make people feel gloomy, We added three indicators to the original index to optimize the model to ensure better security and comfort.

Therefore, we build the following regression model

$$\begin{cases} NLPI = LPI^* + \mu_1 * \dfrac{E}{E_i} - \mu_2 * TAC - \mu_3 * LC + \varepsilon i \\ LPI^* = W_1 * Eco + W_2 * Dai + W_3 * Dec \\ E = \dfrac{d\phi}{dS} \\ LC = \begin{cases} \dfrac{4159 - CT}{CT}, CT < 4159 \\ \dfrac{4553 - 4159}{CT}, 4159 < CT < 4553 \\ \dfrac{CT - 4553}{CT}, CT > 4553 \end{cases} \end{cases} \tag{15}$$

Where

- $NLPI$ (new light pollution index) represents New light pollution risk indicator , representing the level of light pollution risk in a country or region
- LPI^* (light pollution index) represents Topsis model modified light pollution risk indicators
- E represents Luminous flux per unit area of the surface
- E_i represents The UK uses the lighting brightness standards prescribed by Division E, The UK standards for the luminance of external building lighting are shown in the Table 2 below.

Table 2. British building façade lighting brightness standards[5,6]

Environment zone Use	E partition in environment file	Average brightness cd/m^2	Maximum brightness cd/m^2
$E1$ (E.g.rural)		0	0
$E2$ (e.g.suburban)		5	10
$E3$ (e.g.towns)		5~10	60
$E4$ (E.g.City)		10~25	150

- TAC (Traffic Accident and Crime)represents traffic accident and crime rate incidence
- LC (Light comfort): represents comfort of light, considering CT(color temperature).(The minimum value of color temperature is 4159K, and the maximum value is 4553K[9])

μ_1, μ_2, $\mu_3$represents regression coefficient

- μ_1 represents coefficient of influence of national or regional light level on the light pollution score index
- μ_2 represents the coefficient of influence of national or regional lighting conditions on the light pollution score index is 4.368[10].

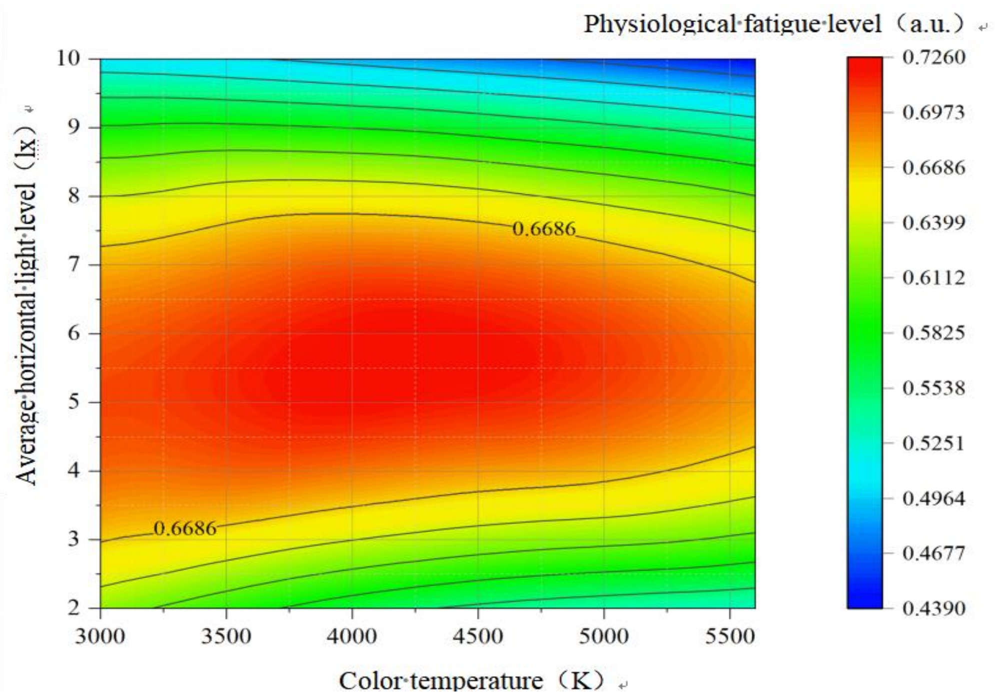

Figure 5. Subjective and comprehensive assessment of the light comfort zone

- μ_3 represents the coefficient of influence of national or regional resident comfort on the light pollution score index As shown in Figure.5, the area where the physiological fatigue level score is greater than or equal to 0.6686 (red area range) is the physiological fatigue level light comfort zone[9].

3. Modelling applications

3.1. Evaluation of light pollution in different locations

Internationally, population density is divided into four classes.According to the international requirements and the information given in the question, we defined urban communities, suburban communities, rural communities and protected land respectively.Based on the given information, we chose Shanghai, Guiyang, Zhaotong , and Yancheng Wetland Reserve respectively. The population densities of the districts are shown in the Table 3 below.

Table 3. Population density

Region	**Population Density (person/ Square kilometers)**	**City**
urban communities	>100	Shanghai
suburban communities	25-100	Baiyun (GuiZhou)
rural communities	1-25	Zhaotong(YunNan)
protected land	<1	Yancheng Wetland Reserve

Shanghai, the largest city in China, is one of the four central municipalities.It is the economic, financial, trade and shipping center of mainland China.Shanghai has created and broken many of the world's best and China's best by the China World Records Association.Shanghai has the largest industrial base and the largest foreign trade port in China, where over 20 million people living and working in the city.

Baiyun, an emerging cultural district in Guiyang, with a population of 456,250 inhabitants.

Zhaotong, located at the border of Yunnan Province, rural area, with a population of 54720 inhabitants.

Yancheng Wetland Reserve, covering 453,000 hectares, is a transition zone between terrestrial and marine ecosystems, forming one of the largest mudflat wetlands along China's coast, harboring a large number of organisms and providing conditions for the migration of millions of waterfowl.The area is an important wintering site for the endangered species of the Danding crane and one of the two largest remaining habitats for the river muntjac population in China.

To more clearly represent the characteristics of the four cities,we selected the five highest weighted factors to presented them in a radar chart(Figure.6).

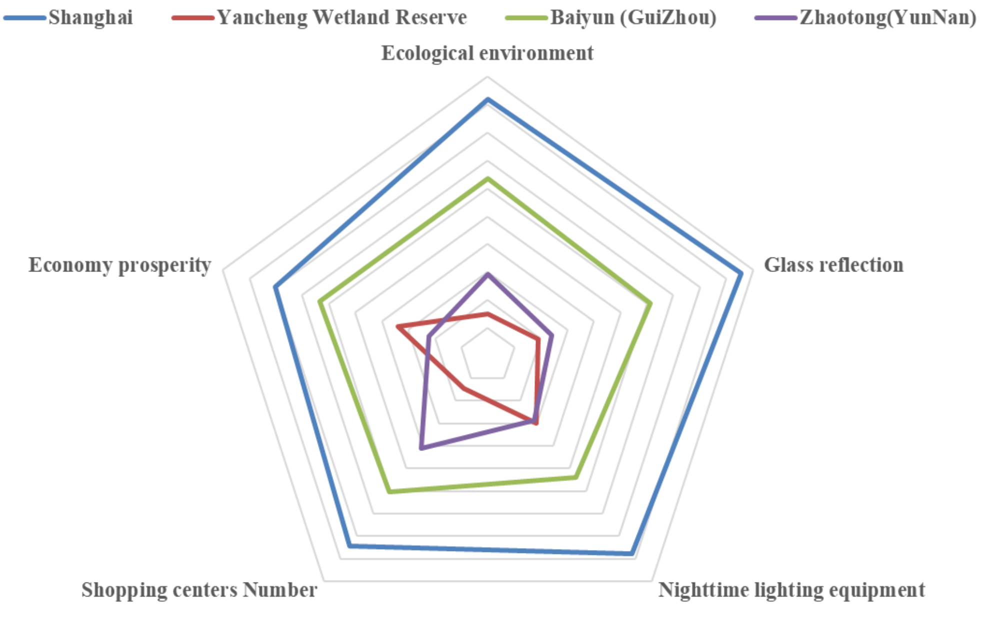

Figure 6. Comparison of the five indicators in the four regions

It is reasonable to see from the radar chart that Shanghai scores much higher than the other three regions in all indicators. And Yancheng Wetland Reserve surpasses the rural area Zhaotong in terms of economy, which we guess is because Yancheng is famous due to the wetland park and the tourism industry has developed as a result, driving the local economy.

According to equation (7) and equation (14), the following scores are obtained by substituting the data of each city.

0.45 (Shanghai)>0.30 (Baiyun)>0.14 (Zhaotong)>0.11 (Yancheng)

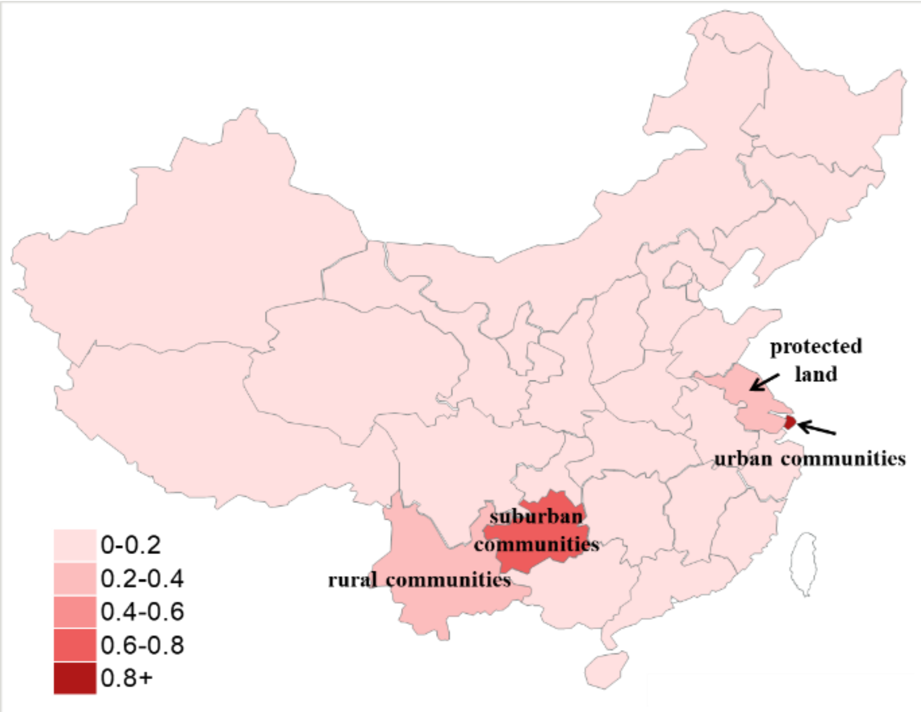

Figure 7. Comprehensive evaluation scores of the four regions

The heat map also gives us a better sense of the level of light pollution risk in the four regions.(Figure.7)

Figure 8. Night View

As shown in Figure.8 that shows the real life pictures of the four regions, we found that the light pollution risk levels derived from the comprehensive evaluation model of Topsis are consistent with the actual light pollution status of each region, which verifies the practicality of our model.

3.2. Urban Communities

Light pollution is most severe in urban communities, and the comprehensive data evaluation explains it in the following aspects.Firstly, the density of buildings, and vehicles in urban communities is significantly higher than in other areas, which brings more decorative light pollution and daily light pollution.Among the three types of light pollution, decorative light pollution accounts for the highest percentage, followed by daily light pollution, therefore these dominant factors contribute to the high levels of light pollution in urban communities.

3.3. Suburban Communities

Suburban communities are somewhere less prosperous than cities in terms of population and economy, and have significantly fewer glass buildings, so they score less in decorative light pollution and daily light pollution than urban communities.However, suburban communities have a significant advantage over rural communities in terms of population and economy, so the overall assessment score is between urban and rural communities.

3.4. Rural Communities

First of all, rural communities are not well developed in transportation and mainly agriculture lead to the economic underdevelopment, so there is little need for decorative lighting so that it will not produce too much decorative light pollution.Secondly, the population base in rural communities is small, infrastructure construction is not comprehensive, greatly reducing the living light pollution.Finally, rural communities have a large area, and the amount of vegetation cover is high.The superior ecological environment also confirms the light pollution less.

3.5. Protected Land

Protected areas are virtually free of decorative light pollution and daily light pollution because of the special nature of the land, which is almost no economic development and population. In addition, the protected area has a large amount of vegetation cover, good ecology and less light pollution.

4. Conclusions

In order to reasonably evaluate the severity of light pollution in different regions, we divide light pollution into three parts: ecological light pollution, daylight pollution and decorative light pollution, select twelve secondary indicators, assigns a value to each indicator using the entropy weight method (EWM),and combine with the TOPSIS to establish a comprehensive evaluation model.Applying the model to four specific areas, namely urban, rural, suburban and protected areas, the results show consistency with the actual situation, indicating the feasibility and credibility of the model developed in this paper. This paper provides a new perspective on light pollution control.

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