Research Light Pollution based on EWM

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Abstract. With the continuous development of society, the use of light becomes more and more frequent. In order to study the factors affecting light pollution, we first created a model to assess the degree of light production, and divided light pollution into 3 types: Photo-phore, Light Trespass and Lighting Effect. Then we weighted these three factors with entropy weight method (EWM) and we calculate that the weights are respectively 0.2671, 0.6004 and 0. 1324. After that, we built a model to measure the bearing capacity of light. We have grouped the influencing factors into 3 categories: Humanity, Biomass and Altitude, with Biomass being a negative indicator. We apply the light pollution level model to 4 samples. They are Jinniu District (city community), Longquanyi (suburban community), Dayi County (rual community) and Longxi Hongkou Protection Zone(protected land). And we determine their scores. The light-polluting production are respectively 0.9799, 0.1232, 0.0887 and 0. The bearing capacity of light are respectively 0.8827, 0.6072, 0.3395 and 0.1250. The pollution level are respectively 0.2222, -0.3590, -0.1658 and 0.

Keywords: light pollution, entropy Weight Method, bearing capacity, pollution level.

1. Introduction

With the development of technology, light is more and more widely used in human life. Light has a wide range of applications in clean energy, electronic communications, medical care and other aspects[1]. However, as people's application of light gradually deepens, it has also become a new environmental pollution source after the pollution of exhaust gas, wastewater and noise, which has brought adverse effects on the natural environment and human life[2].

The level of nighttime light pollution in an area is related not only to the amount of light produced in the area, but also to the ability of the place to tolerate light pollution[3]. Therefore, we built a total of three model regions to measure the light generation, light pollution tolerance and light pollution degree of a region respectively[4]. On this basis, we analyzed the degree of light pollution in four different places in Chengdu, Sichuan Province.

2. Model to Measure Light Production

To measure light pollution, we break it down into two parts. The first part is to measure how much light is produced in a place.

In the calculation of light production, we choose light trespass, photo-phore and light effect as our variate. The variate is shown in Fig.1.

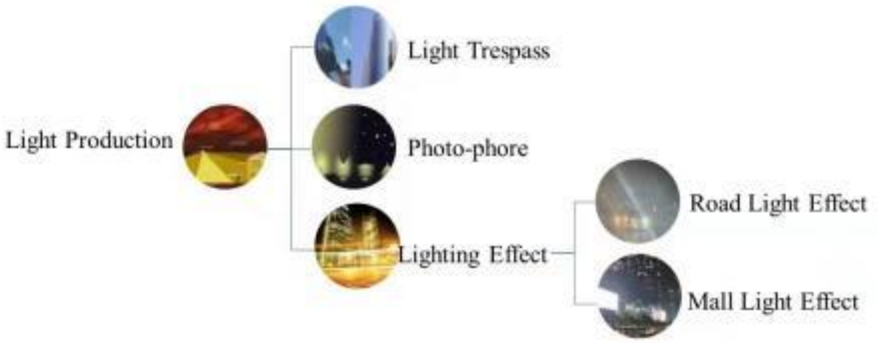

Figure 1: Light production

2.1 Index Introduction

(1) Photo-phore: We use streetlights to illuminate the roads. However, most of the time, the light from the street lamp does not reach the road, which may be due to the way the bulb is installed, or the lamp shade. The light enters other places from a supposed space, reducing the brightness of the light that actually shines on the ground or where it should be shone, which will reduce the utilization rate of light. The Fig.2 can explain this phenomenon. We use the OPS method to calculate and analyze the degree of light overflow in a place.

$$G = \frac{E_d + E_T}{S_d + S_T} \tag{1}$$

$$R = \frac{G}{E_g} \tag{2}$$

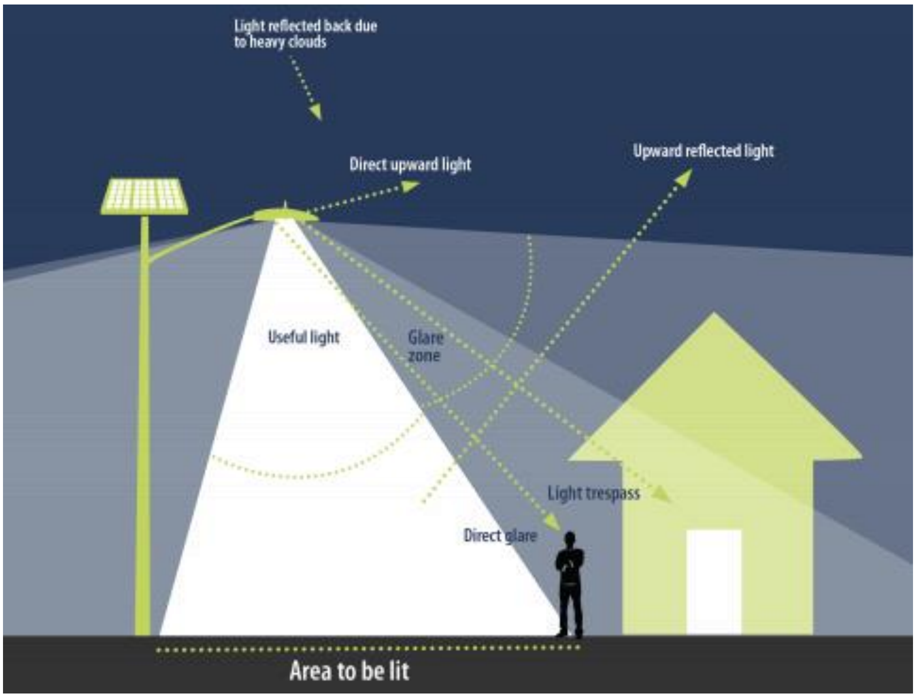

Figure 2: The Explanation Picture of Light Pollution

where G denotes the photo-phore, R denotes the overflow ratio of light, Ed denotes the average illumination of each measuring point on each side of the cube space, E_d denotes the average illuminance of each measuring point on the top surface of cube space, S_d denotes the sum of the sides of the cube space, S_T denotes the top surface area of cube space, E_g denotes the average illuminance of each measuring point on the bottom surface of cube space.

To simplify the model, we assume that the same street lights are evenly and symmetrically distributed on both sides of each road. The area of the cube is the area enclosed by two street lights on both sides of a road, that is, the length(l) of the cube is the spacing of two street lights on the same side, the width(w) of the cube is the width of the road, and the height(h) of the cube is the height of the lamp. And we assume that all six faces of the cube have the same illumination. So we can get the Eq.3.

$$R = \frac{1}{w \times l} \tag{3}$$

(2) Light Trespass: Light trespass refers to the light entering unexpected areas. In addition to the light overflow caused by street lamps on both sides of the road, the most serious problem is the light curtain formed in the sky by the strong light mainly generated from the busy areas of the city, which will increase the ambient light intensity of a community at night. If the intensity of the light curtain is strong enough, it will have a greater impact on the physiological activities of the people in the community. The intensity of this curtain of light is inversely proportional to the distance from the bustling city.

We use the urban overflow astigmatism model proposed by Garstang with our appropriate modification to measure the degree of light intrusion, as shown in the Eq.4.

$$L_T = \begin{cases} L_0 \times \left(\dfrac{P}{10000}\right)^{0.1} & Dis \leq 3Km \\ L_0 \times \left(\dfrac{P}{10000}\right)^{0.1} \times \dfrac{1}{Dis} & 3Km < Dis < 10Km \\ 0 & Dis \geq 10Km \end{cases} \tag{4}$$

where L_T denotes light the degree of light trespass in a place, L_0 denotes the intensity of spillage and astigmatism at the top of each head. P denotes the flow of people, dis denotes the distance between a place and a city center.

(3) Lighting Effect:

Road Lighting Effect

At night, the light from the street lamp outside the window or the strong light from a distance may shine in, affecting people's sleep. Here we mainly discuss the effect of light

produced by street lamps near Windows. According to relative literature, we use the Eq.5 to measure the road lighting effect.

$$T = 32.285 + 0.002L - 1.935S + 2.719H - 0.620D \tag{5}$$

where T denotes encroachment degree; L denotes flux of light; S denotes the distance be- tween the road and the residence; H denotes the light pole height; D denotes the spacing of the same side lights. All the coefficients come from the thesis [1]

Mall Light Effect

Blacklight, rotating light, flashing light and other color light sources constitute color light pollution. Facing these colored lights for a long time is not only bad for the eyes, but also can interfere with the central nervous system of the brain, and even have a greater psy- chological impact. Here we mainly consider whether some small shops in the community attract customers with colored light sources, or the invasion of colored lights from nearby large shopping malls. We assume that the influence of the color light pollution is:

$$CML = \alpha\rho \int_1^{L_{max}} \frac{0.5 l_x}{L} dL \tag{6}$$

where CML denotes the influence of color light; α denotes the transfer coefficient of color light, here we choose $\alpha = 1$; ρ denotes the population density; L denotes the distance from the market to the apartments; L_{max} denotes the largest service range of the mall; l_x denotes the intensity of light generated by the mall.

In the final evaluation of the light pollution level, We treat the weight of these two parts are the same.

2.2 Weight Determination

The weight calculated by EWM(Entropy Weight Method) is determined by the informa- tion entropy of the index which implies the variation degree of the index. The wider the infor- mation entropy is, the more significant it is in the evaluation. Therefore, it is objective to use EWM to determine the weight of the index when calculating the model.

Our data used to assess the indicators is from numerous of data sets, which not only includs well-known websites like CNKI, but also involves some municipal database. When the data gap is too large, we appropriately delete it from the evaluation list. For some indicators with a relatively large amount of data or necessary indicators, we use the average value of nearby terms or data from similar countries to fill the gap. In this way, we have obtained relatively accurate and sufficient information. After data processing, we finally got three indicators.

We use EWM to calculate the weight of photo-phore, light trespass and light damage. First, we calculate the weight of jth indicator in the ith sample.

$$p_{ij} = \frac{r_{ij}}{\sum\limits_{i=1}^{n} r_{ij}} \tag{7}$$

According to the concept of self-information and entropy in information theory, the infor- mation entropy E_j of each evaluation indicator can be calculated,and thus

$$E_j = -\frac{\sum\limits_{i=1}^{n} f_{ij} ln(w_{ij})}{ln(n)} \tag{8}$$

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

$$W_j = \frac{1 - E_j}{n - \sum\limits_{j} E_j} \tag{9}$$

We found the national standards for some variables from the national standards document in Tab.1.

Table 1: National Standard

Region	Standard (unit)	Value Range
City	Distance between urban roads and residential areas (m)	≥ 5
	High of street lights in urban communities (m)	$4 \sim 5$
	Wide sidewalks in urban communities (m)	$1.5 \sim 2$
	Average illumination of residential area (lx)	15
	Street light spacing in urban communities (m)	≈ 5
Rural	Distance between a country road and a residential area (m)	$--$
	High street lights in rural communities (m)	$3 \sim 5$
	Wide sidewalks in rural communities (m)	$--$
	Average illumination of rural communities (lx)	5
	Street light spacing in rural communities (m)	$15 \sim 20$
Suburban	Average illumination of suburban communities (lx)	5
	Spacing of street lamps (m)	$10 \sim 20$
	Height of street lamp (m)	$8 \sim 15$
	Vehicle lane width (m)	≈ 3.5

We assume that the suburban communities use the street lamps to light, and the residential buildings are on both sides of the two-lane road. In the rural communities, we assume that the residential buildings are on both sides of one-lane road.

And then we get the weights of the little terms in each aspect in Tab.2.

Table 2: Weight

Index	Weight
Photo-phore	0.2671
Light Trespass	0.6004
Lighting Effect	0.1324

Finally, we multiplied the weight by the score of each part to get the degree of light pollution infringement of each simple.

$$L_{pro} = W_{pp} \times R + W_{LT} \times LT + W_{LE} \times 0.5(CML + T) \tag{10}$$

where L_{pro} denotes the score from EWM, W_{pp} , W_{LT} , W_{LE} denotes the weight of photo-phore, light trespass and light effect that is calculated by using EWM method.

3. Model to Measure the Bearing Capacity of Light

In the second part, we set up the bearing capacity of light model to test the light tolerance of different area types, such as the protected land, the rural community, the suburban community, and the urban community. At the same time, the model is affected by three factors, respectively human factor,biodiversity,and latitude. We still use different types of areas in Chengdu as the sample model.

3.1 Human factor

Human factor is divided in to two parts, population and GDP.

Population: Population is an important part of test of light tolerance. The more people in this region, the greater the demand for light and the stronger the ability to accept light. Therefore, we establish a formula about population and the bearing capacity of light.

$$BC_{pop} = \frac{e^P - e^{-P}}{e^P + e^{-P}} \tag{11}$$

where, BC_{pop} represents the bearing capacity of light, and P represents the population density, that is, how many ten thousand people per kilometer.

GDP: GDP is a another important part of human factor. The higher the GDP level of a region, the higher the development level of the region. A high level of development represents a high degree of light use, which denotes that the region has a higher tolerance for light.

$$BC_{GDP} = 1 - \frac{1}{e^g} \tag{12}$$

where, BC represents the bearing capacity of light, and g represents the ratio of GDP per capita in different regions to GDP per capita in Chengdu.

3.2 Biodiversity

Biodiversity is an essential part of evaluating the light pollution. Light pollution will not only harm human beings, but also adversely affect animals and plants to some extent. Take plants as an example, most of them grow in the daytime and rest at night, with obvious growth periodicity. If the plants are irradiated for a long time at night, it will destroy their work and rest rules, even make the leaves and stems yellow, and then wither.

Therefore, it is not difficult to find that the richer the biodiversity of a region, the weaker its ability to withstand light pollution, and there is a negative correlation between the two.

Before analysing our four samples, we classified them into four sub-type variables according to their biodiversity richness: $BC_u = 1$, $BC_s = 0.75$, $BC_r = 0.5$, $BC_p = 0.25$. In these four formula, BC is the bearing capacity of light, u is the urban community, s is the suburban community, r is the rural community, and p is the protected land.

3.3 Latitude

Latitude also affects the level of light pollution to some extent. Using the Northern Hemi- sphere as an example, we believe that the more untimely light pollution occurs, the more severe it is. That is why we study the situation at night and in the summer semester. However, areas in the high latitudes of the northern hemisphere are characterized by long days and short nights in the summer semester, and the duration of daylight is long, which has a greater negative impact on work and rest than people and animals. Considering that our research object is only Chengdu, and the latitude difference between regions is not large, the latitude is not in our consideration.

3.4 Calculate the Bear Capacity of Light

We assume that the weights of human factor and biodiversity are the same and the weights of population and GDP are the same. So we can get that:

$$BCL=0.5BCj+0.25BCpop+0.25BCGDP \quad (13)$$

where BCL denotes the bear capacity of light; j = u, s, r, p

4. Models to Measure Light Pollution

Light pollution is not just pollution caused by having too much light, but also by not enough lighting. So we use the LP model to measure the degree of light pollution in a place.

$$Lpol = Lpro - BCL + C \quad (14)$$

Where Lpol denotes the level of light pollution; C denotes correction constant. We set Lpol of the protected area is 0, so we calculate that C = 0.125.

4.1 Model Application

We chose four places to apply our model in Chengdu city, capital of Sichuan province in China, namely Jinniu District (city community), Longquanyi (suburban community), Dayi County (rual community) and Longxi Hongkou Protection Zone (protected land). The RS photo of Sichuan province is shown in the Fig.3.

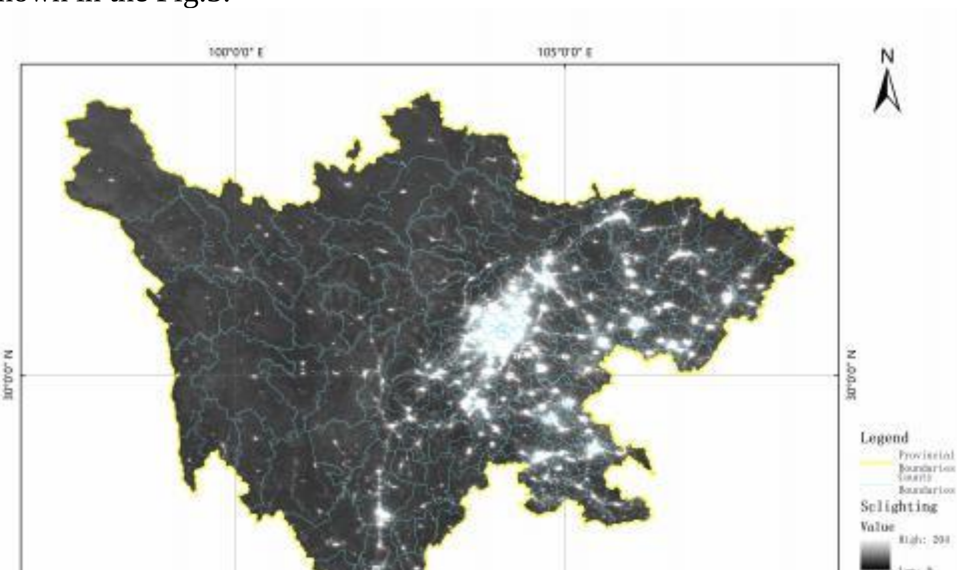

Figure 3: RS photo of Sichuan province

We draw 3 figures to show the solution of light production, bearing capacity of light and light pollution. They are Fig.4, Fig.5 and Fig.6

Figure 4: Geography Distribution of Light Production

Figure 5: Geography Distribution of Bearing Capacity of Light

Jinniu District

In our model, we can conclude that the level of light pollution is highest in Jinniu Dis- trict. Jinniu District is located in the urban area, close to the central area, with serious light intrusion; The economy is developed, the population is large, the demand for light resources is large, and the amount of light overflow is also large; There are many shop- ping malls and entertainment places in Jinniu District. The color light pollution caused by color light sources such as black light, rotating light and flash light is severe and the degree of light damage is high, which is also the reason for the large amount and high degree of light pollution in Jinniu District.

Figure 6: Geography Distribution of Light Pollution

As an urban area, Jinniu County should have strong ability to resist light pollution, but its population is only 1.2 million, even less than some suburban cities, and its GDP per capita is only 116.4 thousands, which is less than 0.4 thousands more of Longquanyi District in the suburbs, showing that Jinniu District’s light pollution tolerance is not excellent. Suburban-level light pollution tolerance cannot match that of city-level light pollution, making Jinniu District one of the most polluted cities in Chengdu.

Longquanyi

Longquanyi District has the lowest pollution level among all our samples. As a suburb, its population has even exceeded that of Jinniu District, which is located in the urban area, reaching 1.3 million, and the total GDP is not much different from that of Jinniu

District, which makes Longquanyi District almost equal to the light pollution tolerance of the urban area.

At the same time, it is located in the suburbs, far from the urban area, far from the central area, and receives less light intrusion, and light intrusion accounts for nearly 0.6 of our weight of light pollution, so Longquanyi District receives relatively little light pollution.

That is, the light pollution level in Longquanyi District is low, which is consistent with our model.

Dayi County

The population density of Dayi County is the smallest in Chengdu, and the per capita GDP is also far away from the overall per capita GDP of Chengdu. Because of its under- developed economy and low population density, sunlight in the region is too scattered, which makes it still inadequate. But because its light pollution tolerance is not high, this makes it not very lack of light.

Longxi Hongkou Protection Zone

Longxi Hongkou Protected Area is a national protected area. In order to ensure that the wildlife in the area can benefit greatly in an environment almost unaffected by human activities, the protected area will not be inhabited. And it's so far away from the city center that it's not affected by any light intrusion from the city center. This is also why we choose LP = 0 as the calculation condition when calculating C in Eq.14.

5. Conclusion

We set up a model to evaluate the degree of light pollution, and provide intervention strategies for solving light pollution.In order to study the factors affecting light pollution, we first created a model to assess the de-gree of light production, and divided light pollution into 3 types:Photo-phore, Light Trespassand Lighting Effect. Then we weighted these three factors with entropy weight method(EWM) and we calculate that the weights are respectively 0.2671, 0.6004 and 0. 1324.After that, we built a model to measure the bearing capacity of light. We have grouped the influencing factors into 3 categories:Humanity, Biomass and Altitude, with Biomass being a negative indicator. Since we're only examining a city's grade, the latitude factor isn't taken into account. By setting the weight of each factor as 0.5, we get the formula to measure the bearing capacity of light pollution, and then we combine the amount of light pollution to finally get the formula to measure the degree of light pollution.In the third part, we apply the light pollution level model to 4 samples. They are Jinniu District (city community), Longquanyi (suburban community), Dayi County (rual community) and Longxi Hongkou Protection Zone (protected land). And we determine their scores. Then we explain the reasons according to each area's results.Below, we present 3 policies to solve the light pollution problem, including marginal popu- lation movement, increase greenery, and expansion of non-light areas, and we describe the impact of each policy.

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