Study on Risk Classification of Light Pollution in Different Regions Based on Entropy Weight Method and Variation Coefficient Method

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Abstract. Light pollution is a new source of environmental pollution after exhaust gas, wastewater, waste residue, and noise. Research shows that light pollution is threatening people's health. In order to accurately measure the level of light pollution risk in a region, this paper established a light pollution risk index level model, and used this model to detect the level of light pollution risk in different types of places. Specifically, by determining the main factors that affect the risk of light pollution, and searching for corresponding data indicators from different countries to calculate the weight, this paper uses a combination of entropy weight and coefficient of variation to obtain the index weight, and establishes a light pollution risk index level model based on the weight. Finally, the model is applied to four specific types of locations to determine their risk level of light pollution.

Keywords: Entropy Weight Method, Coefficient of Variation Method, Light Pollution Level.

1. Introduction

At present, most regional or global light source measurements rely on satellite instruments, such as the Visible Infrared Imaging Radiometer Kit (VIIRS), which can take daytime and nighttime images of the Earth's surface. In 2017, scientists used the VIIRS observation to find that the global light pollution increased by about 2% every year. But this kind of instrument is blind to the light of blue wavelength, which is emitted by more and more common LED lamps. In addition, the perspective of the celestial eye mainly sees the light that directly shoots into the space, rather than the light scattered in the atmosphere. Therefore, many researchers believe that the 2% value is underestimated [1]. We can get European light pollution detected by VIIRS in 2021, as shown in Figure 1.

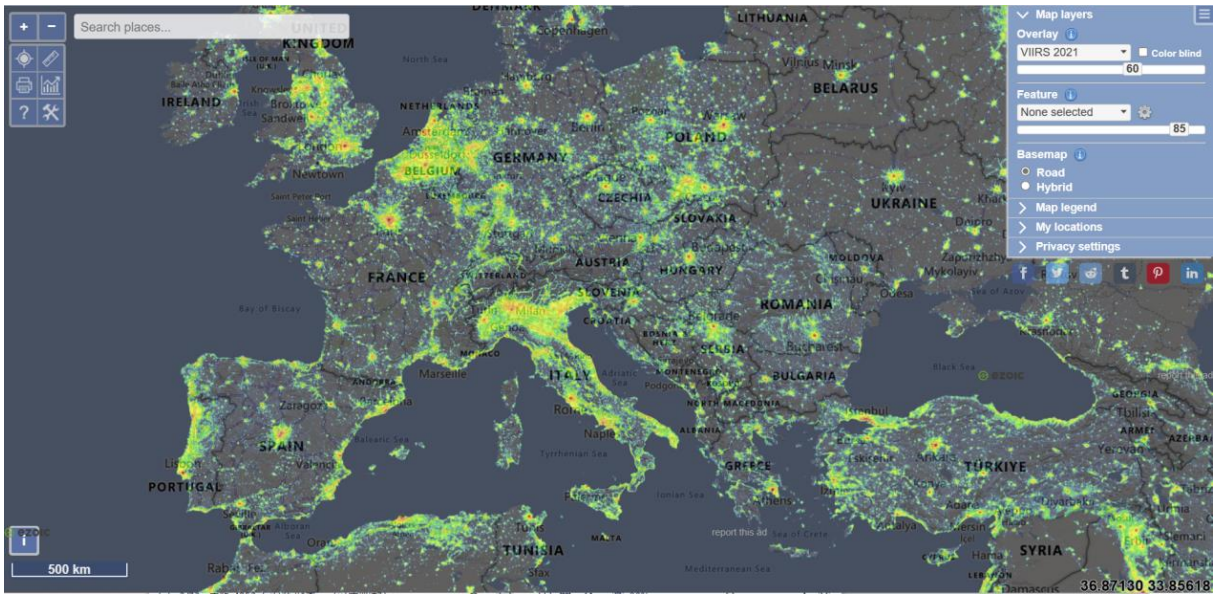

Figure 1. European light pollution detected by VIIRS in 2021 [2]

The improvement of urban lighting level can improve the night safety of the city, and also reflect the degree of urbanization. But this will inevitably lead to light pollution, which will also bring many negative effects.

In terms of economy, nighttime lighting will absorb more funds and energy. The nighttime lighting the human use far exceeds the actual light source demand. The International Dark Sky Association estimates that about one-third of the lighting is wasted. This amount of light costs about $2.2 billion a year.

In terms of ecology, coal-fired power plants will emit a large amount of carbon dioxide pollution into the atmosphere every year. According to some estimates, in terms of air quality, reversing light pollution is equivalent to reducing 9.5 million cars on the road. Rapid urbanization and economic development have caused environmental problems [3], and even in modern big cities, people cannot see the stars directly [4].

In terms of biology, light pollution will also affect animals, especially the most active species at night. Artificial light will interfere with migration, hunting, foraging and breeding. It reduces the time for nocturnal animals to find food, shelter and mate. It can also help predators see their prey around the clock.

In terms of physical health, a study found that there was a link between the low level of melatonin in developed countries and the rising incidence rate of breast cancer. Another study showed that compared with women living in areas with bright lights at night, women living in areas with bright lights at night had a 73% higher risk of breast cancer.

The impact of light pollution may depend on local development level, population, biodiversity, geography and climate.

In order to accurately measure the level of light pollution risk in a region, this paper establishes a light pollution risk index level model, and uses this model to detect the level of light pollution risk in different types of places.

Massetti et al.[5] analyzed the light pollution of five different places in Tuscany, Italy, analyzed the night sky brightness data from 2016 to 2019, and evaluated the relationship between the night sky brightness of each place and local seasonal changes, lunar phase cycle and weather conditions. In cities, the average night sky brightness on rainy days may reach 15.4 mpsas (about 436 times the natural background brightness).

For cities, the distribution characteristics of light pollution also follow the law of economic development. Liu Ming et al. [6] analyzed the satellite visual observation data in Dalian, and found that light pollution in developed areas, such as commercial areas, is the most serious; the distribution of color temperature in the city is characterized by the high average value of color temperature in residential areas.

This article first use McKinsey logic tree to analyze the factors that affect the severity of light pollution, and use the data found to establish a model to express the light pollution risk index of each region, so as to divide the degree of light pollution.

Then the article uses the established model to measure the degree of light pollution in different types of areas.

2. Light Pollution Risk Index Level Model Based on Weight

2.1. Selection of Indicators

There are many factors affecting the severity of light pollution in a region, which can be divided into two parts: non-human factors and natural factors. The essay will use McKinsey Logic Tree to analyze the factors that affect the severity of light pollution in a certain area from these two aspects to measure the light pollution risk index. Because it is difficult to collect and sort out the indicators in too small areas, the essay choose the country as the regional unit after analysis, and the selected indicators are shown in Figure 2 below.

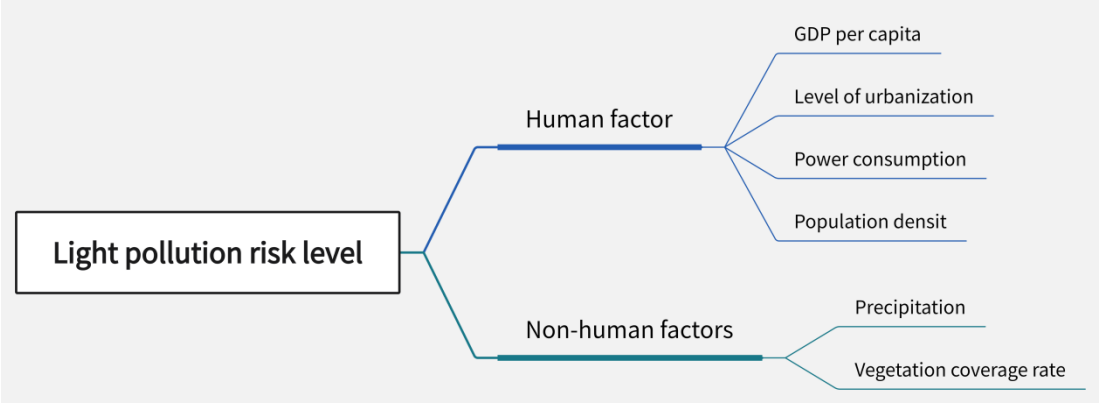

Figure 2. Selection of Indicators

2.1.1 Human Factor

Light pollution is a new source of environmental pollution, which mainly includes white light pollution, artificial day pollution and color light pollution. From the definition, the essay can know that light pollution is mainly caused by human beings. The gross national product is an important indicator to measure a country's development level. Generally speaking, the development of a country is closely related to the gross national product. The higher the gross national product, the more prosperous the country will be, and the more serious the light pollution will be.

Per capita power consumption is one of the important factors reflecting light pollution. The essay assume that everyone uses Q% of their own power consumption as lighting, so the more power consumption per capita, the more power consumption for lighting, and the more serious light pollution.

The level of urbanization reflects the proportion of the population living in large, medium and small towns in the total urban and rural population of a country. The higher the level of urbanization, the more prosperous a country's cities are and the more serious light pollution will be.

Population density is the number of people per unit area of a country, which to a certain extent reflects the population density of a country. The denser the population is, the stronger the light pollution is; moreover, this factor reflects the fact that some developing countries have more serious light pollution than developed countries to some extent.

2.1.2 Non-human Factors

In addition to human factors, some specific natural conditions will also aggravate the risk of light pollution to a certain extent. Average annual precipitation is the total amount of precipitation and snowfall in a country in a year. Relevant research shows that the newly fallen snow and thick clouds are both climatic factors that aggravate the severity of light pollution. Therefore, the essay chooses to use the average annual precipitation of each country as one of the indicators that affect the risk level of light pollution.

What’s more, biological factors are also one of the factors affecting light pollution. The essay chooses the vegetation coverage rate of each country as the measurement index. The higher the vegetation coverage rate, the lower the transmission range of light pollution under certain conditions, and have certain benefits for human health.

2.2. Data Preprocessing

The essay collected six items of data on the risk level of light pollution from 200 countries, which came from the World Bank, the International Energy Agency and other websites. According to the lack of data, the essay have sorted out and deleted the countries with more missing values, and the countries with less missing values have used interpolation method, finding the data of countries with the same quality, and finally obtained the indicator data of more than 100 countries.

2.2.1 Data Forward Transition

Among our indicators, there are very large indicator types, such as GDP per capita, population density, etc; there are also very small indicator types, such as vegetation coverage. For very small data, the essay needs to forward it.

$$X_{ij} = max(x_i) - x_{ij} \ , \tag{1}$$

Where i represents the index number, j represents the country.

Because of the above transition, all indicator types are transformed into extr emely large ones.

2.3. Weight Calculation

2.3.1 Entropy Weight Method

Entropy weight method [7-9] is an objective weighting method. It believes that the smaller the degree of variation of the index, the less information it reflects, and the lower its corresponding weight value. It has been widely used in social economy and engineering fields. The essay uses the entropy weight method as a part of the weight determination.

For the data after forward transition, the essay needs to standardize it in order to eliminate the impact of dimension.

$$Y_{ij} = \frac{X_{ij} - min\,(X_i)}{max(X_i) - min\,(X_i)} \ , \tag{2}$$

For the data $Y = \{Y_1, Y_2, \dots, Y_6\}$ obtained after normalization of forward data $X = \{X_1, X_2, \dots, X_6\}$, the essay calculates the information entropy E:

$$E_i = -\frac{1}{In\ 6}\sum_{i=1}^{6} P_{ij} In\ P_{ij} \ , \tag{3}$$

Where, the probability of each data is:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{6} Y_{ij}} \ , \tag{4}$$

When $P_{ij} = 0$, the essay can get

$$\lim_{P_{ij} \to \infty} P_{ij} In\ P_{ij} = 0 \ , \tag{5}$$

Then the essay can get the weight determined by entropy weight method as

$$W_i = \frac{1 - E_i}{n - \sum_{i=1}^{6} E_i} (i = 1,2,3 \dots, k) \ , \tag{6}$$

2.3.2 Coefficient of Variation Method

The coefficient of variation method [10-11] is also an objective weighting method. According to this method, the essay can determine the importance of the indicators by obtaining the weight of the indicators with large variation difference and the weight of the indicators with small variation difference.

$$cv_i = \frac{SD_i}{\bar{x_i}} , \tag{7}$$

Where, SD_i is the standard deviation of all data under the No.i indicator, and $\bar{X_i}$ is the average of all data under the No.i indicator.

The coefficient of variation can be obtained from the following formula:

$$W_{cv_i} = \frac{cv_i}{\sum_{i=1}^{n} cv_i} , \tag{8}$$

2.3.3 Combined Weight Calculation

The index weight determined by entropy weight method sometimes has the defect of equilibrium. In order to avoid this problem, the essay uses the method of combining entropy weight and coefficient of variation to obtain the index weight. Assuming the preference coefficient of the weight is λ, the combination weight is

$$W_{new,i} = \lambda W_i + (1-\lambda) W_{cv_i} \quad \lambda \in (0,1)\,, \tag{9}$$

The essay sets the preference coefficient $\lambda = 0.5$ to get the comprehensive weight of each index, as shown in Figure 3 below.

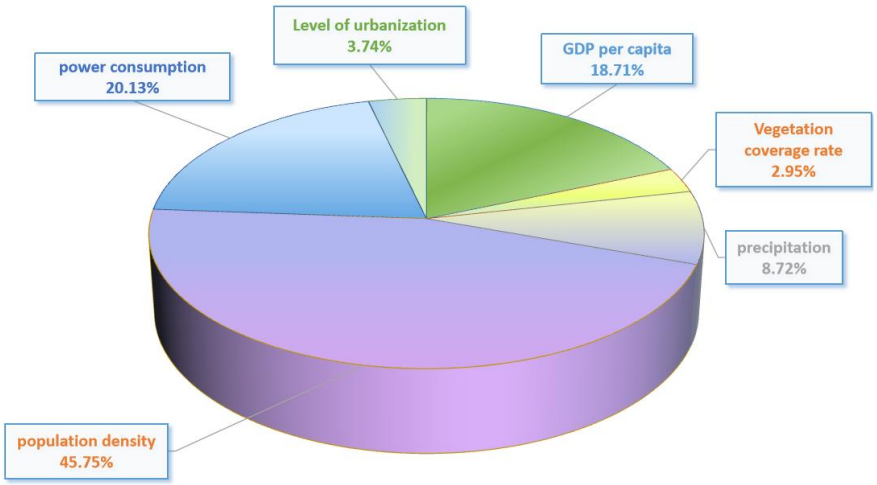

Figure 3. Comprehensive Weight of Each Index

Where, the largest proportion is population, which is 0.4575; the second is power consumption, accounting for 0.2013; GDP per capita followed closely, accounting for 0.1871; However, Level of urbanization and vegetation coverage only accounted for 0.0374 and 0.0295. The essay can see that human factors occupy an obvious dominant position, which is consistent with the fact that the abnormal light pollution in real life is mainly caused by human factors, and natural factors only play an auxiliary role.

2.4. Establishment of Model

After obtaining the comprehensive weight, the essay uses the method of dividing weights and summing to obtain the light pollution risk index of a region.

$$\mathrm{Q} = \sum_{i=1}^{6} W_{new,i} X_{ij}\,, \tag{10}$$

Through cluster analysis, according to the light pollution risk level of each country, the essay divides all countries into three categories: High-level light pollution areas, Medium-level light pollution areas, Low-level light pollution areas. The Table 1 reflects the result of cluster analysis.

Table 1. Classification of Light Pollution Risk Level

Level of risk	The number of countries	Typical areas
High	8	USA、Qatar、Singapore
Middle	24	China、UK、Germany
Low	85	Peru、Cuba、Brazil

The essay can see that the medium-high level light pollution areas include the vast majority of developed countries and some relatively developed developing countries, while most of the relatively backward countries are low-level light pollution risk areas. This is also the same as our understanding.

The more developed and prosperous countries are, the more serious light pollution is. Light pollution is concentrated in parts of the world.

3. Results

3.1. Model Validation

According to verify the accuracy of the model, the essay will apply our model to four specific types of sites, including a protected area, a rural community, a suburban community and an urban community. In order to ensure the reliability of the data, the essay selected China, a country with moderate level of light pollution, and took its four regions of different nature as the verification set to verify our model.

The reasons for choosing China are as follows: China is a developing country with a vast territory. The development of cities in different regions of the country varies greatly. The essay can easily choose different types of cities as the basis for verification. In the search process, the data of cities and towns in China's provinces are relatively intact, reliable and more convincing. The article collected data from four different types of regions in China, and their light pollution index is shown in the Figure 4 below.

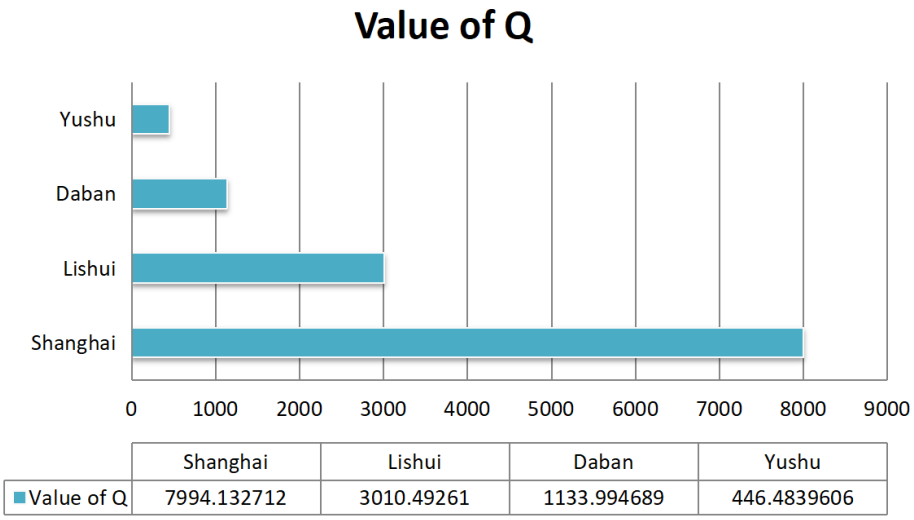

Figure 4. Value of Q in Different Region

According to the above clustering results, the light pollution level in China's urban areas is roughly above the medium-level light pollution, the suburban areas are roughly at the junction of the medium-level light and low-level light pollution, while the rural and protected areas are in the low-level light pollution area, while China is also below the middle-level light pollution area in general, which is consistent with the reality, indicating that this model is reliable and trustworthy.

4. Conclusions

In order to determine the risk level of regional light pollution, the essay plans to develop a widely applicable measurement standard. The essay calculate the weight by determining the main factors affecting the risk of light pollution and looking up the corresponding data indicators of different countries. The essay also use the method of combining entropy weight and coefficient of variation to obtain the index weight, and then establish the level model of light pollution risk index based on the weight. According to this model, the essay have classified more than 100 countries into high, medium and low levels of light pollution risk, and the results obtained are basically consistent with the data found, thus verifying the accuracy of the model.

The essay apply our model to four specific types of locations, and use four regions of different nature in China as verification sets to verify our model. According to the results of clustering, it shows that the pollution level in urban areas is above the middle level, the suburban areas are roughly at the

junction of the medium-level light and low-level light pollution, and the light pollution in protected areas and rural areas is at a low level.

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