

Study On the Risk Level of Light Pollution Based on Principal Component Analysis

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Abstract. In this paper, based on the principal component analysis, the evaluation indication of light pollution is established, and the effective control strategy is put forward. Through the statistical analysis of a large number of samples, light pollution is divided into four risk levels: no pollution, mild pollution, moderate pollution and moderate pollution. Then, seven parameters affecting light pollution are selected, the parameters of four areas are statistically analyzed, and eight groups of data are obtained. Through the principal component analysis, the dimension of the three principal components is reduced, and finally the relationship between the grade score of light pollution and the three principal components is obtained. In this study, scores were used as a universal measure to determine the risk level of light pollution in a place. According to the analysis of this study, the intervention strategy is put forward, for New York, Shanghai, Beijing and other national central cities, economic development is a priority, enterprises and households use light is huge, the need to strengthen the detection of lighting equipment and the introduction of relevant policies. Similarly, economic development is not a priority for Shanghai suburbs and Yamagata counties, and businesses and households will reduce the use of lighting. Finally, for nature reserves such as Sanjiangyuan, the development goal is to ensure that the environment will not be damaged. As a result, the light pollution index in these areas is very low.

Keywords: Light Pollution, Principal Component Analysis, Intervention Strategies.

1. Introduction

Artificial light sources have greatly increased the brightness of the night sky in the past decade, so much so that the number of stars visible to the naked eye has plummeted, according to Science magazine. If this situation continues, less than half of the stars will be visible to the naked eye in less than 20 years. Some studies have pointed out that light pollution will affect the natural life of animals and plants and destroy the balance of the ecosystem. In the human body, it can destroy the body clock, disrupt the endocrine balance, and lead to physical and psychological problems. Excessive lighting will also consume unnecessary electricity, resulting in a huge waste of energy. The picture below shows light pollution around the world. As can be seen from the picture, light pollution has gradually become one of the inevitable problems in our lives[1]. In life, people do not have a clear understanding of the source of light pollution. In the treatment of light pollution, people often ignore the hidden characteristics of light pollution[2], which is also a great challenge to the control and control of light pollution. In addition, although it has been used for centuries, artificial light at night has not been thought to be the cause of environmental problems until recently[3]. In order to promote the protection of ecological environment, it is also very important to improve the awareness of the harm of light pollution at night[4]. Figure 1 shows the distribution map of global lighting pollution (Map source: www.lightpollutionmap.info).

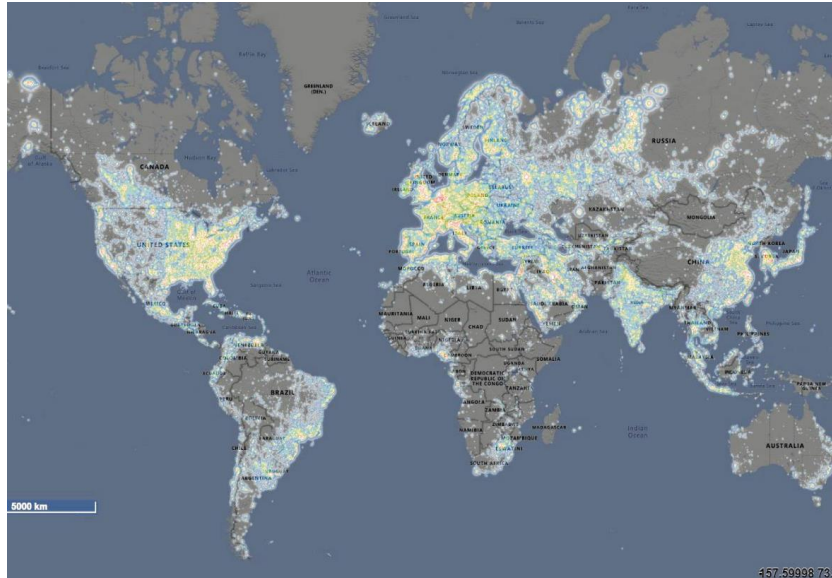


Figure 1: Lighting pollution worldwide

Taking into account the background information and constraints identified in the problem statement, this study needs to address the following issues:

- Develop a universal measure to determine the level of light pollution risk in an area by considering various factors.
- Apply the above measures in four scenarios including protected land location, rural community, suburban community, and urban community, and inter-pret the results of model fitting.

2. Materials and methods

2.1. Data acquisition and preprocessing

This study collected the data of illuminance, zenith brightness, effective illuminance, illumination time, per capita electricity consumption, per capita GDP, urbanization rate and so on in different cities, suburbs, villages and protected areas, which may lead to light pollution. By understanding the intervention strategies of light pollution in different countries and regions, this study found how to use shielding and directional lighting, turning off lights when not in use, using voice-activated and light-controlled lights, switching to low-wattage light bulbs, issuing lighting regulations, educating the public, using environmentally friendly materials efficiently, using advanced green technology, and strengthening urban management, reasonable selection of building materials and projection methods. The data sources are summarized in Table 1.

Table 1: Data source collation

Database Names	Database Websites Data	Type
NOAA	https://www.noaa.gov/	Geography
Light Pollution Map	https://www.lightpollutionmap.info/	Environment
CNKI	https://kns.cnki.net/	Academic paper
NBS	http://www.stats.gov.cn/	Statistics
CNEMC	http://www.cnemc.cn/	Statistics
Google Scholar	https://scholar.google.com/	Academic paper

Through the analysis, this study found that there are still some missing values and outliers in the data, so this paper has carried out some data processing, preprocessing and data cleaning.

2.2. Method introduction

This paper presents a method to measure the risk level of light pollution and an intervention strategy on how to deal with light pollution. According to four different types of site parameters, a general model for measuring the risk level of light pollution is established by principal component analysis. The specific measures of possible intervention strategies are put forward, and the impact of these strategies on the risk level of the corresponding sites is discussed. Principal component analysis, invented by Carl Pearson in 1901, is usually used to reduce the dimensionality of data in machine learning. Its advantage is to reduce the complexity of data and identify the most important features.

3. Light Pollution Risk Level Measurement Model

Light pollution is determined by a variety of factors, namely, Illumination, zenith brightness, effective illumination, illumination time, per capita electricity consumption, per capita GDP, urbanization rate and other factors, all of which will affect the risk level of light pollution. Therefore, a method of multivariate analysis should be used to solve such a complex multivariable system. While principal component analysis can eliminate the correlation influence among evaluation indicators and reduce the dimension of the data space studied, it can also know which factors take the heaviest proportion among the dependent variables we want, so as to facilitate the subsequent evaluation of the scheme and model. Therefore, the model based on principal component analysis is a good approximation for predicting the level of light pollution risk.

3.1. Light Pollution Risk Level Standard

After referring to the classification standards of other countries and consulting a large amount of literature data, we divided the risk of light pollution into four levels: no pollution, light pollution, moderate pollution and heavy pollution. The specific fractions are shown in the Table 2:

Table 2: Level standard

Levels	Score Interval
No Pollution	[0 , 20)
Light Pollution	[20 , 60)
Moderate Pollution	[60 , 90)
Heavy Pollution	[90 , 100]

According to the above scoring criteria, this study selected several typical global samples, corresponding to four regions. Through statistical analysis, the following conclusions are drawn:

The four sections can approximately correspond to four kinds of sites, that is, protected lands correspond to no pollution, rural communities correspond to light pollution, suburban communities correspond to moderate pollution, and urban communities correspond to heavy pollution.

3.2. Principal Component Analysis Level Modeling

First of all, this study consulted the relevant data, calculated the average value through statistical analysis, and obtained the parameters of 8 locations, as shown in Table 3:

Table 3: Parameters for 8 different regions

	<i>IL</i>	<i>ZB</i>	<i>EI</i>	<i>IT</i>	<i>EC</i>	<i>GDP</i>	<i>UR</i>	<i>ARL</i>
<i>UC1</i>	500	150	30	14	8500	65000	100	95
<i>SC1</i>	200	50	70	10	6000	35000	90	85
<i>RC1</i>	50	10	90	8	3500	20000	50	50
<i>PL1</i>	1	1	100	2	80	800	7	5
<i>UC2</i>	200	50	10	12	5000	20000	85	80
<i>SC2</i>	50	20	40	7	3000	10000	60	45
<i>RC2</i>	1	1	50	4	1000	2500	30	20
<i>PL2</i>	0.01	0.01	60	1	20	40	1	2

Then, according to the data in the table, with the second to seventh columns as independent variables and RL as dependent variable, principal component analysis was carried out on these eight groups of data. After data standardization and principal component extraction, The results obtained are shown in Table 4:

Table 4: Cumulative contribution rate

	<i>IL</i>	<i>ZB</i>	<i>EI</i>	<i>IT</i>	<i>EC</i>	<i>GDP</i>	<i>UR</i>	<i>ARL</i>
<i>Rate</i>	83.4677	94.2728	99.3696	99.7544	99.9381	98.9882	98.6785	99.7783

As can be seen from the figure above, the cumulative contribution rate of the first three principal components has reached 99.3969%, so we choose the first three principal components, and the following Figure2 can be obtained:

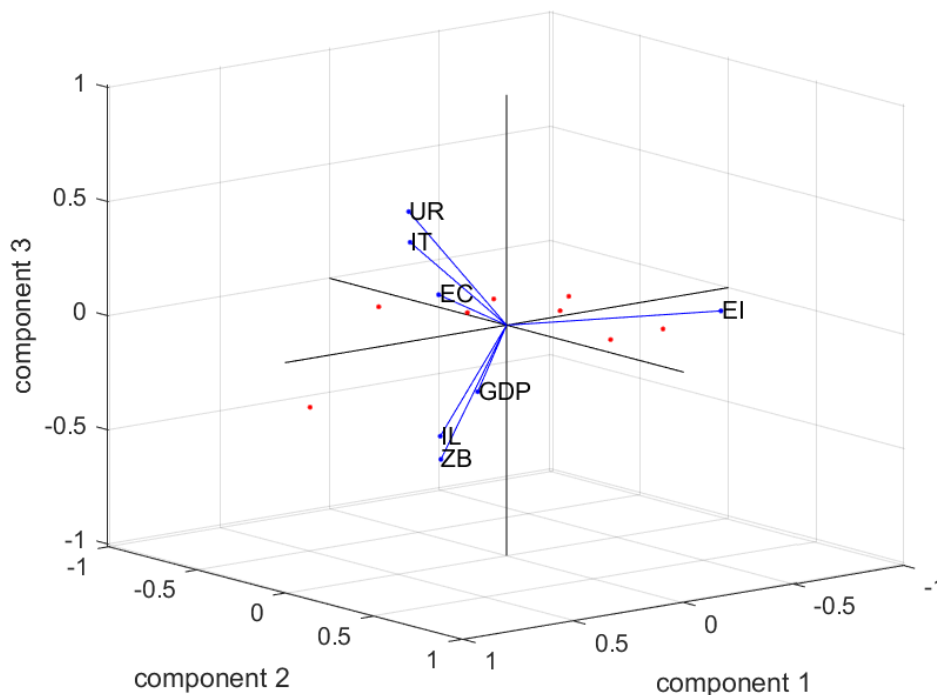


Figure 2: The relationship between the principal component and the original variable

This figure reflects the relationship between the extracted three principal components and the original variables, and is drawn with the coefficients of each original variable and the three principal components Z_1 , Z_2 and Z_3 as coordinates. The red dots are sample scores. According to the calculated coefficients, the expressions of the three principal components are written as follows:

$$Z_1 = 0.3987IL + 0.3918ZB - 0.2434EI + 0.3968IT + 0.4070EC + 0.3930GDP + 0.3883UR \quad (1)$$

$$Z_2 = 0.1210IL + 0.1161ZB + 0.9176EI - 0.0530IT + 0.1223EC + 0.3272GDP - 0.0713UR \quad (2)$$

$$Z_3 = -0.3970IL - 0.5005ZB + 0.2097EI + 0.4168IT + 0.2245EC - 0.1610GDP + 0.5458UR \quad (3)$$

Thus, for the principal component Z_1 , all variables except EI play a role. For the principal component Z_2 , EI plays a major role, and for the principal component Z_3 , IT and UR play a major role. The global luminous data visualization in 2021 and the latitude and longitude dynamics of NTL intensity from 2000 to 2015 are shown in Figure 3(Map source: www.lightpollutionmap.info).

Finally, according to the calculated principal component and the cumulative contribution rate, the expression of fitting risk level FRL can be calculated as follows:

$$FRL = 83.4677Z_1 + 10.8105Z_2 + 5.118723 \quad (4)$$

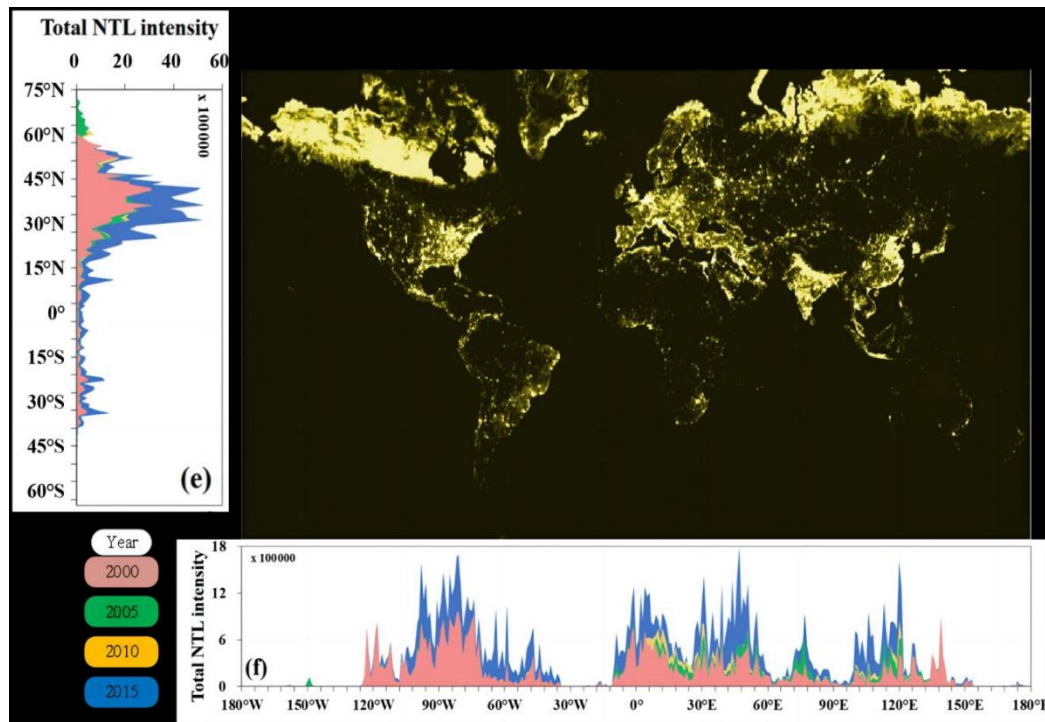


Figure 3: Visualization of global night light data in 2021 and dynamics of NTL intensity by latitude and longitude from 2000 to 2015

3.3. Application of Model I and Analysis of results

When this study obtained the formula of the model, this paper selected nine different locations to apply the light pollution risk level model of this study. Through cluster analysis, the nine sites are divided into three categories by using the three principal component scores of each sample. The results of cluster analysis are shown in Figure 4. The result of regional visualization in China based on cluster analysis is shown in Figure 5 (Map source: www.lightpollutionmap.info).

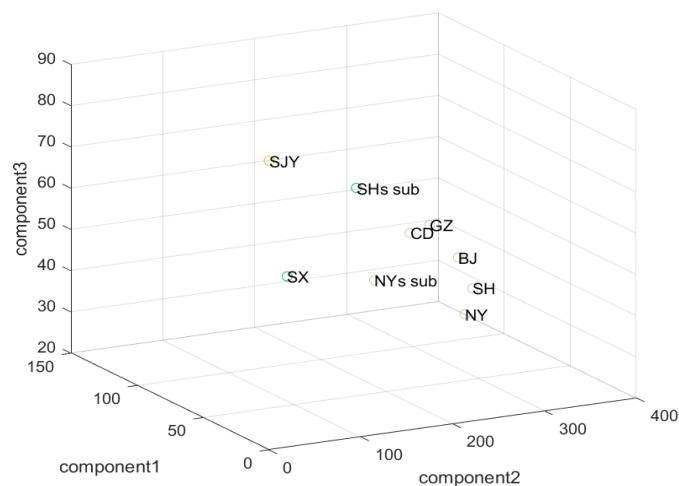


Figure 4: Cluster analysis results

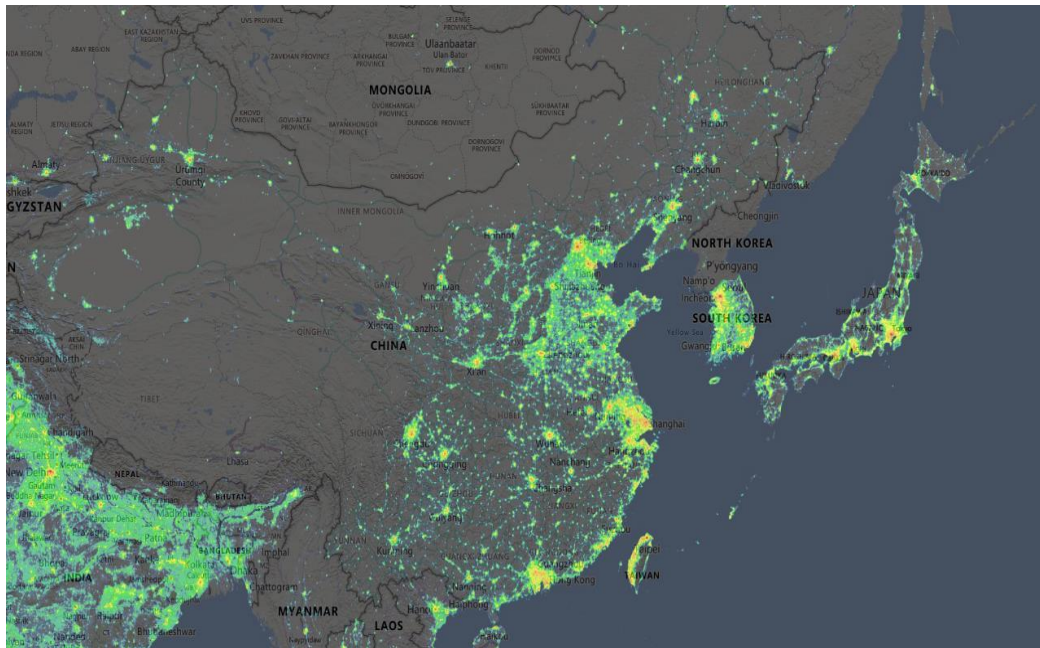


Figure 5: Visualization results of China region by Cluster analysis

The symbolic representation area in the figure is shown in Table 5:

Table 5: The regions corresponding to the symbols.

Symbols1	Symbols2
NY --NewYork	NYssub--SuburbofNewYork
BJ --Beijing	SH --Shanghai
SHssub --Suburbof Shanghai	GZ --Guangzhou
CD --Chengdu	SJY --Sanjiangyuan
SX --Shanxing County	

As can be seen from the above picture, the third principal component of SHs sub and SX is higher than that of other regions except SJY, and the first and second principal components also account for a certain proportion, so they are classified into the first category. The first and second principal components of NY, NYs sub, BJ, SH, GZ and CD are higher, while the third principal components are relatively low, so they are classified into the second category. The third principal component of SJY is relatively high, and the first and second principal components have almost no effect on SJY, so SJY is classified into the third category.

Next, the actual parameters of 9 regions are substituted into the expression of FRL obtained in this study and the results are shown in Table 6:

Table 6: Parameters for 9 different regions

	IL	ZB	EI	IT	EC	GDP	UR	FRL
NY	400	130	20	13	8300	63000	100	93
NYs sub	240	87	40	10	8000	51000	96	83
BJ	350	100	40	12	5000	16000	85	70
SH	380	110	30	13	5400	22000	84	74
SHs sub	170	52	70	8	2900	11000	57	45
GZ	310	94	50	10	4500	18000	84	63
CD	280	88	50	10	3000	10000	76	55
SX	30	7	60	10	3500	21000	50	52
SJY	0.5	0.2	90	20	60	540	3	3

Compared with the FRL calculated in the above table and the existing AFL, we can see that the model established in this study well reflects the actual risk level of light pollution, and the final conclusion is consistent with the conclusion of data statistical analysis: the location of protected areas and rural communities are rated as mild pollution, and suburban and urban communities are rated as moderate pollution. Their scores increased in turn, and there were few areas without pollution or heavy pollution[5]. However, due to the special geographical conditions of the protected area, the problems of incomplete collection of relevant parameters or partial distortion of parameters can not be ruled out.

4. Discussion

4.1. Intervention strategies one

In the actual prevention and control work, the new energy-saving glass material can replace the original glass curtain wall, or add a layer of low radiation coating on the basis of the original glass, so as to reduce the degree of light pollution to a certain extent. In addition, as far as the light source is concerned, if the lighting equipment is qualified, there will be no light pollution. Therefore, it is necessary to make strict requirements for the manufacture and appearance of lighting equipment, such as requiring it to record its light intensity level and energy consumption on the label and conduct a sampling review before entering the market[6-7].

4.2. Intervention strategies two

Take China as an example, the natural environment and economic level of cities in China are quite different, so it is not suitable to directly apply the relevant standards of other countries or the International Organization for Standardization (ISO). On the contrary, according to the actual situation, the risks of different degrees of light pollution to human health should be extensively investigated and scientifically demonstrated, and the light environment standards should be established according to the evaluation results[8].

4.3. Intervention strategies three

One of the most effective strategies is the relevant policies of the government, such as the formal implementation of the newly revised Shanghai Environmental Protection regulations on August 1, 2022. The biggest highlight of this amendment is that "light pollution" is listed as a key topic, and a more comprehensive institutional arrangement for the prevention and control of light pollution has been made for the first time in the practice of environmental protection legislation, which can be called a legislative breakthrough with the significance of weather vane. [9]The government has issued a policy to reduce light pollution, which will guide enterprises to improve the mode of production and reasonable competition. In addition, it can affect education and let residents know the seriousness of light pollution.

5. Conclusion

The above results are mainly due to different development strategies in different places. For national central cities, such as New York, Shanghai and Beijing, economic development is the first priority, and the economic aggregate created by them is very important to the national economy. A large number of resources and talents gather together in such cities, creating a huge consumer market. The amount of light used by businesses and households is enormous.

Similarly, for the suburbs of Shanghai and Yamagata Prefecture in Japan, where economic development is not a priority, businesses and households will use less light.

Finally, for a nature reserve like Sanjiangyuan, the development goal is to ensure that the environment is not destroyed. The economic development here is relatively backward, and the

consumption desire of residents is not strong. The life goal of residents here is to enjoy nature and ensure good health. As a result, light pollution indicators in such areas are very low.

With the progress of human science and technology, the once bright starry sky has long been replaced by urban lighting groups. Behind the light pollution, human development has destroyed the balance between man and nature[10].

Did you see it? Before we know it, we can no longer see bright stars in our cities, and the culprit is—— Light Pollution.

Light pollution refers to the phenomenon that excessive light radiation has a bad effect on human living and production environment. It can damage our eyes, destroy biodiversity and even induce cancer. But we can reduce light pollution by turning off lights in time, optimizing light sources, and using light or sound sensing lights. Protecting the ecological environment is protecting ourselves !

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