

Quantification of Light Pollution Levels Based on Principal Component Analysis and Hierarchical Analysis Approach

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Abstract. The level of light pollution risk is influenced by a number of factors. In this paper, we established a model to evaluate the risk level of light pollution in a certain area by considering various factors. Through the principal component analysis of the 12 indicators selected by us, three principal components are extracted, and then the analytic hierarchy process is used to evaluate the three principal components, so as to establish the corresponding weight of the three principal components, and finally establish the relevant evaluation function.

Keywords: Light pollution; Risk level assessment model; Principal component analysis.

1. Introduction

Light pollution refers to the general term of the negative effects caused by interference light or excessive light radiation (including visible light, ultraviolet and infrared light radiation) on human beings, ecological environment and astronomical observation, mainly including light invasion, glare and sky glow. This phenomenon often occurs in the evening city sky, but often in remote areas [1-2].

Light pollution can have an impact on the development of the environment, while also changing our view of the sky, and affecting our physical and mental health and safety [3]. It may not only cause the rate of plant maturity, such as delay or acceleration, but also affect animal migration; more serious, excessive artificial light may cause problems in our day and night rhythm, cause our sleep quality and have some impact on physical and mental health problems, and the glare caused by artificial light is one of the important causes of traffic accidents [4-5].

However, artificial light has both positive and negative effects, affecting different positions in different ways. When low lighting is adopted to mitigate the effects of light pollution, nighttime crime in the community increases simultaneously. We decided to establish a series of models and algorithm solution, by studying the relationship between each index and the risk level of light pollution, establish a risk level of light pollution evaluation model, to determine the level of light pollution risk [6].

2. Light pollution risk level evaluation model

2.1. Data Processing

Taking China as an example, we conducted data investigation and research. First, we roughly learned that the level of light pollution was basically positively correlated with regional GDP, so we selected six provincial administrative regions in China (indicating the highest, medium and lowest GDP levels respectively)[7].

Then, from the perspective of "human" and "non-human", we determined three categories of "economic development indicators", "ecological civilization indicators" and "people's life indicators" respectively, and determined 12 evaluation indicators according to the specific impact of light pollution on social aspects.

Using reliable data websites such as Our World in Data and National Data, we queried and collected the specific data of 12 indicators in 6 provinces during 10 years and compiled them into a table [8-9].

Data normalization: Normalization is a simplified calculation method, where a dimensional expression is transformed into a nondimensional expression and becomes a scalar; data dimension reduction is a way of high-dimensional original data mapping to another set of low-dimensional coordinate system to achieve data dimension reduction. In this model, due to the high data dimension, the data is too abstract, and too many data types, which causes too much dimension to conduct the next analysis, which may lead to some poor models. Therefore, we first normalize and reduce the data before using the data [10].

2.2. Model Establishment and Results

We selected the following 12 variables X_i as indicators of the light pollution level in a certain area. Considering the multiple collinearity problem among the indicators, we conducted principal component analysis on these indicators. Light pollution risk assessment is shown in figure 1.

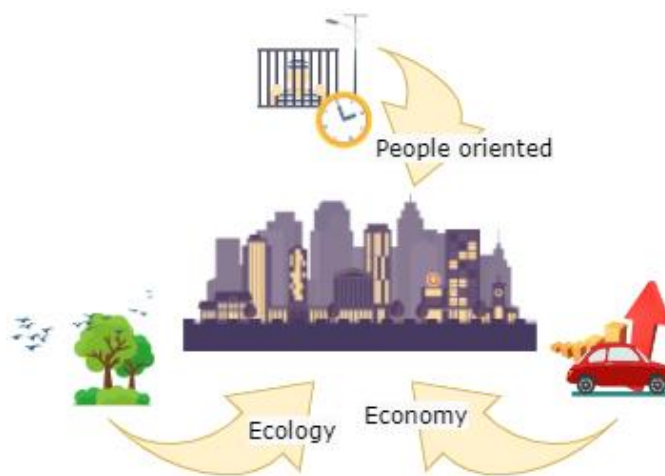


Figure 1. Light pollution risk assessment.

Table 1. Index & serial number.

Number	1	2	3	4
Target X_i	P opulation	Urbanroad lighting	DN mean value	Number of criminals
Number	5	6	7	8
Target X_i	Gdp per capita	Animal migration	C ivilian vehicles	Regional area
Number	9	10	11	12
Target X_i	sunshine duration	Average sleep time	forest resources	Yield of major crops per unit area

Table 2. Initial eigenvalue.

Element	Accumulative total
1	60.286
2	78.794
3	87.759
4	94.216
5	97.585
6	99.670
7	99.914

It can be seen from table 1 and table 2 that when the number of principal components extracted is 7, the risk level of light pollution in a certain area can be significantly reflected.

Table 3. Component Score Coefficient Matrix.

	α_i	β_i	γ_i
Population	.965	.146	-.044
Urban road lighting	.932	.144	-.040
DN mean value	.921	.133	.024
Number of criminals	.916	.154	-.087
Gdp per capita	.889	.274	-.004
animal migration	-.846	.411	-.230
civilian vehicles	.839	.319	.001
Regional area	-.803	.540	.071
sunshine duration	-.534	.747	.017
Average sleep time	-.390	-.692	.537
forest resources	-.401	.645	.432
Yield of major crops per unit area	.541	.219	.729

Component Score Coefficient Matrix is shown in table 3. The seven selected principal components were clustered. As can be seen from the above pedigree diagram and principal component matrix, principal components 1, 2 and 3 focus on assessing the risk level of light pollution from economic, ecological and human-oriented aspects respectively. Principal components 1, 2 and 3 were evaluated using analytic hierarchy process. Judgment matrix is shown in figure 2.

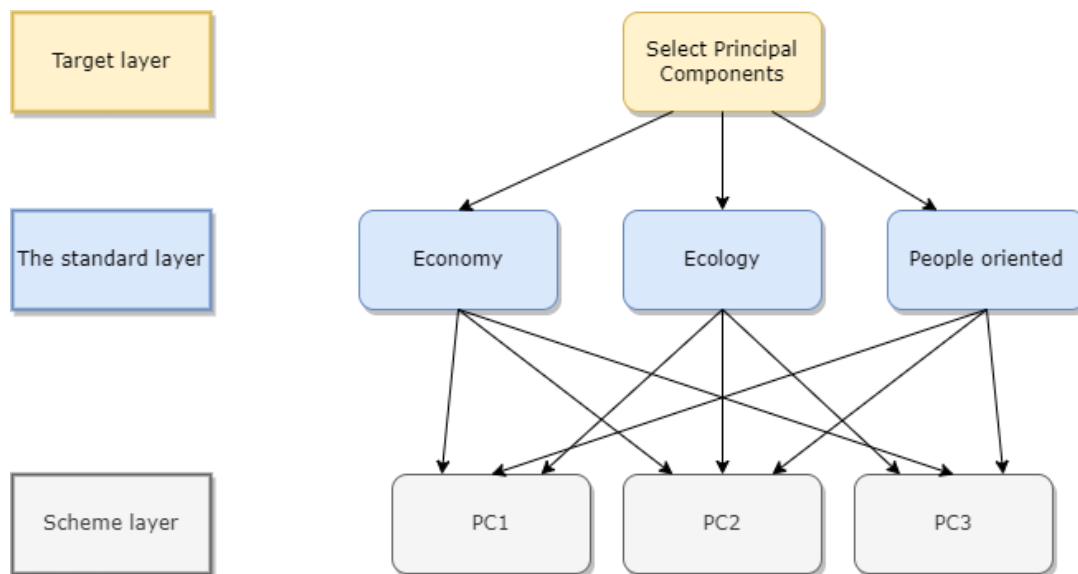


Figure 2. Judgment matrix.

The consistency index $CI=0.0324$, as can be seen from the table $RI=0.52$.

$$CR = \frac{CI}{RI} \tag{1}$$

Consistency ratio $CR= 0.0624 < 0.10$, the consistency of the judgment matrix is acceptable.

Table 4. Score for each principal component.

Economy	Arithmetic method	Geometric method	Eigenvalue method	Mean value
PC1	0.7235	0.7306	0.7306	0.73
PC2	0.1932	0.1884	0.1884	0.19
PC3	0.0833	0.0810	0.0810	0.08

Score for each principal component is shown in table 4, table 5 and table 6. The same test methods were adopted, the consistency ratio $CR= 0.0904 < 0.10$, Pass the conformance test.

Table 5. Score for each principal component.

Ecology	Arithmetic method	Geometric method	Eigenvalue method	Mean value
PC1	0.1018	0.0989	0.0989	0.10
PC2	0.5321	0.5368	0.5368	0.54
PC3	0.3661	0.3643	0.3643	0.36

The same test methods were adopted, the consistency ratio CR= 0.0825<0.10, Pass the conformance test.

Table 6. Score for each principal component.

People oriented	Arithmetic method	Geometric method	Eigenvalue method	Mean value
PC1	0.1038	0.1007	0.1007	0.10
PC2	0.2311	0.2255	0.2255	0.23
PC3	0.6651	0.6738	0.6738	0.67

Table 7. Weight matrix.

	Weight	PCI	PCI	PCI
Economy	0.4	0.73	0.19	0.08
Ecology	0.3	0.1	0.54	0.36
People oriented	0.3	0.1	0.23	0.67

Weight matrix is shown in table 8. The weight of principal component PC 1 in neutralization evaluation:

$$W_{PC1} = 0.4 \times 0.73 + 0.3 \times 0.1 + 0.3 \times 0.1 = 0.352 \tag{2}$$

The weight of principal component PC2 in neutralization evaluation:

$$W_{PC2} = 0.4 \times 0.19 + 0.3 \times 0.54 + 0.3 \times 0.23 = 0.307 \tag{3}$$

The weight of principal component PC3 in neutralization evaluation:

$$W_{PC3} = 0.4 \times 0.08 + 0.3 \times 0.36 + 0.3 \times 0.67 = 0.311 \tag{4}$$

We construct a final light pollution risk level assessment function:

$$\sum_{i=1}^{12} 0.352\alpha_i X_i + 0.307\beta_i X_i + 0.311\gamma_i X_i \tag{5}$$

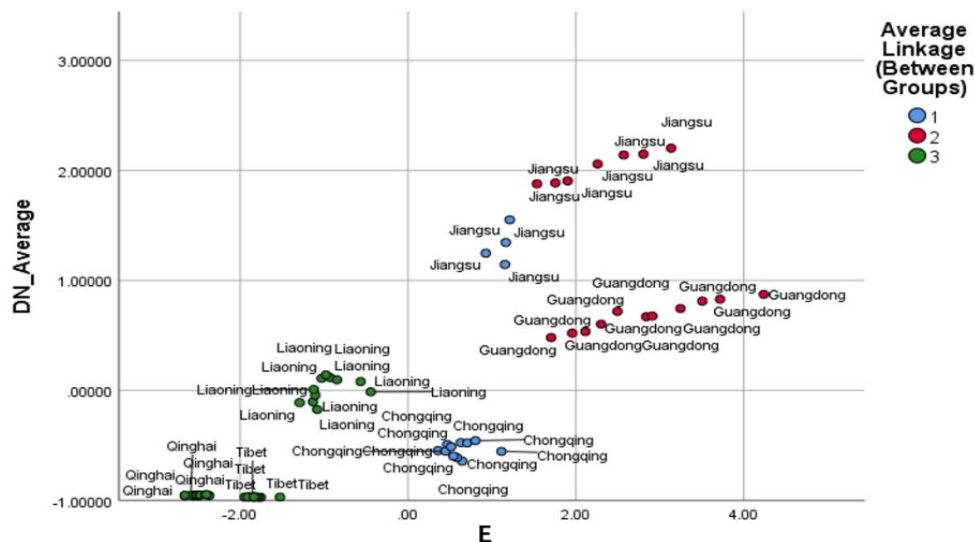


Figure 3. Judgment matrix 3.

The provinces are classified according to index E and the scatter plot is shown in figure 3. It can be roughly seen from the scatter plot that the light pollution risk level of the above provinces can be divided into three categories: serious, medium and slight.

3. Conclusions

We select through the analysis of 12 may affect a region of light pollution risk level, because of the characteristics of multiple collinearity between these indicators, we adopt the method of principal component analysis to extract the seven principal components, and then use the clustering method of the principal components as economic focus, ecological emphasis and people-oriented three kinds of evaluation index. We extract the first three principal components as the evaluation index, and then use the hierarchical analysis method to obtain the corresponding weight of each principal component, and finally construct our evaluation index.

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