Research on Light Pollution Based on Comprehensive Evaluation Model

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Abstract. With the rapid development of technology and economy, the place where live has become more shining and prosperous. But while can enjoy a more technological and modern living environment, it has also caused a lot of light pollution problems. Light pollution is not only harmful to human physiology and psychology, but also destroys the balance of the ecological environment. Therefore, the determination of light pollution risk levels and the development of intervention strategies for light pollution have received our attention. First, the paper screened out 12 indicators from five categories of light pollution indicators as factors affecting the light pollution level by hierarchical analysis, and derived the comprehensive weights of each indicator with the help of entropy weighting method and hierarchical analysis method and combined with related literature. Finally, the scores of the research subjects were calculated and ranked by the Topsis method, which was used as a measure to judge the degree of light pollution in an area. In applying the metric to four different types of locations, adjustments were made in the data of the environmental brightness index, and subsequently the scores of the four locations were obtained along the lines of Model 1.

Keywords: Light Pollution, Light Pollution Lrevention and Control, Comprehensive Evaluation Model.

1. Introduction

Light pollution usually refers to the phenomenon of spill light, reflected light and glare produced by modern urban buildings and night lighting that interferes with or negatively affects various objects such as people, animals, plants, space, weather, earth and water.[1] Light pollution is epochal, a product of industrialization and urbanization, there was no light pollution before the industrial society, people's knowledge of light pollution, began in the 1930s astronomy research. 2 A group of astronomers reflected that because of the city lights are too bright, caused a great impact on astronomical observation. At that time, people's understanding of light pollution is not deep, only the astronomical light pollution that makes the starry sky disappear, since then the impact of light pollution on human life is becoming more and more obvious, and even serious damage to the natural environment, and become an ecological pollution affecting human and natural environment, so light pollution problem big "gradually aroused concern, become a global environmental issue. Classification based on different, different countries and regions, different researcher's field of view, the type of light pollution has different divisions.[2] The Czech Republic, Japan, France, Switzerland, Italy and other countries are early to start the practice of light pollution management, in response to the light pollution problem, a series of effective management measures, in the legal norms, environmental standards, management methods and other aspects of the accumulation of useful experience. Light pollution is a new type of pollution brought along with industrial and urban development. [3] We can see light pollution everywhere around us, light pollution can be divided into white bright pollution, artificial daylight, colored light pollution. [4] Light pollution not only damages human health, but also restricts urban development and even threatens biodiversity Light pollution is a new type of environmental pollution, and the traditional water pollution. Like atmospheric pollution and soil pollution, it can destroy the ecological balance and threaten biodiversity. Light pollution not only harms the ecological environment, but also affects our life. Therefore, we should pay attention to light pollution, in order to prevent light pollution and protect our health.[5] （Data Sources：www.contest.comap.com）

2. Light pollution model

2.1. Light pollution risk level model

Due to light pollution, people are gradually losing the night sky to watch, light pollution and other pollution, as well as the impact on nature, causing harm to the human body. A survey report in the United States shows that about 2/3 of the world's people live in light pollution. Moreover, the pollution caused by man-made light is increasing year by year, with Germany increasing by 6% per year, Italy and Japan increasing by 10% and 12% per year, respectively. This shows that light pollution not only affects a large range and can cause some physiological damage to various organisms.[6] Based on this, but we also selected some light pollution indicators, used entropy weighting method and hierarchical analysis to find out the subjective and objective weights of each indicator, and averaged the subjective and objective weights to get the total weight of each factor.

2.2. Establishment of evaluation system

With the rapid growth of the global economy and the increasing concentration of carbon dioxide in the atmosphere, the concept of sustainable development is of great concern. Scientific and sustainable night lighting requires that the impact of the artificial light environment on the surrounding physical environment should be minimal, and light pollution as a by-product of urban night lighting is contrary to the concept of sustainable development. Therefore, it is necessary to establish effective light pollution evaluation methods and procedures to evaluate and monitor various links that may cause light pollution in order to achieve the optimization of design and rational allocation of resources to reduce harmful light to a level that is not harmful to the surrounding environment and people.

The paper requires us to focus on "human and non-human" issues, so we first establish evaluation indicators, and we divide the indicators affecting light pollution into five categories: population, economic level, regional layout, location and natural environmental factors, as shown in Table 1.

Table 1: Light pollution indicators

Type	Specific indicators	Measurements
Population	Population size	Local census numbers
	Population quality	Percentage of local university students
Economic level	Employment rate	Local employment / total local population
	GDP	National Statistics National Economy
Regional Layout	Nighttime streetlight on hours	The time period from when the streetlight is on to when the streetlight is off
	Area share of built-up area	Area of built-up area / local area

2.3. Seeking subjective weights

Once the evaluation indexes are established, the subjective weights of each evaluation index can be obtained using the entropy weight method.[8]To measure the level of light pollution in an area, only the intensity of luminous light. It is unreasonable, but it is more necessary to comprehensively consider the natural and cultural aspects of the region In this study, a combination of hierarchical analysis and entropic weight method was used to determine the weight of the indicators. Hierarchical analysis is used to establish a hierarchical structure between indicators, while entropy weight method is used to calculate the weight of each index. Since the entropy weighting method is a more objective way of determining the weight of indicators through the amount of information, it can reduce the bias generated when the weight of indicators is determined by subjective factors, and make the results more realistic. Among them, the entropy value can be used to determine or evaluate the degree of variation of indicators in the index system, and if the degree of variation for a certain indicator is larger, it means that the weight for that indicator is smaller, and vice versa, it is larger. Therefore, the tool of information entropy can be used to calculate the weight of each indicator to provide a basis for comprehensive evaluation of multiple indicators. Through the feedback of relevant literature[7][8]and questionnaire survey data, we fitted it through experience and facts, determined the relative importance of each index in the decision-making, and then calculated the final weight. Because the four primary indicators of population, economic development, regional layout, and geographic location correspond to two second, as shown in Table 2 - 5.

Some of the data are based on the Luojia 1 remote sensing satellite (http://59.175.109.173:8888/app/login.html) and from the China Economic Network statistical database (https://db.cei.cn/jsps/Home (2021)) or calculated from basic data.

Table 2: Indicator weights (1)

Population	Weights
Population size	0.3
Population quality	0.7

Table 3: Indicator weights (2)

Economic Development	Weights
Employment rate	0.5
GDP	0.5

Table 4: Indicator weights (3)

Regional Layout	Weights
Area share of built-up area	0.4
Nighttime light hours	0.6

Table 5: Indicator weights (4)

Location	Weights
Coastal Distance	0.7
Latitude	0.3

The judgment matrix was obtained by reviewing relevant information and distributing relevant questionnaires, as shown in Table 6 and Table 7.

Table 6: First-level indicators

	Population	Economic Level	Regional Layout	Location	Natural Environmental Factors
Population	1	0.5	2	3	2
Economic Level	2	1	4	5	4
Regional Layout	0.5	0.25	1	2	2
Location	0.33	0.2	0.5	1	0.5
Natural environmental Factors	0.5	0.25	0.5	2	1

Table 7: Environmental factors corresponding to the secondary indicators

Environmental Factors	River Basin Area	Natural Conditions AQI	Proportion of green area	Ambient brightness
Proportion of river basin area	1.00	0.25	0.25	0.17
Natural Conditions AQI	4.00	1.00	0.75	0.33
Proportion of green area	4.00	2.00	1.00	0.50
Ambient brightness	6.00	3.00	2.00	1.00

Perform a consistency test with the following steps.

Calculation of consistency index CI:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

In the formula, RI is the parameter about the average random consistency of the judgment matrix, and the value of RI is determined by n. Find the corresponding average random consistency index RI, as shown in Table 8.

Table 8: The average RI value for random consistency

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Calculate the consistency ratio CR

$$CR = \frac{CI}{RI} \tag{2}$$

If CR < 0.1, the consistency of the judgment matrix can be considered acceptable [9]; otherwise, the judgment matrix needs to be revised. The judgment matrix of the calculated primary indicators CI=0 .0181 CR=0.0204, Judgment matrix of secondary indicators of environmental factors CI=0.0626 CR=0.0703 Two tables CR < 0. 1, then the consistency of the two judgment matrices can be considered acceptable, the results of the two judgment matrix weights are then calculated by the program, as shown in Table 9 and Table 10.

Table 9: Judgment Matrix (1)

	Arithmetic Averaging	Geometric averaging	Eigenvalue method	Average weight
Population	0.23	0.213	0.23	0.224
Economic Development	0.444	0.243	0.447	0.377
Regional Layout	0.144	0.193	0.143	0.16
Location	0.072	0.168	0.071	0.104
Environmental Factors	0.11	0.183	0.108	0.134

Table 10: Judgment Matrix (2)

	Arithmetic Averaging	Geometric averaging	Eigenvalue method	Average weight
River Basin Area	0.063	0.184	0.062	0.103
Natural Conditions AQI	0.195	0.244	0.192	0.21
Proportion of green area	0.272	0.266	0.274	0.271
Ambient brightness	0.47	0.306	0.472	0.416

The final subjective weights are calculated by the program as follows Table 11.

Table 11: Subjective weights

Indicators	Subjective weights
Population size	0.067
Population quality	0.159
Employment rate	0.189
Salary Level	0.189
Area share of built-up area	0.064
Nighttime lighting hours	0.096
Coastal Distance	0.073
Latitude	0.031
River Basin Area	0.008
Natural Conditions AQI	0.026
Green area	0.037
Ambient brightness	0.063

Due to the strong subjectivity of the Analytic Hierarchy Process, the determination of the judgment matrix depends on the experts, and their own subjective judgments have a significant impact on the results. Therefore, the entropy weight method is introduced to calculate weights more objectively.

2.4. Finding objective weights

Information entropy is a fundamental concept in information theory. It is used to describe the uncertainty of each possible event occurring in the information source. This article defines it as.

$$H(X)=\sum_{i=1}^{n}[p(x_i)I(x_i)]=-\sum_{i=1}^{n}[p(x_i)\ln(p(x_i))] \tag{3}$$

The countries affected by light pollution are mainly some medium to large cities in developed and developing countries, such as the United States, European countries, Japan, as well as New Delhi in India and some core cities in China. Here are seven cities in China as examples, as shown in Table 12. Its data are mainly obtained through the data from the National Bureau of Statistics (https://www.stats.gov.cn/)and China Statistical Yearbook database (https://www.shujuku.org/) and combined with the corresponding data analysis of the current environment.

Table 12: Initial data for each city

Indicators	City 1	City 2	City 3	City 4	City 5	City 6	City 7
Number of population (10,000 people)	830	820	2170	473	396	1104	462
Population quality (%)	37.9	27.7	28.7	29.5	26.6	50.7	30.8
Employment rate (%)	94.7	91.5	94.6	94.3	95.7	82.8	73.9
Economic development (trillion yuan)	1.26	1.17	3.75	0.859	0.087	1.633	0.09
Area share of built-up area (%)	37.86	11.14	8.95	14.61	14.16	9.64	22.6
Night road streetlight on hours (h)	9	9	10	10	8	7.82	8.5
Coastal distance (km)	370	290	120	1130	1500	0	750
Latitude (degrees)	31.8	41.8	39.9	26.6	36	30.27	37.8
River basin area (%)	6.7	10.03	2.73	3.17	0.12	6.8	0.69
Natural Conditions AQI	74	63	64	41	104	65	67
Green area (%)	2.6	1.6	1.2	11.6	3.7	12	10.7
Ambient light brightness(nits)	25.4	22.1	72.3	29.7	28.6	90	23.7

The weights of each indicator are found as follows Table 13:

Table 13: Objective weights

Indicators	Objective weights
Population size	0.085
Population quality	0.105
Employment rate	0.108
Salary Level	0.059
Area share of built-up area	0.09
Nighttime lighting hours	0.108
Coastal Distance	0.077
Latitude	0.066
River Basin Area	0.077
Natural Conditions AQI	0.084
Green area	0.055
Ambient brightness	0.086

Therefore, by combining the above, the subjective and objective weights were averaged to obtain the following total weights for each factor, as follows Table 14.

Table 14: Total wight of each factor

Indicators	Indicators
Population size	0.076
Population quality	0.132
Employment rate	0.1485
Salary Level	0.124
Coverage of built-up area	0.077
Street light density	0.102
Coastal Distance	0.075
Latitude	0.0485
River Basin Area	0.0425
Natural Conditions AQI	0.055
Green area	0.046
Ambient brightness	0.0745

Based on the total weights, we have drawn the following pie chart Fig 1:

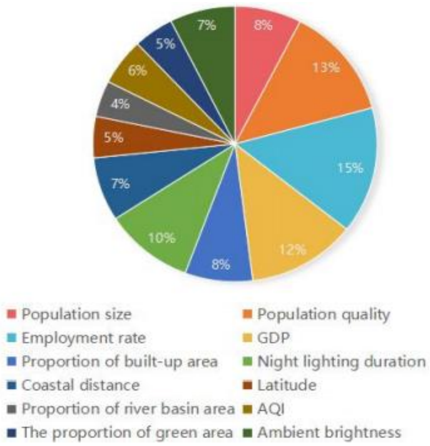

Fig 1: Weighted pie chart

TOPSIS (Technique for Order Preference by Similarty to Ideal Solution) method is commonly referred to as the "superior-inferior solution distance method" or the "order method that approximates the ideal value". [10] It is a common method for multi-objective evaluation of finite solutions, and the key point of this method is to construct two ideal solutions, positive ideal solution is the optimal combination of evaluation indexes in the evaluation solution, and negative ideal solution is the most unfavorable combination of evaluation indexes in the evaluation solution. The TOPSIS method is applied to the evaluation problem by calculating the weighted Euclidean distance between the evaluated solution and the positive and negative ideal solutions, obtaining the relative closeness of each solution to the ideal solution, and ranking the solutions according to the relative closeness.[11] This method is easy to use and has a wide range of applications. The method is formulated as follows:

First, the matrix is normalized by the formula

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{4}$$

After obtaining the normalized matrix, the Euclidean distance formula is calculated as follows.

$$\begin{cases} Sd_i^+ = \sqrt{\sum_{j=1}^{n}\left(s_j^+ - r_{ij}\right)^2} \\ Sd_i^- = \sqrt{\sum_{j=1}^{n}\left(s_j^- - r_{ij}\right)^2} \end{cases}, i = 1,2\ldots\ldots, m \tag{5}$$

The relative closeness is then calculated as follows.

$$\eta_i = \frac{Sd_i^-}{Sd_i^- + Sd_i^+}, i = 1,2\ldots\ldots, m \tag{6}$$

Therefore, the higher the score, the more serious the light pollution. Thus, the level of light pollution in each city is judged. This indicator can be used as a quantification of the light pollution level, as shown in Fig 2.

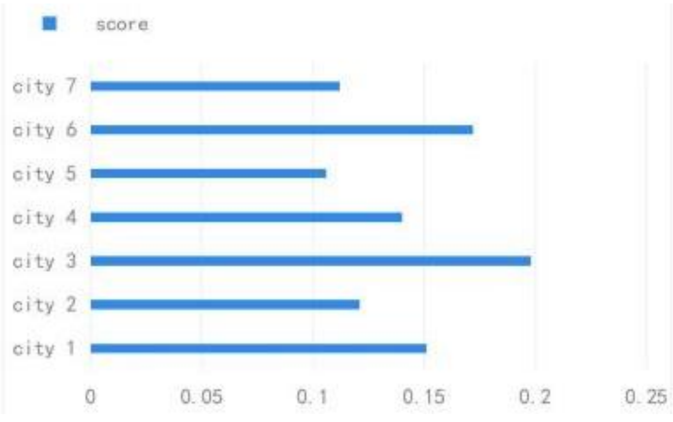

Fig 2: Final score statistics chart

2.5. Light pollution risk determination model for four types of sites

According to the response of the relevant literature, the difference between these four locations is mainly reflected in the degree of light pollution that the environment itself can withstand. In urban community's artificial light leads to an environment that must be brighter and thus has a higher demand for light brightness and a higher threshold of light pollution.[12]

Four types of sites: protected land locations, rural communities, suburban communities, urban communities, study object: four different types of areas in the same region. Observe the first question model, which has an indicator-environmental brightness, in the indicator with the environmental brightness-light pollution threshold can get the real will cause light pollution environmental brightness indicators. Then combined with the Topsis model to get the light pollution assessment scores of the four places for data processing to go with the first conclusions.

In order to facilitate the data statistics, we chose four different types of locations in a city (Beijing), we collected relevant data against the indicators for the four areas, the ambient brightness Y1 as the breakthrough point of the problem, and with the support of the literature to find out the threshold value of light pollution δ in these four places, through the calculation will get the real harmful ambient brightness Y2 , with the formula.

$$Y_2 = Y_1 - \xi \tag{7}$$

The model applied to derive the final quantification of light pollution risk, and after data processing, the level of light pollution risk is compared with the findings.

3. Conclusions

In summary, there is no single factor affecting light pollution, and many factors can cause the increase of light pollution. We have developed a light pollution risk level model that can initially measure the level of light pollution. We also developed intervention strategies to provide recommendations for light pollution mitigation. We have derived a more comprehensive evaluation model based on data analysis and also taking into account socio-environmental factors.

With the progress of technology and accelerated urbanization, light pollution has become a serious environmental problem. Light pollution not only has a negative impact on human health, but also threatens the survival of wildlife and ecological balance. However, the treatment of light pollution is not an overnight success but requires the joint efforts of the whole society.

In the future, we have enough confidence that we can manage the light pollution problem. This requires the government, enterprises and the public to work together and adopt various means and technologies to gradually reduce the level of light pollution. Through the joint efforts of the whole society, we believe that the future city will not only become more beautiful, but also more environmentally friendly and healthy.

References

[1] Liu YH, Zhang W. Effects of light pollution on the health of secondary school students and its prevention [J]. China High-Tech, 2017(21): 221-222.

[2] Liu, Tianyuan. Light pollution management: a two-way examination of domestic practice and foreign experience [J]. Journal of Northwestern University for Nationalities (Philosophy and Social Science Edition), 2022, No. 247(01): 109-116.

[3] Feng Kai, Dai Shujian, Hao osi. Preliminary study on the evolution characteristics of light pollution based on VIIRS images —— in four cities in China [J]. Journal of Lighting Engineering, 2022,33 (04): 172-185.

[4] Zhang Chenhao.The dilemma and outlet of urban light pollution prevention and control legislation in China[D]. University Of Science and Technology of Hunan,2020.

[5] Qin Xin, Wu Yu, Huang Heng, et al. Investigation on the current situation of light pollution and prevention measures in Shenzhen District —— Take Dongmen Pedestrian Street as an example [J]. China Lighting Appliances, 2022, (05): 39-43.

[6] Luo Zhenqing, Su Hang, Wang Zhuoli, et al. Urban lighting planning and the hierarchical classification of dynamic light pollution in the night light environment [J]. Journal of Lighting Engineering, 2022,33 (04): 193-202.

[7] Jiang Yifan, Jia Zhuoyue, Wang Yilin, etc. Model and example study of light pollution evaluation in different regions [J / OL]. The Practice and Knowledge of Mathematics, 1-9 [2024-03-31].

[8] Jiang Mengmeng. Evaluation of light pollution risk level based on entropy weight method and TOPSIS method [J]. Light source and lighting, 2023, (06): 40-42.

[9] Jian W, Fang L, Jiawei Z, et al.Design of task priority model and algorithm for imaging observation problem [J]. Journal of Systems Engineering and Electronics, 2020, 31(02): 321-334.

[10] Li Yinghua, Xie Jingya, Gu Huayu, et al. Mathematical model design on the risk assessment and strategy assessment of light pollution [J]. Software, 2023, 44 (08): 133-138.

[11] Chen Qihua, He Yuheng, Zeng Yongzhong, etc. Application of TOPSIS method in the comprehensive evaluation of steam air preheater for waste incineration power generation boiler[J]. Chinese Journal of Electrical Engineering, 2020, 40(04)

[12] Xu Wanshu. Legislative thinking on the prevention and control of light pollution [J]. Legal Expo, 2019(06): 8-10.