A Scoring Model for Regional Light Pollution

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Abstract. The use of artificial light has greatly facilitated people's lives. In order to assess the level of light pollution in a region, a model based on AHP and multiple indicators is developed. Using this evaluation model, the light pollution indices of two cities, Wudalianchi Farm and Suzhou, are evaluated for more in-depth discussion and solution proposal.

Keywords: AHP, Multiple Indicators, Evaluation Model.

1. Introduction

With the rapid development of science and technology, the modernization level of the city is rising. At the same time, light pollution is starting to become a problem that cannot be ignored. The effects of light pollution can be profound and long-lasting, not only affecting our ability to see the night sky, but also damaging ecosystems and contributing to climate change[1].

Researchers at the University of Exeter in the UK conducted a study highlighting the environmental impact of light pollution. They found that artificial light at night disrupts the natural behavior of many species, from insects to birds and mammals, which can have major impacts on entire ecosystems[2]. Another study, published in the Journal of Environmental Management, found that light pollution can contribute to the spread of invasive plant species in urban areas, further disrupting local ecosystems[3].

This paper explores the factors that influence the level of light pollution in a region and develops corresponding indicators to create a scoring model. In contrast to other studies that focus on the characteristics of light itself, this paper considers the influence of macro factors on light pollution levels in a region, as it is more practical. The model is also used to score two example areas to further investigate their problems and improvements. The flowchart of this paper can be seen in Figure 1.

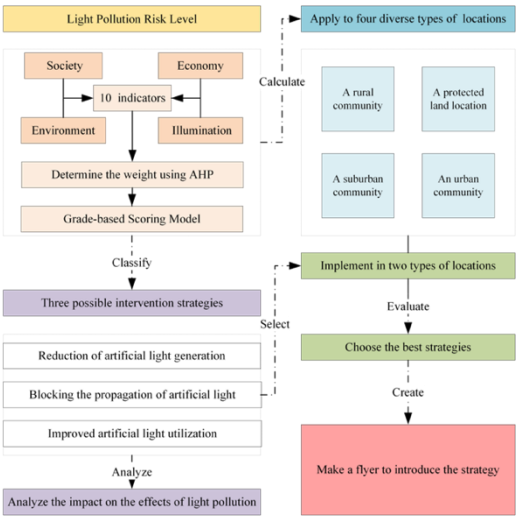


Figure. 1 Flowchart of this paper

2. The fundamental of scoring model

2.1. Selection of evaluation indicators

To evaluate the degree of light pollution risk in an area, this paper needs to define a widely applicable metric to measure. To make this metric assess light pollution as accurately as possible, this paper selected 10 indicators to describe light pollution. By reducing the dimensionality of the indicators, this paper can grasp the law more macroscopically. This paper divided these 10 indicators into 4 sets. Figure 2 shows the metrics and their attribution.

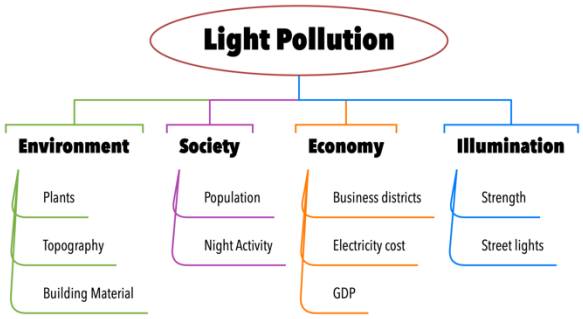


Figure. 2 The metrics and their attribution

2.2. Preparation of the model

The core idea is to determine the importance of different indicators through direct pairwise comparison of the criteria[4]. Table 1 shows the numbers and corresponding importance:

Table 1 Meaning of different scales

Scale	Meaning	Scale	Meaning
1	Equally important	**7**	Strongly important
3	Slightly more important	**9**	Extremely important
5	Obviously important	**2, 4, 6, 8**	The median of the above two adjacent judgments

2.3. Determination of weight

This paper first analyzes the first criterion layer and construct the judgment matrix as follows:

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

Among them, n represents the order of the square matrix of the matrix, and λ_{max} represents the largest eigenvalue of the square matrix.

Then calculate the consistency ratio CR:

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

Among them, RI is the corresponding average random consistency index[5]. After table lookup and calculation, the values corresponding to the judgment matrix are $RI = 0.89$, $CI = 0$, $CR = 0 < 0.1$, which show that the consistency of the matrix is acceptable.

After normalizing the judgment matrix, the arithmetic mean method is used to calculate the weight, and the calculation formula is as follows:

$$\omega_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{m=1}^{n} a_{mj}} \tag{3}$$

a_{ij} represents the value in column j, row i of the judgment matrix.

Substitute it into the formula to get the weight ω.

3. Results

3.1. The establishment of a Grade-Based Scoring Model

Table 2 shows the weight of different indicators.

Table 2 The weight of different indicators

First grad indexes	Weight	Second grade indexes	Weight	Effect
Environment	0.25	Plants	0.11	-
		Topography	0.03	*
		Building Material	0.11	*
Society	0.125	Population	0.062	+
		Night Activity	0.063	+
Economy	0.25	Business Districts	0.10	+
		Electricity Cost	0.05	-
		GDP	0.10	-
Illumination	0.375	Strength	0.25	*
		Streetlights	0.125	*

In this table, the influence of "+" is a positive attribute (the larger the more), the influence of "-" is a negative attribute (the smaller the more), and the influence of "*" is an interval attribute (the closer to a certain interval [a, b] the better).

3.2. Light Pollution Risk Level Coefficient

This paper designs the following formula to calculate Light pollution risk level coefficient:

$$PRL = \sum_{n=1}^{10}(x_i \times w_i) \tag{4}$$

Among them, w_i represents the weight of the *i*-th index, and x_i represents the score of a region in the *i*-th index; for a positive index, the increase of the score will aggravate the light pollution; for the negative index, the decrease of the score will aggravate the light pollution; for the intermediate indicators, the closer to a certain range, the score increases.

In the scoring process, to quantify the evaluation of an indicator, this paper designed a rating mechanism. According to the contribution of this indicator to light pollution, this paper has designed 4 grades for the city's score, namely A, B, C, D, and E. It corresponds to 100 points, 80 points, 60 points, 40 points, and 20 points respectively. The higher the score, the more severe the light pollution.

3.3. Scoring Standard

Plant： This paper uses the per capita park green area to judge the level of vegetation in a city. Table 3 shows the scoring standard of plant.

Table 3 Scoring Standard of Plant

Per capita Park green area (m^2/person)	**≤ 10**	**10~20**	**20~30**	**30~50**	**≥ 50**
Grade	A	B	C	D	E
Score	100	80	60	40	20

Topography: Since there are many factors that affect terrain, including geographical location, altitude, etc., this score needs to be discussed in a specific city.

Building Material: Government requirements for building materials are different. Therefore, housing materials need to be discussed in detail according to the area.

Population: Since population density depends on both population and area, this paper only considers population size here. Table 4 shows the scoring standard of population.

Table 4 Scoring Standard of Population

Population (million)	**≥ 10**	**5~10**	**1~5**	**0.5~1**	**≤ 0.5**
Grade	A	B	C	D	E
Score	100	80	60	40	20

Night Activity: This paper uses the brightness of lights at night to judge the intensity of people's activities in an area at night. The data of the brightness of lights at night comes from *lightpollutionmap.info.* To visually see the brightness of the light from the map, this paper use Zenith sky brightness as the standard, as shown in Figure 3 below:

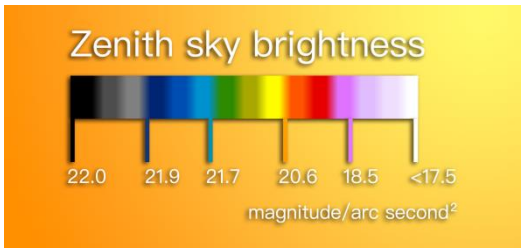


Figure. 3 Zenith sky brightness

Business Districts: The ratings for business district development are not consistent for each type of district. Therefore, the scoring of this indicator needs to be discussed for specific regions.

Electricity Cost: The price gap is often caused by the geographical location and the degree of development of the region[6], so it cannot be directly judged whether it is good or bad. This paper needs to analyze each location individually.

GDP: This paper use GDP data to measure the development level of a city. The scoring standard of GDP is shown in Table 5.

Table 5 Scoring Standard of GDP

GDP ($billion)	**≥ 436.8**	**116.48~436.8**	**14.56~116.48**	**1.456~14.56**	**≤ 1.456**
Grade	A	B	C	D	E
Score	100	80	60	40	20

Strength: While retaining the evaluation of nighttime activities, combined with the business district index, the scores of more developed areas will be raised to a certain extent.

Streetlights: This paper use the number of streetlights per kilometer to measure the size of street lighting arrangements in an area. Table 6 shows the scoring standard of streetlights.

Table 6 Scoring Standard of Streetlights

Number of streetlights per kilometer	**≥ 100**	**80~100**	**60~80**	**40~60**	**≤ 40**
Grade	A	B	C	D	E
Score	100	80	60	40	20

3.4. Selection of the two targeted cities

3.4.1. A protected land location: Wudalianchi Farm

Wudalianchi Nature Reserve is located in the Wudalianchi volcanic field in northeastern China, which is known for its unique volcanic landscape[7], including several crater lakes, hot springs, and geothermal features. It is home to a wide range of plant and animal species, many of which are rare or endangered.

3.4.2. A suburban community: Suzhou

A suburban community is one that is located in a moderately sparsely populated area of the country, or that is easily accessible from an urban community[8]. Its population density is relatively low compared to Shanghai[9]. In addition, Suzhou has a strong suburban feel, with more emphasis on green space and a slower pace of life. .

3.5. Score of the two areas

Table 7 shows the score of Wudalianchi Farm.

Table 7 Score of Wudalianchi Farm

Index	Plant	Topo.	Building Material	Pop.	Night Activity	Business Districts	Elec. Cost	GDP	Strength	Street lights
Grade	D	B	D	E	E	E	B	E	E	E
Score	40	80	40	20	20	20	80	20	20	20

Table 8 shows the score of Suzhou.

Table 8 Score of Suzhou

Index	Plant	Topo.	Building Material	Pop.	Night Activity	Business Districts	Elec. Cost	GDP	Strength	Street lights
Grade	B	C	B	C	A	B	C	B	A	C
Score	80	60	80	60	100	80	60	80	100	60

Wudalianchi Farm is located at a higher altitude and is a protected area built on the top of the mountain. There is no shelter around on the high mountain, and the light is easy to spread. In addition, the higher altitude makes it easy for light to hit the sky and cause light pollution[10]. This paper grades the Topography as B-level, 80 points. Suzhou is a city located on the outskirts of the Shanghai metropolitan area. Its terrain is low and surrounded by water. This paper grades it a grade C with 60 points for its Topography.

Most of the building materials used in Wudalianchi Farm are bricks and tiles, which are not easy to reflect light. However, due to some facilities made of special materials, which may intensify the reflection and refraction of light, the score is grade D, 40 points.Suzhou is a modern suburban city. There are many buildings with glass surfaces, which will cause repeated reflection and refraction of light. This paper grades building materials as grade B, 80 points.

The Farm is far away from the commercial area, so the commercial area is scored as E grade with 20 points.As a member of Shanghai's metropolitan area, even in the outermost periphery, Suzhou has commercial advantages that rural cities cannot have. This paper gives the business district a B, 80 points.

The government has special discounts on electricity charges for the Farm, which may intensify the use of lamps and light pollution, so the electricity charge score is B, with 80 points. The electricity fee in Suzhou is a standard charge, which is comparable to that of ordinary suburban cities, so the electricity tariff score is C, with 60 points.

To sum up, after substituting the scoring formula, the total score for Wudalianchi Farm is 29.3 points and for Suzhou is 80.92 points.

3.6. Analysis

In determining the weights of the indicators, this paper chooses the hierarchical analysis method, whose indicator weights are less dependent on the sample. In determining the indicators, this paper considers environmental, social, economic, and light factors to determine 10 secondary indicators, thus the model building is more comprehensive and precise. Besides, this light pollution risk level factor has a large scalability and can be extended to other environmental pollution.

However, some indicators lack data support. The model can be more accurately verified if more detailed data are found.

3.7. Conclusion

This paper derives a regional light pollution risk score by selecting broad and accurate indicators, assigning weights through hierarchical analysis, and finally ranking the levels of each indicator. With the total score and the scores of each indicator, one can develop targeted improvement strategies for these target areas, thus increasing the efficiency of the work and reducing unnecessary economic expenses.

This paper also provides new ideas for scoring mechanisms such as environmental quality scoring. Taking macro factors into account in the selection of indicators, one can greatly improve the broad applicability and accuracy of the model without the need for specific data.

References

[1] SCHULTE-RÖMER N, MEIER J, SÖDING M, et al. The LED paradox: how light pollution challenges experts to reconsider sustainable lighting [J]. Sustainability, 2019, 11(21): 6160.

[2] BENNIE J, DAVIES T W, DUFFY J P, et al. Contrasting trends in light pollution across Europe based on satellite observed night time lights [J]. Sci Rep, 2014, 4(1): 3789.

[3] GASTON K J, WARREN P H, THOMPSON K, et al. Urban domestic gardens (IV): the extent of the resource and its associated features [J]. Biodiversity & Conservation, 2005, 14: 3327-49.

[4] MENDOZA G A, PRABHU R. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study [J]. Forest ecology and management, 2000, 131(1-3): 107-26.

[5] ERGU D, KOU G, SHI Y, et al. Analytic network process in risk assessment and decision analysis [J]. Computers & Operations Research, 2014, 42: 58-74.

[6] SU Z, WANG Y, XU Q, et al. A secure charging scheme for electric vehicles with smart communities in energy blockchain [J]. IEEE Internet of Things Journal, 2018, 6(3): 4601-13.

[7] ZHAO Y-W, LI N, FAN Q-C, et al. Two episodes of volcanism in the Wudalianchi volcanic belt, NE China: Evidence for tectonic controls on volcanic activities [J]. Journal of Volcanology and Geothermal Research, 2014, 285: 170-9.

[8] FORSYTH A. Defining suburbs [J]. Journal of Planning Literature, 2012, 27(3): 270-81.

[9] JIANG Y, SHI T, GU X. Healthy urban streams: The ecological continuity study of the Suzhou creek corridor in Shanghai [J]. Cities, 2016, 59: 80-94.

[10] WALCZAK K, GYUK G, GARCIA J, et al. Light pollution mapping from a stratospheric high-altitude balloon platform [J]. International Journal of Sustainable Lighting, 2021, 23(1): 20-32.