Random Forest-TOPSIS Based Light Pollution Evaluation System

Sizhe Zou [*, 1], Jingting Zhang [2], Lingzhi Li [1]

[1] Institute of Computer and Information Technology, Beijing Jiaotong University, Beijing, China, 100044

[2] School of Economics and Management, Beijing Jiaotong University, Beijing, China, 100044

* Corresponding Author Email: 21722080@bjtu.edu.cn

Abstract. Economic development inevitably brings many negative problems, among which the negative impact of light pollution is growing and attracting the attention of more and more scholars. To establish a light pollution evaluation system, in this paper, through the three main of light pollution, i.e., glare, light spillover, and light infringement, the formulae for calculating the three were obtained through research papers in this field and evolution of advanced scholars, and the weights of different indicators were obtained by applying Random Forest-TOPSIS, which were 0.74,0.14,0.12, and thus a comprehensive evaluation system of light pollution was established. The light pollution evaluation system established in this paper is important for measuring the degree of light pollution.

Keywords: Random Forest, TOPSIS, Light pollution evaluation system.

1. Introduction

Aused by excessive use of artificial lighting or incorrect management. Once the sun goes down, it is most often seen in large cities where the sky is illuminated in a brilliant glow. But light pollution can also affect ecosystems, our health and the safety of more isolated areas. The three components of this study are glare, spill light, and light violation [1-2]. These three types of light environments are found in residential nighttime lighting environments [3]. Glare is a light environment that is uncomfortable due to the extreme contrast of brightness in the environment. Glare is a light environment that is uncomfortable due to the extreme contrast of brightness in the environment. Glare is a light environment that is uncomfortable due to the extreme contrast of brightness in the environment. Spill light environment, which is formed by excessive light shining into the sky. Light trespass is the type of light environment that has received the most attention in residential research. Therefore, all three types of light are included in the light pollution evaluation system in this paper [4-6].

2. Light Pollution Factor Quantification Method Model

In the 1920s, light pollution research started. It is separated into two sections. On the website of the Lighting Research Center in the United Kingdom, outdoor light pollution is split into three categories: light spillage, glare pollution, and starlight pollution. Included in this category are sky glow or upward light flow, glare, and light trespass [7].

2.1. Quantitative model of glare pollution

Bennett et al. introduced the CBE (Cumulative Brightness Evaluation) technique in 1984. The advantage of this method over the GCM glare evaluation method is that it not only considers the mental factor in road glare evaluation, but also the effect of the change in vehicle speed during road travel, and the formula is specifically used to evaluate the uncomfortable glare produced by road lighting [8]. Thus, this assessment approach is more relevant and appropriate for assessing road glare that causes discomfort. The following is Bennett's method for computing the combined luminance glare rating:

$$CBE_{Tol} = \frac{67.1}{L_b^{0.5}} \sum_n \left(\frac{L_i^{1.67} \times \omega_i}{8.8 \times 10^{-3} \times \theta_i^2 + 1.35} \right) \quad (1)$$

$\mathbf{CBE_{Tol}}$ is the integrated brightness glare constant.
$\boldsymbol{\omega_i}$ is the stereo angle of the ith light source.
$\boldsymbol{\theta_i}$ is the angle of the glare produced by the ith light source.
$\mathbf{L_i}$ is the luminance of the i-th light source.
$\mathbf{L_b}$ is the background brightness for glare environments.
n is number of light sources for glared.

It can be known that: to use the formula for the calculation of uncomfortable glare, the luminance of each light source, the glare angle formed by the light source, the stereo angle of the light source, and the background luminance of the glare observed by the human eye need to be known. In the process of measuring the actual glare environment, the above-mentioned parameters are not easy to obtain accurately due to the measurement instruments and measurement methods [9].

Since the above equation does not show the calculation parameter representing speed, it can be considered that: The calculation method applicable to road glare evaluation is related to the observer's action speed, but it is still possible to use the brightness and angle of the light source and other parameters to transform the effect of speed on glare evaluation [10].

Therefore, in this experiment, according to the formula for calculating the luminous flux and average luminous intensity of the light source 2; the formula for calculating the relationship between luminance and light intensity 3, the formula for calculating the stereo angle of the light source 4 is as follows.

$$L = \frac{I}{S\cos\theta}, \quad \varphi = \frac{A}{r^2}, I = \frac{F}{4\pi} \quad (2)$$

I is the luminous intensity of the light source.F is the luminous flux of the light source.L is the brightness of the light source, S is the projection surface of the light source in the direction of the line of sight, θ is the angle between the normal of the light source and the line of sight of the human eye.φ is the light source stereo angle, A is the area of the sphere formed by the light source in the direction of the line of sight. r is the distance from the light source to the human eye.

Bennett's glare evaluation formula is fitted to the above three formulas as follows:

$$CBE_{Tol} = \frac{67.1}{L_b^{0.5}} \sum_n \left(\frac{F_i^{1.67} \times 0.037}{\cos\theta_i^{1.67} r^2 (8.8 \times 10^{-3} \times \theta_i^2 + 1.35)} \right) \quad (3)$$

In this instance, the intensity of unpleasant highway glare is proportional to the luminous flux of the light source, the distance between the light source and the human eye, and the glare angle formed. For each model, the glare angle and the distance between the light source and the human eye are considered. Calculating the combined luminance glare value of the 36 models, CBE. The CBE value is then used to determine its connection with the readily accessible values of lamp height and ground illuminance in the glare scenario.

2.2. Mathematical model for quantification of light infringement

The degree of light trespass in the residential area, T, can be determined by the percentage of windows along the street façade in the residential area with illuminance exceeding 31x. T is equal to the total number of windows on the corresponding building façade with illuminance exceeding 3lx divided by the total number of windows on the building façade, in %.

The model of the multiple linear regression equation is $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$ where β is a constant.

$$T = 32.285 + 0.002L - 1.935S + 2.719H - 0.620D \quad (4)$$

T is residential light infringement along the street.
L is the total luminous flux of the luminaire.
S is road and residential spacing.

H is the distance from the same side of the light pole installation.

D is the height of the light pole.

The above formula can be used to determine the degree of light trespass on residential buildings. In the actual evaluation process, by adding the measured impact factor parameters, the overall light trespass degree can be quantitatively analyzed easily and quickly. By defining and quantifying the degree of light trespass, it is useful to evaluate and compare the degree of light trespass of buildings along the street. It provides useful guidance for building a more environmentally friendly and comfortable living environment.

2.3. Quantitative mathematical model of light scattering

After summarizing and analyzing the literature on light spill criteria, the national criteria for light spill control can be summarized into two aspects: first, control of the uplighting ratio, and second, control of the lighting method.

The uplighting ratio of a light source is the ratio of the luminous flux produced by the light source to the total luminous flux emitted by the light source when the light source and the luminaire work together. The main means of reducing the upward luminous flux is the use of luminaires with shading angles. For this reason, national standards for light spill control are mainly based on the control of the shading angle of the luminaire.

In the process of urban lighting, due to the use of inappropriate lighting design, non-energy-saving lamps and light sources, coupled with the city hardened ground has a reflective effect on light, so that a large amount of light directly or indirectly shines into the sky. The diffuse reflection of urban dust creates a large "light cloud" of high brightness over the city. It is the excessively bright sky that obscures the stars that would otherwise be clearly visible in the sky. For the general public, this phenomenon only affects the effect of viewing the night sky, just the number of stars becomes less, while for astronomers and light environment researchers, the brightness of the city seriously affects astronomical observations, and seriously affects the natural laws of migration and activities of birds and insects, thus indirectly affecting humans. Therefore, more and more scholars have started to pay attention to this field and have developed the theory of evaluating light pollution in the sky to assess the extent of the impact of urban light pollution on the outer sky; and by measuring and calculating the brightness of the sky over the city, we can evaluate and calculate how much urban light spills into the sky. The light angel is shown in figure 1.

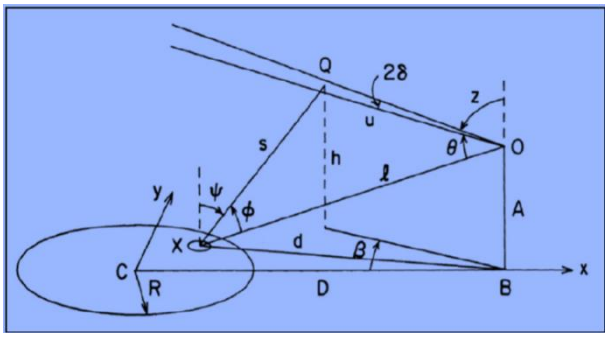


Figure 1: The light angel

In 1984, Garstang et al. first proposed a computational model for the evaluation of urban spillover light1. The model has been widely accepted by IDA, CIE and other scholars around the world. The large circle C in the figure is Garstang's hypothetical city with height h from the sea level and the center of the circle C. The observer is at point O at a distance D and height A from the city. Before building the model Garstang has an initial assumption. Assuming that each person in the city emits Llm of spill light over his head, the amount of spill light emitted by a city with population P as a whole is:

$$LP = L_0(\frac{p}{100000})^{0.1} \quad (5)$$

LP is amount of spill light emitted for the city as a whole.
$\mathbf{L_0}$ is the amount of spillover light emitted overhead for a hypothetical person.
p is the total population of the city.

$$L_{up} = \frac{LP}{2}[2G(1-F)\cos\varphi + 0.554F\varphi^4] \quad (6)$$

$\mathbf{L_{up}}$ is the luminous intensity in the direction of φ.
LP is amount of spill light emitted for the city as a whole.
F is the assumed amount of urban spill light shining directly into the sky.
G is the hypothetical spill light that does not shine directly into the sky.

Combining the other formulas described above, the relationship between light spill and luminaire elevation angle is adopted as follows:

$$S = 1.381 - 0.03a + 0.009a^2 - 3.5e0.05a^2 \quad (7)$$

S is the Light spillover. a is the projection angle of the luminaire.

2.4. Light pollution evaluation system

The Random Forest-TOPSIS model evaluation process, as shown in Figure 2.

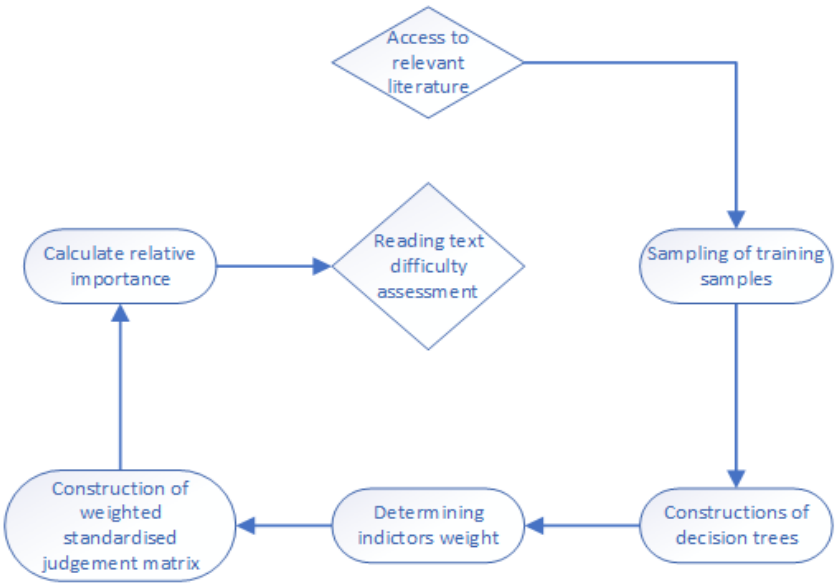


Figure 2: The Random Forest-TOPSIS model evaluation process

The research literature suggests using random forests, and the fundamental concept behind them is an integrated classifier that is built on several decision trees. Taking many distinct groups of training data allows for a greater degree of differentiation across the various categorization models. As a consequence of this, the technique enhances the predictive capacity of the model in addition to enhancing its ability to generalize. The Random Forest approach may be broken down into its two primary components, training and classification.

By the use of the bootstrap self-sampling approach, the process of training the model draws a subset of K samples from the training sample. The training samples that were not chosen for use in the model are referred to as out-of-bag data. After that, CART is applied to each of the K sample subsets in order to build the decision tree that corresponds to it. Every node in a single decision tree has a put-back that allows them to draw p features and divide the growth by computing the amount of information that is included in each feature. In order to reach the final classification result, the decision classification procedure entails integrating the decision outcomes obtained from each decision tree via the use of simple majority voting, as shown in the equation.

$$\delta(x) = argmax(y)\sum_{i=1}^{k} I(h_i(x) = y) \quad (8)$$

Where $\delta(x)$ denotes the final random forest classification result, $h_i(x)$ denotes the single decision tree model classification result, y is the target variable, and $I(\cdot)$ denotes the indicative function.

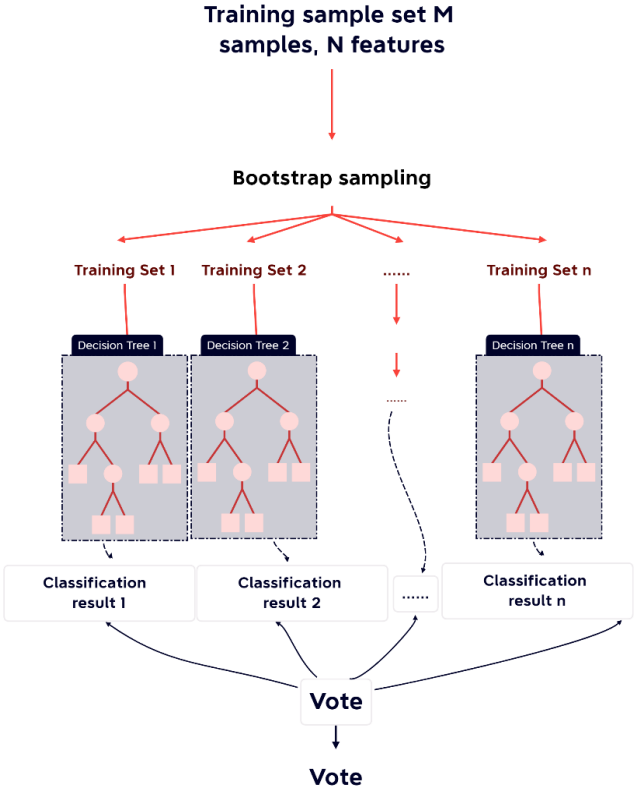


Figure 3: Random Forest-TOPSIS Process

Random Forest-TOPSIS Process is shown in figure 3. The Random Forest-TOPSIS model establishes an ideal value, also known as a positive maximum and a negative maximum and ranks the assessed items in order of their significance to arrive at a conclusion on their relative importance.

Using matlab programming to solve the above random forest model, the amount of light pollution degree, glare, light scattering and light spillover were used as the assessment index weights.

For the light pollution degree assessment index, the more important one is glare, followed by light scattering and light spillover, whose weights are 73.6461%, 13.9253% and 12.4286%, respectively.

The results obtained by integrating the weights trained by random forest into TOPSIS and adding the corresponding percentages are shown in Fig. 5The calculated results show that there is a clear hierarchical difference in the degree of light pollution in the four types of areas: urban, suburban, rural and protected areas. This is consistent with the actual map performance captured by the satellite, which confirms the validity of the assessment model. Three evaluation index weights are shown in figure 4.

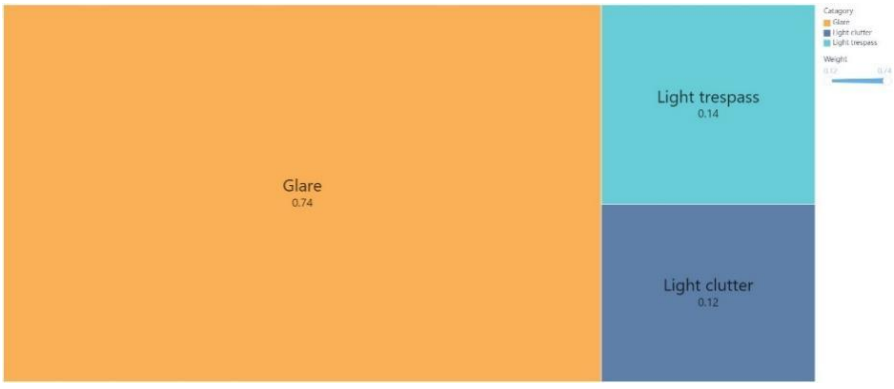


Figure 4: Light pollution three evaluation index weights

And we performed the scoring process by random forest-TOPSIS method, as follows figure 5:

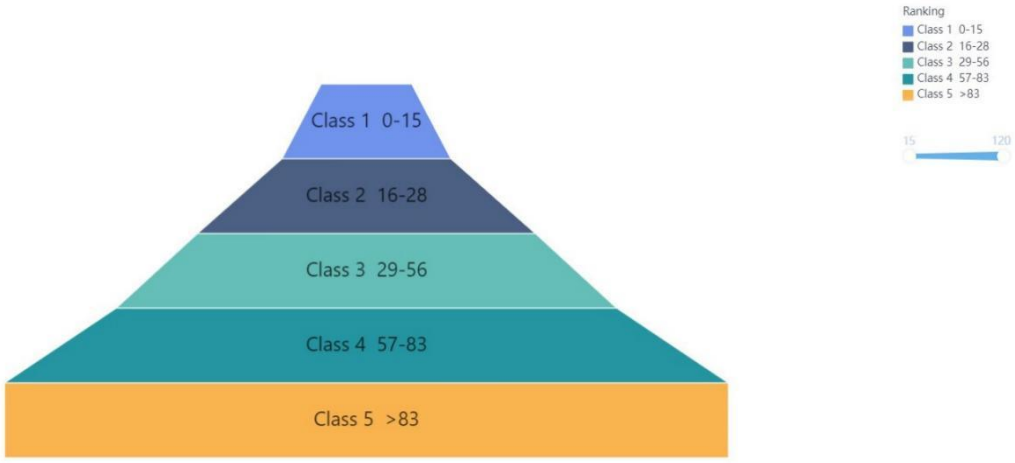


Figure 5: Light pollution level grading

In order to verify the correctness of our 3,000 nationwide area measurement assessment, we compared the calculated map style with the actual satellite photographic light map and found our conclusions to be correct after comparison.

3. Conclusions

To establish the sub-evaluation index calculation procedure for light pollution, the calculation procedure for each light pollution assessment index was finished by applying statistical principles to the computed data collected during outside inspections and simulations. The third step is to develop an assessment methodology for home light pollution in China. To develop a light pollution evaluation model, this paper combines the analysis of light pollution factors in residential areas with the analysis of cluster analysis to integrate various light pollution factors, then propose a light pollution model and a method for calculating light pollution degree.

References

[1] Jiang Benyan, Zhang Yuli, Li Shan, Li Jianjun, Zheng Zihao, Wang Hongguang. Spatial and temporal dynamics and sensitive distances of the nighttime light environment in the Pearl River Delta Nature Reserve [J/OL]. Journal of Applied Ecology: 1-10 [2023-05-19].

[2] Xiong Ruiyu,Chen Zheng. A review of nocturnal light pollution effects on whole health and key thresholds [J]. Chinese Garden, 2023, 39(02): 32-37.

[3] Baby Li. Environmental impact assessment and pollution prevention measures for photovoltaic projects [J]. Resource Conservation and Environmental Protection, 2023(01): 127-130.

[4] Qin Yan, Liu Ruxing, Kang Zhen, Li Hongguang, Gong Jingzhu, Sun Yunan, Zhao Juncheng. Research on extreme brightness measurement method based on high dynamic range imaging [J]. Applied Optics, 2023, 44(01): 168-174.

[5] Feng K, Hao LOSI, Zeng KUN. Exploring the evolution characteristics of urban lighting light pollution--analysis of VIIRS images [J]. Journal of Lighting Engineering, 2022, 33(06): 1-10.

[6] Zhuang X.B., Lin J.G., Chen Y.S. Analysis of the area of LED display and its distance limit from nearby residence [J]. Light Source and Lighting, 2022(S1): 58-60.

[7] Han Xiaomeng. Exploring the protection path of "dark night star" from the perspective of national park [J]. Journal of Hebei Institute of Environmental Engineering, 2022, 32(06): 47-50+61.

[8] Hao Y., Zhang P., Gao G., Bai Y. Analysis of light pollution management policies and interference light limitation standards for LED advertising screens [J]. China Environmental Monitoring, 2022, 38(03): 199-206.

[9] Zhuang Z-B, Wang W-H, Tai H-D, Wang J-J. The effect of contrast threshold effect on runway visual range measurement [J/OL]. Journal of Beijing University of Aeronautics and Astronautics: 1-9 [2023-05-19].

[10] Zhou Chunhui, Zhao Junnan, Wang Zheng, Gan Langxiong, Liu Zongyang, Xu Yanmin. Research on the evaluation method of urban light show on light pollution of navigable waters [J]. Journal of Wuhan University of Technology (Transportation Science and Engineering Edition), 2021, 45(02): 351-355.