A study of the main characteristics of light pollution in different regions - based on Random Forest-TOPSIS model

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Abstract. With the accelerated urbanization, human encroachment on the natural environment has become more and more serious. Among them, light pollution has become an issue of great concern. Based on the light pollution evaluation system created, this paper applies metric and interpret its results on the following four diverse types of locations: a protected land In this paper, we explore the causes of light pollution in each of the four types of locations: a protected land location, a rural community, a suburban community, and an urban community through factor analysis, The main sources and characteristics of light pollution in different regions are derived. This study is important for reducing light pollution in specific regions.

Keywords: Light pollution, Random Forest, TOPSIS

1. Introduction

With the continuous development of cities, human demand for light is increasing. However, the large number of light sources also brings a series of problems, one of which is light pollution. Light pollution is an environmental problem caused by excessive or incorrect use of artificial light[1]. It can affect the habitat and migration of wildlife, interfere with astronomical observations, and undermine human health and safety. In cities, excessive light pollution prevents the night from truly falling, prevents people from observing the stars with the naked eye, and wastes energy with the amount of light. Therefore, reducing light pollution has become an important issue that we should face and solve[2].

Much research has been done by previous scholars on the issue of light pollution. As early as the 1970s, the American astronomer John Bingham began to warn people about the harmful effects of light pollution. Since then, more and more scientists and experts began to pay attention to the problem and took a series of measures. For example, they promote the use of LED lights, design more energy-efficient street lights, require buildings to limit light pollution, and so on[3-4].

In addition, scientists have also conducted in-depth research on the effects of light pollution. For example, they found that excessive light brightness at night will affect the brain secretion of melatonin, which in turn affects the quality of sleep and physical health[5-6]. In addition, for wild animals, excessive light pollution will also affect their nature and behavior patterns. Therefore, the research of previous scholars not only gives us a deeper understanding of light pollution, but also provides important guidance for us to take effective measures. This paper will explore the main sources of light pollution in different regions.

2. A Random Forest-TOPSIS Based Model for Evaluation System of Light Pollution

In this study, a random Forest-TOPSIS model is suggested for estimating light pollution levels. The random Forest-TOPSIS model is a technique that employs random forest to establish indicator weights and proximity to assess significance, which has the benefits of maximizing the usage of raw data, little information loss, and objective and accurate computation outcomes[7].

2.1. The Establishment of the Random Forest-TOPSIS

The Random Forest-TOPSIS model evaluation process, as shown in Figure 1.

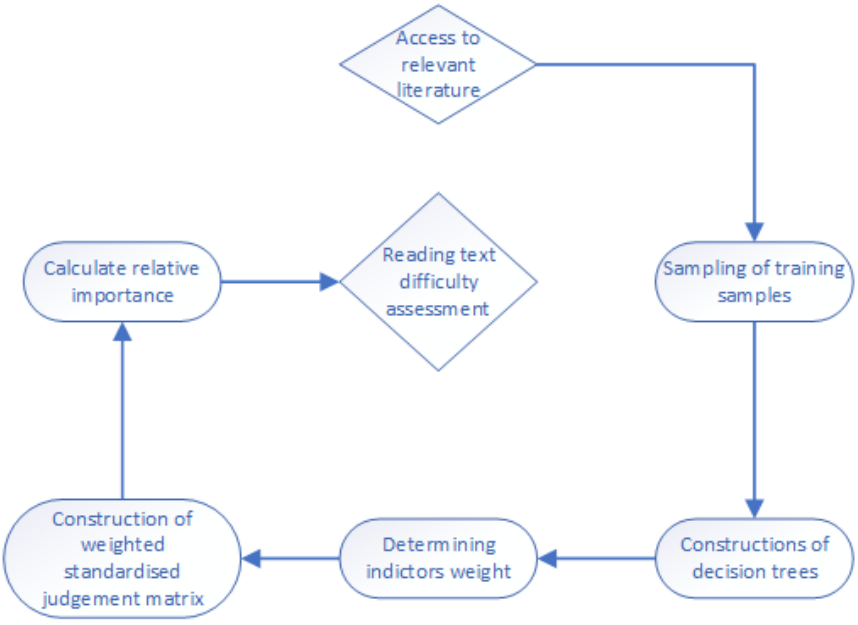


Figure 1. The Random Forest-TOPSIS model evaluation process

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[8-9].

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[10].

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

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

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.

Step 1: Build the initial matrix using the evaluation items as the building blocks.

There are m assessment items and n evaluation indicators in this matrix.

$$X = (x_{ij})_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, (i = 1,2,\dots,m; j = 1,2,\dots,n) \tag{2}$$

Where X is the initial matrix, x_{ij} is the jth evaluation indicator data of the ith evaluation object.

Step 2: Data standardisation.

Each indicator's scale differs in order of magnitude. The indicators must be standardized to avoid the influence of diverse scales on the assessment outcomes. This study processes the data using the extreme value approach. Random Forest-TOPSIS Process is shown in figure 2.

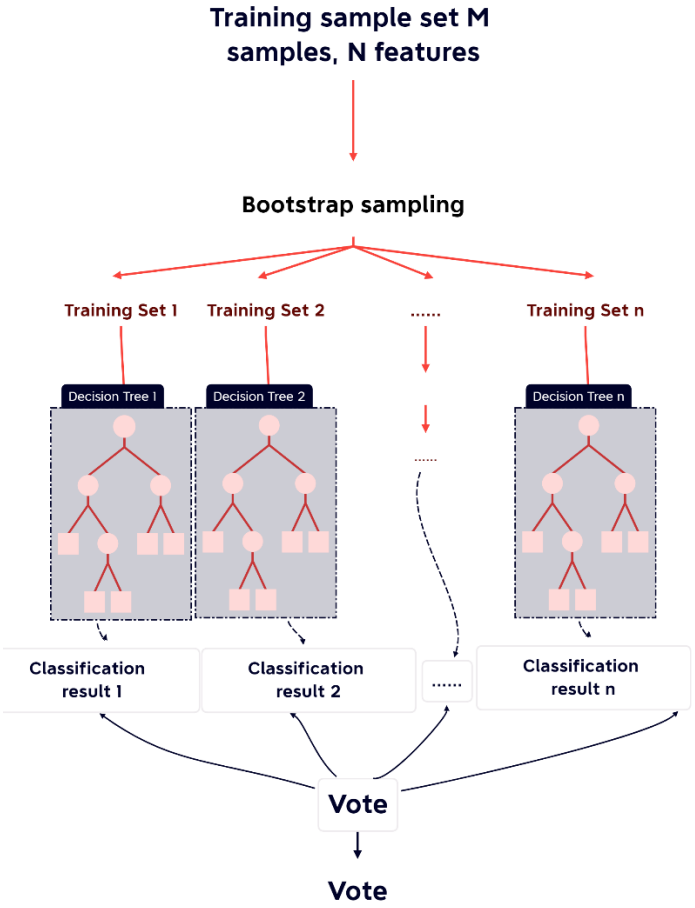


Figure 2. Random Forest-TOPSIS Process

When is a positive indicator:

$$Xv_{ij} = \frac{x_{ij} - min\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\}}{max\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\} - min\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\}} \tag{3}$$

When is a negative indicator:

$$v_{ij} = \frac{max\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\} - x_{ij}}{max\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\} - min\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\}} \tag{4}$$

Where $max\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\}$ is the maximum value of each indicator and $min\{x_{1j},\ x_{2j},\ \cdots,\ x_{nj}\}$ is the minimum value of each indicator.

Step 3: Calculate the Gini index score $VIM_j^{(Gini)}$ for each evaluation indicator, which is the mean value of the amount of change in the impurity of node splitting in all decision trees in the random forest for the jth evaluation indicator.

The Gini index is calculated using the formula:

$$GI_m = \sum_{k=1}^{|K|} \sum_{k' \neq k} p_{mk} p'_{mk} = 1 - \sum_{k=1}^{|K|} p_{mk}^2 \tag{5}$$

Step 4: Calculate and determine the weights.

The difference between the Gini index before and after node branching is:

$$VIM_{ij}^{(Gini)} = \sum_{m \in M} VIM_{jm}^{(Gini)} \tag{6}$$

Suppose there are n trees in a random forest.

$$VIM_{j}^{(Gini)} = \sum_{i=1}^{n} VIM_{ij}^{(Gini)} \tag{7}$$

Lastly, each assessment indicator's weight was determined by normalizing the weight scores that had been collected VIM_j.

$$VIM_j = \frac{VIM_j}{\sum_{i=1}^{c} VIM_i} \tag{8}$$

Step 5: Construct a weighted standardised judgement matrix.

$$Z = (VIM_j v_{ij})_{m \times n} = \begin{bmatrix} VIM_1 v_{11} & VIM_2 v_{21} & \cdots & VIM_n v_{1n} \\ VIM_1 v_{21} & VIM_2 v_{22} & \cdots & VIM_n v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ VIM_1 v_{m1} & VIM_2 v_{m2} & \cdots & VIM_n v_{mn} \end{bmatrix} \tag{9}$$

Step 6: Calculate the relative proximity.

Let the decision problem have m each objective $f_j(j = 1,2, \dots, m)$, n feasible solutions and let the positive and negative ideal solutions of the normalized weighted objective of the problem be is Z^+,Z^-, respectively.

$$Z^+ = \left(maxz_{i1}, maxz_{i2}, \dots, maxz_{ij}\right) \tag{10}$$

$$Z^- = (minz_{i1}, minz_{i2}, \dots, minz_{ij}) \tag{11}$$

Where z_{ij} is the data weighted value of the jth evaluation indicator of the ith evaluation object, $z_{ij} = VIM_j v_{ij}$.

Using the Euclidean parametrization as a measure of distance, the distance from any feasible solution is:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(Z_{ij} - Z_j^+\right)^2} \tag{12}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(Z_{ij} - Z_j^-\right)^2} \tag{13}$$

Where S_i^+ is the proximity of i to a positive maximum and S_i^- is the proximity of i to a negative maximum.

Step 7: Determine the level of importance.

The formula for calculating the importance of each evaluation object is as follows.

$$ZC_i = \frac{S_i^-}{S_i^- + S_i^+} \tag{14}$$

Where C_i is the importance of the ith evaluation object, judged by the distance of C_i close to 0 or 1, the closer to 1, the higher the importance, and vice versa, the closer to 0, the lower the importance.

2.2. Measurement of light pollution in different areas

In the long history of residential road system planning and design development, western countries have gone through three stages. The first stage was before the Woonerf renovation in the Netherlands. Before that, the Radbum system was used for the traffic system of the settlement. In a nutshell, the system was to separate the pedestrian road system from the motorized road system in the residential area on a separate plan. As shown in Figure 5-1, the thick line in the figure shows the motorized road system, while the pedestrian road system is concentrated inside the vehicular road.

The second stage of development of road system planning method was between the 1960s and 1990s, after the beginning of the traffic tranquillization movement. At this time, the internal road system of residential areas returned to the coexistence of people and vehicles. However, the courtyard road system used in this time was different from the previous one, in which the speed of motor vehicles was strictly limited by installing hard facilities or adding soft policies on the motorway.

Thus, the harmonious coexistence of people and vehicles was achieved, as shown in Figure 5-2. The third stage is the emergence of a residential road system planning approach based on public transportation and pedestrian roads after the 1990s. This system emphasizes the importance of the pedestrian system, while trying to reduce private car travel and reduce the speed of vehicle travel, such residential road system is more suitable for walkers and bicyclists to travel.

In contrast to the characteristics of foreign residential road systems, our residential road system is more in line with our national conditions and has its own characteristics. According to the current situation of the research on the night light environment of residential areas, the internal road system of residential areas in China can be basically divided into three major categories. The first category, and is currently the most adopted road system model in China, the model corresponds to the second stage of the development of foreign road systems, that is, mixed road system for pedestrians and vehicles. However, in our country, this type of road system mainly controls the speed of traffic through the speed limit belt, while in many cases of settlements, there is no speed limit on these roads, and the speed control comes from the compliance with the moral code. Many cases also confirm that this type of road system includes two more types of roads.

Firstly, the road system has only vehicular roads (present in the early built residential areas); secondly, the pedestrian and vehicular roads are parallel, while the pedestrian and vehicular roads are separated in plan by landscaping facilities such as floor tile color and hedges. The second type of road system used in China's residential areas is the road system of pedestrian-vehicle branch. This model is similar to the first stage of the development of foreign road systems, Redmond system.

That is, the car road around the perimeter of the settlement, while the internal settlement is the use of pedestrian space road system. Such road system is used in the construction of settlements are relatively late, mostly after 2000. However, with the development of the times, more and more settlements adopt this road system, and it has the tendency to become the mainstream road mode. The third type of road system corresponds to the third stage of the development of foreign road systems, but with Chinese characteristics, that is, the pedestrian road system. The internal ground of the settlement with this system is strictly forbidden for cars to enter.

Private cars enter the special underground garage through the specific entrance set up in the settlement, and people enter the house directly through the vertical traffic facilities. In this type of road system, the pedestrian road system can be arranged in the form of recreational plazas and garden walks, where residents can move in a directional or non-directional way. Regardless of the form of the pedestrian road, the humanization of the road system is greatly improved by the absolute separation of pedestrian and vehicular traffic within the settlement using this type of pedestrian road system.

The nighttime light environment of residential areas in China is complex and diverse. However, according to the classification of China's residential nighttime light environment in the above three subsections, it can be seen that China's residential nighttime light environment can be divided into low illumination settlements, high illumination settlements and mixed illumination settlements according to the form of the internal road system of residential areas.

Different types of residential nighttime light environment have their own characteristics, at the same time, as a component of the light environment, light pollution environment also presents certain characteristics due to the different residential areas.

The distribution of light pollution inside different residential areas is different

In the nighttime light environment of low-light residential areas, the main light environment is formed by the lighting of the pedestrian pathway system and the leisure activity area. Pair plot of three factors are shown in figure 3.

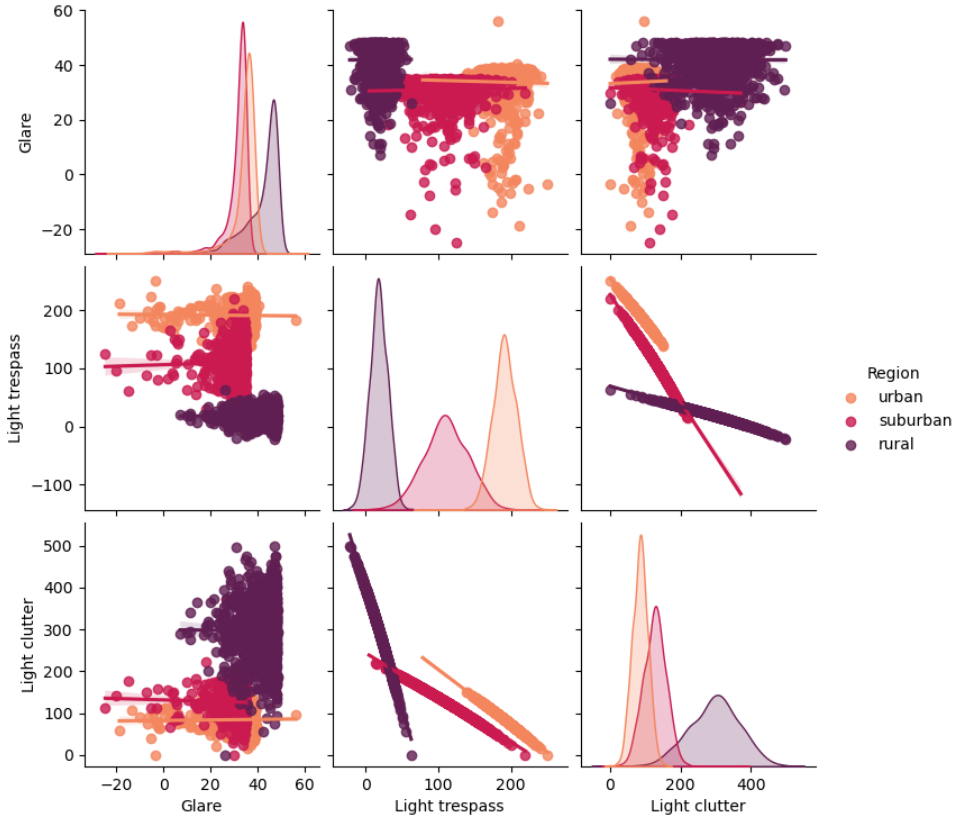


Figure 3. Pair plot of three factors

In the lighting design of such an environment, that is, there are considerations for functional lighting, but also for landscape lighting considerations. Therefore, the layout of lamps and lanterns is free, and there are many forms of lamps and lanterns. Sometimes a large area of the landscape area using spotlights, sometimes using low lawn lighting, many decorative, functional and heavy garden lights, landscape lights are also used in large numbers.

Although, the projection angle of these lamps and lanterns is large, the shading angle of lamps and lanterns is also limited to less, but the lighting target is very clear. Therefore, the light pollution generated by lighting in this area is mainly light spillover and glare pollution. Since the speed of residents' activities is low and the direction of vision is uncertain, the degree of glare pollution does not affect the safety of drivers and pedestrians like the glare on the carriageway, so the evaluation of glare in this area is not as strict as the evaluation of glare in the carriageway.

In the high illumination residential area, because the residential area adopts the form of mixed road for people and vehicles, in order to meet the needs of the car, the entire residential range of internal roads are designed using the standard of the car road, the road illumination is very high, the overall effect of the community is also very bright. At the same time, because the construction age of this type of community is relatively early, the environmental quality of the community is not high, the building density of these communities are usually relatively large, the landscape environment is less.

Therefore, along the road construction of community housing is susceptible to the impact of light infringement of community road lighting. This kind of impact covers a large area, and residents reflect strongly. Light infringement is a key point in the evaluation of cell light pollution. In some old, old neighborhoods, due to the design of lighting on the illumination uniformity of the consideration is not enough, or intentionally avoid high light poles along the road residents window light infringement, the use of lower light poles and larger spacing between poles. This has caused a serious lack of uniformity in some of these neighborhoods, road glare is obvious.

Therefore, the glare pollution in this type of community is also more prominent. The use of driveway lighting design approach, in order to increase the uniformity of illumination in the direction

of the road cross-section, more appropriate to increase the angle of inclination of the street lamp head. Such practices are common and reasonable, but also caused a certain amount of light spillage.

Since this kind of light environment exists simultaneously with the form of road glare pollution and light infringement pollution inside the district, and covers a large area, it should be controlled and calculated for this kind of environment. In the mixed illumination settlement, the surrounding road lighting light pollution environment is similar to that of the mixed illumination settlement, and the middle of the settlement is similar to the light pollution environment of the low illumination settlement. Therefore, the evaluation and calculation of light pollution level in such settlements should correspond to the area orientation.

3. Conclusions

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. Using a combination of field research and software modeling of the nighttime light environment in residential areas, the light pollution environment in residential areas was researched and assessed in this work. In addition, this paper summarizes the research findings on the actual environment of residential areas in China, as well as the evaluation method for comprehensive light pollution in residential areas, which consists of glare pollution environment, infringement light pollution environment, and spill light pollution environment. The evaluation method for comprehensive light pollution in residential areas, which consists of glare pollution environment, infringement light pollution environment, and spill light pollution environment, summarizes the study's findings regarding the actual environment of residential areas in China.

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] Liu, Mengjun. Research on the application path of green construction technology in building engineering based on the perspective of green development concept [J]. China Construction Decoration, 2022(24):71-73.

[4] Zhu Weikai, Zhou Peng, Wang Hongliang, Wuziyang, Chen Jia. A study on urban night lighting design and light environment quality evaluation method based on the background of double carbon and double reduction--taking Hangzhou Yanzhong Building as an example[J]. Journal of Lighting Engineering,2022,33(05):144-156.

[5] Lai S.D., Wang C.T., Lin X.L. Environmental regulation and green development in spatial spillover perspective - dilemma or reconciliation? [J]. China Environmental Management,2022,14(04):80-90.

[6] Tang Zhiya. Research on building construction technology based on green concept [J]. Ceramics,2022(08):149-151.

[7] Feng K, Dai SHJ, Hao LOSI. A preliminary investigation on the evolution characteristics of light pollution based on VIIRS image--four cities in China[J]. Journal of Lighting Engineering,2022,33(04):172-185.

[8] Wu Cai Ke. Research on innovative ways of construction management based on green management concept[J]. Engineering Technology Research,2022,7(15):143-145.

[9] Li Jiayi, Xu Yongming, Cui Weiping, Wu Yuyang, Wang Jing, Su Boyang, Ji Meng. Nighttime light pollution monitoring in Nanjing based on Liaojia-1 night light remote sensing data[J]. Remote Sensing of Natural Resources,2022,34(02):289-295.

[10] Liu Xiaoshuang. Analysis and prediction of urban nighttime light environment evolution based on time series[D]. Dalian University of Technology, 2022.