

Let Starry Light the World

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Abstract: When the night is no longer lit up by stars, when the light that man once craved gradually swallows up the world, light pollution leaves the night sky without its back-ground, and life on the blue planet is immersed in the pain of light invasion. How to measure and solve light pollution has become an urgent global problem in today's world, and we are deeply worried about it. So, we built an indicator model and developed effective methods to improve light pollution. For TASK I : In order to enhance the wide applicability of our model, we established TOPSIS Method based on AHP Model and Entropy Weight Method, which was used to analyze the indirect factors reflecting light pollution to the degree of regional pollution and their respective proportions. It is showed on the results that the regional vehicle ownership is the indirect factor reflecting the greatest degree of light pollution. After that, we deeply analyzed the more specific factors reflecting the impact of light pollution on the area by establishing a random forest model. Finally, we learned that biodiversity was the most important factor reflecting the impact of light pollution, accounting for 37% among the factors we consider. For TASK II: In order to control the influencing factors, light intensity and color temperature were divided into four levels as first-level factors, and the influence of artificial light was taken as second-level factors. Satellite images were simulated and optimal interval method and linear regression model were used to establish the contribution model of light pollution. Through this model, we proposed three intervention strategies and evaluated each of the four regions. The results showed that the scheme using lampshades worked best in suburban and urban communities, reducing light pollution risk levels by about 52 percent. For TASK III: We selected the most effective strategies for improving light pollution in Shanghai and produced a leaflet at last.

Keywords: Random Forest Model; Optimal interval range; Linear regression.

1. Introduction

1.1. Problem Background

"The global spread of artificial light is eroding the natural nocturnal environment, and light pollution has become a global problem, and it is continuing to worsen, and it is likely to worsen at an increasing rate." said by Dr. Alejandro Sánchez de Miguel. According to a recent study led by the University of Exeter, global light pollution has increased by at least 49% in 25 years. And that number includes even light visible through satellites, which scientists estimated is far more severe than that. After adjusting for the data, scientists said the global increase in light pollution was as high as 270%, and in some regions as much as 400%. And there is something need to know. If the urban sky light source is too irradiated, it will not only affect the day and night routine of humans, but also destroy the migration route of birds, reduce the range of animal habitats, and disrupt the physiological rhythm of plants. Therefore, it is urgent to improve light pollution, and we urgently need a reasonable and effective model to for malate corresponding countermeasures.

So how exactly does light pollution occur? About 600,000 years ago, humans learned how to use campfires for heating and torch lighting, and the first artificial light was born. As a necessary product of technological development and modern society, artificial light is almost everywhere, from the bustling urban neon lights to the looming incandescent lights in the suburbs. Although artificial light has its indispensable role, such as bringing light to human beings in the dark night and maintaining the normal operation of society, it will produce light pollution due to excessive use or wrong placement. What exactly is it measured by? And how does it affect a social environment, a region and a person? Only after carefully exploring and finding out the answers to these questions can

we develop the right strategy to solve the problem of light pollution.

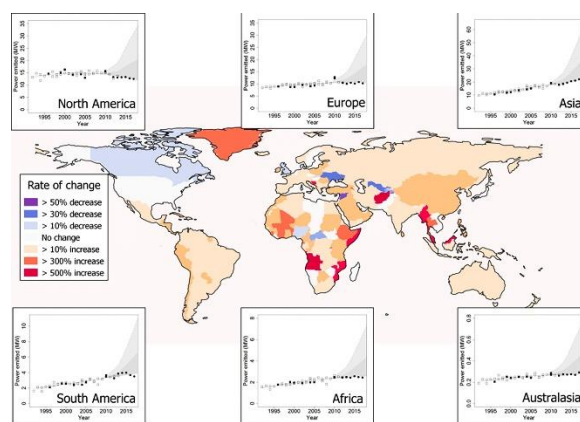


Figure 1. Rate of change in artificial light at night by satellites across continents. (1992 - 2017) [1]

1.2. Our Work

This problem requires us to help people raise awareness of the impact of light pollution and develop intervention strategies to mitigate these impacts. Our work includes the following aspects:

To enhance the usability of the model, we have established TOPSIS model based on AHP, entropy weight model and random forest regression model.

The factor grade and contribution model of light pollution are given, and three measures are put forward considering the positive impact of artificial light, and the ideal model is introduced for evaluation.

The control function is introduced for sensitivity analysis to verify the feasibility of our model.

2. Assumptions and Justifications

Considering that practical problems always contain many complex factors, first of all, we need to make reasonable assumptions to simplify the model, and each hypothesis is closely followed by its corresponding explanation:

Assumption 1: Shanghai in China, Seattle in the United States, Bangladesh and Amazonas State in Brazil can be regarded as idealized cities, suburbs, rural areas and protected areas respectively, that is, we can extract their feature points and create a matrix with numerical values.

Explanation: In reality, there are many interference factors in these four regions due to geographical differences and other reasons, so the ideal model can avoid the possible influence of some differences, which is more conducive for us to develop reasonable strategies.

Assumption 2: During the implementation of our strategy, there will be no emergencies, such as epidemics, major disasters.

Explanation: If an emergency occurs during this period, the feedback data obtained after the implementation of our strategy will be too volatile, thus affecting the calculation and evaluation of our model and damaging its sensitivity.

Assumption 3: Our strategy can be fully and smoothly implemented. Explanation: Because if all or part of the strategy cannot be implemented, then the data results we get based on the strategy simulation will produce huge errors.

Additional assumptions are made to simplify analysis for individual sections. These assumptions will be discussed at the appropriate locations.

3. Notations

Table 1. Notations

Symbol	Description
ϵ	Night crime rate
η	Glare degree
μ	Driving safety at night
λ	Light at night wastes energy
φ	Level of social development
ζ	Degree of biological clock influence
L	Luminosity
T	Color temperature
E	Illumination duration

4. Light pollution risk level assessment model

4.1. Combined with TOPSIS method of analytic Hierarchy process

4.1.1. Data Selection

In order to consider the influence of micro factors more comprehensively, we decided to start with four macro factors, namely, vehicle ownership, per capita income, population and artificial light intensity, which are the unnatural factors such as economy and population. It is worth mentioning that several models are used in this question. Because the construction of comprehensive evaluation index considers the difference of each index more comprehensively, it can avoid the limitations brought by single index evaluation.

4.1.2. The establishment of the model

TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is a commonly used and effective method in the analysis of multi-objective decision making. It can make full use of the information of the original data. The

results can accurately reflect the gap between evaluation schemes. Therefore, we initially use this basic model to analyze the influence of different light pollution factors.

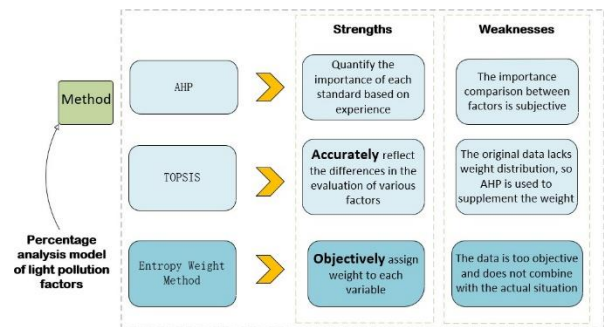


Figure 2. The analysis of our combined model

4.2. Entropy weight method improves weight distribution

However, to judge the pollution degree of influencing factors of light pollution, it is necessary to melt the above four criteria into a synthetic standard reasonably. Here we use the entropy weight method to assign weights to each criterion, which was used as a normal model by us. Although the TOPSIS method to obtain weights through the analytic hierarchy process is good, it is too subjective, so the following Entropy weight method is introduced, which is an objective weighting method and tells us the weights through the data itself. So, this is the result of weight analysis on the index of macro factors of light pollution.

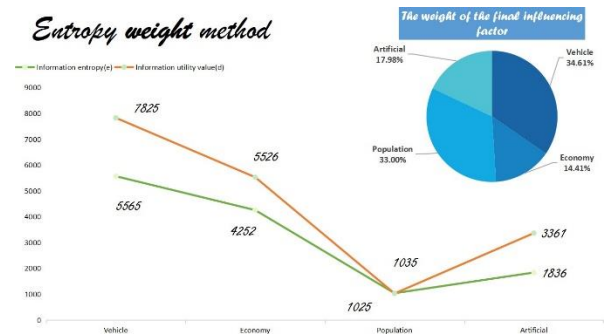


Figure 3. The degree of influence of the dominant factors

4.3. Random forest model was adopted

4.3.1. Model improvement and reasons

After the study of the above macro factors, we believe that a widely applicable micro metric can be developed to determine the light pollution risk level of a site. But the model we used was not accurate enough. Besides, the indicator we selected before are too sweeping. Therefore, we established a new evaluation model as an extended model and introduced specific formulas to transform dependent variables into more specific factors for the subsequent analysis and use of the model. It can be used as a reference to evaluate the light pollution in different types of areas. Therefore, seven factors were selected to determine the level of light pollution risk. Which was applied to Random forest model to obtain our evaluation model. [3, 5]

Random forest model consists of multiple decision trees. The basic principle of random forest is to use bootstrap method with replacement sampling to extract samples from the original data set as the training set, build a decision tree for each training set, and use the remaining unextracted samples as the test set (out-of-bag sample) to evaluate the

prediction effect. The remaining out-of-bag samples are used as the test set to evaluate the prediction effect. When constructing each decision tree, RF randomly selects a number of variables from all variables (or features) at each node of the decision tree as candidate variables, and selects the most important variables from them to participate in the node partitioning of the decision tree. Repeat the above process N times. The random forest classifier classifies and discriminates the new data, and the prediction of the classification result is determined by the vote of the classifier model.

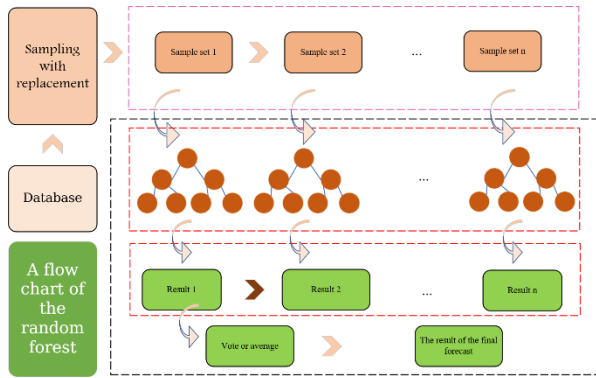


Figure 4. The process of our model

4.3.2. Calculation of risk levels of light pollution and Conclusion

So, we evaluated the light pollution risk of a region by combining economic, population, biodiversity and geographical factors. These indicators can be quantified by human development index (HDI), population factor Pop, biodiversity BI (the change rate of the number of organisms obtained by the recapture method), geographic Geo, weather Clime, urbanization rate UR, and population density PD, and the degree of light pollution can be quantified by night brightness LPRLI.

In order to determine the extent to which light pollution affects each indicator, we first established a fitting regression model based on the collected data from different regions of the world. Normalized dimensionless processing was carried out on the data, and fitting regression analysis was carried out by programming, and the results were as follows:

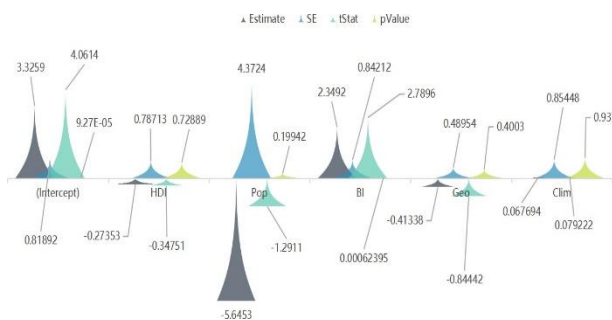


Figure 5. The results

According to common sense, the result obtained by this method has a large error. Using Random Forest to analyses, the importance of indicators was obtained as follows:

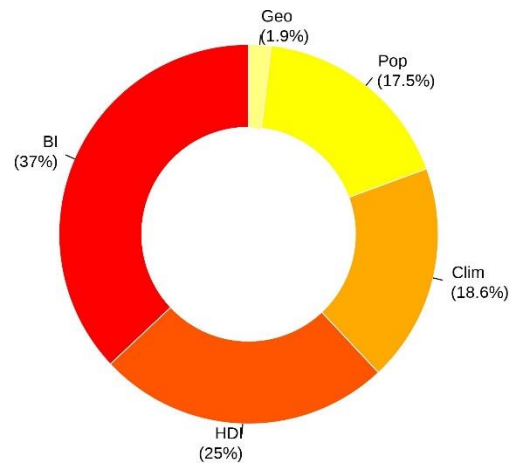


Figure 6. Importance of Indicators

5. Effective intervention strategies

5.1. Model improvement

While we are anxious about the negative effects of artificial light, we cannot ignore the positive effects of artificial light. Lighting, for example, can make cities safer, reduce crime and road accidents. Promote economic development and tourism attraction and other positive effects. Therefore, when proposing three possible intervention strategies, we could not blindly reduce light pollution. Therefore, we formulated new indicators, obtained the optimal interval required for control through the new score, and proposed our strategy through the Optimal interval range.

5.2. Preparation before strategizing

In order to determine the factors to be controlled, we incorporated the indicators in TASK1 into the new scoring criteria, i.e., luminosity, color temperature, and light duration. In order to simplify the calculation, we divided these three factors into four levels from 1 to 4, which will be more simplified in the subsequent processing. Secondly, we use various factors to carry out linear regression on luminosity, color temperature and illumination duration respectively, and calculate the weight of each factor, so as to obtain the result score of influence on different factors.

5.2.1. Secondary factor selection

There are many effects brought by artificial light, which we mainly divide into positive and negative effects. Among the positive factors, we chose social development level, night driving safety and night crime rate the negative factors we selected were glare level, energy waste level of artificial light at night and biological clock.

Level of social development: The level of social development reflects the scale or level of social and economic phenomena in different periods. Generally, speaking, the more artificial light sources there are, the higher the level of social development there is.

Driving safety at night: The more artificial light, the more visible the road, making it safer to drive at night.

Night crime rate: The greater the amount of artificial light, the better the visibility at night, which helps to discourage most people from committing crimes, thus reducing the nighttime crime rate in the entire area.

Glare degree: Glare is one of the most important factors affecting the quality of lighting, and glare is a measure of how uncomfortable the light is. The negative effects of artificial light on people depend heavily on the glare.

Energy waste level of artificial light at night: The more artificial light sources there are, the more concentrated they are, the more energy is wasted in the area. This can lead to higher levels of energy waste at night in the area, wasting energy.

Degree of biological clock influence [6, 7]: The circadian schedule is regular and healthy for all living things. But because of artificial light, rest is often forced to delay, disrupting the circadian rhythm.

5.2.2. Fitting of first-order factors

After the second-level factors are completely processed, the least square method is used to carry out linear regression, and the following model formulas for the influence of second-level factor pairs and factors can be obtained respectively

$$L = -1.425 - 0.031\epsilon + 0.175\eta - 0.048\mu - 0.158\lambda + 0.184\phi + 0.147\xi$$

$$T = -2.046 + 0.012\epsilon + 0.247\eta + 0.029\mu - 0.168\lambda + 0.196\phi + 0.125\xi$$

$$E = -0.088 - 0.003\epsilon + 0.022\eta + 0.009\mu + 0.014\lambda - 0.009\phi - 0.001\xi$$

And we then average the level 1 factors at different levels to get the following data.

Grade	Photometric contribution	Color temperature contribution	Light duration contribution
4	0.3964	0.789	-0.0575
3	0.0896	0.4802	-0.04525
2	0.1044	0.3514	-0.065
1	-0.083	-0.0044	-0.044

Figure 7. The specific data

5.2.3. The establishment of scoring model

Since different contributions have different weights, we use the weight ratio in TASK1 for calculation, which can be seen in the following formula:

$$W_n = A_i + B_j + C_k, \quad i, j, k = 1, 2, 3, 4$$

Where, A is the contribution of luminosity, B is the contribution of color temperature, C is the contribution of illumination duration, and W is the artificial illumination score obtained by us.

The higher the score we get above, the better the overall benefit of artificial light. Through calculation, 64 data were obtained, respectively representing different influencing factors, and the following image was drawn:

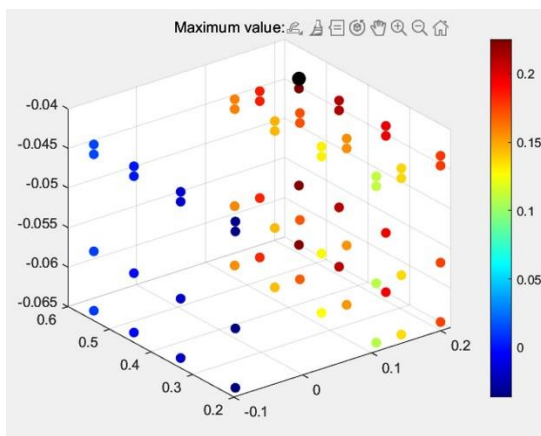


Figure 8. The optimal interval that we got

Among them, we can get the luminosity, color temperature and light duration interval when the score is highest. It can be obtained from the figure that the maximum value is 0.267323, and the corresponding x, y and z values are (0.214400, 0.469000, -0.065000) respectively. Conclusion: In other words, our strategy requires a light level of 3 and a color level of 2 for light duration.

5.3. Strategy proposal

5.3.1. Reasons and ideas for improvement

From the above we can get the luminosity, color temperature and light duration that we need to control. Generally speaking, we need to keep the luminosity high but not too high, and reduce the color temperature and light duration appropriately. However, the effectiveness of intervention strategies may vary by location. Therefore, in order to make our intervention strategies more personalized and achieve the purpose of adapting to local conditions, we need to use light pollution risk level indicators to evaluate the effects of different intervention strategies and select the most effective strategies.

5.3.2. The process of our test

So, we took the night satellite images of four locations (Figure 15-18) and wrote a program to simulate the night light intensity model of four typical areas. According to relevant literature, the risk level of light pollution in a region can be roughly calculated according to the following formula:



Figure 9. Amazonas

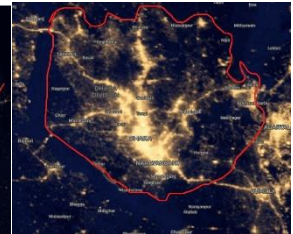


Figure 10. Bangladesh



Figure 11. Seattle Figure

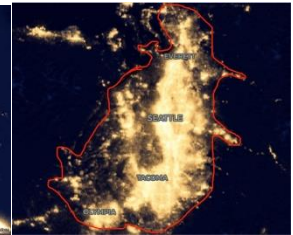


Figure 12. Shanghai

$$\text{Risk_level} = \text{mean_light_intensity} - 1090$$

Besides, we wrote a program to determine light pollution risk levels for four locations. The results are as follow (Figure 17-20):

Risk levels before intervention:

Protected land: -0.03395061728395062

Rural communities: 0.537962962962963

Suburb: 2.066358024691358

City center: 3.9583333333333334

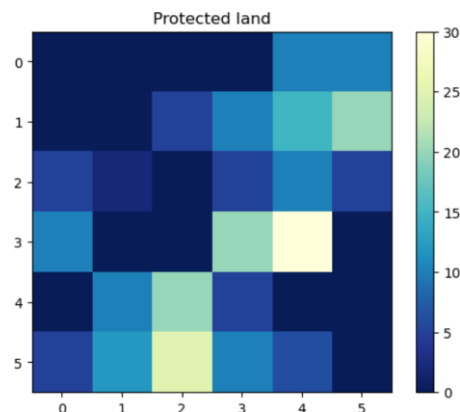


Figure 13. The result of Amazonas

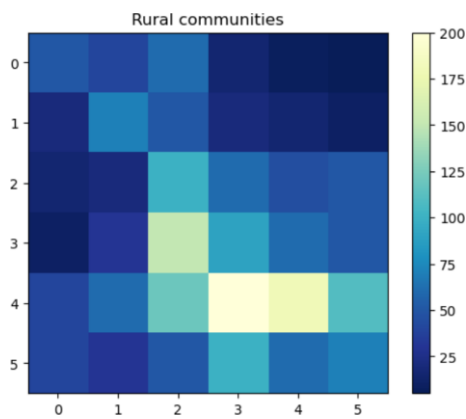


Figure 14. The result of Bangladesh

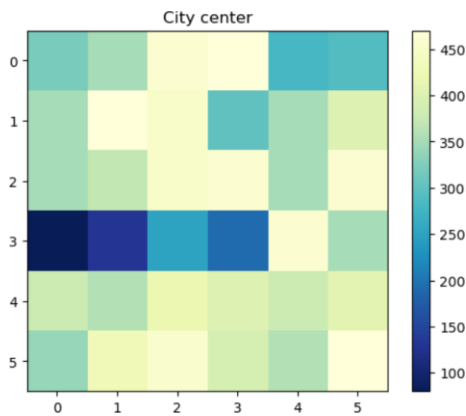


Figure 15. The result of Seattle

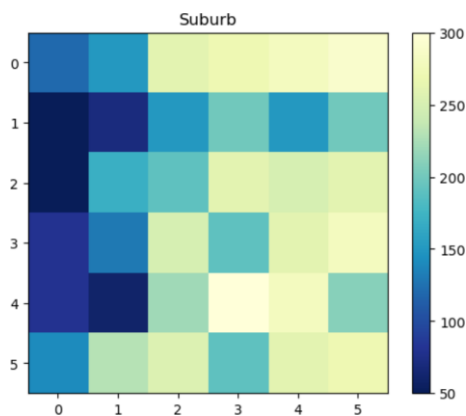


Figure 16. The result of Shanghai

5.4. Three intervention strategies and their effects

Each intervention strategy has its own unique potential impact. For example, turning off light fixtures may reduce lighting levels and affect people's movement and safety at night. On the other hand, the use of light blockers may increase costs and maintenance requirements, while also potentially reducing lighting levels. Therefore, selecting the most appropriate intervention strategy for a particular site requires a combination of factors, such as environmental conditions, use needs, and cost-effectiveness. It is also important to note that an intervention strategy may work in one location but not in another. Therefore, assessments need to be made on a case-by-case basis.

Next, we used light pollution risk level indicators to assess the effects of these three interventions at different sites.

Strategy 1: Add lampshades to reduce light scattering by half Risk levels after intervention:

Protected land: -0.07253086419753087
 Rural communities: 0.21342592592592594
 Suburb: 0.9776234567901234
 City center: 1.9236111111111117
 Strategy 2: Plant lots of trees, natural light blockers Risk levels after intervention:
 Protected land: -0.05308641975308642
 Rural communities: 0.4530864197530865
 Suburb: 1.699074074074074
 City center: 2.989197530864198
 Strategy 3: Lighting control Risk levels after intervention:
 Protected land: -0.05679012345679012
 Rural communities: 0.42530864197530865
 Suburb: 1.5848765432098766
 City center: 2.736111111111111

6. Final conclusion

In the above procedure, we calculated light pollution risk levels in four regions and compared the effects of three intervention strategies. It can be seen that for site 1, the effect of the three intervention strategies is similar, without any light pollution risk. For site 2, all three strategies have little effect. For sites 3 and 4, the use of lampshade has a better effect, which can reduce the risk level by about xx, while the effect of tree planting is equivalent to that of light control. Considering the impact of light control on economic and social security, tree planting has the best effect between them.



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