

Study on the Selection of Light Pollution Interventions Based on Goal Planning Model

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Abstract. With the continuous development of economy and technology, light pollution has become a new form of environmental pollution affecting human health and ecosystem. To assess the level of light pollution risk in a place, we used the HALOEN model to analyze the local light pollution situation, taking into account the health level of the local population, economic energy consumption, light pollution index, natural environment and urban planning. Using this model, we evaluated and ranked the risk levels of light pollution in four types of areas: protected land, rural communities, suburban communities and urban communities. Quantified according to the data of urban areas in Hubei Province, a total of 20 eligible cities in Hubei Province were selected as samples. Finally, the result of risk level is protected land < rural community < suburban community < urban community. Second, we designed specific interventions to address the problem of light pollution. Our team proposed specific actions in terms of lighting facilities, humanities education and urban planning, and explained the potential impact of these actions on light pollution. Finally, the causes of light pollution in Wuhan and Rio de Janeiro are analyzed, relevant intervention measures are proposed, and the effectiveness of their combination is calculated.

Keywords: Light Pollution, Intervention, Goal Planning.

1. Introduction

1.1. Research Background

With the rapid development of economy and science and technology and the increasing popularity of electricity, the night in cities is getting brighter and brighter, which facilitates people's life. However, the excessive use of artificial light has brought about a new problem -- light pollution, which has become a form of environmental pollution affecting human health and ecological system. After water, gas, sound, solid waste gas and other four major pollution, another cannot be ignored new pollution. Light intrusion, over illumination and light clutter are common phenomena of light pollution. Nowadays, with the popularization of electricity, these phenomena are not only happening in urban areas, but also in remote areas. The degree of light pollution in a certain area is closely related to human factors such as urban construction level, as well as non-human factors such as geography and climate. Light pollution will not only harm human health but also the overuse of artificial light will destroy the ecological balance and lead to the reduction of biodiversity. In fact, light pollution has caused many problems. Some countries and regions have issued relevant light pollution standards. In order to reduce the negative effects of light pollution, officials need to develop reasonable measures to manage the use and construction of relevant aspects of the community. We need to analyze the measures in place to reduce light pollution and select the best control measures for the area.

1.2. Literature Review

So far, a large number of researchers have made part of the research on the hazards of light pollution and related intervention policies. In terms of the harm of light pollution, Cinzano et al. pointed out that artificial light sources would have a negative impact on astronomical observation, ecosystem, human health and other aspects [1]. Rich and Longcore discuss the effects of artificial nighttime pollution on wildlife, plants, and ecosystems, noting the effects of light pollution on animal biological clocks, seasonal behavior, migration, plant production, flowering, and fruiting [2]. Falchi

et al. discussed the effects of artificial light pollution at night on human health, the environment, and astronomical observations, showing that long-term exposure to light pollution can affect the circadian clock, sleep quality, immune system, and other health problems [3]. Fabio Falchi and Salvador Bara have analysed data from citizen scientists to reveal a worrying increase in light pollution over the past decade [4]. Research by Carolyn S Burt, Jeffrey F Kelly and others suggests that light pollution is a global threat to biodiversity, particularly migratory organisms, and that emerging tools for measuring light pollution and its effects, as well as ecological forecasting techniques, offer new approaches to conservation efforts, including interdisciplinary approaches [5]. Cao Miao; Xu Ting; Yin Daqiang has studied the effects of light pollution on human life rhythms and various diseases, noting that a better understanding of the health threats caused by light pollution could facilitate risk assessment and better regulation of artificial lighting to create a healthy lighting environment [6]. Degen Tobias, Kollath Zoltan, Degen Jacqueline suggests incorporating the concept of ecological light pollution into air Spaces as an important habitat to provide valuable insights into the mechanisms of artificial light response at night [7]. A great deal of research has been done on the prevention and control measures of light pollution. Jin Shuai explored the prevention and control methods of urban light pollution by using green energy-saving buildings mainly from the aspect of building structure distribution. [8] Fu Sha, Wei Xinyu et al. put forward suggestions on the legislative prevention and control of light pollution by comparing the international legislation on light pollution with the domestic status quo. [9] Shith Syabiha; Ramli nor Azam et al. found that artificial light had certain damage to the ozone layer [10].

To sum up, most of the studies on the harm of light pollution and related intervention strategies only focus on the direct impact but fail to consider the deep impact (such as GDP, population, etc.) it can cause. This gives us a thinking direction for our research.

1.3. Our Work

Our work mainly includes the following contents.

To assess local levels of light pollution risk, we used a model that combines residents' health, economic, environmental and urban planning factors, called the HALOEN model. HALOEN is a state surrounded by light, reflecting the urgency of light pollution.

The model is applied to four different types of regions, and the calculated results are explained. Based on the relevant indicators of the HALOEN model, we present three possible intervention strategies and specific actions for each strategy, and analyze how these actions affect light pollution risk levels. Two sites in Rio de Janeiro and Wuhan were selected to analyze intervention strategies, and the optimal strategies for each region were obtained through planning. Finally, it explains how these strategies affect risk levels in the region.

2. Assumptions and Justifications

Based on the analysis of the problem and the comprehensive consideration of model building, we put forward the following reasonable assumptions.

Assumption 1: There was no severe economic crisis or environmental disaster such as earthquake, flood, or nuclear leakage during the study period

Justification 1: When assessing the risk level of light pollution, the data measured should be normally generated and should exclude the influence of small probability events in life; The law of large numbers states that these extreme cases cannot occur, and this assumption is reasonable to avoid unnecessary modeling headaches.

Assumption 2: It does not take into account the existence of migration or large-scale population movements in the study area, and the large fluctuations of policies.

Justification 2: There are many factors affecting the risk level of light pollution, which cannot be taken into account. Considering only the core influencing factors of this problem and ignoring the

secondary factors, the model can be constructed more reasonably and facilitate the analysis and evaluation results.

Assumption 3: Assume that the individual artificial light sources people use do not vary significantly in energy consumption.

Justification 3: Actual individual artificial light sources have certain differences in energy consumption. We assume that their differences are controlled within a certain range so that internal differences will not greatly affect the overall energy consumption, thus simplifying our model.

3. Notations

Important notations used in this paper are listed in Table 1.

Table 1. Important notations

Symbol	Description
HR	Health status of residents
EEC	Economic energy consumption
OI	Optical index
NE	Natural environment
UP	Urban planning
SQM	Sky Quality Metert
ω	Weight vector
μ	Cost factor
α	Preference coefficient
β	Cost ratio factor
X_i	Implement the i- th strategy

4. Analysis of risk levels in four regions

To evaluate the level of local light pollution risk, the HALOEN model uses PCA to identify 14 factors affecting the risk of light pollution, grouped into five categories. then applied the AHP and entropy weight method to assign each factor's weight and use TOPSIS to get evaluation result.

Based on the HALOEN model, we evaluated the light pollution risk levels in four different types of sites: protected lands, rural communities, suburban communities, and urban communities. For the selection of regions, the evaluation of national units is too vague, so we focus on cities. Shennongjia Forest area is one of the largest protected areas in China; Jingzhou has been an important grain producing area in South China since ancient times. Xiangyang is the second largest city in Hubei Province with a high degree of urbanization. Wuhan is the largest city in central China. In addition, according to the population density of the four cities, we regard Shennongjia forest area as a protected area, Jingzhou as a rural community, Xiangyang as a suburban community, and Wuhan as an urban community. At the same time, in order to ensure the accuracy of the data, we extracted five groups of regions from four types of cities and calculated the evaluation results through the evaluation system, as shown in the Figure 1:

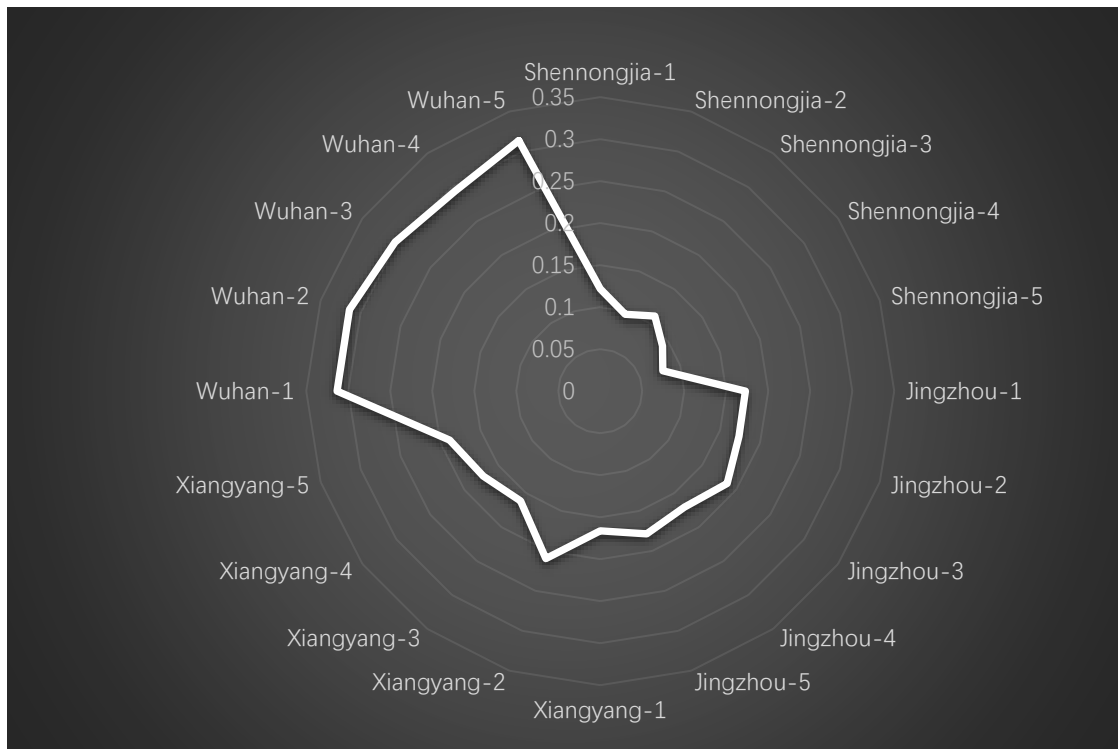


Figure 1. Four kinds of community evaluation results

In general, the light pollution risk level in Protected Land < Rural Community< Suburban Community< Urban Community. This is consistent with the common sense of life.

At the same time, according to the data of each group and the established indicators, it can be found that there are strong differences in the average life expectancy, per capita green area and forest coverage of Protected Land. However, the Urban Community has strong differences in per capita electricity consumption, per capita GDP, the number of suspended particles in the atmosphere and the built-up area of roads.

It can be concluded that the low risk level of Protected Land is mainly due to its high ecological environment quality and healthy living conditions of residents. The main reason why Urban Community has a higher risk level is that it is significant in urbanization and energy use. In contrast, Rural Community and Suburban Community are in the middle. The former is more concerned with ecological environment quality, while the latter is more concerned with urbanization level.

5. The Presentation of Intervention Strategies

From the perspective of government officials, group organizations, or individuals, there are various intervention strategies that can be used to address light pollution. The following are three specific intervention strategies and their potential impacts:

5.1. Reduce lighting measures at night

This strategy focuses on promoting the use of lighting measures that minimize light pollution while still providing adequate lighting. For example, Japan has made provisions on the proportion of the upper light in the total light pass of the lamps according to the different nature of the area and the level of lighting. Specific actions we can take are:

Controlling lighting time by limiting the time when lights are turned off. Although some lighting may need to be retained after lights are turned off due to social production and life needs, in most cases, turning off lights is a sign and boundary of human activity changes. Therefore, unnecessary lighting can be forcibly turned off after lights are turned off to protect the normal rest and activity of humans and various organisms.

Potential impacts of this measure may include:

- Reducing the negative impact on human health, such as disruptions to circadian rhythms and sleep patterns.
- Lowering energy consumption and costs associated with lighting.
- Potentially increasing the danger at night and promoting certain criminal behavior.

5.2. Strengthen publicity and education on light pollution and establish clear legislative standards

This strategy helps to enhance public awareness of light pollution and increase people's awareness of preventing and controlling light pollution; establishing clear standards for controlling light pollution makes the prevention and control of light pollution legally enforceable and more effective. Specific actions that can be taken include:

Promoting light pollution-related knowledge to the public through various means such as lectures, online courses, and fun activities.

Potential impacts may include:

- Improve citizen consciousness of prevention and treatment of light pollution, prevent light pollution on the habits.
- Establishing legal standards to deepen the public's understanding of the harm caused by light pollution.
- Light pollution publicity and rewards and punishments may consume costs and require government funding support.

5.3. Improve city planning

This strategy mainly focuses on reasonable planning of urban construction aspects such as road area, streetlight quantity, and green space area, to reduce the negative impact of light pollution while ensuring normal life. Specific measures include:

Increasing green space and improving the vegetation coverage of the area; vegetation can resist the impact of light pollution to some extent, and increasing green space is beneficial for reducing the impact of light pollution.

Reasonably planning the spacing and quantity of streetlights; the spatial distribution of light sources in specific locations may also be a factor causing light pollution. Improper streetlight settings can cause light pollution and also reduce lighting efficiency, resulting in energy waste.

Reasonably planning road area and limiting the number of vehicles or the time when vehicles are allowed to drive; the light pollution caused by vehicles should not be underestimated, and limiting the number of vehicles can contribute to reducing light pollution.

Potential impacts may include:

- Increasing lighting efficiency and reducing energy consumption.
- Traffic may be affected.

6. The selection of the optimal strategy

Based on the differences of various indicators in the forest areas of Rio de Janeiro, Wuhan and Shennongjia, the main characteristics of light pollution in Rio de Janeiro and Wuhan are analyzed, and the results are shown in the Figure 2 below.

Indicators 1-14 in the figure respectively represent natural growth rate, average life expectancy, per capita electricity consumption, per capita GDP, urbanization rate, gray value of light, sky quality index, number of suspended particles, per capita green area, forest coverage rate, ecological environment index, number of motor vehicles owned by 1,000 people, number of street lamps in built-up areas and highway density. According to the analysis of the calculation results, Rio de Janeiro mainly comes from environmental degradation, while Wuhan mainly comes from urbanization needs.

Based on this, we will select the most effective interventions for the two cities based on the established indicator system.

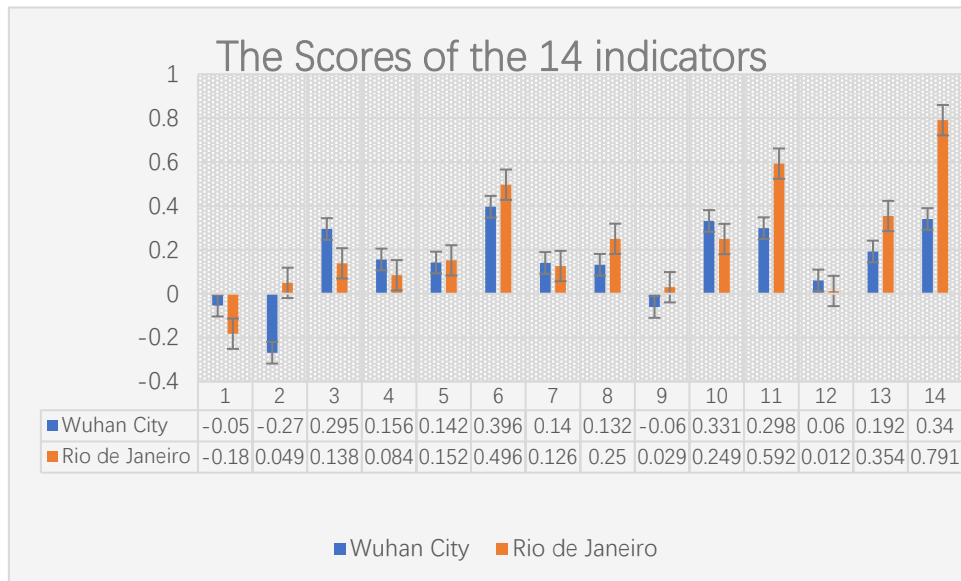


Figure 2. Index comparison chart

The following will construct the objective function and constraints.

$$\text{Income} = \sum \omega x (\omega \text{ represents the weight coefficient of each indicator}) \tag{1}$$

$$\text{Cost} = \sum \mu x (\mu \text{ represents the cost coefficient of each indicator}) \tag{2}$$

$$\text{Goal} = \text{Income} - \text{Cost} \tag{3}$$

Demand plan is the most effective, that is, to consider $\max(\text{Goal})$, at the same time, also need to assume the government experience is limited, can't simultaneously all the intervention measures.

$$\max \text{Goal} = \max(\text{Income} - \text{Cost}) \tag{4}$$

$$\left\{ \begin{array}{l} \sum \omega = 1 \\ \omega, \mu \geq 0 \\ x = 0,1 (0 \text{ means do not select, } 1 \text{ means select}) \\ \max(\text{Cost}) = a * \text{GDP} (a \text{ is a constant}) \end{array} \right. \tag{5}$$

Due to the fact that the light pollution problem in Rio de Janeiro is mainly an environmental issue, the measures taken should mainly focus on how to protect the environment and ecosystem. This indicator system involves improving green areas and the ecological environment index. According to the above model, the most effective intervention strategy for Rio de Janeiro is to simultaneously increase the per capita green area and forest coverage. This can improve the environmental benefits by about 8% within a limited cost.

Mechanism of Action: Increasing green coverage and forest coverage can improve air quality, promote biodiversity, and restore the self-healing ability of the local natural environment, thus further resisting the risks brought by light pollution.

Due to the light pollution problem in Wuhan City mainly caused by urbanization, the intervention measures mainly focus on how to reduce the degree of light pollution risk by slowing down the urbanization process. The indicators involved in this index system include moderately reducing the urbanization rate and limiting the per capita electricity consumption. According to the above model,

the most effective intervention strategy for Wuhan City is to simultaneously moderately reduce the urbanization rate and limit the per capita electricity consumption. This can improve approximately 10% of environmental benefits within a limited cost.

Mechanism of Action: By moderately reducing the urbanization rate and limiting the per capita electricity consumption, the population density in the area can be reduced, thereby reducing the per capita energy demand and light usage, and ultimately reducing the risk of light pollution at the source.

7. Conclusion

To assess the level of light pollution risk in a place, we used the HALOEN model to analyze the local light pollution situation, taking into account the health level of the local population, economic energy consumption, light pollution index, natural environment and urban planning. According to the population density and actual situation, a total of 20 sites in Shennongjia Forest area, Jingzhou City, Xiangyang City and Wuhan City were selected as samples to analyze the evaluation results. The results show that the risk level is protected land < rural community < suburban community < urban community, and the natural environment and urbanization level are the main factors leading to this result. Second, we designed specific interventions to address the problem of light pollution. Our team proposed specific actions in terms of lighting facilities, humanities education and urban planning, and explained the potential impact of these actions on light pollution. Then, based on the main factors of light pollution in different regions, the light pollution in Wuhan and Rio de Janeiro was studied, and the planning problem was established with intervention strategy, cost and net utility as the planning factors. The best intervention strategies for Wuhan include moderately reducing urbanization rates, limiting per capita electricity consumption and reducing the risk of light pollution by 10 percent. The best intervention strategy in Rio de Janeiro was to increase green and forest cover, thereby reducing the risk of light pollution by 8%.

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