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Study on Regional Light Pollution Risk Classification Based on Game Combination—Rank Sum Ratio Method

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Abstract

With the continuous development of society, light pollution has become a hot issue in the field of regional governance and sustainable development. It is of high research value to make accurate and based classification of light pollution risk levels in a region. In this paper, 31 provinces and regions in China were selected as research samples, combined with social development, population, and other five levels, and multi-stage indicators were used to construct a light pollution risk level evaluation index system. The subjective and objective weights of each index were determined by the analytic hierarchy process (AHP) and entropy weight method, and the combined weights were determined by minimizing the deviation between the basic weights based on game theory. The results showed that the top three weights were regional per capita GDP, urban population density, and per capita consumption expenditure of all residents respectively. On this basis, a rank-sum ratio comprehensive evaluation model was established. The light pollution risk levels of 31 research samples were divided into four levels, including 3 high-risk areas, 13 medium-high-risk areas, 13 medium-risk areas, and 2 low-risk areas.

Keywords

Entropy-hierarchical analysis, Principles of game theory, Rank-sum ratio comprehensive evaluation method, Light pollution risk level

1. Introduction

In recent years, environmental and social problems caused by light pollution have become more and more serious. Light pollution was first proposed by the international astronomical community in the 1930s, and astronomers feel that the bright light of cities has a great impact on astronomical observations [1-3]. Light pollution is a new source of environmental pollution, mainly including white and bright pollution, artificial day pollution, and lighting pollution, at the same time, the phenomenon of light pollution is called light intrusion, excessive lighting, and stray light. Today, light pollution refers more to any excessive or poor use of artificial light, simply a type of light that has a negative impact on humans and the natural environment. Secondly, the impact of light pollution is difficult to ignore, it not only changes the starry sky vision, and affects human health, but also has a negative impact on wildlife and the ecological environment.

Scholars have also conducted relevant studies on the impact of light pollution. Khanduri, et al. [4] studied the presence of light pollution in and near protected areas from 2012 to 2020, which seriously affected the activities of riparian animal groups. Czaja, et al. [5] studied how light pollution affected the spring development of urban trees and shrubs, and found that light pollution would affect the spring phenology and physiology of deciduous tree species. For example, light pollution can reduce the content of soluble sugar in the apices of populus chinensis, grey tree flower, Paulownia japonica, and A. Campestri. Su [6] studied the nighttime light pollution environment in residential areas, which mainly included glare pollution, encroaching light pollution, and overflow astigmatism pollution. The goal of his research is to realize the quantitative evaluation of light pollution environment, and finally form a set of relatively perfect residential modes of quantitative evaluation of residential light pollution. Jiang [7] studied the use of the entropy weight method and the TOPSIS method to establish a light pollution risk assessment model. The selected indicators include the level of economic and social development, the level of ecological environment, and the level of biodiversity, and proposed intervention strategies to reduce the risk of light pollution in the region. They were combined with the background of the 2023 American Mathematical Contest in Modeling (Our team won the F award in this American Mathematical Contest in Modeling, that is, nominated for the Grand prize). Data source: https://www.comap.com/contests/mcm-icm), from the local development level, population, biodiversity, climate, and geographical factors, such as selection of indicators to build a mathematical model to determine areas of light pollution risk grade level.

2. Evaluation index system of light pollution risk level

2.1 Build an indicator system

As China is the largest developing country in the world, there is relatively uneven development among provinces in mainland China, so it is of high research value to classify the light pollution risk levels of provinces in mainland China and establish a comprehensive evaluation model of light pollution.

The effects of light pollution may depend on: (1) The level of local development: the higher the level of development of a region, it often represents a higher degree of urbanization in the region, urbanization will lead to more population and economic activities, and places with higher levels of development usually have more commercial, industrial and recreational facilities, thus increasing artificial lighting and night activities, resulting in more serious light pollution. (2) Local population: With the growth of population, the regional population density will also increase. The demand for artificial lighting in cities has increased. At the same time, densely populated areas usually have more buildings and roads, and these buildings and street lights produce a lot of light at night, further increasing light pollution. (3) Local biodiversity: light pollution can disrupt the ecology of plants, disrupting their normal behavior and physiological functions; Hindering the reproduction and migration of animals; Disrupting the internal biological clock of organisms has a significant impact on the life cycle of organisms, physiological processes, and ecological interactions. (4) Local geography: Local geographical location can have an impact on the degree of light pollution. Some geographic locations are located in nature reserves, and dark sky reserves, and may experience less light pollution. (5) Local climate: local rainfall can wash particles in the atmosphere and reduce the scattering and propagation of light pollution; more rainfall can remove particles in the atmosphere and reduce their contribution to light pollution; less rainfall may lead to the accumulation of particles and increase light pollution; Certain weather conditions may affect the observation and perception of light pollution.

Considering the endogenous correlation between light pollution and its influencing factors, this paper selected 31 provinces and regions in mainland China from the National Bureau of Statistics of China (http://www.stats.gov.cn/) as research samples and constructed the evaluation index system of light pollution risk level as shown in Table 1.

Table 1. Evaluation index system of light pollution risk level

Target layer A	first-level indicator B	Second-level indicator C	Unit
Light pollution risk level (A)	Level of Development (B1)	Consumer Price Index (C1)	/
		Gross regional Product per capita (C2)	Hundred million yuan
		Per capita consumption expenditure (C3)	Yuan
	Population (B2)	Birth rate (C4)	‰
		Population density (C5)	People per square kilometer
	Biodiversity (B3)	Forest coverage (C6)	%
		Total Agricultural Output Value Index (C7)	/
	Geography (B4)	Harmless disposal rate of domestic waste (C8)	%
		Water resources per capita (C9)	Cubic meter per person
	Climate (B5)	SO2 emissions per unit area (C10)	Tons per square kilometer
		Nitrogen oxide emissions per unit area (C11)	Tons per square kilometer

2.2 Determining Indicator weights

(1) The analytic Hierarchy Process (AHP) was used to determine the subjective weights of indicators. This is a common method for quantitative processing of qualitative problems under complex structure and multi-criteria decision-making proposed by Saaty, an American operations research scientist [8]. In this paper, the judgment matrix of first-level index B to target layer A is constructed as follows:

$$\begin{pmatrix} 1 & 4 & 7 & 7 & 7 \\ 1/4 & 1 & 5 & 5 & 4 \\ 1/7 & 1/5 & 1 & 1 & 1/3 \\ 1/7 & 1/4 & 3 & 3 & 1 \\ 1/7 & 1/3 & 2 & 2 & 1/2 \end{pmatrix}$$

Similarly, the index layer C is constructed against the criterion layer Bi (i=1,2... 5) The judgment matrix.

According to the process of AHP, Pyhton is used to solve the maximum eigenvalue of the paired comparison matrix, and $\lambda max=5.249$, the normalized eigenvector WB= (0.55947, 0.22670, 0.09692, 0.04527, 0.0.04527) T is obtained. Where CI=0.0621, RI=1.11, CR=0.056 < 0.1, the matrix meets the consistency requirements. Similarly, through calculation, WB1-WB5 meets the consistency requirements. Finally, we use SPSSPRO subjective weights w1 = (0.048, 0.36, 0.152, 0.038, 0.191, 0.033, 0.011, 0.032, 0.064, 0.018, 0.053) T.

(2) The entropy weight method is used to determine the objective weight of indicators. This is an objective weighting method based on the principle that the smaller the degree of variation of the index, the less information it reflects and the lower the corresponding weight. Steps for processing, according to the entropy weight method used to solve the get: objective weight w2 = (0.06, 0.123, 0.123, 0.032, 0.239, 0.013, 0.012, 0.068, 0.034, 0.081, 0.215) T.

(3) The combination weight is determined by game theory. In order to improve the reliability of index weighting, the analytic hierarchy process (AHP) and entropy weight method were selected to calculate subjective and objective weights respectively, and combined weights were calculated based on the principle of game theory [9] to minimize the deviation between combined weights and subjective and objective weights. Using Python calculation to solve the resulting combination weights can be obtained w = (0.051, 0.295, 0.144, 0.036, 0.204, 0.027, 0.011, 0.042, 0.056, 0.035, 0.098) T.

Based on the weight results of the above indicators, the top three indicators affecting the light pollution degree of a region are the regional per capita GDP, urban population density, and the per capita consumption expenditure of all residents. Therefore, the above three aspects should be considered when the degree of light pollution in the region needs to be controlled.

3. Classification of regional light pollution risk levels

The rank-sum ratio method [10] is an effective multi-index evaluation method. There are evaluation objects and B evaluation indicators in a matrix. Dimensionless statistics (RSR) are obtained through rank transformation, and the advantages and disadvantages of evaluation objects are ranked according to the RSR value. The higher the RSR value of the evaluation object, the better the performance. The rank sum ratio comprehensive evaluation method is used to classify the light pollution risk level. The non-integral rank method is used to compile the rank, which overcomes the shortage that the integral rank method is easy to loses the quantitative information of the original index, and is a quantitative linear correspondence between the rank order and the original index value.

(1) Establish a linear regression model: With RSR as the dependent variable and Probit as the independent variable, SPSSPRO was used to conduct linear regression analysis on RSR and Probit, and the fitting degree of the regression equation R2=0.922>0.9. It can be seen that the independent variable Probit and the dependent variable RSR in the proposed equation had a very high linear correlation.

(2) F-test was performed on the regression equation: P=0 was obtained, the linear regression equation had significant statistical significance, and VIF was all less than 10, indicating that the model had no multicollinearity.

(3) RSR grading comparison table: We divided the sample into 4 levels, 1-4 respectively representing the light pollution risk degree of the sample area as low risk, medium risk, medium-high risk, and high risk. The specific results are as follows: Grade 4: Tianjin, Shanghai, Jiangsu Province; Grade 3: Beijing, Zhejiang Province, Ningxia Hui Autonomous Region, Shaanxi Province, Guangdong Province, Shandong Province, Anhui Province, Henan Province, Xinjiang Uygur Autonomous Region, Hebei Province, Liaoning Province, Shanxi Province, Inner Mongolia Autonomous Region; Grade 2: Fujian, Qinghai, Gansu, Yunnan, Sichuan, Heilongjiang, Hainan, Guangxi Zhuang Autonomous Region, Hunan, Hubei, Jilin, Jiangxi, Chongqing; Grade 1: Guizhou Province, Tibet Autonomous Region.

It can be seen from the classification results that: (1) There are 3 high-risk areas and 13 medium-high-risk areas. There are 13 medium-risk areas and two low-risk areas. (2) The light pollution risk levels of high, medium, and high risk indicate that the light pollution in the region is serious, and too high light pollution will cause the brightness of the sky to increase, making the starry sky observation blocked. At the same time, prolonged exposure to too much light may also have adverse effects on people's health and interfere with people's biological rhythms. The light pollution risk level is medium risk, indicating that there is a certain amount of light pollution in the region, but the degree is not high. A light pollution risk rating of low risk indicates that there is no light pollution in the area, but the lack of adequate lighting may affect traffic road safety.

4. Summary and future outlooks

With the continuous development of society and the rapid development of urbanization and industrialization, light pollution has become one of the important issues in regional governance. Selecting appropriate indicators and establishing a scientific evaluation system to grade the degree of regional light pollution risk can improve people's and local relevant departments' understanding of the degree of regional light pollution. Therefore, better management, detection, and control of light pollution and mitigation of the impact of light pollution on local residents and the ecological environment are of great significance to regional governance and sustainable development. In future research, our team will focus on collecting more relevant data on cities and regions, and classify the degree of light pollution in more regions through the light pollution risk assessment model established, hoping to provide relevant help for local governments and relevant departments in understanding and managing light pollution. At the same time, the team will continue to improve the light pollution risk level assessment model in the collected data.

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