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Light Pollution Risk Assessment Indicator System and Regional Analysis

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Abstract: This paper presents a light pollution risk assessment indicator system based on the four principles of index system construction. The system consists of eight categories of primary indicators and 15 secondary indicators, established through three rounds of Delphi screening and correlation analysis. Using the Topsis entropy weighting method, the paper scores the indicators and finds that urban communities have the highest score and the most serious light pollution, while protected areas have the lowest score and the least light pollution. By using one-way ANOVA to analyze the influence of secondary indicators on light pollution in each region, the paper concludes that there is a significant difference between the different area types in the composite score index, with protected land sites being the least contaminated by risk and urban communities being the most contaminated.

Keywords: Expert analysis, Entropy method Topsis, Light pollution.

1. Introduction

Most countries are still plagued by light pollution, which negatively impacts both daily life and productivity. Urgent action is needed to address this issue, including the development of a comprehensive light pollution risk index system to accurately predict levels and devise effective intervention strategies.

In order to address the issue of light pollution, several steps can be taken. First, a metric needs to be developed to evaluate the level of light pollution at a site, and a model can be created to facilitate this process. This metric can then be applied in various locations to assess the extent of light pollution present and interpret the results. Next, three potential strategies can be identified to mitigate light pollution, and these strategies can be implemented to analyze their impact on the issue. Two specific sites can then be selected to determine the most effective intervention strategy to reduce risk. Finally, a one-page flyer can be created to promote one of these sites and its chosen intervention strategy. Through these steps, progress can be made in addressing the issue of light pollution and its potential impact on the environment.

2. Model Establishment and Solutions

2.1. Establishment of light pollution risk assessment index system

2.1.1. Delphi method

The final indicators are determined through three rounds of consultation using the Delphi method at. The feedback from each round of consultation will be summarized and analyzed to form the next round of consultation form and then further evaluated and supplemented by the risk assessment experts.

Experts gave their opinions on the first round of screening results. They believed that the overall proportion of lighting does not accurately represent the situation of light pollution due to distribution problems. The low evaluation of the standard coordination of environmental brightness is because the indicator refers more to the relationship between screen brightness and ambient light, which is more relevant to household appliances. Test results showed that light interference with the light source and strong reflective surface are common causes of low recognition, mainly in urban glare or natural sunlight on reflective surfaces such as glass. The concentration of light pollution is higher on the earth's continental plate than on the ocean plate. The indicators related to light color and up-lighting ratio control are subjective and do not represent the relevant situation of light pollution.

In the second round of screening, poorly presented indicators and those rated below three by experts were removed, and the remaining indicators were rated again in the third round. The expert opinions converged, and all indicators were retained in the final system. After three rounds of consultation, the light pollution risk assessment index system was finalized through continuous revision and improvement. The results are shown in the table below.

2.1.2. Model Solving

After three rounds of consultation, the light pollution risk assessment index system was finalizedthrough continuous revision and improvement.

The target level is the overall goal to be achieved by each country's light pollution risk assessment, in order to measure the light pollution risk level more accurately, and the result can provide the basis for future government policy making or social governance.

Table 1. Results of the third round of expert consultation

Secondary index	5	4	3	2	1	Mean
Brightness partition	5	3	2	0	0	4.3
Light color partition	3	3	3	0	1	3.7
The relationship between regions	4	2	2	2	0	3.8
Light out time	4	1	3	1	1	3.6
Ecological reserve definition and species distribution	4	3	0	2	1	3.7
Definition of light off time in natural environment	2	4	3	1	0	3.7
Lighting installation location and environmental characteristics	5	1	1	1	2	3.6
Light color and ambient brightness limits	2	6	1	0	1	3.8
Community or national observatory location identification	1	6	2	1	0	3.7
Sky luminance distribution	4	1	4	0	1	3.7
Location and visibility of signs	1	6	2	1	0	3.7
Evaluation of traffic glare	3	2	4	0	1	3.6
Evaluation of urban glare	3	2	3	2	0	3.6
Control time	5	3	0	1	1	4
Control distribution	5	2	3	0	0	4.2

Table 2. Light pollution risk assessment index system

First-order index	Secondary index
Spatial level	Brightness partition Light color partition The relationship between regions
Time level	Light out time
Natural environment	Ecological reserve definition and species distribution Definition of light off time in natural environment
Dwelling district	Lighting installation location and environmental characteristics Light color and ambient brightness limits
Astro observation	Community or national observatory location identification Sky luminance distribution
Transportation	Location and visibility of signs Evaluation of traffic glare
Urban space	Evaluation of urban glare
Technical control	Control time Control distribution

Level 1 risk assessment indicator layer: is to assess the overall level of light pollution risk and change trends selected for a number of basic categories including space, time, natural environment, residential areas. astronomical observations. transportation, urban level, technical control of the eight major risk categories.

The secondary risk assessment indicator layer is an extension of the overall target indicators, and will refine the primary indicators. The assessment system under the "Existing" status has 15specific secondary indicators.

2.1.3. Analysis and Evaluation of results

Description of secondary indicators

Secondary indicators show that changes in space, time, natural environment, lighting installation, astronomical observations, traffic, urban glare rating, and technical control all impact light pollution. Cities are quantifying brightness and light color to judge the degree of light pollution and using zoning rules for environmental planning. Ecological reserves and species distribution influence light pollution, with areas having higher species richness having less human activity and light pollution. Lower urban glare ratings correlate with higher light pollution levels in the city. Technical control involves controlling time and distribution.

Spearman's correlation coefficient analysis

The Spearman correlation coefficient was defined as the Pearson correlation coefficient between the rank variables. For a sample of sample size n, n raw data were converted to rank data with correlation coefficient ρ

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \quad (1)$$

The raw data were assigned a corresponding rank based on their average descending position inthe overall data This is shown in the following table.

Table 3. Data Level Table

Xi	**Descending position**	**Rank xi**
0.8	5	5
1.2	4	4
1.2	3	3
2.3	2	2
18	1	1

In practice, the link between the variables is irrelevant, so one can calculate ρ. The difference

between the ranks of the two variables being observed in a simple step, then ρ is

$$\rho=1-\frac{6\sum d_i^2}{n(n^2-1)} \quad (2)$$

2.2. Comprehensive Evaluation

In this paper, in order to better divide the data into definite categories of variables and eliminate the influence brought by different scales, so that evaluation indicators of different scales can be introduced at the same time for comprehensive evaluation, so that area type 2 is added to area type 1, and area types are grouped into four categories according to the title, so that the specified indicators can be better analyzed for these four areas, so that the original data information can be fully utilized to quantitatively reflect different evaluation object's degree of strength and weakness.

2.2.1. Entropy Topsis Method

This paper uses the TOPSIS method with the entropy weight method to accurately compare evaluation schemes based on selected indicators of light pollution in four different places.

(1) Calculate the weights.

(2) Assume that there are n objects to be evaluated, and m give a forwarding matrix composed of indicators as follows.

(3) Define minimum value and maximum value.

(4) The degree of proximity of each evaluation object to the optimal and inferior solutions can be calculated.

(5) The i-th (i=1, 2, ... , n) unnormalized scores of the evaluation subjects.

$$z_{ij}=x_{ij} \Big/ \sqrt{\sum_{i=1}^{n} x_{ij}^2} \quad (3)$$

$$X=\begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{mn} \end{bmatrix} \quad (4)$$

$$Z^+=(Z_1^+\ ZZ_2^+,\ Z_3^+)=(\max\{Z_{11},\ Z_{21},\ldots,Z_{n1}\},\ \max\{Z_{12},\ Z_{22},\ldots,Z_{n2}\},\ldots\},\ \max\{Z_{1m},\ Z_{2m},\ldots,Z_{nm}\}) \quad (5)$$

$$Z^-=(Z_1^-\ ZZ_2^-,\ Z_3^-)=(\min\{Z_{11},\ Z_{21},\ldots,Z_{n1}\},\ \min\{Z_{12},\ Z_{22},\ldots,Z_{n2}\},\ldots\},\ \min\{Z_{1m},\ Z_{2m},\ldots,Z_{nm}\}) \quad (6)$$

$$D_i^+=\sqrt{\sum_{j=1}^{m} w_j(Z_j^+-Z_{ij})^2} \qquad D_i^-=\sqrt{\sum_{j=1}^{m} w_j(Z_j^--Z_{ij})^2} \quad (7)$$

$$S_i=\frac{D_i^-}{D_i^-+D_i^+} \quad (8)$$

This results in a composite light pollution score indicator, and the data is sorted to obtain a partial data plot as follows.

Regional type	Synthesis Sc	Regional type	Synthesis S	Regional type	Synthesis S	Regional type	Synthesis Sc
Protected land	0.879517565	Rural communi	0.695188337	Suburban comm	0.48441056	city communit	0.173676935
Protected land	0.825102105	Rural communi	0.70208532	Suburban comm	0.472122857	city communit	0.163917119
Protected land	0.844230633	Rural communi	0.720965732	Suburban comm	0.486622944	city communit	0.193744646
Protected land	0.85282894	Rural communi	0.704487235	Suburban comm	0.512754249	city communit	0.152632526
Protected land	0.839059541	Rural communi	0.724389821	Suburban comm	0.486207155	city communit	0.159136541
Protected land	0.822431441	Rural communi	0.712969024	Suburban comm	0.477952876	city communit	0.177998405
Protected land	0.873065628	Rural communi	0.695826529	Suburban comm	0.480768417	city communit	0.146833056
Protected land	0.826805782	Rural communi	0.702709373	Suburban comm	0.50811105	city communit	0.172965286
Protected land	0.830769599	Rural communi	0.694548642	Suburban comm	0.507262441	city communit	0.178326185
Protected land	0.833478226	Rural communi	0.697206478	Suburban comm	0.499412783	city communit	0.152527597
Protected land	0.84924593	Rural communi	0.722554253	Suburban comm	0.499002656	city communit	0.175545678
Protected land	0.84818714	Rural communi	0.669675805	Suburban comm	0.516364615	city communit	0.188746295
Protected land	0.844026029	Rural communi	0.685480357	Suburban comm	0.497216121	city communit	0.179877069
Protected land	0.818368017	Rural communi	0.698883962	Suburban comm	0.531161682	city communit	0.17628922
Protected land	0.849748252	Rural communi	0.66963344	Suburban comm	0.513796879	city communit	0.160569192
Protected land	0.843262451	Rural communi	0.675380841	Suburban comm	0.494934303	city communit	0.16045233
Protected land	0.838036338	Rural communi	0.696932956	Suburban comm	0.488379168	city communit	0.163323981
Protected land	0.832252795	Rural communi	0.68836112	Suburban comm	0.498650109	city communit	0.18551223
Protected land	0.836027903	Rural communi	0.697622792	Suburban comm	0.474395738	city communit	0.178144675
Protected land	0.863252065	Rural communi	0.694310201	Suburban comm	0.506020232	city communit	0.163064237
Protected land	0.847162635	Rural communi	0.703562522	Suburban comm	0.528454454	city communit	0.183402971
Protected land	0.833403643	Rural communi	0.695491143	Suburban comm	0.476474572	city communit	0.174811119
Protected land	0.859132322	Rural communi	0.700458579	Suburban comm	0.494044978	city communit	0.190440646
Protected land	0.841583627	Rural communi	0.687280223	Suburban comm	0.500392958	city communit	0.145103733
Protected land	0.800991242	Rural communi	0.696854629	Suburban comm	0.50216117	city communit	0.187172914

Figure 1. Data ranking of the score indicators combining light pollution

From the graph we can learn that: from the above graph we can see that urban communities have the highest scores and the most light pollution; protected areas have the lowest scores and the least light pollution.

2.3. Analysis and Evaluation of results

2.3.1. One-way ANOVA

Since the question requires an analysis to illustrate the impact of four different regions on the indicators selected in this paper, the combined scores of the different regions are derived after using the TOPSIS entropy weighting method to be able to compare the impact of light pollution in each different region. One-factor ANOVA is not limited by the number of comparison groups, the role of the elements with more averages in the comparison group, the interaction between the elements that can be analyzed, the conditions of application of ANOVA, and independence, then the one-factor ANOVA can be used to determine the verification of the interaction of each of each region.

2.3.2. Grouping and normality test

The quantitative variables (Y) are grouped according to the fixed class variables (X) and their normality tests are examined separately to see if the overall distribution of the data shows a normal distribution, and if the test fails, further analysis is required. The grouping variable here is "area type 2" and the variable Y is "composite score index".

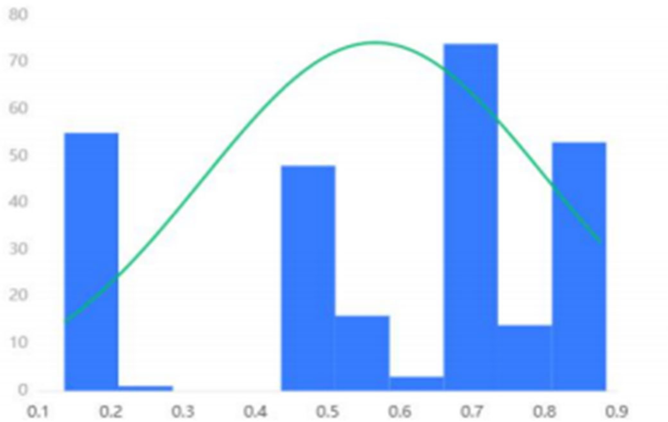

Figure 2. Results of the normality test of the data of the composite score index of quantitative variables

The normal graph basically shows a bell shape (high in the middle and low at the ends), indicating that the data, although not absolutely normal, are basically acceptable as a normal distribution.

2.3.3. Grouping and normality test

Here, the grouping variable is "area type 2" and the variable Y is "composite score index", and the chi-square test is performed.

Table 4. Results of chi-square test

	Regional type 2 (standard deviation)					
	Protected land location (n=57)	Rural Community (n=67)	Suburban Community (n=64)	urban community (n=76)	F	P
Composite score index	0.016	0.052	0.093	0.147	79.828	0.000***

Note: ***, ** and * represent the significance level of 1%, 5% and 10% respectively

According to the graph it can be seen that: $p < 0.05$ so the analysis term is significant, rejecting the original hypothesis both the hypothesis is not valid, indicating that the data present significance at the level of the original hypothesis is rejected, therefore the data do not meet the variance chi-square. However, the one-way ANOVA presents significance, and the variance can also be quantified with the help of quantitative analysis of effects.

2.3.4. One-way ANOVA comparison

The variability was quantified with the help of quantitative analysis of effects. One-way ANOVA comparison plots were obtained.

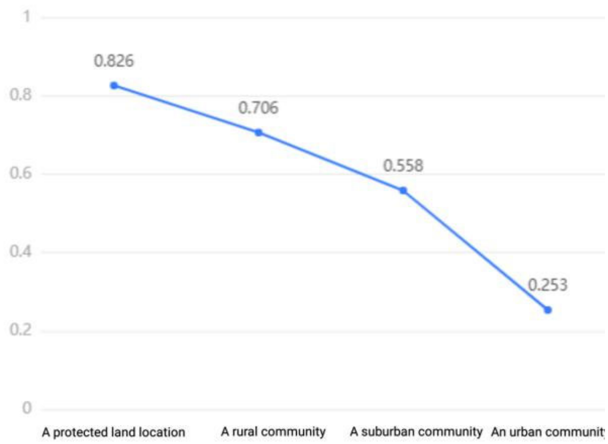

Figure 3. One-way ANOVA comparison chart

As can be seen from the figure, the mean value of the four regions is decreasing level, so the overall mean value is not equal, then the variance between the groups will be greater than the variance within the group, which shows that the variability of light pollution in the four regions is obvious.

Table 5. Table of ANOVA results

variable name	variable value	Sample size	Average value	Standard deviation	F	P
Composite score index	Protected land location	57	0.826	0.016	466.981	0.000***
	Rural community	67	0.706	0.052		
	Suburban community	64	0.558	0.093		
	urban community	76	0.253	0.147		
	summury	264	0.566	0.239		

Note: ***, ** and * represent the significance level of 1%, 5% and 10% respectively

The mean values of conservation land location and rural versus suburban versus urban communities on the composite score index were 0.826*/0.706*/0.558*/0.253*, respectively; the ANOVA resulted in a p-value of 0.000***≤0.05, thus the statistical results were significant, indicating that there were significant differences in the composite score index between the different area types.

Table 6. Quantitative Analysis of Effectiveness Table

analysis item	difference between groups	Total deviation	Bias to Eta(Partial η^2)	Cohen's f number
Composite score index	12.647	14.994	0.843	2.321

The Above table shows the results of the quantitative analysis of effects, including between- group differences, total differences, partial Eta square η^2, and Cohen's f-values, used to analyze the differences between the data.

The results of the quantitative analysis of effects showed that the Eta square (η value) was 0.843 based on the composite score index, indicating that 84.3% of the variation in the data was derived from differences between groups. the Cohen's f value was 2.321, indicating that the degree of variation in the quantification of effects of the data was large degree of variation.

3. Conclusions

In summary, this paper uses the four principles of index system construction to establish a light pollution risk assessment indicator system consisting of eight categories of primary indicators and 15 secondary indicators. The topsis entropy weighting method is used to score the indicators, and the results show that urban communities have the highest score and the most serious light pollution, while protected areas have the lowest score and the least light pollution. One-way ANOVA analysis is used to quantify the variability of the secondary indicators in each region, and the results indicate that there is a significant difference between different area types in the composite score index, and the protected land sites are the least contaminated by risk and the urban communities are the most contaminated. Acknowledgement.

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