Research on Light Pollution Evaluation System Based on PSR Model

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Abstract. In this paper, a light pollution evaluation model is developed based on the PSR model through hierarchical analysis and entropy weight method, and a widely applicable indicator system is developed to determine the light pollution risk level of a place. The indicator system takes into account various factors related to light pollution and can be widely applied to different types of areas in the world. In this paper, we compare it with the real light pollution index to verify the accuracy of the model and the stability of the system.

Keywords: PSR Model, Analytic Hierarchy Process, Entropy Weight Method, Light Pollution.

1. Introduction

Light pollution means that human activities may cause damage to the surrounding light environment, making the original light environment uncomfortable. This phenomenon mostly occurs at night in big cities, which is a new source of environmental pollution, including light trespass, over-illumination, light clutter and other phenomena [1-4]. This paper develops a widely applicable metric based on the PSR model to determine the risk level of light pollution risk in a place. The metric takes into account various factors related to light pollution and can be widely applied to different types of areas in the world.

2. PSR Model

2.1. PSR

PSR model is a set of assessment system models often used in environmental quality assessment discipline. This model uses the thinking logic of "pressure state response" to reflect the relationship between various influencing factors in a certain situation [5]. Among them, P is a pressure indicator used to reflect the role of human activities in the situation, S is a status indicator used to reflect the role of objective conditions in the situation, and R is a response indicator used to reflect how society can remedy the adverse effects that have occurred [6].

Here, we consider nighttime light intensity and human activities as pressure indicators, local disease incidence rate as status indicators, and the efficiency of local government remedial measures as response indicators. The model structure diagram is shown in Figure 1.

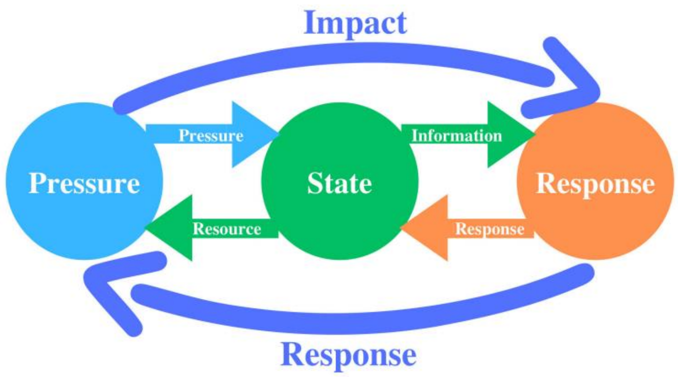

Figure 1. Schematic diagram of PSR model

2.2. Construction

(1) Identify indicators

After carefully analyzing the relevant information, we determine the indicators shown in the Table 1 below.

Table.1. Evaluation system

Target layer	Criterion layer	Indicator layer	Impact Trends
Regional light pollution light risk assessment	Pressure P	Night light intensity (I)	+
		Population density (S)	+
		Regional GDP (A)	+
	Status S	Average annual rainy day ratio r_1	+
		Disease incidence r_2	+
		Traffic accident increase rate r_3	+
		Crime rate r_4	+
		Species change ratio of rhythm r_5	+
	Response R	Effective rate of remedial measures r_6	-

(2) Range method pretreatment normalization

After formulating the evaluation system and collecting data, we decided to normalize these data by range pre-processing, eliminate the differences in measurement units, and convert the absolute value of the evaluation indicators into relative value. Then further calculation is carried out.

The evaluation indicators are divided into positive indicators and negative indicators. Symbol'+'means that for the indicator, bigger is better. Similarly, symbol '-' means smaller is better. For positive indicators, the calculation formula is as follows:

$$x_{ij} = 0.998\frac{x_{ij}-\min x_i}{\max x_i-\min x_i} + 0.002 \tag{1}$$

For the inverse indicators, the calculation formula is as follows:

$$x_{ij} = 0.998\frac{x_{ij}-\max x_i}{\min x_i-\max x_i} + 0.002 \tag{2}$$

(3) Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision analysis method that combines qualitative and quantitative methods to solve complex problems with multiple objectives [7]. This method combines quantitative analysis with qualitative analysis, and uses the experience of decision-makers to measure the relative importance of the criteria for whether the objectives can be achieved, and reasonably give the weight of each criterion for each decision-making scheme [8]. Use the weight to find out the good and bad order of each scheme, which can be effectively applied to those topics that are difficult to be solved by quantitative methods. The calculation formula is as follows:

$$\epsilon = \alpha_1 P + \alpha_2 S + \alpha_3 R \tag{3}$$

Including:

$$P = \sum_{i=1}^{n} W_{1i} P_i \tag{4}$$

$$S = \sum_{j=1}^{n} W_{2j} S_j \tag{5}$$

$$R = \sum_{k=1}^{n} W_{3k} R_k \tag{6}$$

Afterwards, we construct the score matrix and calculate the weight of each indicator.

(4) Entropy weight method

As we all know, AHP has some subjectivity due to the score matrices. Hence, we calculate the weights using Entropy Weight Method (EWM). The smaller the degree of variation (variance) of the indicator, the less information it reflects, the greater the entropy of information is, and the lower the corresponding weight is. The higher the information entropy of a random variable is, the higher the amount of information it brings. Correspondingly, the amount of information of other variables will be relatively low [9]. The data has been standardized previously, so it is directly normalized. The formula is as follows:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{7}$$

Then calculate the information entropy of each indicator, calculate the information utility value, and normalize to get each indicator, the formula is as follows:

$$e_j = -k \sum_{i=1}^{n} \left(P_{ij} \times \ln P_{ij}\right)(k = \frac{1}{\ln n}) \tag{8}$$

Next, calculate the weight

$$g_j = 1 - e_j \beta_j = \frac{g_j}{\sum_{j=1}^{r} g_j} \tag{9}$$

The above is the method and process of entropy weight method to calculate the weight of each indicator of the light pollution risk assessment system. The results will be counted in the following table together with the AHP mentioned above [10]. The weights are shown in the Table 2 below.

Table.2. Index weight of light pollution risk assessment system

Indicator layer	Weight symbol	EWM weight	AHP weight
Night light intensity I	w_1	0.167	0.275
Population density S	w_2	0.212	0.175
Regional GDP A	w_3	0.173	0.075
Average annual rainy day ratio r_1	w_4	0.023	0.15
Disease incidence rate r_2	w_5	0.095	0.1
Traffic accident increase rate r_3	w_6	0.110	0.025
Crime rate r_4	w_7	0.075	0.025
Species change ratio of rhythm r_5	w_8	0.080	0.075
Effective rate of remedial measures r_6	w_9	0.065	0.05

(5) Calculation of weights

To calculate the average weight coefficient of indicators, we obtained two groups of weights through the AHP and entropy weight method. For higher reliability, we averaged them. The formula is as follows:

$$W_j = \frac{w_{sm} + \beta_j}{2} \tag{10}$$

Where W_{sm} is the weight of the jth indicator obtained by AHP. The histogram of results obtained from the above process is shown in Figure 2.

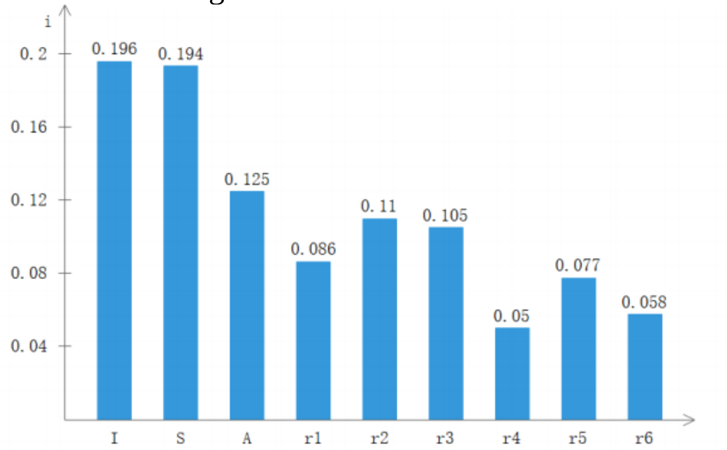

Figure 2. Average weight histogram

Calculate the light pollution risk level metric ε.

$$\varepsilon = \sum W_i x_i \tag{11}$$

Then, we developed light pollution measurement layers as in Table 3.

Table.3. Light pollution index layer

Indicator layer	Light pollution degree
0–0.200	excellent
0.200–0.400	good
0.400–0.600	Mild light pollution
0.600–0.800	Moderate light pollution
0.800–1.000	Heavy light pollution

3. Conclusions

In this paper, a light pollution evaluation model is established by hierarchical analysis and entropy weight method, we searched the global light pollution data, and selected 20 countries for evaluation, and found that it was basically consistent with the light pollution map, thus verifying the universality of our indicators.

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