Technology Times based on multiple regional types of light pollution analysis

HeZi Wang[#], Hui Xu[#,*], Ming Sun[#]

School Of Electrical Engineering, Northeast Electric Power University, Jilin, China, 132012

*Corresponding author: ahuia3355@163.com

[#]These authors contributed equally.

Abstract. With the continuous development of modern society, the problem of light pollution has gradually attracted people's attention. This paper studied the risk level of light pollution and developed effective intervention strategies based on the optimized TOPSIS model. We selected Heping District, Faku County, Heping Township, and a national nature reserve—Changbai Mountain National Nature Reserve in Shenyang to apply our model. The comparison is concluded that the final light pollution risk level is as follows: Urban > Suburban > Rural > Protected area.

Keywords: Correlation analysis, Intervention strategy, Light pollution risk assessment, TOPSIS of the modification of entropy weight method.

1. Introduction

With the rapid development of modern society, more and more artificial light sources in the city, the impact of light pollution on people is more and more can not be ignored[1], therefore, the prevention and control of light pollution, under the premise of meeting the basic lighting requirements to reduce the amount of light damage to the surrounding environment and people is the current imminent need to solve the problem[2].

The risk level of light pollution needs to be determined in a certain area based on data from different locations. Moreover, some protected land locations are applied to measure and analyzed based on the model we constructed.

Hence, in order to establish a universal light pollution risk index model, we first conducted analysis at the level of impact factors, selected 7 indicators, and then combined with the night light index obtained by existing remote sensing satellite observation technology, conducted correlation analysis with light damage index (SQM) to determine the effectiveness of the indicators. Furthermore, TOPSIS model improved by entropy weight method was used to evaluate and analyze 29 regions, and the light pollution risk index was obtained.

We selected Shenyang city and applied our model to the central urban area—Heping District, the suburbs—Faku County, the village—Heping Township and the adjacent protected area—Changbai Mountain National Nature Reserve. The results are analyzed and interpreted based on our methodology.

Section I mainly introduces the background of the problem which we tend to solve. Section II illustrates the hypothesis and other preliminary work for our model. Section III constructs the light pollution evaluation model and applies it to several specific areas. Section IV analyzes the properties of our model, including the advantages and disadvantages. Section V, conclusion.

2. Preliminary

2.1. Hypothesis

(1) We assume that the data we collect from websites and reports is reliable and accurate, the data we use in our model comes mainly from statistical websites such as the Government Statistical Yearbook and the National Geographic System Science Data Center.

(2) It is assumed that all the policies in each country are implemented effectively after we come up with the corresponding solutions. We assume that the countries selected for analysis have relatively stable political, social and economic environments.

(3) It is assumed that a country's GDP, population, social electricity consumption, geography, climate and other factors are relatively stable and will not fluctuate much in the short term.

(4) We assume that the indicators of factors, countries have a uniform definition of the standardize.

2.2. Symbols notation

Table 1 shows the symbols used in the following contexts.

Table 1. Symbols

Symbols	Definition	Units
PD	Population density	Ten thousand people per square kilometer
PCGS	Per capita park green space	%
GDP	Gross national product per capita	Trillion
POUC	Proportion of urban construction land in urban area	%
REC	Regional electricity consumption	billion/KWH
DN	Average light intensity	/
TB	The number of high-rise buildings over 200m in the city	/

3. Light pollution evaluation model

3.1. Selection of evaluation model indexes

To evaluate and analyze the risk level of light pollution in a certain region, we first need to understand the influencing factors of light pollution. We have learned that light pollution mainly appears in cities at night, so we mainly discuss the main causes of urban light pollution at night. Outdoor light pollution in cities at night can be divided into sky light and nearby light according to the direction of light source propagation.

Among them, the light emitted into the sky is mainly due to the unreasonable lighting Settings, which leads to the direct projection of the illumination light to the sky. In addition, some light will reflect through the surface of the ground surface to the sky, thus forming a sky glow and increasing the brightness of the sky. The light emitted to the nearby area is caused by the scattering of light from lighting facilities outside the range of illumination, also known as the overflow astigmatism, which makes the surface layer of light pollution one of the main forms, closely related to human life.

The light environment of a certain area mainly consists of two parts, namely natural background light and artificial lighting light. Therefore, in terms of the selection of influence factors of light pollution, we preliminarily choose to divide it into two major aspects: the influence of natural conditions and the influence of man-made conditions.

3.1.1 Influence on natural conditions

In the night sky, the natural background light produced by various atomic and molecular radiation, including the light generated by natural phenomena such as moonlight and aurora, is the dominant factor in the night light environment without artificial lighting. Among them, the light emitted and reflected by celestial bodies is the main component, but its influence on the natural background light varies with the season and phase, so it is difficult to collect model data in this aspect. Meanwhile, with the development of lighting equipment, artificial lighting gradually plays a dominant role in the nighttime light environment. Therefore, the influence of natural conditions is not considered too much here.

3.1.2 The influence of human factors

Human factors have a greater impact on urban areas[3]. Lighting needs develop along with the urbanization process. The development of other cities increases the number of commercial blocks and recreational places at night, which leads to the increase of ambient brightness at night and produces different degrees of light pollution[4].

Global light hazard[5] showed that the brightness of the sky in more developed areas is higher than that in other areas, among which Western Europe, eastern North America, eastern Asia and southern Asia are all more developed areas or densely populated areas. Gross Domestic Product (GDP) is the most commonly used indicator to reflect the economic development level of a region, while population density is the most commonly used indicator to reflect the population density of a region[6].

At the same time, we take into account that the city light at night in a region should be closely related to the amount of electric energy used in the region, and can also reflect the development level of the region to a certain extent. Therefore, the electric energy consumption of a region is also included in our index to establish the reference range.

Through consulting the data, we found that in addition to directly illuminating the sky, outdoor artificial light in a certain area also reflected or scattered to the surrounding environment through various urban surfaces, resulting in light pollution in the overall urban space. Therefore, the surface characteristics of a certain area will also affect the light pollution index to some extent. The surfaces that can affect light propagation can be roughly divided into two types: the outer surface of man-made buildings and the surface of vegetation.

For the external surface of the building: the lighter the color of the artificial external surface of the building, the greater the reflection coefficient on light and the greater the influence on light pollution, that is, the building may have a positive correlation with the risk index of light pollution. At the same time, in the process of data statistics, the higher the skyline of a city, the greater the degree of light pollution. For tall buildings, the use of high reflection coefficient building materials will also aggravate the degree of light pollution to a certain extent, and to a certain extent is related to the development of a certain area. Here, we introduce the number of high-rise buildings over 200m in a region to reflect this index.

For vegetation surface, it not only reflects regional artificial light, but also blocks light in the propagation. For example, trees will reduce the light in the sky by blocking artificial light. Therefore, we believe that vegetation has a negative correlation with the light pollution risk index.

Considering the availability of data sources, we added an index of vegetation coverage in a certain region into the model. For urban areas, we added the proportion of urban construction land in the urban area and the index of per capita green park area.

Above, the influence of the light pollution degree index in a certain region is indirect[7]. To ensure that the model we established can more directly reflect the light pollution index in a certain region, we introduced an important index: the night light data of a certain region. Night light is a remote sensing data. Sensors on satellites can detect the Earth's lights and firelight at night, so the data is a good proxy for human activity.

The advantage of remote sensing is that it can observe the surface of the surface in a large range and for a long time. Many people believe that compared with social statistics, remote sensing is more reliable and a very practical data. DMSP/OLS 1992-2020 Global Remote Sensing influence stabilized light image is an annual raster image that calibrates the average nighttime light intensity[8]. The image includes lights of cities, towns and other places with persistent light sources, and removes the influence of occasional noises such as moonlight cloud, fire, and oil and gas combustion. The pixel DN value of the image represents the average light intensity, which ranges from 0 to 63. There is a direct and close relationship between the light pollution degree and the average light intensity in a certain area. Therefore, the DN value of a certain region is also introduced into our evaluation index system[9]. The indexes above are shown in Figure 1.

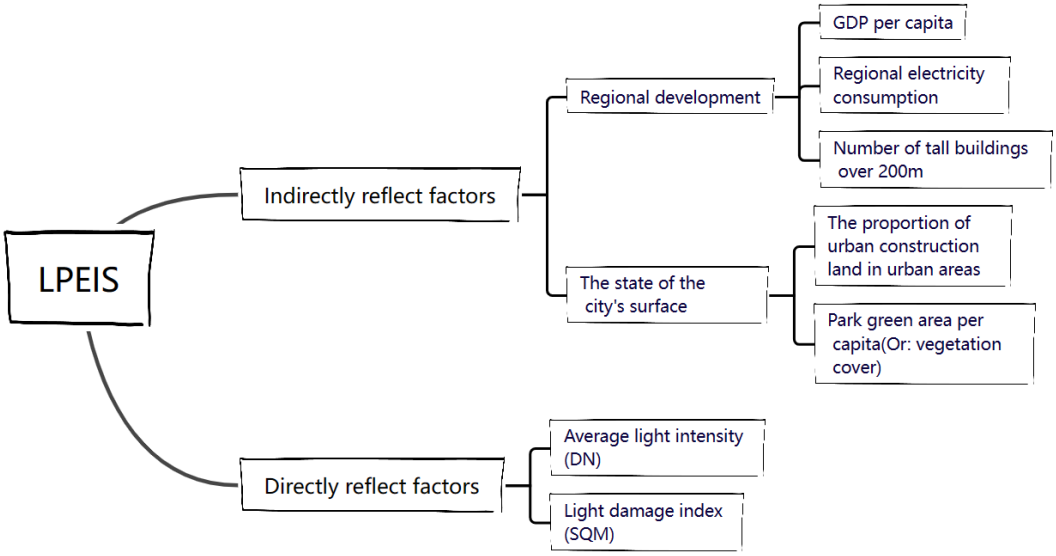

Figure 1. Classification of evaluation indicators

3.2. Establishment of risk index model of light pollution

After determining the above 8 valid data, we need to determine the geographical location of the selected region. This model selects the values of the above 8 indicators in 29 Chinese cities. All the data are from the Chinese government Statistical yearbook, the National Geographic System Science Data Center and various government websites.

We selected a city in almost all the provinces in China to get the corresponding specific indicators for each country. Firstly, the entropy weight method was used to determine the weight of the selected index, and the variation degree of the index was used to objectively reflect the influence degree of the selected index on the final score. Then, the entropy weight method was used to determine the proportion of the distance between good and bad of each index calculated by TOPSIS algorithm, and finally the light pollution status index of each city was obtained.

The overall process is roughly shown in Figure 2.

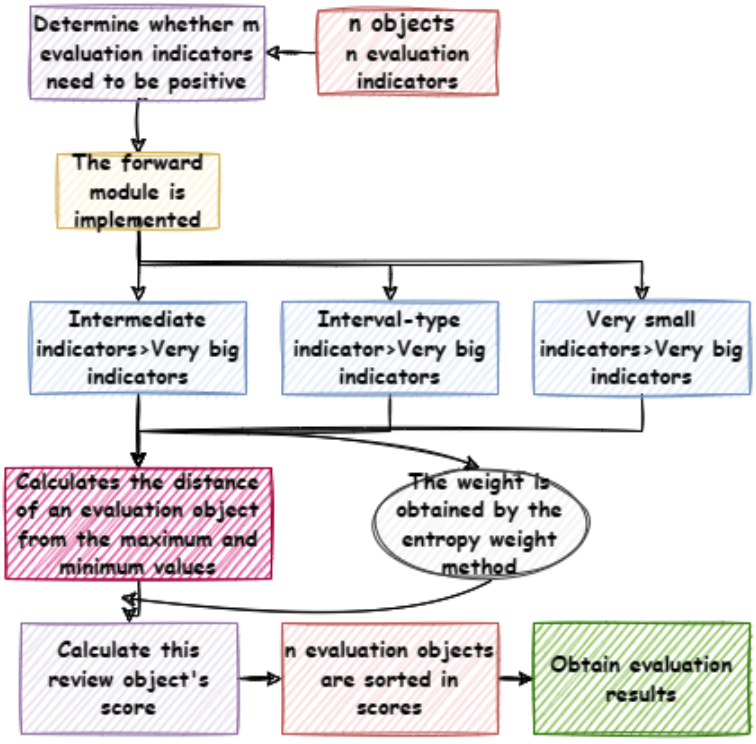

Figure 2. Entropy weight Method—TOPSIS model building flowchart

4. Measurement of light pollution index in different regions

For the site selection of evaluation measurement in the above four areas, we believe that the site selection should meet the following two conditions.

(1) The four regions are close enough geographically. That is, there is no comparability of light pollution index between urban and suburban areas of different cities. The suburbs of a city in a more developed area will have a higher level of development than the urban areas in a less developed area. Therefore, the results of our analysis can be greatly or slightly affected.

(2) The data of the selected region are easily available. Due to the small size of the area to be evaluated for light pollution level, many of the data indicators we choose may not be meaningful to the local area, so the lack of data will cause problems in our model evaluation.

After considering the above two aspects and other practical factors, we choose Shenyang, a provincial capital city in northeast China. Table 2 shows the choices of four specific regions and a brief introduction [10].

4.1. Data Processing

For urban and suburban areas, the selected data indicators are searchable and do not require excessive data processing. However, the geographical location range of villages and protected areas is small, or some indicator data is not very significant for these two areas, so we need to process the indicator data.

For villages, we replaced the GDP index with the local government fiscal revenue and carried out standardized processing, and replaced the green area of urban parks with the local per capita cultivated land area.

As a nature reserve, the local human disturbance has reached the lowest level. Therefore, we directly set the population density, the proportion of urban construction land in the urban area, the power consumption of the region, and the number of high-rise buildings over 200 meters as the minimum standards. However, for the per capita green area of the park, This is an index used to measure the effect of local vegetation on reducing light pollution. We can directly use vegetation coverage instead. Table 2 illustrates the detailed information of each region.

Table 2. Regional type introduction

Regional type	Geographical location	Specific information
Urban site selection	Heping district	The central area of Shenyang is the political, economic, scientific, educational and cultural center of the city.Liaoning Province comprehensive strength first region.
Suburban site selection	Faku County	Located in Shenyang City, Changbai Mountain Range and Yinshan Mountain range confluence, right bank of Liao River,It is 90 kilometers away from the center of Shenyang.
Village site selection	Heping Township	Located in the northeastern Faku County, there is an industrial enterprise,There are 28 general stores with a business area of more than 50 square meters.
Site selection of protected area	Changbai Mountain National Nature Reserve	It is located on the border of North Korea with a total area of 196,465 hectares and is a national nature reserve of China.Rich in natural species, has been listed in the International Union for Conservation of Nature Conservation Green List.

4.2. Result Analysis

After the final evaluation, the light pollution index scores of these four regions are shown in the Figure 3.

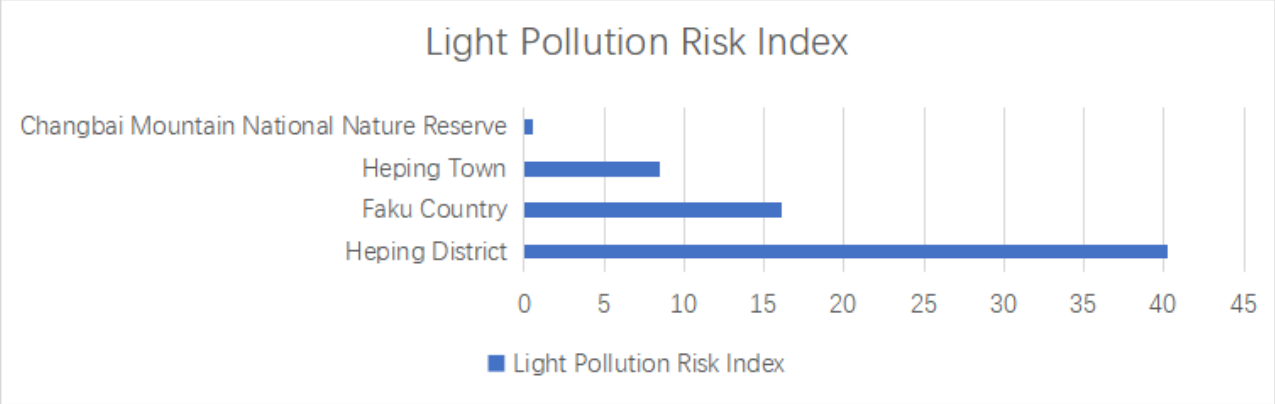

Figure 3. Comparison of risk indices in four regions

The light pollution index of the whole city of Shenyang is 36.17, while the light pollution index of the Peace District, the most central area of the whole city, is 40.28, which is higher than the average light pollution level of the whole city. As the political, economic, scientific, educational and cultural center of the whole city, Shenyang has a dense population and rich industrial types, and its economic development level is at a relatively high level. Urban skyscrapers, nightlife is rich, natural light pollution index is high.

As for Faku County in the suburb, it is far away from the urban area, the urban population is small, and in urban planning, the suburb is mostly used for the construction of industrial plants, and the industries with large population are mainly concentrated in the urban area. Under normal circumstances, the light damage index will naturally be lower than that in the urban area. In the area we selected, Faku County is one of the most remote districts and counties within the jurisdiction of Shenyang. The light pollution index will be much different from the normal suburban and urban areas.Comparison of final light pollution risk levels:

Urban > Suburban > Rural > Protected area

5. Conclusion

We proposed a new model for evaluating and analyzing the light pollution of some areas. The model named TOPSIS is mainly improved by entropy weight method, which reflect the risk degree of light pollution in certain places accurately. Furthermore, we selected several typical ares for rural, urban and other types areas to verify the model. The results show that the pollution risk levels is:Urban > Suburban > Rural > Protected area. In the future, it is also meaningful to apply the model to other circumstances and broad the application value of it.

References

[1] Broad-spectrum light pollution suppresses melatonin and increases West Nile virus–induced mortality in House Sparrows (Passer domesticus)[J]. Meredith E Kernbach;Vincent M Cassone;Thomas R Unnasch;Lynn B Martin. The Condor. 2020.

[2] WALKER W.H, BUMGARNER J.R, WALTON J.C, et al. Light pollution and cancer[J].International Journal of Molecular Sciences,2020,21(24):1-18.

[3] Methods for Assessment and Monitoring of Light Pollution around Ecologically Sensitive Sites[J]. John C. Barentine. Journal of Imaging. 2019(5).

[4] Beyond All-Sky: Assessing Ecological Light Pollution Using Multi-Spectral Full-Sphere Fisheye Lens Imaging[J]. Andreas Jechow;Christopher C.M. Kyba;Franz Hölker. Journal of Imaging. 2019(4).

[5] Operti F G , Oliveira E A , Carmona H A , et al. The light pollution as a surrogate for urban population of the US cities[J]. North-Holland, 2018.

[6] Quantified effects of artificial versus natural nighttime lighting on the Eurasian grasses Bothriochloa bladhii (Poaceae) and Bothriochloa ischaemum (Poaceae) and the North American grasses Panicum

virgatum (Poaceae) and[J]. Nicholas D Flowers;David J Gibson. Journal of the Torrey Botanical Society. 2018(2).

[7] Artificial nighttime lighting impacts visual ecology links between flowers, pollinators and predators.[J]. Briolat Emmanuelle S;Gaston Kevin J;Bennie Jonathan;Rosenfeld Emma J;Troscianko Jolyon. Nature communications. 2021(1).

[8] The Effects of Anthropogenic Sound and Artificial Light Exposure on Microbiomes: Ecological and Public Health Implications [J]. Robinson Jake M.;Cameron Ross;Parker Brenda. Frontiers in Ecology and Evolution. 2021.

[9] Mareike Dreier, Julia Ludwig, Martin Härter et al. Development and evaluation of e-mental health interventions to reduce stigmatization of suicidality – a study protocol[J] BMC Psychiatry, 2019, 19(1).

[10] The editorial board and editorial staff of the China Urban Construction Statistical Yearbook 2021 Editor in Chief Hu Zijian, China Urban Construction Statistical Yearbook, China Statistical Publishing House, April 5, 2021, Yearbook.