Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
E		2311633

Shining a Light on The Pollution: Light Pollution Metric and Mitigation Strategies for Hefei

Summary

Thanks to modern technology, people around the world have been able to live under a night sky of artificial light instead of darkness. Electric lights can be a beautiful thing, guiding us home when the sun goes down, keeping us safe, and making our homes comfortable and bright. However, Excessive or poorly designed artificial lighting can have many adverse effects, including obscuring the stars, disrupting animal and plant behavior, and harming human health. As with many other pollution problems, light pollution is growing up as a global issue. Therefore, it is a matter of great urgency for community officials and local groups to mitigate the negative impacts of light pollution.

In task 1, a metric Regional Light Pollution Risk Index (**RLPRI**) is developed to measure the risk of light pollution in a given location. **RLPRI** is based on these five factors: urban public sector electricity consumption, urban population size, regional building additions, regional passenger traffic, and regional cargo traffic, with higher scores indicating greater risk of light pollution. A model is built by using **linear regression** and **least squares** to find the parameters about LPRI. Then we use Mathtype to solve the linear regression matrix, finally get a model regression equation of **RLPRI**. Checked by **goodness of fit analysis**,

In task 2, based on the previous task, we apply the Regional Light Pollution Risk Index (RLPRI) to four different regions: protected land, rural community, suburban community, and urban community in Hefei. We consider the characteristics of the four regions and adjust the independent variables of the model to predict whether there is a significant difference in the Y value obtained in the different regions.

In task 3, we propose three strategies to address light pollution in different areas: public electricity use, population size, and the number of completed houses in real estate developments. Using the collected data and graphs, we discuss the potential impact of each strategy on the impact of light pollution in general.

In Task 4, based on the consideration of practicality and effective application value, we chose the core urban area of Hefei City and the conservation area of Chaohu County as the study subjects. Finally, we conclude that in terms of the changing trend, although the strategy of controlling the population size has a great advantage at the beginning, reducing public lighting electricity consumption will gradually become the optimal solution as the city grows. Therefore, reducing PCE is selected as the best strategy to address light pollution.

In Task 5, we produce a 1-page flyer to promote the strategy for Hefei City.

Finally, we analyze the strengths and weaknesses of the model and conduct the **sensitivity analysis** and **error analysis.** We hope our research can provide some reasonable ideas for reducing the light pollution, as "Shining a Light On the Pollution", to make contribute to our planet.

Keywords: RLPRI, linear regression, least square, Goodness of fit test, sensitivity analysis, error analysis

Contents

1. Introduction

1.1 Problem background

Light illuminate humans and protect them from darkness. However, excessive use of artificial light disrupts natural cycles and ecosystems, negatively impacts the health of humans and wildlife, and wastes energy and resources. The light pollution has become a major concern in recent years. Due to light pollution, we can no longer see the spectacular starry sky from our cities. The vast majority of the world's population lives under light-polluted skies, no longer experiences natural nights.

The use of artificial lighting has become increasingly widespread with the growth of urbanization and modern society's 24/7 lifestyle. Rapid population growth and urbanization have led to a significant increase in the use of artificial lighting, which has resulted in a corresponding increase in light pollution. As more and more people move into urban and suburban communities, the demand for lighting has grown, and many urban areas are now bathed in a permanent glow of artificial light at night.

As the importance of protecting the environment and promoting sustainable development continues to grow, there is an urgent desire to find effective solutions to light pollution. That is why we are developing applicable indicators and setting models to determine the level of light risk and trying to find possible intervention strategies to address light pollution.

1.2 Restatement of the Problem

Light pollution is an environmental problem that negatively affects human health, wildlife and ecosystems. To address this growing issue, this paper will develop an indicator that can identify the level of light pollution risk at a specific location. In addition, possible intervention strategies to address light pollution will be presented and specific actions to implement each strategy will be discussed.

We need to solve the following problems:

- Develop a broadly applicable metric to identify the level of light pollution risk in a location.
- Apply developed metric and interpret its results on the following four diverse types of locations:
  a protected land location,
  a rural community,
  a suburban community, and
  an urban community.
- Describe three possible intervention strategies to address light pollution. Discuss specific actions to implement each strategy and the potential impacts of these actions on the effects of light pollution in general.
- Choose two of the four locations and use the metric to determine which intervention strategies is the most effective for each of them. Discuss how the chosen intervention strategy impacts the risk level for the location.
- Finally, for one of the identified locations and its most-effective intervention strategy, produce a 1-page flyer to promote the strategy for that location.

1.3 Literature Review

With the uncontrolled development of industry, our planet is facing an unprecedented environmental crisis. Like land pollution and air pollution, light pollution is also a growing problem that has attracted great attention in recent years. As an excessive use of artificial light, light pollution has serious environmental consequences for humans, wildlife and the global climate. Light pollution is a side effect of industrial civilization. Its sources include exterior and interior lighting of buildings, advertising, commercial properties, offices, factories, street lights, and illuminated stadiums.[1] Cinzano, Falchi, and Elvidge (2001) present the first world atlas of the zenith artificial night sky brightness at sea level. [2] They analyze the data obtained from the global picture provided by DMSP satellite to quantify the level of light pollution worldwide. About two-thirds of the world's population and 99 percent of the population in USA and EU live under skyglow, and over one-fifth of the world population live under severely light-polluted skies. Over ten percent of the world population even no longer view the heavens with the eye adapted to night vision, because of the sky brightness. The authors argue that the atlas provides a tool to assess the current state of light pollution and to develop effective policies to mitigate it.

Longcore and Rich (2004) studied the ecological effects of light pollution on wildlife. The extent and intensity of artificial nighttime lighting has increased to the point that it is having a substantial impact on the biology and ecology of species in the wild. [3] They distinguished between "astronomical light pollution" and "ecological light pollution". The consequences of lighting on certain taxonomic groups can be catastrophic, such as the mortality of migratory birds around tall, lighted structures and the death of hatchling sea turtles confused by lights on the beaches where they were born. The more subtle effects of artificial night lighting on species behavior and community ecology are not well understood and constitute a new focus of ecological research and an urgent conservation challenge. The authors call for policies that minimize the adverse effects of light pollution on wildlife.

Stevens (2006) studied the link between artificial light and breast cancer. [4] The risk of breast cancer is high in industrialized societies and has increased with the westernization of developing countries. One possible reason for this is the disruption of circadian rhythms caused by various aspects of modern life, particularly the increasing use of electricity to illuminate the night and to provide a sunless environment inside buildings during the day. The study presents evidence from epidemiological and laboratory studies that support the hypothesis. Policies should be developed to limit exposure to artificial light at night to reduce the risk of breast cancer.

Kyba, Mohar and Posch (2017) sought a standard figure for the brightness of moonlight. [5]Trying to identify the potential impact of moonlight on light pollution. Satellite images were used to quantify the amount of light scattered by the moon and compare it to the amount of artificial light emitted by cities. The light scattered by the moon is much dimmer than artificial light and has a negligible effect on light pollution. The authors argue that these findings are critical for developing effective lighting policies to minimize light pollution.

Hölker et al. (2010) provide a comprehensive analysis of the causes and effects of light pollution. [6] In response to climate change and energy shortages, many countries, regions, and communities are developing new lighting programs and concepts with a strong focus on energy efficiency and greenhouse gas emissions. They see an urgent need for light pollution policies that go beyond energy efficiency to include human well-being, the structure and functioning of ecosystems, and inter-related socioeconomic consequences. Such a policy shift will require a sound transdisciplinary understanding of the significance of the night, and its loss, for humans and the natural systems upon which we depend. Knowledge is also urgently needed on suitable lighting technologies and concepts which are ecologically, socially, and economically sustainable.

Light pollution is a complex problem with adverse effects on the environment, human health, and wildlife. This review highlights the causes, effects, and solutions of light pollution from five papers based on different perspectives. The articles present evidence that light pollution is a global problem and that effective policies are urgently needed to mitigate its adverse effects. Interdisciplinary research is needed to develop effective policies that balance the benefits of artificial light with ecological and health impacts.

1.4 Our Work

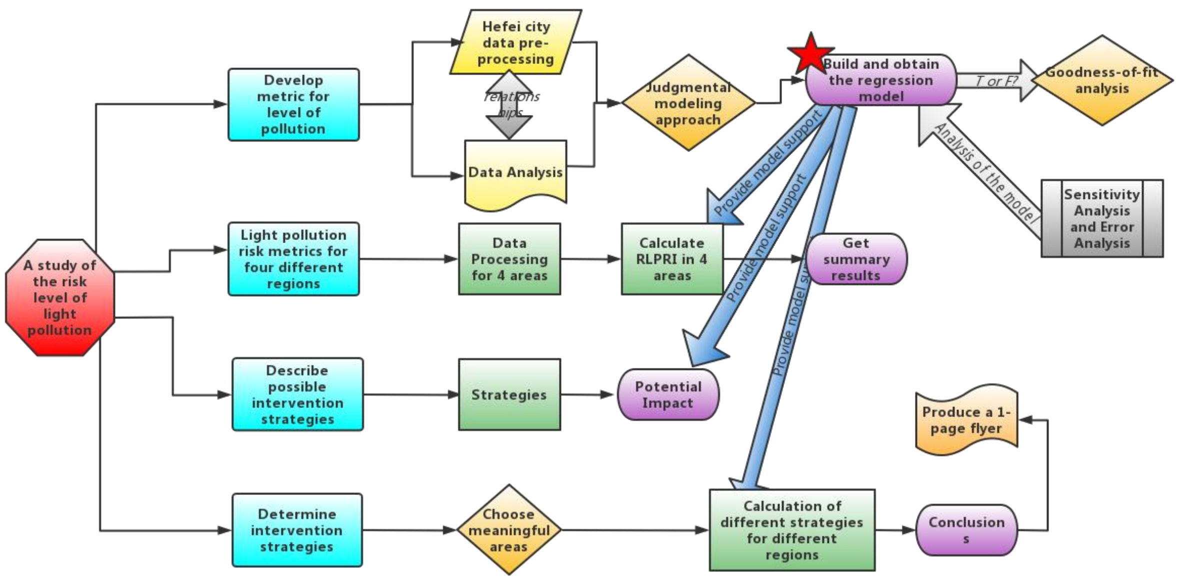

Figure 1. The flow chart of this paper

2 Assumptions and Justifications

Assumption 1: We assume that **public sector electricity consumption** has a significant impact on the regional light pollution risk levels.
Justification 1: The level of light pollution risk is largely influenced by street lights, landscape lights and other public power supply facilities. And the electricity consumption of these facilities can be largely reflected by the public sector electricity consumption.

Assumption 2: We assume that the **regional population size** affects the lighting in the region in some major ways, which in turn affects the regional light pollution level.
Justification 2: The change in the number of people in a region corresponds to the change in the number of residents in that region, and light pollution is in many ways influenced by residential

lighting, so the change in the number of people in a region can correspond to the change in the level of residential lighting in that region.

Assumption 3: The area of **completed houses in real estate development enterprises** has a significant impact on regional lighting and light pollution levels.
Justification 3: The contour light of urban buildings is one of the main factors in generating light pollution, so the area of completed houses in real estate development enterprises can effectively reflect the change level of light pollution in an area.

Assumption 4: We propose a conjecture that the **transportation industry** in an area can have a significant impact on the level of light pollution in that area.
Justification 4: The lighting generated in the transportation industry is an important indicator of light pollution, so we determine the level of development of the transportation industry in a region by the number of passengers and goods transported in a region, and thus determine the impact of the development of the transportation industry on the level of light pollution.

3. Definitions and Notations

3.1: Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations used in this paper

Symbol	Description	Unit
PEC	the value of Public sector Electricity Consumption	100 million kWh
RP	the amount of Regional Population size	10,000 people
CH	the number of Completed Houses in real estate development enterprises	10,000 square meters
PT	the number of Passengers transportation	10,000 people
GT	the value of Goods transportation	10,000 tons
RLPRI	Regional Light Pollution Risk Index	DN-value

3.2 Principal component analysis

3.2.1 KMO test and Bartlett's test

We present here five variables, but we do not know if there is a certain relationship between these five variables. Therefore, we are going to use principal component analysis to explore whether there is a correlation between these five variables.

First, KMO and Bartlett's tests were performed to determine whether principal component analysis could be performed. For the KMO value: on 0.8 is very suitable for principal component analysis, between 0.7-0.8 is generally suitable, between 0.6-0.7 is less suitable, between 0.5-0.6 indicates poor, and under 0.5 indicates extremely unsuitable. For Bartlett's test, if P is less than 0.05 and the original hypothesis is rejected, it means that principal component analysis can be done, and if the original hypothesis is not rejected, it means that these variables may provide some information independently and are not suitable for principal component analysis.

Table 2. KMO test and Bartlett's test

KMO test and Bartlett's test		
KMO value		0.822
Bartlett's sphericity test	Approximate cardinality	121.136
	df	10
	P	0.000***
Note: ***, **, * represent 1%, 5%, 10% significance levels, respectively		

Table 3. Explanation of variance table

Total variance explained			
Ingredients	Feature Root		
	Feature Root	Explanation of variance (%)	Cumulative variance explained (%)
1	4.738	94.757	94.757
2	0.175	3.504	98.261
3	0.076	1.522	99.783
4	0.01	0.197	99.979
5	0.001	0.021	100

3.2.1:Conclusions

The results of the KMO test showed that the value of KMO was 0.822, while the results of the Bartlett's spherical test showed that the significance p-value was 0.000***, presenting significance at the level and rejecting the original hypothesis that the variables are correlated and the principal component analysis is valid to the extent that it is suitable.[12]

The Explanation of variance table shows that PEC, RP, and CH have a large effect on the dependent variable, so we will consider them in the subsequent questions and modeling as appropriate.[13]

3.3 Definition

Regional Light Pollution Risk Index (RLPRI): The RLPRI is calculated based on five main factors: urban public sector electricity consumption, urban population, regional building

additions, regional passenger traffic, and regional cargo traffic. The RLPRI is the sum of these five factors, and a higher score indicates a higher risk of light pollution.
DN- value: The unit of Regional Light Pollution Risk Index (RLPRI).

4.Task 1: Develop Metric for Level of Pollution

4.1 Data Description

We collected data from 2002 to 2013 on urban public sector electricity consumption, urban population size, regional building additions, regional passenger deliveries, and regional cargo transportation in the Hefei region. The data span 12 years, and all data aspects of Hefei show some degree of growth during this period. We also collected the nighttime light index data by means of the data and processed the data in conjunction with these data.

Table 4. Summary table of all indicators 2002-2013

Year	PEC	RP	CH	PT	GT	RLPRI
2002	2.1612	448.08	226.3	5726	3629	101.8052
2003	2.4255	456.6	264.45	6034	4641	111.092
2004	2.967	444.68	298.74	6772	5767	115.7978
2005	3.8535	455.7	413.77	7080	6134	119.9295
2006	4.518	469.85	450.73	7813	6776	128.0998
2007	7.224	478.9	512.06	8923	7186	153.1091
2008	10.221	486.74	463.42	14382	12181	150.6393
2009	15	491.43	477.66	17322	14798	150.8769
2010	19.6875	493.42	579.38	19805	18873	161.3882
2011	21.552	706.13	664.23	29157	29287	165.2983
2012	21.3285	710.53	725.28	34417	33720	166.383
2013	31.959	711.5	1072.32	40107	39131	172.6835

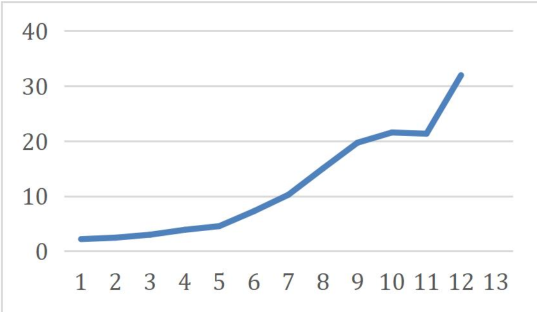

Figure 2.PEC variations from 2002 to 2013

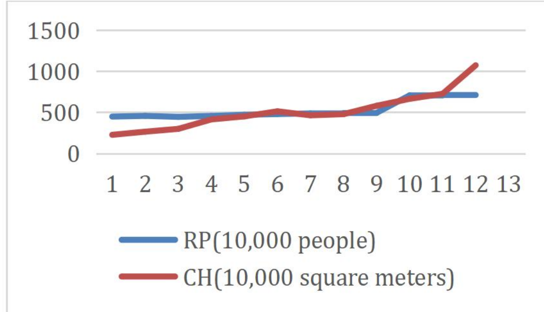

Figure 3.RP and CH variations from 2002 to 2013

[7] [8]

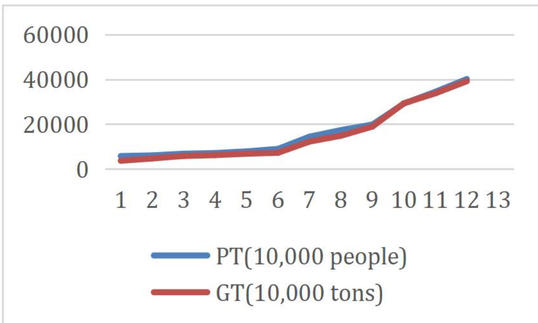

Figure 4.PT and GT variations from 2002 to 2013

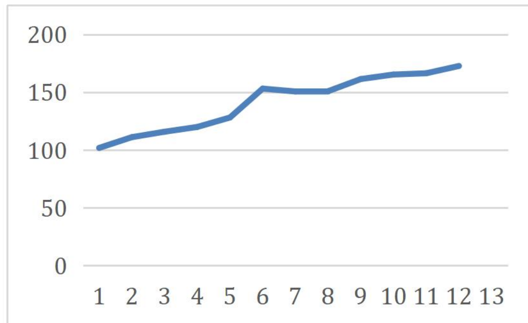

Figure 5. DN-value variations from 2002 to 2013

Tips: We set 2002 as the base year and use the numbers 1-13 in Table 2 to indicate 2002-2013.

4.2 The Establishment of light pollution risk level of a location.

4.2.1 Analysis

1.Analyze whether the original hypothesis that the overall regression coefficient is 0 ($p<0.05$) can be significantly rejected by analyzing the F-value, and if it is significant, it indicates that there is a linear relationship between, and the strength of the linear relationship needs to be further analyzed.
2.Analyze the model fit by R^2 values and also the VIF values.
3.Analyze the significance of independent variables separately; if significant ($P<0.05$) is presented, it is used to explore the relationship between the effects of PEC, RP, CH, PT, GT on RLPRI.
4.Compare and analyze the degree of influence of the five independent variables on RLPRI by combining the regression coefficient B values.
5.Determine to get the model equation: Light pollution risk level prediction model

4.2.2. Evaluation of the model

For the change of light pollution risk level is often influenced by several factors, such as PEC, RP, CH, PT, GT, and so on factors will affect the light pollution risk level, and the units of these influencing factors (independent variables) are obviously different therefore, we choose to conduct multiple regression analysis. We convert all variables, including the dependent variable, into standard scores before conducting linear regression, at which point the regression coefficients obtained reflect the importance of the corresponding independent variables.

4.3 Theory and establishment of the model

4.3.1 Theory

The regression equation here is called the standard regression equation and the regression coefficient is called the standard regression coefficient. We introduce for each independent variable on top of this.

$$y^* = \alpha_i + \sum_{\substack{i=1 \\ j=1}}^{n} \beta_{ij} x_{ij} \tag{1}$$

4.3.2 Establish

For the five variables, we develop a five-element linear regression model.

$$RLPRI^* = \alpha_0 + \beta_{i1}\, PEC + \beta_{i2}\, RP + \beta_{i3}\, CH + \beta_{i4}\, PT + \beta_{i5}\, GT \tag{1}$$

For RLPRI, we perform the least squares method for parameter estimation.

$$\sum RLPRI^* = n\alpha_0 + \beta_{i1} \sum PEC + \beta_{i2} \sum RP + \beta_{i3} \sum CH + \beta_{i4} \sum PT + \beta_{i5} \sum GT \tag{2}$$

4.3.3 Solving matrix

$$\begin{bmatrix} RLPRI^*{}_1 \\ \vdots \\ RLPRI^*{}_{11} \end{bmatrix} = \begin{bmatrix} \beta_{1,1} & \cdots & \beta_{1,11} \\ \vdots & \ddots & \vdots \\ \beta_{11,1} & \cdots & \beta_{11,11} \end{bmatrix} * \left[\begin{pmatrix} x_{1,1} & \cdots & x_{1,11} \\ \vdots & \ddots & \vdots \\ x_{11,1} & \cdots & x_{11,11} \end{pmatrix} \right] + \begin{bmatrix} a_1 \\ \vdots \\ a_{11} \end{bmatrix} \tag{1}$$

4.3.4 Solving with Mathtype

Through Mathtype, the result table of linear regression analysis is obtained as follow.

Table 5. Linear regression analysis

Linear regression analysis results n=12										
	Non standardized coefficient		Standardization coefficient	t	P	VIF	R²	adjustR²	F
	B	Standard error	Beta						
constant	58.503	88.144	-	0.664	0.532	-	0.826	0.68	F=5.679 P=0.028**
PEC	3.518	2.726	1.405	1.291	0.244	40.755			
RP	0.117	0.209	0.52	0.56	0.596	29.699			
CH	0.028	0.053	0.266	0.529	0.616	8.654			
PT	0.002	0.007	0.768	0.214	0.837	441.307			
GT	-0.004	0.008	-2.024	-0.502	0.634	560.044			
Dependent variable: Y									

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

Tips: B is the coefficient with a constant case.

Standard error = B/t value.

Standardized coefficient is the coefficient obtained by normalizing the data.

VIF is the covariance

The above table shows the analysis results of this model, including the standardized coefficient of the model, T-value, VIF value, R², adjustment R², etc., for testing the model and analyzing the formula of the model. According to the analysis of the results of F test, the significance P value is 0.028**, showing significance at the level, rejecting the original hypothesis that the regression coefficient is 0, so the model basically meets the requirements.

After Mathtype calculation and analysis of the above linear regression analysis table, we can have:

$$a_0 = 58.503,\ \beta_1 = 3.518,\ \beta_2 = 0.117,\ \beta_3 = 0.028,\ \beta_4 = 0.028,\ \beta_5 = 0.004$$

That is, the model regression equation is obtained:

$$\begin{aligned}&\mathrm{RLPRI}^* \\ &= 58.503 + 3.518\mathrm{PEC}^* + 0.117\mathrm{RP}^* + 0.028\mathrm{CH}^* + 0.002\mathrm{PT}^* \\ &- 0.004\mathrm{GT}^*\end{aligned} \tag{1}$$

3.4.5 Goodness of fittest analysis

According to the linear regression analysis table, the goodness of fit (R^2) can be obtained as 0.826. According to the goodness of fit test principle, if the value is greater than 0.617, the goodness of fit test is deemed to have passed.

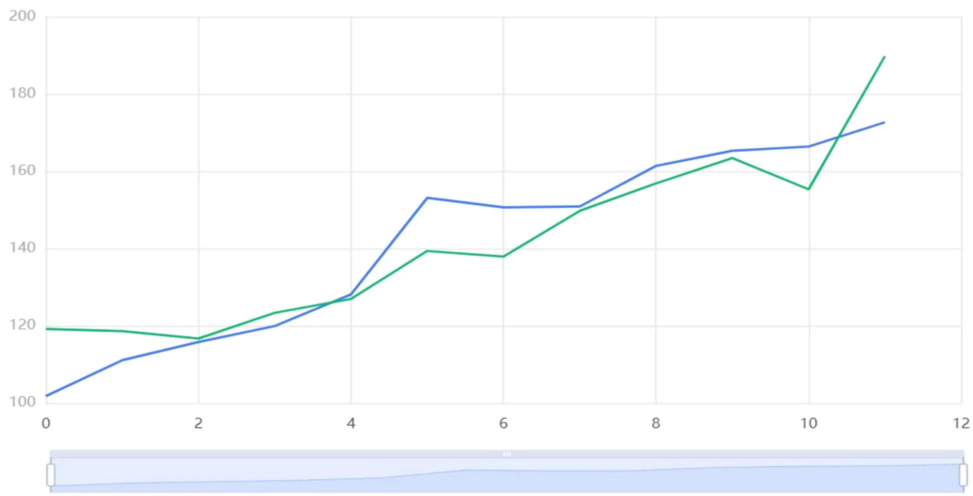

Figure 6. Fitting effect graph

Tips: True Value Predicted value

5 Task2： Light pollution risk metrics for four different regions

5.1 Analysis

We choose the following four counties in Hefei: Chaohu County, Changfeng County, Feixi County, and the main urban area (including Baohe District, Shushan District, and Yaohai District) to represent the a.a protected land location, b.a rural community, c.a suburban community, and d.an urban community. The PEC, RP, CH, PT, and GT values of each county were collected from 2002 to 2013.

5.2 Data Processing

Table 6. Chaohu District 2002-2013 data summary table

Year	PEC	RP	CH	PT	GT
2002	0.2418	20.14	2.324	515.34	326.61
2003	0.2551	21.32	2.45	543.06	417.69
2004	0.2615	20.95	3.53	609.48	519.03
2005	0.3109	21.81	3.567	637.2	552.06
2006	0.3446	23.28	4.12	703.17	609.84
2007	0.4561	24.14	4.67	803.07	646.74
2008	0.5123	24.54	3.634	1294.38	1096.29
2009	0.5541	25.56	4.584	1558.98	1331.82
2010	0.5981	25.34	4.748	1782.45	1698.57
2011	0.6019	27.67	5.267	2624.13	2635.83
2012	0.6028	27.24	6.78	3097.53	3034.8

2013	0.7801	27.76	11.56	3609.63	3521.79

Table 7. Changfeng District 2002-2013 data summary table

Year	PEC	RP	CH	PT	GT
2002	0.280956	58.2504	29.419	744.38	471.77
2003	0.315315	59.358	34.3785	784.42	603.33
2004	0.38571	57.8084	38.8362	880.36	749.71
2005	0.500955	59.241	53.7901	920.4	797.42
2006	0.58734	61.0805	58.5949	1015.69	880.88
2007	0.93912	62.257	66.5678	1159.99	934.18
2008	1.32873	63.2762	60.2446	1869.66	1583.53
2009	1.95	63.8859	62.0958	2251.86	1923.74
2010	2.559375	64.1446	75.3194	2574.65	2453.49
2011	2.80176	91.7969	86.3499	3790.41	3807.31
2012	2.772705	92.3689	94.2864	4474.21	4383.6
2013	4.15467	92.495	139.4016	5213.91	5087.03

Table 8. Feixi District 2002-2013 data summary table

Year	PEC	RP	CH	PT	GT
2002	0.410628	85.1352	42.997	1087.94	689.51
2003	0.460845	86.754	50.2455	1146.46	881.79
2004	0.56373	84.4892	56.7606	1286.68	1095.73
2005	0.732165	86.583	78.6163	1345.2	1165.46
2006	0.85842	89.2715	85.6387	1484.47	1287.44
2007	1.37256	90.991	97.2914	1695.37	1365.34
2008	1.94199	92.4806	88.0498	2732.58	2314.39
2009	2.85	93.3717	90.7554	3291.18	2811.62
2010	3.740625	93.7498	110.0822	3762.95	3585.87
2011	4.09488	134.1647	126.2037	5539.83	5564.53
2012	4.052415	135.0007	137.8032	6539.23	6406.8
2013	6.07221	135.185	203.7408	7620.33	7434.89

Table 9. Main urban area District 2002-2013 data summary table

Year	PEC	RP	CH	PT	GT
2002	0.86448	179.232	90.52	2290.4	1451.6
2003	0.9702	182.64	105.78	2413.6	1856.4
2004	1.1868	177.872	119.496	2708.8	2306.8
2005	1.5414	182.28	165.508	2832	2453.6
2006	1.8072	187.94	180.292	3125.2	2710.4
2007	2.8896	191.56	204.824	3569.2	2874.4
2008	4.0884	194.696	185.368	5752.8	4872.4
2009	6	196.572	191.064	6928.8	5919.2
2010	7.875	197.368	231.752	7922	7549.2
2011	8.6208	282.452	265.692	11662.8	11714.8
2012	8.5314	284.212	290.112	13766.8	13488
2013	12.7836	284.6	428.928	16042.8	15652.4

For all the data, we bring them into the model and prepare them for measuring the reasonableness and accuracy of our metrics.

5.3 Calculate

First for Chaohu, the place we identified as a protected area, we got the following results: $\mathrm{RLPRI}_{Chaohu} = 4.4224$
Next is the Changfeng district, which we identify as a rural community, which has this data: $\mathrm{RLPRI}_{C\mathrm{hanfeng}} = 5.26$
Then we calculated the Fei Xi district, which can be considered as a suburb in the whole area of Hefei city. The data for this district are: $\mathrm{RLPRI}_{\mathrm{Feixi}} = 4.86$
The final data obtained is for the main urban area, and the three areas of Hefei that have been divided since 1992 are the main body of this data measurement. Combining the data from these three small areas, we can get this result: $RLPRI_{Main\ urban\ area} = 79.3901$

5.4. Conclusion

1： Anhui Hefei Chaohu Lake Lakeside National Wetland Park is located on the north shore of Chaohu Lake in Baohe District, Hefei City, Anhui Province, south of Hefei Binhu New District, with a total area of 1535.31 hectares, 1317.77 hectares of wetlands, and a wetland rate of over 85%. Because a large amount of the area is protected, the residential area of Chaohu Lake is the smallest of all the areas in Hefei, so Chaohu Lake has the lowest RLPRI_{Chaohu} value.

2: Changfeng County is a part of Hefei City, Anhui Province. As of 2021, Changfeng County has 12 towns and 2 townships, and the county government is located in Shuihu Town. Changfeng is the largest county under Hefei, so we consider it as a typical rural area. Due to the extensive rural construction in China, it now has public lighting in vast rural areas, so it has the second highest $\mathrm{RLPRI}_{Chanfeng}$ factor.

3: Feixi is named after the west of Hefei. This area is the western edge of the core urban area of Hefei, so we consider it as a suburb. Because most suburban areas in China do not have good transportation, these areas tend to be sparsely populated. Therefore, it has the penultimate $\mathrm{RLPRI}_{\mathrm{Feixi}}$ factor.

4: The resident population of Hefei is 9.634 million, with an urbanization rate of 84.64%. Hefei is also a new first-tier city in China and thus has a very high urbanization process and the highest $RLPRI_{Main\ urban\ area}$

6.Task 3: Describe possible intervention strategies

6.1. Analysis

Based on the model we developed, we considered each type of data that could affect the level of light pollution risk and decided to propose an implementable strategy in three areas: public electricity consumption, population size, and the number of Completed Houses in real estate development enterprises.

6.2. Strategies

(1) Reduce public electricity consumption: Starting at 11:00 p.m., all public facilities use electricity at intervals, for example, five of the ten street lights are lit at intervals, and other public lighting such as landscape lights also use this strategy

(2) Control population size: Urban areas are very densely populated, so the government should encourage citizens to gradually move to the outskirts of the city to reduce the population size of an area.

(3) reduce number of Completed Houses in real estate development enterprises: With the rapid development of Hefei, more and more tall buildings are being built. The government can encourage the reuse of buildings instead of building new buildings indefinitely to meet the demand.

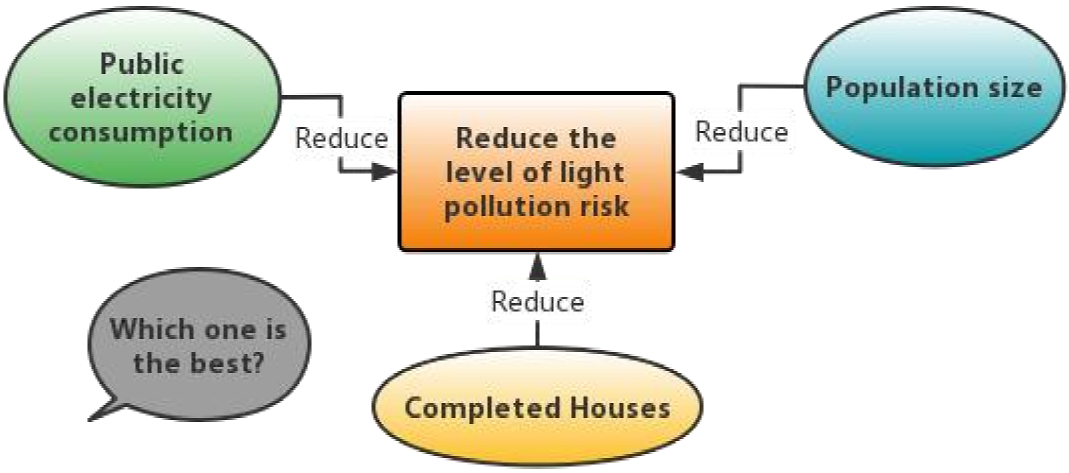

Figure 7: a simple flow chart for three strategies

6.3: Potential Impact

Hefei provides public lighting from 7 p.m. to 5 a.m. According to the strategy, we turn off half of the public lighting facilities from 11 p.m. to 5 a.m., which means a 25% reduction in public lighting consumption. We run this data in place of the model. [9]

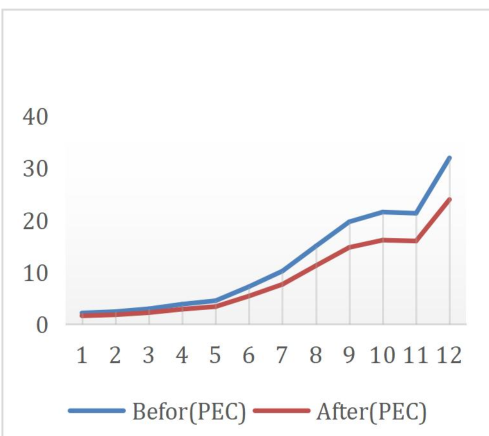

Figure 8: PEC contrast chart

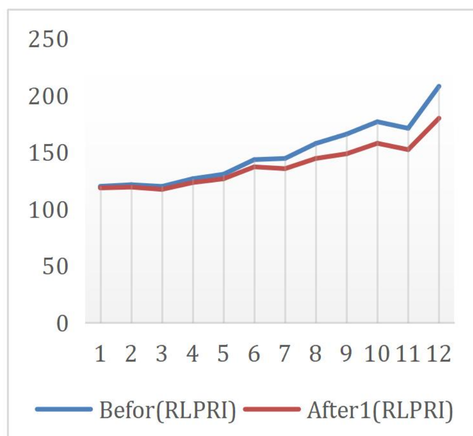

Figure 9: RLPRI contrast chart

From figures, we can find that along with the decreasing trend of PEC, PLCRI also shows the same decreasing trend, so our strategy can effectively reduce the light pollution risk level.

The city is overpopulated and our strategy is to encourage 20% of the annual population of Hefei to be able to move out of the city and settle in other parts of Anhui province.

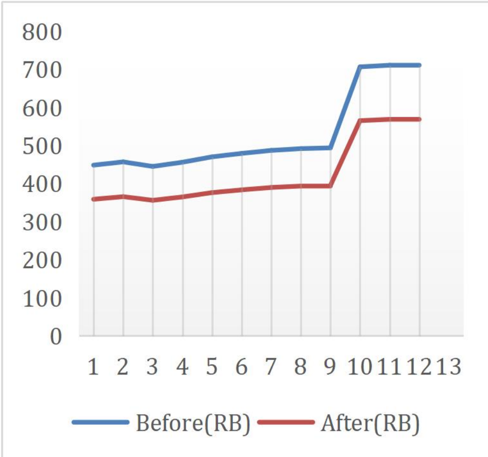

Figure 10: RB contrast chart

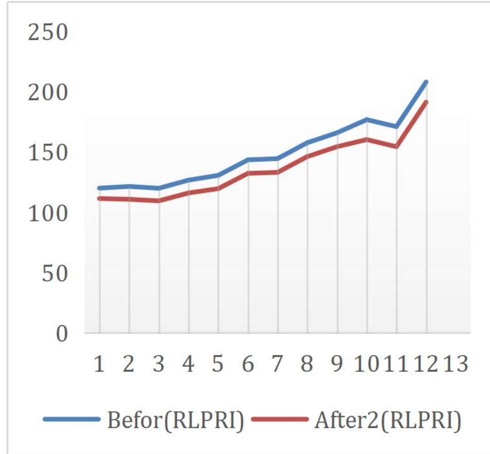

Figure 11: RLPRI contrast chart

Based on the comparison of the two charts, we can clearly see that if we control the RB, then we can also effectively control the RLPRI.

Urban development is often accompanied by a large number of buildings being built, but about 21.4% of these are not used in a timely manner, and their developers tend to decorate lights on the outer contours of these buildings. These lights and the stimulating sunlight reflected by these buildings cause light pollution, so we hypothesize how the annual removal of 21.4% of unused new housing will affect the level of light pollution risk. [10]

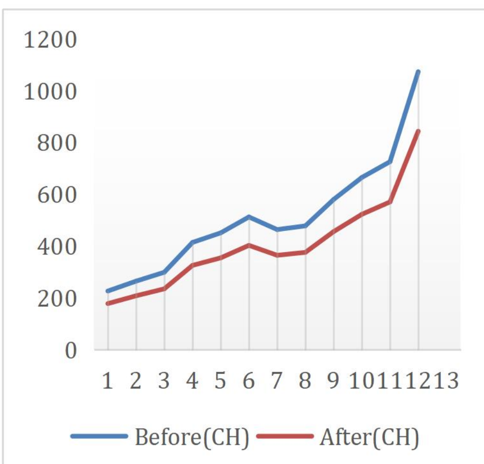

Figure 11:CH contrast chart

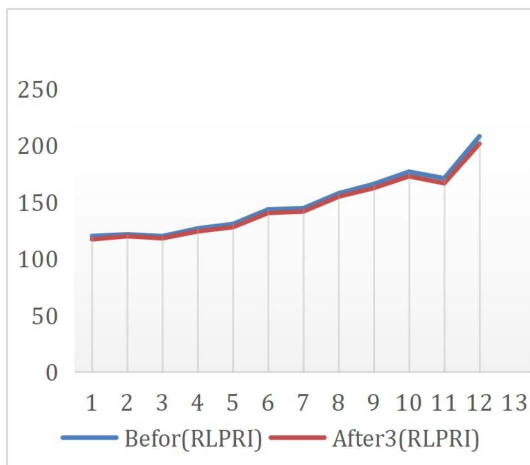

Figure 12: RLPRI contrast chart

According to the graphical analysis, along with the control of CH value, RLPRI can also be controlled to some extent, although the amount of control for RLPRI is small, but it can also show that the strategy has played a certain effect.

7: Task 4: Determine Intervention Strategies

7.1: Analysis

Light pollution is a growing problem in many cities and protected areas around the world. Cities are bustling hubs of activity with bright lights and advertisements that often stay on all night. These lights can have a negative impact on the environment and human health. In addition, protected areas, such as national parks and wildlife refuges, are often threatened by artificial light sources that interfere with natural habitats and ecosystems. [7]

Based on the consideration of practicality and effective application value, we decided to select the core urban area of Hefei City and Chaohu County as the research subjects and apply the strategies in the third question to these two regions.

7.2: Operation

For Chaohu Lake, which is considered as a protected area, we ran each of the three strategies using the model and compared the results of the runs with the PLCRI levels in the no-action scenario.

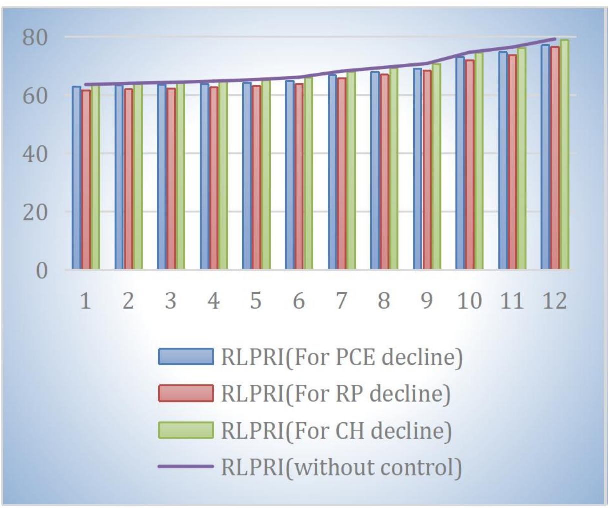

Figure 13: RLPRI's variation in the Chaohu area

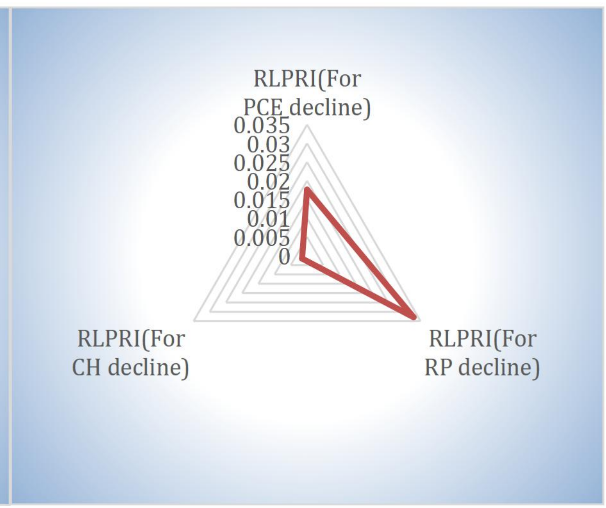

Figure 14: PLCRI's average decrease in Chaohu area

Based on the results of the calculations, we obtain the following conclusions:

(1) For a reduction PCE strategy, RLPRI decreases by an average of 1.765% year-over-year.

(2) For a reduction RP strategy, RLPRI decreases by an average of 3.286% year-over-year.

(3) For a reduction CH strategy, RLPRI decreases by an average of 0.153% year-over-year.

For the core urban area of Hefei City, we ran each of the three strategies using the model and compared the results of the runs with the RLPRI levels in the no-action scenario.

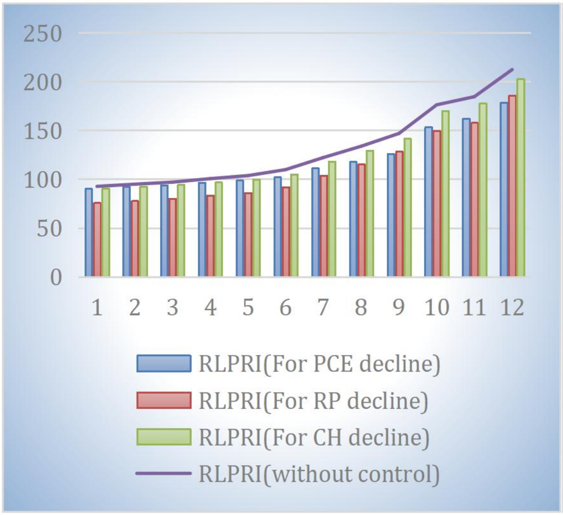

Figure 15. Effectiveness of implementation stratigies in the core urban area

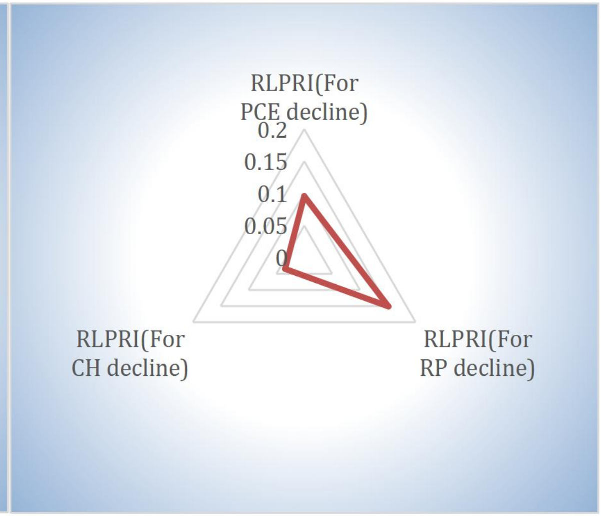

Figure 16. PLCRI's average decrease in the core urban area

Based on the results of the calculations, we obtain the following conclusions:
(1) For a reduction PCE strategy, RLPRI decreases by an average of 9.587% year-over-year.
(2) For a reduction RP strategy, RLPRI decreases by an average of 15.121% year-over-year.
(3) For a reduction CH strategy, RLPRI decreases by an average of 3.441% year-over-year.

7.3: Conclusions

Therefore, we can determine that reducing population in Chaohu is the most effective strategy to reduce the risk level of light pollution for Chaohu Lake (protected area), while CH appears to be not so effective. Realistically considering that there are few new buildings in the protected area every year, but there is a high movement of people such as tourists. When there are fewer visitors local lighting such as some light shows for tourists will be reduced, and the visitors themselves will carry less light, thus reducing the overall level of light pollution risk, and this result has credibility.

From this line graph and radar chart, we can clearly observe that both the control of population size and the reduction of public electricity consumption can mitigate the risk of light pollution to a great extent. A reduction in population would make the city less densely populated, which would effectively reduce light pollution from personal electricity use, while reducing public lighting at night is a very direct measure to reduce unnecessary waste of resources.

In terms of changing trends, although the strategy of controlling the population size has a great advantage at the beginning, as the city grows, reducing public lighting electricity consumption will gradually become the optimal solution.

8. Task 5: Produce a 1-page flyer


HeFei
Turn off a lamp
and
light up a life.
We will plan to turn off
half of the street lights after 21:00,
which can not only reduce
light pollution, but also protect our lives.
I
H
F

This flyer depicts the city of Hefei at night and emphasizes the importance of saving energy. The text on the poster reads "We plan to turn off half of the street lights after 21:00. This not only reduces light pollution, but also protects our lives." The flyer aims to raise awareness of light pollution and the need to save energy, and to encourage individuals to take action to reduce energy use during off-peak hours. The flyer's image of the city at night reinforces the idea that we can all do our part to protect the environment and preserve resources for future generations.

9. Sensitivity Analysis and Error Analysis

9.1 Error Analysis

In task1, we statistically collected the data of PEC, RP, CH, PT, GT affecting the light pollution risk level RLPRI in Hefei city for each year from 2002 to 2013 and obtained the linear regression equation of PEC, RP, CH, PT, GT with RLPRI using linear regression (least squares method):

$$\mathrm{RLPRI}^* = 58.503 + 3.518\mathrm{PEC}^* + 0.117\mathrm{RP}^* + 0.028\mathrm{CH}^* + 0.002\mathrm{PT}^* - 0.004\mathrm{GT}^*$$

Now we take the average of the indicators from 2002-2013 i.e.

$$\overline{PEC} = 11.9081,$$
$$\overline{RP} = 529.463,$$
$$\overline{CH} = 512.362,$$
$$\overline{PT} = 16461.5,$$
$$\overline{GT} = 15176.9167,$$
$$\overline{RLPRI} = 141.4252.$$

Substituting the resulting mean values into the original linear regression equation, the regression mean of RLPRI was obtained as

$$\overline{RLPRI}^* = 148.9071$$

Therefore, the error level of our model of light pollution risk level in Hefei is

$$e^* = \frac{\overline{RLPRI}^* - \overline{RLPRI}}{\overline{RLPRI}} * 100\% = 5.2904\%$$

9.2 Sensitivity analysis.

Based on the linear regression equation we obtained $\overline{RLPRI}^* = 58.503 + 3.518\overline{PEC} + 0.117\overline{RP} + 0.028\,\overline{CH} + 0.002\overline{PT} - 0.004\,\overline{GT} = 148.9071$, we performed sensitivity analysis for each metric.

Sensitivity Analysis of PEC*

$\overline{PEC} = 11.9081$, and to test the sensitivity of its change to the overall model change, we assume that it changes by ten percent, $\overline{PEC_1} = 11.9081 *（1 + 10\%）= 13.09891.$

Substituting $\overline{PEC_1}$ back into the original linear regression equation, we obtain the new equation $\overline{RLPRI_1}^* = 58.503 + 3.518\overline{PEC_1} + 0.117\overline{RP} + 0.028\,\overline{CH} + 0.002\overline{PT} - 0.004\,\overline{GT} = 153.0936.$

The rate of change of RLPRI at this point is

$$\Delta\text{RLPRI} = \frac{\overline{RLPRI_1}^* - \overline{RLPRI}^*}{\overline{RLPRI}^*} * 100\% = 2.81\%$$

which means that for every 10% change in PEC*, the output of the model will change by 4.16%.

Sensitivity Analysis of RP*

$\overline{RP} = 529.463$, and to test the sensitivity of its change to the overall model change, we assume that it changes by ten percent, as $\overline{RP_1} = 529.463 * (1 + 10\%) = 582.4093$. Substituting $\overline{RP_1}$ back into the original linear regression equation, we obtain the new equation $\overline{RLPRI_2}^* = 58.503 + 3.518\overline{PEC} + 0.117\overline{RP_1} + 0.028\,\overline{CH} + 0.002\overline{PT} - 0.004\,\overline{GT} = 155.0991$

The rate of change of RLPRI at this point is $\Delta\text{RLPRI} = \frac{\overline{RLPRI_2}^* - \overline{RLPRI}^*}{\overline{RLPRI}^*} * 100\% = 4.16\%$, which means that for every 10% change in PEC*, the output of the model will change by 4.16%.

Sensitivity Analysis of $\overline{CH}$

$\overline{CH} = 512.362$, and to test the sensitivity of its change to the overall model change, we assume that it changes by ten percent, as $\overline{CH_1} = 512.362 * (1 + 10\%) = 563.5982$. Substituting $\overline{CH_1}$ back into the original linear regression equation, we obtain the new equation $\overline{RLPRI_3}^* = 58.503 + 3.518\overline{PEC} + 0.117\overline{RP} + 0.028\,\overline{CH_1} + 0.002\overline{PT} - 0.004\,\overline{GT} = 150.3389$

The rate of change of RLPRI at this point is $\Delta\text{RLPRI} = \frac{\overline{RLPRI_3}^* - \overline{RLPRI}^*}{\overline{RLPRI}^*} * 100\% = 0.963\%$, which means that for every 10% change in PEC*, the output of the model will change by 0.0963%.

Sensitivity Analysis of $\overline{PT}$

$\overline{PT} = 16461.5$, and to test the sensitivity of its change to the overall model change, we assume that it changes by ten percent, as $\overline{PT_1} = 16461.5 * (1 + 10\%) = 18107.65$. Substituting $\overline{PT_1}$,back into the original linear regression equation, we obtain the new equation $\overline{RLPRI_3}^* = 58.503 + 3.518\overline{PEC} + 0.117\overline{RP} + 0.028\,\overline{CH} + 0.002\overline{PT_1} - 0.004\,\overline{GT} = 152.1967$

The rate of change of RLPRI at this point is $\Delta\text{RLPRI} = \frac{\overline{RLPRI_4}^* - \overline{RLPRI}^*}{\overline{RLPRI}^*} * 100\% = 2.211\%$, which means that for every 10% change in PEC*, the output of the model will change by 2.211%。

Sensitivity Analysis of $\overline{GT}$

$\overline{GT} = 15176.9167$, and to test the sensitivity of its change to the overall model change, we assume that it changes by ten percent, as $\overline{GT_1} = 15176.9167 * (1 + 10\%) = 16694.61$. Substituting $\overline{CH_1}$ back into the original linear regression equation, we obtain the new equation $\overline{RLPRI_5}^* = 58.503 + 3.518\overline{PEC} + 0.117\overline{RP} + 0.028\,\overline{CH_1} + 0.002\overline{PT} - 0.004\,\overline{GT} = 142.824$

The rate of change of RLPRI at this point is ΔRLPRI $= \frac{\overline{RLPRI_5}^* - \overline{RLPRI}^*}{\overline{RLPRI}^*} * 100\%$ =-4.077%, which means that for every 10% change in PEC*, the output of the model will change by -4.077%。

10. Model Evaluation and Further Discussion

10.1 Strength

The prediction model of light pollution risk level in Hefei City we established is closely related to the daily life of the general public and fully takes into account all aspects that may affect the risk level of light pollution.

The data of various indicators of Hefei city and its county-level regions from 2002 to 2013 were collected and collated from real and reliable sources. It was ensured that the model was built and calculated based on real data in reality.

At the same time, we conducted a goodness-of-fit analysis of the model, and the results show that our model fits well and the model has high credibility and application value.

We reflected the effects of light pollution on various aspects of human life in our model using variable substitution, and not only that, we also took into account the effects of light pollution on various organisms in nature and even the whole ecosystem.

According to our error analysis, our model has a small level of error.

Our model is also a realistic guide to what we should do to reduce the level of light pollution risk and, in conjunction with the previous sensitivity analysis, to which areas we should target to bring the most utility.

10.2 Weaknesses

Due to limited ability to collect information and data, our team was only able to collect data from about 15 years ago. The lag of data led to the lag of our model. Due to the limited ability of our team members to consider only five influencing factors in the model, the model has some limitations.

10.3 Further Discussion

In the next discussion, we will try to improve our model by considering as many factors as possible that may affect the risk level of light pollution, so that our model is universal. We also use the method of principal component analysis to identify the factors that have a significant effect on the risk level of light pollution among many factors, and eliminate the factors with a small level of influence, so as to optimize the model.

11.Conclusion

In conclusion, light pollution is a growing concern with adverse effects on the environment, human health and wildlife. This paper develops a metric Regional Light Pollution Risk Index

(RLPRI) to measure light pollution risks in different regions, and applies it to four different regions in Hefei City to identify their risk levels. This paper describes three intervention strategies to address light pollution. Through data analysis, it is found that controlling public lighting electricity consumption (PLE) is the most effective way to control RLPRI. The flyer produced in Task 5 provides an opportunity to raise people's awareness of the impact and importance of light pollution and encourage them to take action against it. By implementing the intervention strategies proposed in this paper, communities can reduce the impact of light pollution. harm and promote sustainable development.

This paper provides some insights into the impact of light pollution and proposes applicable indicators, models and intervention strategies and flyer to address this growing problem. By taking steps, rural and urban regions can reduce the risk of light pollution and promote sustainable development, ultimately contributing to a healthier environment and a better quality of life for everyone.

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Appendices

```
import numpy
import pandas
from spsspro.algorithm import statistical_model_analysis
#Generate case data
data_x1 = pandas.DataFrame({
    "A": numpy.random.random(size=100),
    "B": numpy.random.random(size=100)
})
data_x2 = pandas.DataFrame({"C": numpy.random.choice(["1", "2", "3"], size=100)})
data_y = pandas.Series(data=numpy.random.choice([1, 2], size=100), name="Y")
result = statistical_model_analysis.linear_regression(data_y=data_y, data_x1=data_x1,
data_x2=data_x2)
print(result)
```