Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
E		2320658

Evaluation Model of Light Pollution by Multi-conditional AHP

Summary

Artificial light has become a great convenience for people but it also brings with it some dangerous side effects. The abuse of artificial light at night not only disrupts the circadian rhythms of animals and plants, but also has irreversible consequences for human health. California's light pollution problem is a classic example. As the use of artificial light rises, the challenge of light pollution is becoming increasingly difficult to overcome. To find the most effective and cost-efficient remedy to light pollution, we must begin by calculating the potential risks associated with it. The effects of light pollution are very extensive and cannot be measured by a single indicator. In order to get a full understanding of the risks associated with light pollution, we need to develop a model for estimating its risk level.

When constructing the light pollution risk assessment model, we can divide it down into three components: economic, demographic, and ecological impacts. In order to accurately estimate the negative impacts of light pollution, we have identified three indicators that can best indicate its risk level: Gross Domestic Product (GDP) per capita, population density and the biological abundance index.

The weights of the three indexes are determined by using an analytic hierarchy process (AHP), and appropriate functions are used to construct the models for the three types of influences. Finally, we add the three impact components together to obtain a model for assessing light pollution risk levels.

In our case study, we chose to examine California for two primary reasons. Firstly, California produces a significant amount of light pollution which needs to be addressed urgently. Secondly, California boasts a rich variety of different landscapes and environments making it an ideal site to evaluate the accuracy of our model.

We identified four typical regions: protected locations, rural, suburban, and urban. Due to the severity of light pollution in California, an effective and inexpensive response is essential to address the issue. Otherwise, the growth of the city may be severely hampered without resolution of light pollution. Therefore, measures should be proposed based on the determinants that contribute to the level of light pollution risk. We propose the following measures in three types of communities:

1. Control the light emitted in and above the horizontal direction.
2. Limit the area of lighting, eliminate over-lighting.
3. Limit the utilization of light sources which emit specific wavelengths.

We focused on the effectiveness of the third measure, which was used in four regions and reduced light pollution risk levels by $0\%, 2.59\%, 2.63$ and 2.50% respectively. Therefore, it can be concluded that the improvement effect of this intervention strategy is relatively significant in the suburban area. It can be inferred that the third measure was relatively effective in reducing light pollution risk levels, as it achieved a decrease of $0\%, 2.59\%, 2.63\%$ and 2.50% in four regions respectively. This improvement effect is especially pronounced in suburban areas.

Contents

1 Introduction

Although the widespread use of artificial lighting has brought about great convenience in our lives, it has also caused serious light pollution problems. More than 80 percent of the world's population currently lives in areas with artificial light, and almost 99 percent of North Americans and Europeans are unable to see the Milky Way[1]. Aside from destroying astronomical views, light pollution has various adverse effects. From increasing the risk of cancer to intensifying traffic accidents, it is adversely affecting people's health in a variety of ways. In day-to-day life, the most common light pollution is caused by the glare of pedestrians and drivers arising from reflection of glass-walled buildings, as well as the distress caused by inappropriate lighting at night. Furthermore, light pollution can cause irreversible damage to ecosystems. The living space of nocturnal creatures is compressed, and the circadian rhythm is also affected to some extent[2].

In short, light pollution is causing a significant amount of economic losses and damaging the environment in many ways. To mitigate these effects, we should take proper steps to reduce its negative impact while still enjoying the benefits of artificial lighting.

Actually, the problem of light pollution has been developing for a long time. In 1972, Andrew Observatory in Scotland and Stomner Observatory in Canberra, Australia, raised the issue of the influence of light in the sky on astronomical phenomena. In 1980 the International Astronomical Union and the International Commission on Illumination jointly published an article on "Reducing sky light in cities near observatories". Even though the scientific community is aware of the seriousness of light pollution, it has not come up with effective solutions. As a result, the severity of light pollution is still increasing.

1.1 Problem Statement

As tasked by COMAP's Illumination Control Mission, this study strives to raise public awareness of the harms associated with light pollution, while also proposing effective measures to mitigate those harms. We are focusing on four different locations in order to comprehensively estimate the level of risk posed by light pollution and to identify potential solutions to any such threats. Due to the multifaceted nature of light pollution, it is difficult to accurately calculate the level of risk. Therefore, our estimating methods and strategies are based on detailed research and a thorough understanding of the existing impacts in the real world.

2 Preparation of the Models

Despite the detrimental effects of light pollution on those exposed to it being real and tangible, quantified data can be difficult to obtain. To ensure accurate analysis and understanding, the relevant terms must be defined accurately and precisely.

2.1 Definitions

Since light pollution is a complex interdisciplinary issue, it is important to define a term with operational care. For this reason, we use the following definitions in this paper for the sake of clarity:

- **Light pollution risk level** of a certain region is a measure of the vulnerability of the region to a certain level of light pollution. It can be calculated as the product of consequence and likelihood values.
- **Gross Domestic Product (GDP) per capita** shows a country's GDP divided by its total population. It is a monetary measure of the market value of all the final goods and services produced and sold (not resold) in a specific time period by countries.

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Definition
RL	Light pollution risk level
RL_1	Light pollution risk level due to **economic factors**
RL_2	Light pollution risk level due to **population factors**
RL_3	Light pollution risk level due to **ecology factors**
GDP	GDP of the certain selected region
r_1	Incidence of non-healthy states caused by light pollution
p	Population of the certain selected region
A	Area of the certain selected region
r_2	Proportion of species significantly affected by light pollution
b	Index of biological abundance of the certain selected region

3 The Models

3.1 The basic model and assumptions

To begin the analysis, we decided to first identify the main targets of light pollution effects, and there exists a certain risk level for each target (Figure 1). This conception gives us the general model of the metric of light pollution risk level.

$$RL = \frac{1}{N}\sum_{i=1}^{N} RL_i$$

We make the following assumptions:

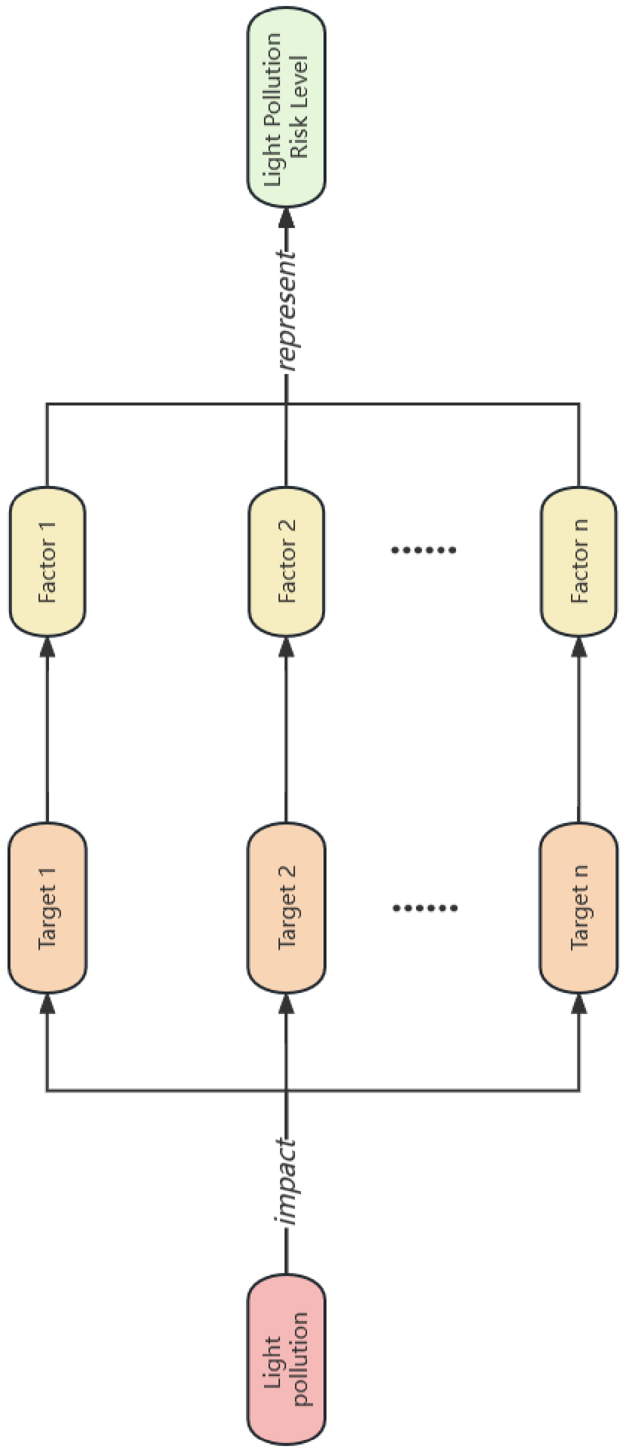


Figure 1: The basic model

- The level of transportation development in a region is positively correlated with the level of economic development
- The level of energy demand of a region is positively correlated with the level of economic development
- Since the assessment system model is based on communities, we assume that the indicators such as population distribution and biological population distribution are homogeneous within the relatively small spatial scale of regions.

3.2 Refinements

Using the initial model as a base, we can now make useful modifications to increase its accuracy and reliability. Our goal is to precisely identify factors such as those mentioned above and incorporating them into the model's expressions.

According to previous studies, the impact of light pollution on a region is divided into three main categories: economic, demographic, and ecological impacts (Figure 2).

3.2.1 Economy risk level factor

The economic impact of light pollution is mainly in two areas: transportation and energy. The adverse effects of light pollution on road vehicles are mainly manifested in the negative impact on the driver's normal field of vision, as well as the distance and movement of vehicles ahead caused by glare, traffic signals, lighthouses and lights and other signs of error in judgment, reducing the efficiency of the driver[2]. Meanwhile, light pollution can lead to a certain degree of energy waste[3]. Therefore, we can conclude that the more developed a place is in terms of transportation and the higher the level of energy demand, the more it is affected by light pollution. According to our assumption, We can use the local GDP per capita to represent the local transportation development level and energy demand level. However, our data suggest that GDP is not proportional to the level of transportation development or energy demand. Upon further study, we found that the transportation and energy industries account for a small share of GDP. However, for the sake of simplicity, we continue to make GDP to represent the level of transportation development and energy demand. This yields a logic model:

$$RL_1 = a_1 \ln\left(\frac{GDP}{p} + b_1\right)$$

Consider a protected land with zero GDP, so it can be assumed that light pollution has no effect on the economy of this area. With this condition we can conclude that $b_1 = 1$.

3.2.2 Population risk level factor

In terms of human beings, nighttime light exposure reduces pineal melatonin production and secretion, which in turn affects normal biological rhythms. Altered biological rhythms may lead to performance, alertness, sleep, and metabolic disturbances. Exposure to light at night inhibits the production of the pineal hormone melatonin, and since melatonin is a cancer suppressor or

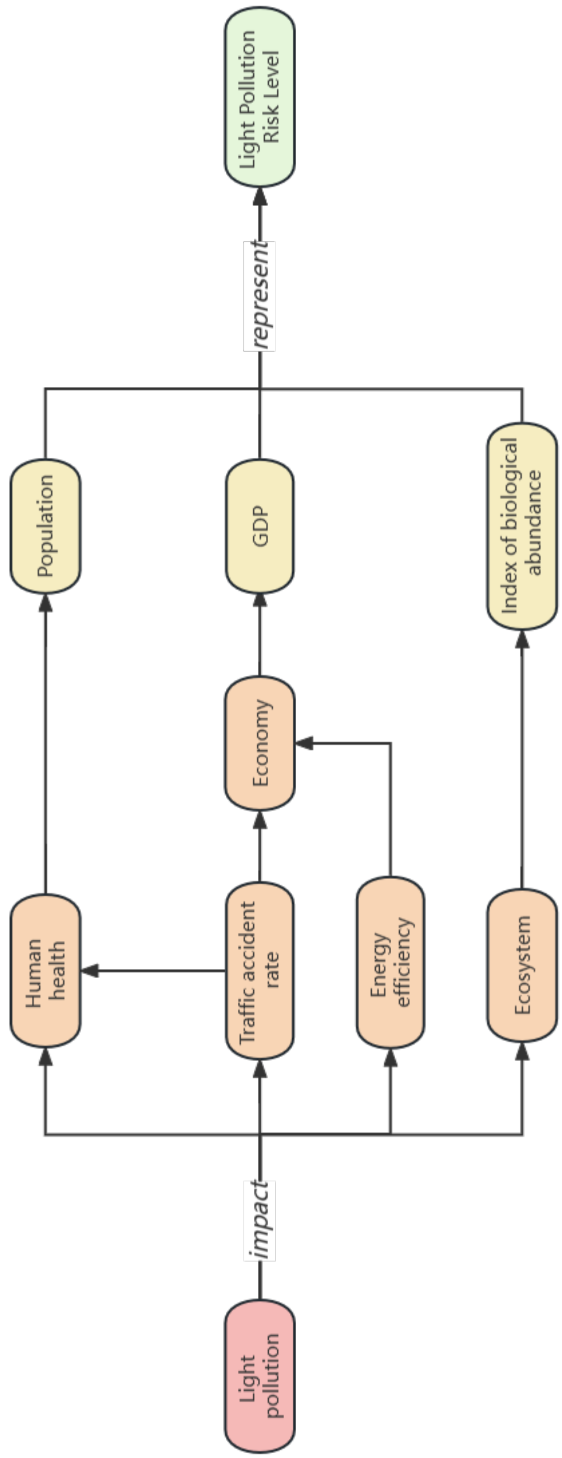


Figure 2: The objects affected by light pollution and their corresponding indicators

anti-cancer agent, lower melatonin levels in the blood may promote the growth of certain types of cancer[4]. Hence, for the same incidence (light pollution-induced non-health status), the higher the population density, the higher the risk of being affected by light pollution. Again, when the area is unpopulated, we also consider the effect of light pollution on the demographic factor to be zero. Our model for population risk level factor is:

$$RL_2 = a_2 \frac{r_1 p}{A}$$

3.2.3 Ecology risk level factor

Light pollution has clear effects on the behavioral and population ecology of organisms in their natural environment. In general, these effects arise from misguided perceptions of organism orientation and attraction or repulsion to altered light environments, which in turn may affect foraging, reproduction, migration and communication. In addition, certain specific species are more vulnerable to the catastrophic consequences of these effects, such as genocide[5]. Thus the model for ecology risk level factor is:

$$RL_3 = a_3 r_2 b$$

3.3 Final model

3.3.1 The model with parameters

In summary, our model is presented as follows:

$$\begin{aligned} RL &= \frac{1}{3}\sum_{i=1}^{3} RL_i \\ RL_1 &= a_1 \ln\left(\frac{GDP}{p} + b_1\right) \\ RL_2 &= a_2 \frac{r_1 p}{A} \\ RL_3 &= a_3 r_2 b \end{aligned}$$

These functions indicate the evaluation level of the degree of damage an area may cause when exposed to a certain level of light pollution.

3.3.2 How to determine the parameters

Firstly, we collect light pollution and population density Geo-data. And visualize these data in the map by python. For example, the Figure 3 represent the Limiting Magnitude of San Francisco. By visualising this data, we have a clearer direction for our model building.

We have completed the basic establishment of the model for predicting the risk level of light pollution, but there are still three parameters a_1, a_2, a_3 in the model. Because of the difference between human environment and natural environment in different regions, we need to use Analytic Hierarchy Process (AHP) to determine the parameters in different situations.

The AHP we use here is the most widely used method in weighting, despite its poor objectivity. However, the weights determined by the objective method do not fully match their importance in practice.

The subjective method of determining the relative importance of three parts is advantageous, as it allows for varying degrees of significance within the subject process. Using the more scientifically-rational AHP method to obtain the weights of the parameters is preferred over more objective models, as the assessment of the importance of each parameter is a subjective judgement. This technique allows us to determine weights based upon our own individual observations and experience.

First of all, we have to distinguish between different communities types. The data we found is the population per square mile, which is calculated with the community as node. For example, the Figure 4 shows that the data allows us to map out regions of high population density.

we can divide out data into the following categories:

$$[0,50],[50,200],[200,600],[600,\infty)$$

And we use N_1, N_2, N_3, N_4 to represent the number of points in each categories. Then we put these data into the real map, and then randomly select the coordinates, by judging the characteristics of the points around the coordinates, to distinguish urban suburban rural areas:

- urban: where you have high population density communities taking up most of the area.

$$\frac{N_3+N_4}{\sum_{i=1}^{4} N_i} \geq 0.7$$

- suburban: there is no high population density community and only a few with median population density.

$$\frac{N_3+N_4}{\sum_{i=1}^{4} N_i} < 0.7 \quad and \quad \sum_{i=1}^{4} N_i \geq 2$$

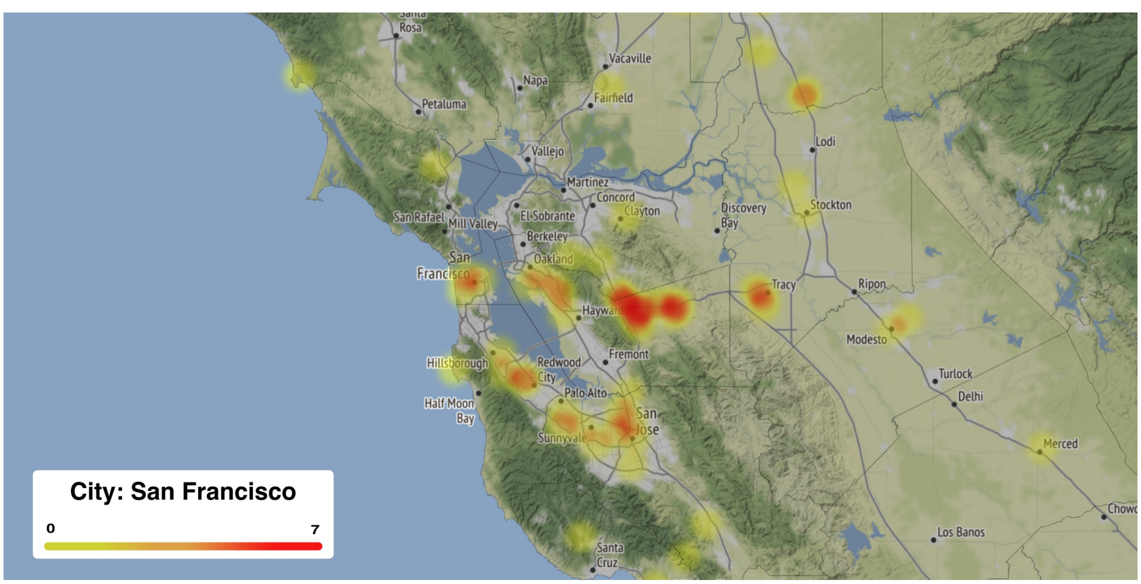


Figure 3: SF artificial light magnitude graph

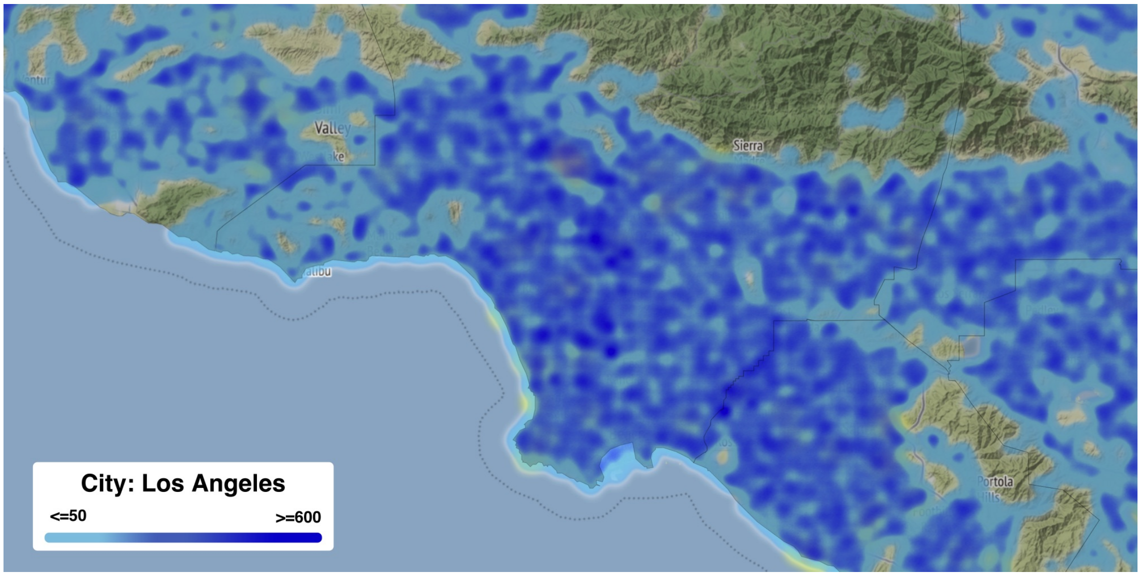


Figure 4: LA population density graph

- rural: there are only very few communities with low population density.

$$N_3 + N_4 = 0 \quad and \quad \sum_{i=1}^{4} N_i \leq 2$$

- protected land: these points are chosen artificially, since there's usually no community in protected land.

$$\sum_{i=1}^{4} N_i = 0$$

Five random points were taken from each of the three categories in the city. The accuracy and objectivity of data can be guaranteed by taking random points. (The detail of the graph will show in the Figure 5.)

Then we apply the AHP to the model and get the parameters.

3.3.3 The final model with determined parameters

As for the determination of the importance of each indicator, the following table is finally obtained after group discussion. We obtained the correlation matrix through the importance score, and then obtained the corresponding weights of different components through AHP for the final calculation of the light pollution risk level. Here is the matrix and weight table:

Table 2: ANP table

Urban community	RL_1	RL_2	RL_3
RL_1	1	2	4
RL_2	1/2	1	2
RL_3	1/4	1/2	1
Suburban community	RL_1	RL_2	RL_3
RL_1	1	1	1
RL_2	1	1	1
RL_3	1	1	1
Rural community	RL_1	RL_2	RL_3
RL_1	1	2/3	1/2
RL_2	3/2	1	3/4
RL_3	2	4/3	1

Table 3: Coefficient

Region Type	a_1	a_2	a_3
A protected land location	0	0	1
A rural community	2/9	1/3	4/9
A suburban community	1/3	1/3	1/3
An urban community	4/7	2/7	1/7

4 Analysis of the model

4.1 Strengths

Our model of light pollution is desirable in many ways.

4.1.1 First strength

The model is straightforward. Its implementation employs a divide-and-conquer paradigm, which divides the complexity of light pollution risk into manageable parts. For this purpose, we have selected three key effects of light pollution to be modeled: economic, demographic, and ecological impacts.

When assessing the economic implications of light pollution, our research revealed that transportation and energy were directly linked to the region's GDP per capita. To properly quantify light pollution's effect on the overall economy, we thus introduced an index of each region's GDP per capita.

When estimating the impact of light pollution on both residents and organisms, we take into account two factors:

- The total number of residents multiplied by the incidence rate
- The proportion of nocturnal organisms multiplied by the abundance index

The data collected from these calculations is then processed to accurately estimate the effects of light pollution on residents and organisms.

4.1.2 Second strength

The model is versatile and applicable to any region and makes it easy to customize parameters in view of the different natural and artificial surroundings. With this model, it's possible to gauge light pollution levels in each locale by simply entering economic, demographic, and ecological data sets, which subsequently allows us to fine-tune relevant prevention and control measures accordingly.

4.2 Weaknesses

1. In order to simplify things, we only used three main factors to estimate the risk level of light pollution. In reality, the impacts of light pollution go beyond these. This model sacrificed some comprehensiveness in exchange for simplicity and universality. Therefore, the comprehensiveness of this model is insufficient.

2. The simplicity of the models can lead to unreasonable and inaccurate scenarios. To address this issue, we need more accurate data. We should collect data more accurately about the biological abundance index in an area where the natural environment varies significantly. This will allow us to better estimate the effects of light pollution on organisms and reduce

the errors caused by data collection problems. By using more precise measurements of the biological abundance index, the model will be able to make more accurate estimates.

5 Case study: California

5.1 Applying the metric model

We have collected the relevant data to use the model. The data are shown in Table 4. We chose the incidence of breast cancer under the influence of light pollution as $r_1 = 0.12\%$[7] and the percentage of California nocturnal animal species in the total animal species as $r_2 = 6\%$[8].

5.1.1 A protected land location

$RL_1 = 0$, $RL_2 = 0$, $RL_3 = 37.08$, $RL = 37.08$

Because organisms in the protected land are extremely sensitive to light pollution and minor light pollution can lead to very serious consequences, the level of light pollution risk is higher than at other types of locations.

5.1.2 A rural community

$RL_1 = 2.3565$, $RL_2 = 0.6659$, $RL_3 = 10$, $RL = 13.0224$

The impact of light pollution in the rural community is relatively low, but it cannot be ignored, and its main affected factors are the local ecological environment.

5.1.3 A suburban community

$RL_1 = 3.7245$, $RL_2 = 0.6804$, $RL_3 = 8.1333$, $RL = 12.5382$

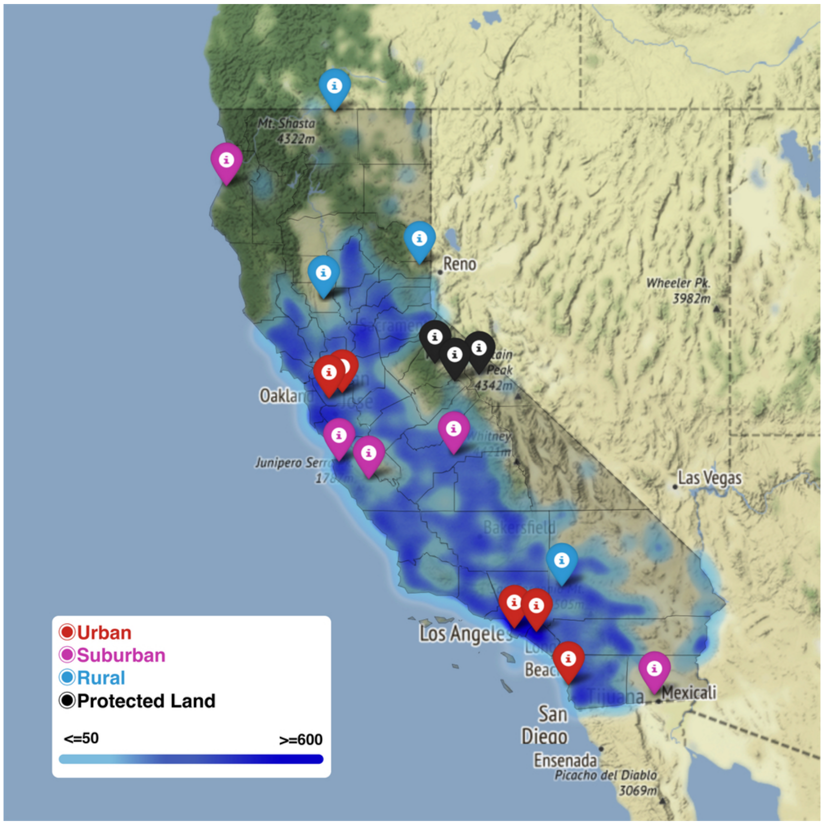
The suburban community are affected by light pollution in a similar way to rural areas, although their economic and demographic aspects are more affected by light pollution.

5.1.4 An urban community

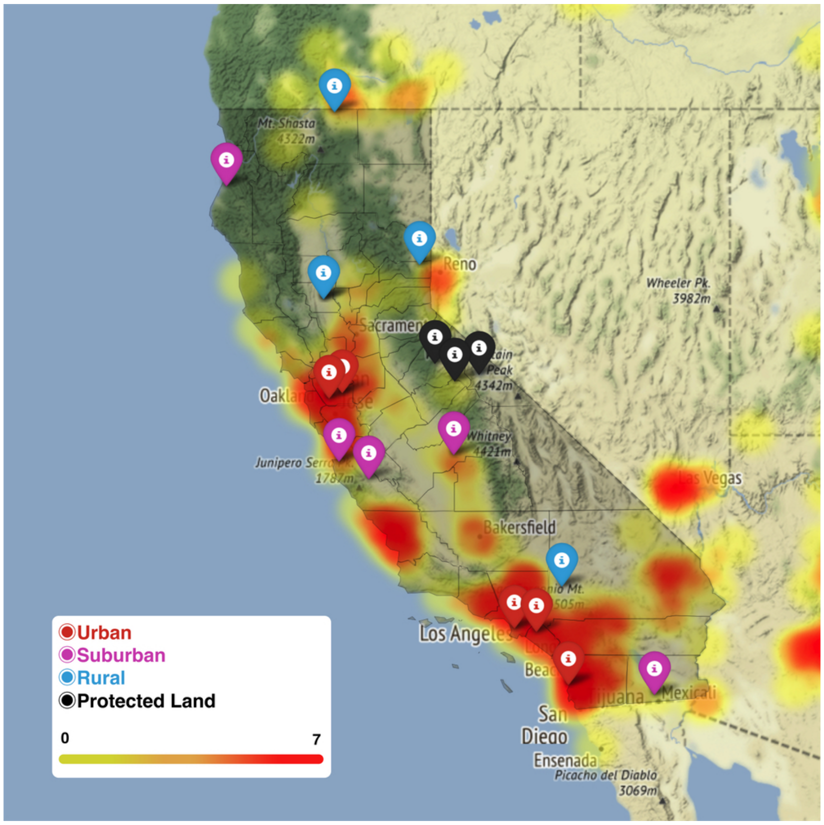
$RL_1 = 6.3002$, $RL_2 = 0.5725$, $RL_3 = 4.4742$, $RL = 11.3469$

Table 4: Data

Region Type	Name	GDP per capita	Population density	Biological abundance
A protected land location	Yosemite	0	3	618
A rural community	Firebaugh, CA	40.31k	1,701	305
A suburban community	Calistoga, CA	71.23k	1,664.8	500
An urban community	El Cajon, CA	61.42k	1,670	522



(a) Population Heat-Map
(darker blue represents the higher population density)



(b) Limiting Magnitude Heat-Map
(darker red represents that this region has more artificial lights)

Figure 5: Four diverse types locations in California

The negative effects of light pollution on the urban environment are mainly experienced economically. However, its impact on biodiversity should not be overlooked, since the chosen area near the Pacific Ocean has a more diverse range of species due to its favorable climate conditions.

5.2 Intervention strategies

According to previous studies, the following intervention strategies can effectively address light pollution[6].

5.2.1 Control the light emitted in and above the horizontal direction

The light emitted to 0 to 45° above the horizontal plane will travel a long distance in the atmosphere, which enhances the additive property of light pollution and seriously exacerbates the problem of light pollution, especially in densely populated areas[6]. Therefore, controlling the emission of light in and above the horizontal direction is an effective intervention strategy to control light pollution.

Actions that can be taken to reduce upward spill light is that the government can issue relevant laws and regulations to restrict the use of lights in commercial billboards, entertainment venues, night lighting and other fields, and limit the lighting angle of light sources.

If the upward spill light can be limited, it can greatly reduce the propagation distance of light in the atmosphere, thereby reducing the scope of light pollution, such as making it difficult for the light in human-inhabited areas to diffuse and affect nearby protected areas (RL_3). Additionally, this restriction will improve road user comfort and visual performance by reducing direct glare from certain light sources[6], thereby reducing traffic safety risks from light pollution.

5.2.2 Limit the area of lighting, eliminate over lighting

When the illuminated area does not actually need to be illuminated, this part of the luminous flux is wasted. Additionally, when the illumination is more intense than the minimum required by the task, this also leads to an extra expenditure of energy and is therefore wasted. As a result, energy is being consumed without achieving a necessary goal.

Actions to limit lighting areas and eliminate over lighting include:

- Accurately design lighting sources to illuminate only the required range with the required light intensity.
- Reduce the lighting intensity or turn off the light source when there is no need for use.

If the above actions can be achieved, the energy waste caused by light pollution will be reduced to a certain extent, thereby reducing the impact of light pollution on the economy (RL_1).

5.2.3 Limit the use of light sources that emit light of certain wavelengths

Study shows certain short-wavelength lights have more pronounced effects on human health[6]. Therefore, it is necessary to limit the wavelength emitted by the light source.

Relevant restrictions can be established from the manufacturer's standpoint in order to guarantee that light sources are constructed in a manner which reduces the effect of light pollution on people. It is essential that production standards be followed so that the human population doesn't experience unnecessary levels of light pollution.

If the wavelength of light emitted by the source can be restricted, it will have a beneficial effect in reducing the amount of light pollution that impacts the human body, thereby reducing the population risk level factor (RL_2).

5.3 Effectiveness of intervention strategies

We choose the intervention strategies in 5.2.1 and 5.2.3 to test the effectiveness of the interventions

By applying the intervention strategy in 5.2.1, since the light pollution suffered by the protected area basically comes from the impact of the surrounding scattered light on organisms, if this intervention strategy is implemented, the biological factors of the light pollution risk level (RL_3)in the protected area will be greatly reduced, thereby reducing the light pollution risk level to an extreme low level. We can therefore determine that this intervention strategy is most effective in the protected land location.

By applying the intervention strategy in 5.2.3, we can consider that the corresponding probability (r_2) decrease to the level before light pollution, that is, a decrease of about 73%. After applying this change we recalculate the light pollution risk level and found that they decreased by $0\%, 2.59\%, 2.63\%$ and 2.50% respectively. Therefore, this intervention strategy is most effective in the suburban community.

6 Conclusion

We have developed a model that can help effectively estimate the light pollution risk index of different regions. By analyzing the variable factors included in this model, we can find the optimal solution strategy to suit the characteristics of each region.

In order to effectively streamline the model, we chose three principal components of light pollution to analyse. After employing suitable operations, we conducted AHP on these parts and arrived at a simple but precise estimation model. Depending on the type of communities, the weight of the three components varies to reflect the risk level of the light pollution better.

For the further study, I suggest that biological factors can be improved. For the sake of convenience, we chose to input the index of biological abundance, which unfortunately reduced the accuracy of our model. However, if we were able to gain more data regarding nocturnal animals, such as their period of activity that has been altered by artificial lights, we could change up the input variables used for biological factors and rebuild the model - allowing us to achieve improved and more accurate results in predicting the impact of light pollution on ecological environments.

References

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Appendix

5	6	7	8	9	10	11	12	13
County_ZIP	LATITUDE	LONGITUDE	CENSUS_TRACT	CENSUS_BLOCK_GROUP	ALL_PLAN		People_sq_mi	TT__Hospitals
Siskiyou_96044	42.00862824	-122.3437145	300	1	521		≤ 50	30
Siskiyou_96044	42.00461651	-122.5877059	400	1	521		≤ 50	30
Siskiyou_96044	42.00407581	-122.653804	400	1	521		≤ 50	30
Siskiyou_96044	42.00253378	-122.6058968	400	1	521		≤ 50	30
Siskiyou_96044	42.00207985	-122.4435443	400	1	521		≤ 50	30
Siskiyou_96044	42.0015992	-122.6394309	400	1	521		≤ 50	30
Siskiyou_96044	42.00136556	-122.6241416	400	1	521		≤ 50	30
Siskiyou_96064	42.00005044	-122.188809	200	1	521		≤ 50	30
Siskiyou_96044	41.99968327	-122.6816158	400	1	521		≤ 50	30
Siskiyou_96044	41.99927605	-122.4002994	400	1	521		≤ 50	30
Siskiyou_96044	41.99886214	-122.6671619	400	1	521		≤ 50	30
Del Norte_95567	41.99813447	-124.2087697	202	1	523		≤ 50	30
Siskiyou_96044	41.9980143	-122.4208618	400	1	521		≤ 50	30
Siskiyou_96134	41.9980143	-121.5829133	100	1	521		≤ 50	30
Siskiyou_96044	41.9978474	-122.355716	300	1	521		≤ 50	30
Del Norte_95567	41.99766714	-124.197954	202	1	523		≤ 50	30
Siskiyou_96134	41.99762709	-121.5594224	100	1	521		≤ 50	30
Siskiyou_96134	41.997567	-121.5981937	200	1	521		≤ 50	30
Siskiyou_96044	41.99693945	-122.6496987	400	1	521		≤ 50	30
Del Norte_95543	41.99655891	-123.7214247	202	3	523		≤ 50	30
Del Norte_95567	41.99641872	-124.1871114	202	1	523		≤ 50	30
Siskiyou_96044	41.99609158	-122.6133887	400	1	521		≤ 50	30
Modoc_96134	41.99608491	-121.3775225	200	1	519		≤ 50	30
Modoc_96134	41.9960582	-121.4354908	200	1	519		≤ 50	30
Modoc_96134	41.99598476	-121.4080922	200	1	519		≤ 50	30
Del Norte_95567	41.99583789	-124.1763316	202	1	523		≤ 50	30
Del Norte_95567	41.99496997	-124.1655698	202	1	523		≤ 50	30
Siskiyou_96044	41.99465618	-122.4319291	400	1	521		≤ 50	30
Del Norte_95567	41.99371481	-124.1436329	202	1	523		≤ 50	30
Del Norte_95567	41.99178529	-124.1220733	202	1	523		≤ 50	30
Siskiyou_96044	41.99166511	-122.414358	400	1	521		≤ 50	30
Del Norte_95567	41.99131793	-124.1330687	202	1	523		≤ 50	30
Siskiyou_96064	41.99086391	-122.1898331	200	1	521		≤ 50	30

Figure 6: Raw population data

ID	ObsType	ObsID	Latitude	Longitude	Elevation(m)	LocalDate	LocalTime	UTDate	UTTime	LimitingMag	SQMReading	SQMSerial	CloudCover	Constellation	SkyComment
2E+05	GAN	####	14.0739	121.325	124.28	2021-01-01	20:23	2021-01-01	12:23	-9999			over 1/2 of sky	Taurus	overcast skies
2E+05	GAN	####	48.6292	9.38716	368.365	2021-01-01	19:54	2021-01-01	18:54	-9999			over 1/2 of sky	Taurus	Himmel stark bewlkt. nicht einmal der Mond kommt so durch.
2E+05	GAN	####	-33.9389	18.8509	98.6686	2021-01-01	21:19	2021-01-01	19:19	2			clear	Orion	
2E+05	GAN	####	39.0393	-77.505	89.1158	2021-01-01	18:03	2021-01-01	23:03	2			clear	Perseus	
2E+05	SQM	####	36.0247	-115.016	605.645	2021-01-01	18:59	2021-01-02	02:59	3	17.96		clear	Orion	
2E+05	GAN	####	39.0558	-76.4988	25.4229	2021-01-02	00:19	2021-01-02	05:19	-9999			over 1/2 of sky	Perseus	Solid overcast and drizzle.
2E+05	GAN	####	33.5766	-111.848	425.86	2021-01-01	22:34	2021-01-02	05:34	3			clear	Orion	
2E+05	GAN	####	14.0739	121.325	123.714	2021-01-02	22:38	2021-01-02	14:38	-9999			over 1/2 of sky	Taurus	overcast skies
2E+05	GAN	####	40.9971	29.0425	12.1538	2021-01-02	18:47	2021-01-02	15:47	1			clear	Orion	Clear sky
2E+05	GAN	####	40.9971	29.0425	12.1538	2021-01-02	18:47	2021-01-02	15:47	1			clear	Orion	Clear sky
2E+05	GAN	####	40.9971	29.0425	12.1538	2021-01-02	18:47	2021-01-02	15:47	1			clear	Orion	Clear sky
2E+05	GAN	####	38.7801	-77.3867	60.111	2021-01-02	07:00	2021-01-02	12:00	7			over 1/2 of sky	Orion	Dark , thick , crisp , black , no clouds
2E+05	GAN	####	33.3182	131.414	672.933	2021-01-03	11:57	2021-01-03	02:57	3			over 1/2 of sky	Taurus	
2E+05	GAN	####	39.0558	-76.4988	25.4229	2021-01-03	04:38	2021-01-03	09:38	-9999			over 1/2 of sky	Orion	Solid overcast and rain.
2E+05	GAN	####	14.0738	121.325	123.989	2021-01-03	21:04	2021-01-03	13:04	1			1/2 of sky	Taurus	generally cloudy skies
2E+05	GAN	####	26.2712	50.6014	0	2021-01-03	18:21	2021-01-03	15:21	3			1/4 of sky	Orion	
2E+05	GAN	####	38.7801	-77.3867	60.111	2021-01-03	07:00	2021-01-03	12:00	7			over 1/2 of sky	Orion	Dark , no clouds no stars , brisk
2E+05	GAN	####	36.1448	-97.0582	277.791	2021-01-03	20:43	2021-01-04	02:43	4			clear	Orion	
2E+05	GAN	####	36.1448	-97.0582	277.791	2021-01-03	20:48	2021-01-04	02:48	4			clear	Orion	
2E+05	GAN	####	39.0558	-76.4988	25.4229	2021-01-04	00:16	2021-01-04	05:16	1			over 1/2 of sky	Orion	Some stars and the Moon are peaking through broken cloud cover.
2E+05	GAN	####	39.0558	-76.4988	25.4229	2021-01-04	03:03	2021-01-04	08:03	3			clear	Orion	A little hazy on the ground, but looking up is relatively clear.
2E+05	GAN	####	32.8791	131.993	217.384	2021-01-04	19:45	2021-01-04	10:45	6			clear	Taurus	
2E+05	GAN	####	35.8201	139.566	21.7223	2021-01-04	21:15	2021-01-04	12:15	3			clear	Taurus	TONIGHT IS NO WIND.
2E+05	GAN	####	32.8529	131.681	221.061	2021-01-04	21:10	2021-01-04	12:10	6			clear	Taurus	
2E+05	GAN	####	14.0738	121.325	123.403	2021-01-04	22:30	2021-01-04	14:30	-9999			over 1/2 of sky	Taurus	overcast skies due to the rains
2E+05	GAN	####	45.7602	15.9795	111.951	2021-01-04	21:11	2021-01-04	20:11	-9999			over 1/2 of sky	Orion	
2E+05	GAN	####	45.7855	15.7258	151.121	2021-01-04	21:35	2021-01-04	20:35	-9999			over 1/2 of sky	Taurus	
2E+05	GAN	####	40.6892	-80.1334	320.931	2021-01-04	18:02	2021-01-04	23:02	2			1/2 of sky	Perseus	some clouds
2E+05	GAN	####	-12.2344	-38.9713	244.018	2021-01-04	20:55	2021-01-04	23:55	4			clear	Orion	
2E+05	GAN	####	6.06213	80.2002	14.3252	2021-01-05	05:29	2021-01-04	23:59	3			over 1/2 of sky	Taurus	Sky is continuously covered with a thin layer of clouds. It is shiny, basically due to the moon light, as the fu
2E+05	GAN	####	40.8247	-80.1285	339.954	2021-01-04	20:10	2021-01-05	01:10	-9999			1/2 of sky	Orion	A large amount of light pollution. The sky appears to be gray. Difficult to sea anything.
2E+05	GAN	####	40.7044	-80.1338	337.972	2021-01-04	20:10	2021-01-05	01:10	-9999			over 1/2 of sky	Orion	The sky was grayish purple, I could not see anything.
2E+05	GAN	####	40.6907	-80.1424	328.585	2021-01-04	08:21	2021-01-04	13:21	-9999			over 1/2 of sky	Orion	It is very cloudy out and there are no stars
2E+05	GAN	####	40.6907	-80.1424	328.585	2021-01-04	08:21	2021-01-04	13:21	-9999			over 1/2 of sky	Orion	It is very cloudy out and there are no stars
2E+05	GAN	####	41.2714	-72.9846	44.8295	2021-01-04	20:57	2021-01-05	01:57	1			1/4 of sky	Orion	there were large clouds earlier but they subsided.
2E+05	GAN	####	33.2162	-111.701	423.386	2021-01-04	19:20	2021-01-05	02:20	4			clear	Orion	
2E+05	SQM	####	28.5341	-81.1577	22.8387	2021-01-04	21:38	2021-01-05	02:38	4	19.3		clear	Orion	
2E+05	GAN	####	33.2767	-111.691	407.315	2021-01-04	20:52	2021-01-05	03:52	2			clear	Orion	
2E+05	GAN	####	47.4966	-117.574	738.346	2021-01-04	20:49	2021-01-05	04:49	4			clear	Orion	Clear after frontal passage. Haze reaching up 15 degrees from horizon, more to NE with skyglow from Spo
2E+05	GAN	####	26.2484	-98.2946	46.0544	2021-01-04	23:42	2021-01-05	05:42	3			clear	Orion	Clear ! Can view constellations
2E+05	GAN	####	39.0558	-76.4988	25.4229	2021-01-05	03:33	2021-01-05	08:33	-9999			over 1/2 of sky	Orion	Solid overcast.
2E+05	GAN	####	40.8247	-80.1285	339.954	2021-01-04	20:10	2021-01-05	01:10	-9999			1/2 of sky	Orion	A large amount of light pollution. The sky appears to be gray. Difficult to sea anything.
2E+05	GAN	####	-12.2343	-38.9713	244.129	2021-01-04	20:04	2021-01-04	23:04	4			clear	Orion	
2E+05	GAN	####	14.0738	121.325	123.403	2021-01-05	22:41	2021-01-05	14:41	2			clear	Taurus	clear skies
2E+05	GAN	####	40.6907	-80.1424	328.585	2021-01-04	08:21	2021-01-04	13:21	-9999			over 1/2 of sky	Orion	It is very cloudy out and there are no stars
2E+05	GAN	####	40.692	-112.088	1360.69	2021-01-01	22:00	2021-01-02	05:00	-9999			over 1/2 of sky	Orion	
2E+05	GAN	####	40.692	-112.088	1360.69	2021-01-02	22:00	2021-01-03	05:00	3			1/4 of sky	Orion	
2E+05	GAN	####	40.692	-112.088	1360.69	2021-01-03	22:00	2021-01-04	05:00	4			clear	Orion	
2E+05	GAN	####	40.692	-112.088	1360.69	2021-01-04	22:00	2021-01-05	05:00	-9999			over 1/2 of sky	Orion	
2E+05	GAN	####	45.7602	15.9795	111.951	2021-01-05	20:31	2021-01-05	19:31	-9999			1/2 of sky	Orion	

Figure 7: Raw light pollution data


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Figure 8: Raw California boundaries Geo-data