

# The Impact of Light Pollution on the Star Photography

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## ABSTRACT

Light pollution, resulting from artificial outdoor lighting, significantly impedes the visibility of celestial objects, posing challenges for both astronomical research and astrophotography. This study investigates light pollution across 40 of China's largest cities, focusing on its relationship with economic indicators, population density, and geographic factors. By combining city-level data on GDP, population, and altitude, we identify patterns in luminous flux that reveal optimal locations for stargazing and astrophotography. The analysis shows that cities with lower economic activity and higher altitudes generally experience reduced light pollution, with Urumqi and Guiyang emerging as the most favorable locations for astrophotography based on combined economic and geographic characteristics. Findings indicate that urban planning and policy measures can play a critical role in managing light pollution, thereby supporting clearer skies and promoting sustainable development. This research provides a framework for identifying low-pollution observation sites and contributes to broader efforts to preserve dark skies for future generations.

## KEYWORDS

Light Pollution; Star Photography; Luminous Flux; Point Spread Functions.

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## 1. INTRODUCTION

Light pollution, defined as the human-made alteration of outdoor light levels from those occurring naturally, is the negative result of unnecessary and inefficient use of outdoor artificial light. It has raised many concerns, like affecting human health and wildlife behavior, but especially our ability to observe stars and other celestial objects in astrophotography. Sources of light pollution include streetlights, commercial and industrial facilities, artificial satellites, and other forms of artificial lighting that brighten the night sky, interfering with the visibility of celestial bodies.

Ground-based astronomical observation is highly sensitive to light pollution. The most obvious everyday manifestation of light pollution is in the increasing illumination of our night sky and the subsequent difficulties in observing astronomical objects from polluted locations (Green et al., 2022). The excessive artificial light scatters in the atmosphere, creating a skyglow that diminishes the contrast of the night sky, obscuring the faint light emitted by stars and other celestial objects. This scattering effect makes it increasingly difficult for astronomers and astrophotographers to detect and capture clear images of astronomical phenomena.

The impact of light pollution on astronomical observation is influenced by various factors, directly or indirectly, such as population density, gross domestic product (GDP), and the geographical area of a region. Highly populated urban areas with higher economic activities tend to generate more light pollution compared to rural or less economically developed regions. The spatial distribution and intensity of artificial lighting within a region are critical in determining the severity of light pollution.

Historically, methods for evaluating light pollution have included ground-based measurements, satellite imaging, and predictive models. Ground-based measurements provide precise data but are limited in scope and geographical coverage. Satellite imaging offers broader coverage but often lacks the resolution necessary to pinpoint specific sources of light pollution. Predictive models can integrate various data sources but may suffer from inaccuracies due to assumptions and limitations in the model parameters.

This research aims to address these challenges by analyzing light pollution in 40 major cities across China. By integrating geographic data—such as altitude, latitude, and longitude—with economic indicators, we assess the distribution and intensity of light pollution, quantifying its impact on potential sites for astrophotography. Our analysis also examines the primary sources contributing to light pollution, both natural and artificial, providing targeted recommendations for mitigating its effects on astronomical observation. This study contributes to understanding the spatial dynamics of light pollution and offers insights into preserving dark skies for astrophotography and scientific observation.

## **2. METHOD AND DATA**

### **2.1. Data Collection**

Geographic data are essential for identifying optimal locations for astronomical observations. To this end, the top 40 cities in China by Gross Domestic Product (GDP) were selected, including both the most economically productive cities and provincial capitals. Fundamental economic indicators, such as GDP, population, and area, were collected for each city, from Shanghai to Shenyang. Geographic data, particularly altitude, were also gathered. All relevant data are presented in Table 1, sourced from the National Bureau of Statistics of China, Sina Finance, and with assistance from ChatGPT. The GDP figures have been converted from yuan to USD using the exchange rate on September 13, 2024 (1 USD = 7.09 yuan). Population density was derived by dividing the population by the area.

Table 1. Limited number of demographic values for the top 40 cities in GDP of mainland China.

City/District	GDP Rank	GDP Billion \$	population million	Area km <sup>2</sup>	Altitude / m	Population Density / km <sup>-2</sup>
Changchun	34	89	9	20565	222	438
Changsha	17	169	10	11819	63	846
Changzhou	26	113	4.7	4370	6	1076
Chengdu	7	285	20.9	14335	500	1458
Chongqing	5	388	31	82403	237	376
Dalian	25	113	7.4	12573	29	589
Dongguan	19	155	10.4	2465	8	4219
Foshan	15	173	8.6	3797.72	16	2265
Fuzhou	23	137	7.8	11968	19	652
Guangzhou	4	406	15.3	7434.4	21	2058
Guiyang	37	75	5	8034	1274	622
Hangzhou	8	255	12	16853.57	12	712
Harbin	32	94	10.2	53110	150	192
Hefei	20	155	9.3	11445	24	813
Jinan	18	161	9.1	10244	28	888
Kunming	24	130	8.3	21473	1892	387
Kunshan	36	78	2.1	931	5	2256
Nanchang	29	99	5.6	7402	21	757
Nanjing	10	231	9.4	6587.02	15	1427
Nanning	35	85	7.4	22189	81	333
Nantong	22	155	7.4	8544	4	866
Ningbo	14	193	9.4	9816	10	958
Peking	2	587	21.8	16410.54	44	1328
Qingdao	12	197	10	11282	77	886
Quanzhou	21	155	8.7	11015	5	790
Shanghai	1	609	24.8	6340.5	4	3911
Shenyang	27	104	8.2	12948	55	633
Shenzhen	3	433	17.6	1996.85	0	8814
Shijiazhuang	30	99	11	15848	81	694
Suzhou	6	330	12.7	8488.42	4	1496

Taizhou	33	94	6	9411	10	638
Taizhou	38	72	4.7	5787	5	812
Tianjin	11	221	13.7	11916.85	5	1150
Urumqi	40	59	3.6	13796	836	261
Wenzhou	31	96	9.3	11784	16	789
Wuhan	9	250	11	8569.15	23	1284
Wuxi	13	195	7	4627.41	5	1513
Xiamen	28	99	4.4	1699.39	0	2589
Zhengzhou	16	172	12.6	7446.2	110	1692
Zibo	39	68	4.7	5965	45	788

## 2.2. Data Processing

According to research on the relationship between population/GDP and light pollution in France (Aksaker, 2020), the logarithms of population and GDP exhibit a linear relationship with the logarithm of luminous flux, which measures the intensity of artificial light. The equations for the linear regressions are provided below:

Total flux versus population in logarithmic scale:  $y=2.12x - 8.85$

Total flux versus GDP(USD) in logarithm scale:  $y=1.80x - 15.1$

Applying these regression models to the Chinese cities' data, we can derive predicted luminous flux values for each city, all expressed on a logarithmic scale. The computed data are presented in Table 2. To visually interpret the relationship between luminous flux and these demographic variables, the data were plotted, as shown in Figure 1.

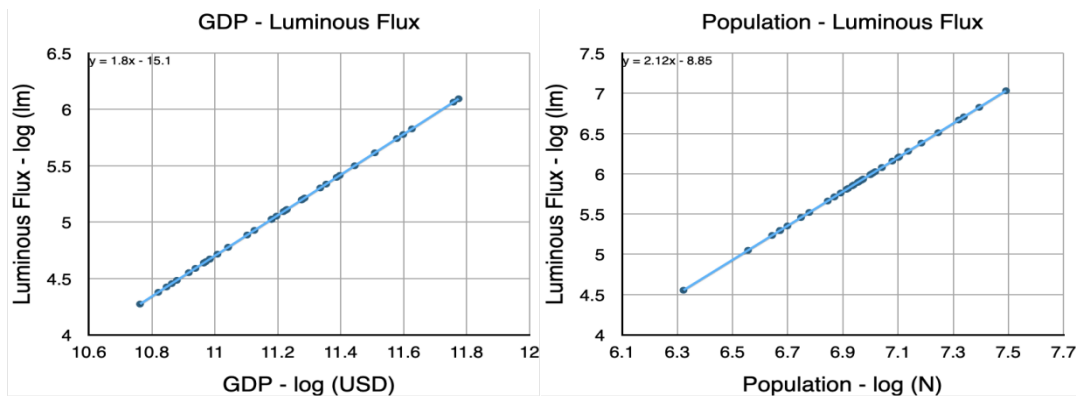


Figure 1. Left Panel: Total flux versus GDP(USD) for the year of 2023 in logarithm scale. The solid line represents the increasing linear regression ( $y = 1.80x - 15.1$ ). Right Panel: Total flux versus population in 2023 in logarithm scale. The solid line represents the increasing linear regression ( $y = 2.12x - 8.85$ ).

Table 2. Calculated logarithm data of GDP, Population, Luminous Flux

City/District	GDP-log (USD)	Luminous Flux - log (lm)	Population - log (N)	Luminous Flux - log (lm)
Changchun	10.94869	4.60765	6.95424	5.89299
Changsha	11.22854	5.11136	7.00000	5.99000
Changzhou	11.05244	4.79440	6.67210	5.29485
Chengdu	11.45471	5.51847	7.32015	6.66871
Chongqing	11.58869	5.75964	7.49136	7.03169
Dalian	11.05244	4.79440	6.86923	5.71277
Dongguan	11.19075	5.04334	7.01703	6.02611
Foshan	11.23926	5.13067	6.93450	5.85114
Fuzhou	11.13613	4.94503	6.89209	5.76124
Guangzhou	11.60875	5.79574	7.18469	6.38155
Guiyang	10.87363	4.47253	6.69897	5.35182
Hangzhou	11.40703	5.43266	7.07918	6.15786
Harbin	10.97543	4.65577	7.00860	6.00823
Hefei	11.19075	5.04334	6.96848	5.92318
Jinan	11.20626	5.07127	6.95904	5.90317
Kunming	11.11314	4.90365	6.91908	5.81845
Kunshan	10.88972	4.50149	6.32222	4.55310
Nanchang	10.99445	4.69001	6.74819	5.45616
Nanjing	11.36420	5.35556	6.97313	5.93303
Nanning	10.92751	4.56951	6.86923	5.71277
Nantong	11.19075	5.04334	6.86923	5.71277
Ningbo	11.28607	5.21493	6.97313	5.93303
Peking	11.76845	6.08320	7.33846	6.70753
Qingdao	11.29548	5.23187	7.00000	5.99000
Quanzhou	11.19075	5.04334	6.93952	5.86178
Shanghai	11.78484	6.11271	7.39445	6.82624
Shenyang	11.01859	4.73345	6.91381	5.80729
Shenzhen	11.63649	5.84569	7.24551	6.51049
Shijiazhuang	10.99445	4.69001	7.04139	6.07775

Suzhou	11.51857	5.63343	7.10380	6.21006
Taizhou	10.97543	4.65577	6.77815	5.51968
Taizhou	10.85692	4.44246	6.67210	5.29485
Tianjin	11.34525	5.32146	7.13672	6.27985
Urumqi	10.77260	4.29069	6.55630	5.04936
Wenzhou	10.98186	4.66735	6.96848	5.92318
Wuhan	11.39733	5.41519	7.04139	6.07775
Wuxi	11.28923	5.22062	6.84510	5.66161
Xiamen	10.99445	4.69001	6.64345	5.23412
Zhengzhou	11.23571	5.12428	7.10037	6.20279
Zibo	10.83060	4.39507	6.67210	5.29485

Further analysis involved plotting the correlation between population density and luminous flux, as demonstrated in Figure 2. This graph clearly shows how increasing population density correlates with heightened levels of light pollution. To refine the model and improve the accuracy of the trendline, five statistical outliers were excluded from the analysis.

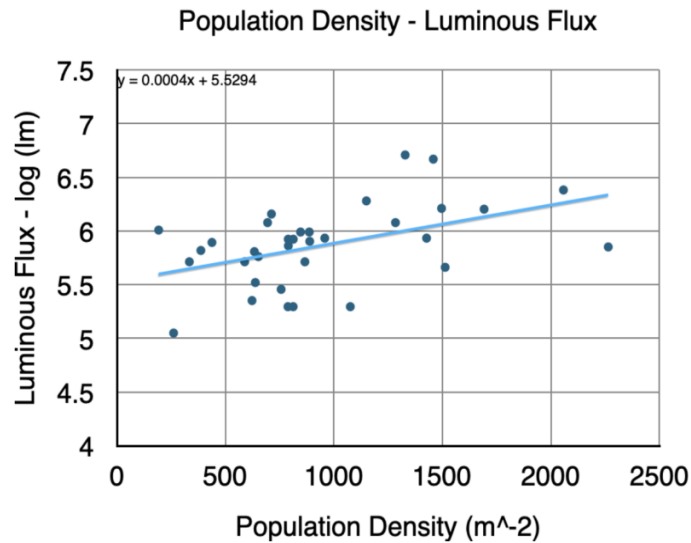


Figure 2. The relationship between population density and luminous flux. The thick solid line is the fitted linear regression ( $y = 0.0004x + 5.53$ ). The increasing linear trend is assumed, just to show that the population density and luminous flux from light pollution are positively related. The equation for the linear regression is not applicable to any other cases, as the value for  $R^2$  is very small.

Based on the methodology outlined in Falchi et al. (2023) concerning light pollution metrics, we computed multiple Point Spread Functions (PSFs), which quantify sky radiance as a function of angular distance from the zenith. The PSF characterizes the intensity of artificial light in the night sky, ranging from zenithal radiance (directly overhead) to horizontal irradiance (near the horizon). Using the logarithmic relationships and coefficients provided by Falchi et al., we calculated the sky brightness at various angles using the observation height ( $h_{obs}$ , or altitude of the observation site), the altitude of light sources ( $h_s$ , constrained such that  $h_s \leq h_{obs}$ ), and the distance  $D$  from the light

source to the observatory, all measured in kilometers. For simplicity, we assumed fixed values for  $h_s = 0.01\text{km}$  and  $D = 50\text{ km}$ . In the case of coastal cities with altitudes at or near sea level, the observation height was set to  $0.01\text{ km}$  to avoid computational errors associated with zero-altitude observations. Using these assumptions, we computed the PSFs for all cities, with the results presented in Table 3.

Table 3. All the cities' altitudes, locations of light source, and light pollution indicators.

City	Altitude / m	hobs / km	hs / km	D / km	$\log_{10} PSF - ZSR$	$\log_{10} PSF - AllSkiAviB$	$\log_{10} PSF - AvBri30$	$\log_{10} PSF - AvBriBelow$	$\log_{10} PSF - Horizon$
Changchun	222	0.232	0.01	50	-5.49270211482202	-3.26992511572574	-3.42916211387038	-2.24468958950579	-3.07765851020194
Changsha	63	0.073	0.01	50	-11.6649022749851	-3.2921968849885	-3.44106775940885	-2.26278242581288	-3.13513304223818
Changzhou	6	0.016	0.01	50	-78.4673301511975	-3.43953611648543	-3.46657859208414	-2.24529881347321	-3.18554345421708
Chengdu	500	0.51	0.01	50	-4.69227916099208	-3.25656701791134	-3.43545076546609	-2.18467122217133	-3.0396029712443
Chongqing	237	0.247	0.01	50	-5.38051327334895	-3.26873930475921	-3.42908535949271	-2.24180392952677	-3.07408529238644
Dalian	29	0.039	0.01	50	-23.5551486535335	-3.30134448750185	-3.45203670929469	-2.25760477525254	-3.1555623192684
Dongguan	8	0.018	0.01	50	-66.3980279595358	-3.35850941774126	-3.46509144191829	-2.24702288249914	-3.1802471739648
Foshan	16	0.026	0.01	50	-39.9277628324318	-3.30614497454441	-3.4593130123472	-2.25231241390275	-3.16732694591303
Fuzhou	19	0.029	0.01	50	-34.4968412000605	-3.30423534932711	-3.45739949868873	-2.25381801732599	-3.16407042212933
Guangzhou	21	0.031	0.01	50	-31.5926842381085	-3.30350344908298	-3.456207421709	-2.25471338499583	-3.16213717901536
Guiyang	1274	1.284	0.01	50	-4.63099474704415	-3.25003299970757	-3.4738533679714	-2.03939861959363	-3.03939908628296
Hangzhou	12	0.022	0.01	50	-50.167394985601	-3.31454892227959	-3.46210007245087	-2.24993893334237	-3.17269897566713

Harbin	150	0.16	0.01	50	- 6.452203680 01353	- 3.277149094 1355	- 3.43109707 648554	- 2.256789228 43545	- 3.09861226 487364
Hefei	24	0.034	0.01	50	- 28.02207631 3536	- 3.302651233 82678	- 3.45453717 750121	- 2.255916320 37396	- 3.15949284 005104
Jinan	28	0.038	0.01	50	- 24.33164930 41553	- 3.301608093 22438	- 3.45251067 279037	- 2.257295372 11577	- 3.15631099 853505
Kunming	1892	1.902	0.01	50	- 4.733961961 29401	- 3.253084357 95476	- 3.50631683 143788	- 1.971579935 05941	- 3.05440848 375936
Kunshan	5	0.015	0.01	50	- 86.04356171 22136	- 3.524633601 86336	- 3.46728193 910832	- 2.244354475 08239	- 3.18881272 566942
Nanchang	21	0.031	0.01	50	- 31.59268423 81085	- 3.303503449 08298	- 3.45620742 1709	- 2.254713384 99583	- 3.16213717 901536
Nanjing	15	0.025	0.01	50	- 42.10631928 10586	- 3.307266935 33609	- 3.45998503 425347	- 2.251761700 80065	- 3.16853707 311663
Nanning	81	0.091	0.01	50	- 9.531520409 41909	- 3.288147148 11356	- 3.43768006 595167	- 2.263000799 74624	- 3.12624936 476683
Nantong	4	0.014	0.01	50	- 94.99689633 70096	- 3.672687606 35284	- 3.46792949 255227	- 2.243347136 39303	- 3.19265429 14972
Ningbo	10	0.02	0.01	50	- 57.26914587 67387	- 3.327420779 25631	- 3.46358082 466276	- 2.248559602 36768	- 3.17609432 975616
Peking	44	0.054	0.01	50	- 16.01364064 0015	- 3.297185646 10755	- 3.44617411 424747	- 2.260944567 15365	- 3.14568396 973404
Qingdao	77	0.087	0.01	50	- 9.910682432 7288	- 3.288991869 35556	- 3.43834165 667081	- 2.263050066 25793	- 3.12814894 8582
Quanzhou	5	0.015	0.01	50	- 86.04356171 22136	- 3.524633601 86336	- 3.46728193 910832	- 2.244354475 08239	- 3.18881272 566942
Shanghai	4	0.014	0.01	50	- 94.99689633 70096	- 3.672687606 35284	- 3.46792949 255227	- 2.243347136 39303	- 3.19265429 14972

Shenyang	55	0.065	0.01	50	- 13.10974970 05474	- 3.294212072 32282	- 3.44297994 502431	- 2.262255331 13616	- 3.13939634 608658
Shenzhen	0	0.01	0.01	50	- 154.7928240 34153	- 7.502360468 53153	- 3.46892355 474357	- 2.238510021 47891	- 3.21864637 385596
Shijiazhuang	81	0.091	0.01	50	- 9.531520409 41909	- 3.288147148 11356	- 3.43768006 595167	- 2.263000799 74624	- 3.12624936 476683
Suzhou	4	0.014	0.01	50	- 94.99689633 70096	- 3.672687606 35284	- 3.46792949 255227	- 2.243347136 39303	- 3.19265429 14972
Taizhou	10	0.02	0.01	50	- 57.26914587 67387	- 3.327420779 25631	- 3.46358082 466276	- 2.248559602 36768	- 3.17609432 975616
Taizhou	5	0.015	0.01	50	- 86.04356171 22136	- 3.524633601 86336	- 3.46728193 910832	- 2.244354475 08239	- 3.18881272 566942
Tianjin	5	0.015	0.01	50	- 86.04356171 22136	- 3.524633601 86336	- 3.46728193 910832	- 2.244354475 08239	- 3.18881272 566942
Urumqi	836	0.846	0.01	50	- 4.593403460 93175	- 3.251146798 88203	- 3.45100320 983591	- 2.113775366 06909	- 3.03239470 569079
Wenzhou	16	0.026	0.01	50	- 39.92776283 24318	- 3.306144974 54441	- 3.45931301 23472	- 2.252312413 90275	- 3.16732694 591303
Wuhan	23	0.033	0.01	50	- 29.12224574 57433	- 3.302919839 56476	- 3.45507881 214998	- 2.255532742 93268	- 3.16034522 78884
Wuxi	5	0.015	0.01	50	- 86.04356171 22136	- 3.524633601 86336	- 3.46728193 910832	- 2.244354475 08239	- 3.18881272 566942
Xiamen	0	0.01	0.01	50	- 154.7928240 34153	- 7.502360468 53153	- 3.46892355 474357	- 2.238510021 47891	- 3.21864637 385596
Zhengzhou	110	0.12	0.01	50	- 7.692344547 92899	- 3.282812485 79753	- 3.43400975 680596	- 2.261407413 99743	- 3.11354629 16467
Zibo	45	0.055	0.01	50	- 15.68868759 64042	- 3.296907548 49142	- 3.44585161 929523	- 2.261096802 54165	- 3.14508750 019803

To further explore how altitude influences light pollution, we generated plots showing the relationship between each city's altitude and its corresponding PSF values. These graphs, ordered by ascending observation height, allow for a clear analysis of trends. By combining line and column charts, as illustrated in Figure 3, we effectively visualize both the data points and the overall correlation between altitude and sky radiance, revealing that higher altitudes are generally associated with lower PSF values, indicating reduced light pollution at elevated observation sites.

### 3. RESULTS

#### 3.1. Economic Indicators

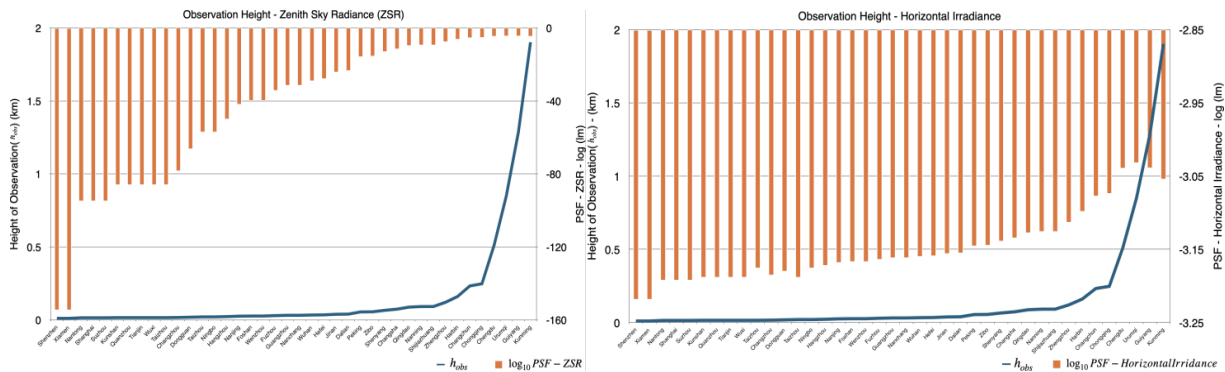


Figure 3. Left Panel: Every chosen city’s height of observation and calculated values of PSF - ZSR. Right Panel: Every chosen city

The analysis of GDP and population data across the top 40 cities in China reveals distinct patterns in luminous flux, a key indicator of light pollution. Cities with lower economic activity and population density generally exhibit reduced levels of artificial lighting. For instance, Guiyang, Taizhou, Zibo, and Urumqi consistently show the lowest luminous flux when assessed from the perspective of GDP. Similarly, in terms of population density, cities such as Kunshan, Xiamen, Zibo, and Urumqi rank lowest in luminous flux levels.

When averaging these two dimensions—economic indicators and population density—we find that Kunshan, Urumqi, and Zibo emerge as the top three cities with the least light pollution. This dual analysis underscores the complex interplay between urban development and light pollution, highlighting the need for targeted strategies in urban planning to mitigate these effects.

#### 3.2. Geographic Indicators

The impact of geographical factors on light pollution is illustrated in Table 3 and Figure 3, where the Point Spread Function (PSF) values are plotted against observation heights. A clear trend emerges: as the altitude of observation sites increases, the PSF values tend to decrease, indicating lower levels of sky radiance and, consequently, reduced light pollution.

Cities such as Chengdu, Urumqi, Guiyang, and Kunming, located at higher altitudes, demonstrate significantly lower sky irradiance. This finding suggests that higher observation sites can offer clearer conditions for astronomical observation, making them preferable for astrophotographers seeking unobstructed views of celestial phenomena.

### 3.3. Combined Conclusion

By integrating both economic and geographic indicators, we can confidently conclude that Urumqi and Guiyang are optimal locations for minimizing light pollution. Both cities not only have favorable economic conditions that limit artificial lighting but also boast geographical features that further enhance the visibility of the night sky.

This comprehensive analysis highlights the importance of considering multiple factors when identifying suitable locations for astrophotography. The results indicate that urban planning and environmental considerations should prioritize maintaining dark skies, which are crucial for both scientific research and recreational stargazing.

## 4. DISCUSSION

This study highlights the significant impact of light pollution on astrophotography, identifying Urumqi and Guiyang as the optimal locations for stargazing in China. Our analysis demonstrates that lower GDP and population density correlate with reduced light pollution, reinforcing findings from previous research (Aksaker, 2020; Green et al., 2022). By combining altitude and geographic data with luminous flux measurements, we provide a comprehensive view of light pollution's spatial distribution. The decreasing PSF values with increased altitude suggest that higher observation sites are more favorable for clearer astrophotography.

However, this research can still be improved in the future. Our reliance on predicted luminous flux values based on regression models may introduce inaccuracies, particularly in areas where local lighting practices differ from expected patterns. Additionally, excluding statistical outliers, while necessary for accuracy, may overlook significant anomalies that could inform future studies. These factors may need to be considered when generalizing our findings to smaller or less economically significant cities.

Further research could investigate the specific effects of different types of artificial lighting—such as streetlights versus satellite lighting—on overall light pollution levels. Long-term monitoring of light pollution in the identified optimal locations could yield valuable insights into trends and the effectiveness of mitigation strategies. Collaborations with local governments to implement dark sky initiatives could further enhance this field of study.

In conclusion, our research contributes to understanding the relationship between light pollution and astrophotography. By pinpointing Urumqi and Guiyang as prime stargazing locations, we offer practical suggestions for astrophotographers. This work emphasizes the urgent need for measures to combat light pollution and serves as a call to action for future research aimed at preserving dark skies for generations to come.

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