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Illuminate: Relationship between Light Pollution, Quality of Life, and Innovation in Selected US Cities

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Abstract

Cities have always been epicenters of economic and social activity. People continue to seek residence in cities to improve their quality of lives (Mouratidis, 2021). In addition to better quality of life, cities can enable better personal and social economic outcomes (Austin et al., 2022). Further, cities have a higher innovation output. They are also characterized by high levels of nighttime illumination. This paper presents meta-analyses to examine the relationships between these attributes of cities. Relevant data were collected from public sources for 48 US cities for three years. Relationships between quality of life, innovation and light radiance were assessed using ANOVA and multiple range (Fisher's mean) tests. It was found that levels of light radiance in cities seems have statistically significant relationship with specific elements of quality of life: safety, health, traffic and pollution. The analyses show that high levels of light radiance correlate with adverse aspects of these elements. This study didn't find a statistically significant relationship between levels of light and innovation. In other words, more brightly lit cities don't seem to be more innovative.

Keywords: *Light Pollution; Quality of Life; Innovation; Cost of Living; Traffic; Purchasing Power; Safety; Climate; Pollution; Property Price to Income Ratio; US Cities*

Introduction

Cities have played an important role in human development. People have gravitated towards cities to find better opportunities (Manning & Trimmer, 2020). It can be argued that cities, typically, offer higher perceived improvement in the quality of life. Furthermore, cities have served as hubs for innovation and progress (Adler & Florida, 2021; Florida et al., 2017). Balland et al. (2020) argued that human activities, such as research, innovation and industry, concentrate disproportionately in large cities. They further mentioned that ten most innovative cities in the US account for 23% of the national population, but for 48% of its patents and 33% of its gross domestic product.

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Advent of electricity has exponentially increased economic and social activities in cities. Electricity has enabled illumination during the night. The night time urban illumination is even visible from the space (NASA, 2008). In fact, large metropolitan areas with dense populations and high economic activity seem to shine the most during the night (Bluhm & Krause, 2022). The intensity of light is so high that experts refer it to light pollution. The National Geographic Society (2022), defines light pollution as "… the excessive or inappropriate use of outdoor artificial light, is affecting human health, wildlife behavior, and our ability to observe stars and other celestial objects." It can therefore be argued that quantifiable relationships might exist between these attributes of a modern city.

Research Questions

There seems to dearth research covering adjacent non-ecological effects of light population. Hence, this study investigated two research questions. Firstly, what relationship, if any, exist between levels of light radiance and innovation is selected US cities? Secondly, what relationship, if any, exist between levels of light radiance and quality of life is selected US cities?

Data Collection

Quality of life related data were obtained from Numbeo.com. The company has been collecting and publishing datasets since 2009. Their data has been used as a source by many internationally reputed newspapers and magazines including BBC, Time, Forbes, The Economist, New York Times, The Telegraph, The Washington Post, USA Today (Adamovic, 2023). For this study the data published by Numbeo.com for the following indices were used: Quality of Life, Purchasing Power, Pollution, Climate, Safety, Traffic, Health, Property Price to Income and Cost of Living. Further details of these indices, and the calculations associated with them are included in Appendix 1. Innovation data were obtained from Innovation-cities.com. The relevant data are collected and published by 2ThinkNow as part of their Innovation Cities™ Index product portfolio. The index is well regarded and has been presented at the United Nations and OECD events (2ThinkNow, 2023). Details of the index are included in Appendix 2. For the purposes of this study, it has been assumed that the data reported by Numbeo.com and 2ThinkNow are accurate and respectively represent underlying concepts related to quality of life and innovation in cities.

The 48 US cities included in this study are limited to those that are commonly included in the data sets published by both Numbeo.com and 2ThinkNow. Furthermore, data from 2018, 2019 and 2021 were included in the analysis for this study. The year 2020 was skipped due to unprecedented events related to the COVID-19 pandemic. Light pollution data for these cities was collected from lightpollutionmap.info's VIIRS 2021 data set. www.lightpollutionmap.info is a mapping application that displays light pollution related content over Microsoft Bing base layers (lightpollutionmap.info, 2023). Radiance data for specific location is provided based on longitude and latitude in terms of watt per steradian per square centimeter. For the purposes of this study, five random radiance readings were averaged for each city and per year. Further, the radiance data were sorted in a descending order and split into three categories: high, medium, low. These categories represent the level of radiance in a specific city and for a specific year.

Data Analysis

The data analyzed for this study includes 123 records from 48 major US cities, for the years 2018, 2019 and 2021. Each record has 11 attributes: Quality of Life index, Purchasing Power index, Property Price to Income Ratio index, Cost of Living index, Safety index, Health index, Traffic index, Pollution index, Climate index, Innovation Cities index and average light radiance, for 5 random locations within the city. 32 cities have attribute data available for all 3 years. 11 cities have attribute data available for 2019 and 2021. 5 cities have attribute data available only for 2021. Descriptive analysis of these attributes is shown in Table 1.

Table 1. Descriptive analysis of city attributes

Attribute	Max	Min	Average	Std Dev	Median	Range	Skewness	Kurtosis
Quality of Life index	216.1	118.9	171.2	17.01	171.0	97.2	-0.3	0.02
Purchasing Power index	172.5	72.6	120.4	19.6	121.2	99.9	-0.1	-0.2
Property Price to Income Ratio	12.3	1.0	4.2	2.37	3.3	11.30	1.5	1.9
Cost of Living index	100.0	60.0	75.3	9.51	73.3	40.0	0.8	-0.03
Safety index	50.9	49.5	25.4	11.1	74.8	49.4	0.0	-0.4
Health index	82.9	54.4	69.7	5.9	70.2	28.5	-0.2	-0.2
Traffic index	60.6	22.0	35.8	7.3	35.4	38.6	0.2	-0.2
Pollution index	66.3	16.6	38.9	11.8	38.6	49.7	0.3	-0.7
Climate index	97.3	41.6	77.8	13.3	81.2	55.7	-0.5	-0.5
Innovation Cities index	59.0	39.0	47.1	4.4	46.0	20.0	0.5	-0.6
Radiance	650.9	55.2	214.1	91.9	201.5	595.7	1.7	5.4

Positive skewness values show that the distribution is skewed to the right while a negative skewness value implies a distribution skewed to the left. A skewness value greater than 1 or less than -1 indicates a highly skewed distribution. A value between 0.5 and 1 or -0.5 and -1 is moderately skewed. A value between -0.5 and 0.5 indicates that the distribution is symmetrical (Kallner, 2017; Lumivero, 2020). In the current dataset Property Price to Income Ratio and Radiance are skewed to the right. Kurtosis characterizes the relative peakedness or flatness of a distribution compared with the normal distribution. Normal distribution should have kurtosis value of zero (Kallner, 2017; Lumivero, 2020). Positive kurtosis indicates a relatively peaked distribution. Negative kurtosis indicates a relatively flat distribution. As before, Radiance and Property Price to Income Ratio distributions have relatively high peaks. Other values are relatively close to zero. Hence, it can be concluded that both Property Price to Income Ratio and Radiance data are not normally distributed.

In order to answer the research questions the data were analyzed using One-Way ANOVA. Property Price to Income Ratio data are not included in the analysis because they are not normally distributed. The 3 levels of Radiance data serve as 3 factors for the One-Way ANOVA. The non-normality of the Radiance data, thus, is not consequential for the analyses (University of California, Los Angeles, 2021). Other attributes, that are normally distributed, are considered dependent variables. The results of the One-Way ANOVA are included in Table 2.

Table 2.Results of One-Way ANOVA

Attribute	F-Ratio	P-Value (95% confidence level)	Statistically Significant
Quality of Life index	14.34	<0.0001	Yes
Purchasing Power index	1.01	0.3680	No
Cost of Living index	0.03	0.9676	No
Safety index	12.03	<0.0001	Yes
Health index	3.81	0.0249	Yes
Traffic index	4.78	0.0101	Yes
Pollution index	15.13	<0.0001	Yes
Climate index	0.12	0.8845	No
Innovation Cities index	1.12	0.3312	No

Note: Radiance with 3 factors High Medium, Low is the independent variable.

For the attributes that have statistically significant relation with Radiance, the Kruskal-Wallis tests were employed to test the null hypothesis that the medians of the relevant attributes within each of the 3 factors/levels of Radiance are the same. The data from all the levels is first combined and ranked from smallest to largest. The average rank is then computed for the data at each level. Results of Kruskal-Wallis tests are included in table 3.

Table 3. Results of Kruskal-Wallis tests for attributes that have statistically significant relation with radiance

Attribute	P-Value (95% confidence level)	Statistically Significant
Quality of Life index	<0.0001	Yes
Safety index	<0.0001	Yes
Health index	0.0317	Yes
Traffic index	0.0076	Yes
Pollution index	<0.0001	Yes

Finally, multiple range tests were employed for attributes with the statistically significant relationship to Radiance. These tests apply Fisher's least significant difference procedure to determine which means are significantly different from which others. The output per attribute, shown in Table 4, includes estimated differences between each pair of means for 3 factors/levels for Radiance. A keyword

Yes has been placed next to pairs, indicating statistically significant differences at the 95.0% confidence level.

Table 4.Multiple range test for selected attributes

Attribute	Radiance Level Pairs	Difference	+/- Limits	Statistically Significant (95% confidence level)
	High – Low	-18.3799	6.8084	Yes
Quality of Life index	High – Medium	-8.2965	6.7683	Yes
	Low – Medium	10.0834	6.7258	Yes
	High – Low	-10.2022	4.4975	Yes
Safety index	High – Medium	-8.9947	4.4710	Yes
	Low – Medium	1.2074	4.4429	No
	High – Low	-3.4781	2.5523	Yes
Health index	High – Medium	-2.3977	2.5372	No
	Low – Medium	1.0804	2.5213	No
	High – Low	4.6620	3.1166	Yes
Traffic index	High – Medium	1.1639	3.0983	No
	Low – Medium	-3.4981	3.0788	Yes
	High – Low	13.0164	4.6973	Yes
Pollution index	High – Medium	5.7867	4.6696	Yes
	Low – Medium	-7.2296	4.6404	Yes

Conclusions and Discussion

The analyses seem to indicate a clear relationship exist between levels of light Radiance and Quality of Life in major US cities. Further, there are statistically significant relationships between level of light Radiance and specific elements of quality of life vis-à-vis Safety, Health, Traffic, and Pollution. Level of light Radiance doesn't seem to have statistically significant relationship with the Innovation, Purchasing Power, perceived Climate, and Cost of Living. As shown in figures 1-2, the multiple range tests demonstrate that high level of radiance is associated with low levels of Safety and Health. Multiple range test depicted in figures 3-4 demonstrate that high level of Radiance is associated with high levels of Traffic and Pollution. Furthermore, existing scientific literature highlights that high levels of light pollution in cities can be measured in terms of light radiance (Falchi et al., 2019; Green et al., 2022; Czarnecka, 2021). Thus, it can be argued that high light pollution is related with other detrimental social attributes. It may, hence, be possible that actions that mitigate light pollution (Mizon , 2012; Narisada & Schreuder, 2013) can also mitigate problems associated with safety, health, traffic, and pollution. The study didn't find statistically significant relationship between levels of light Radiance and amount of innovation. This seems to indicate that high amount of lighting in a city may not be contributing to this aspect of economic output. Consequently, it can be argued that the level of lighting in the cities could be reduced without any adverse effect on the innovation output of a city.

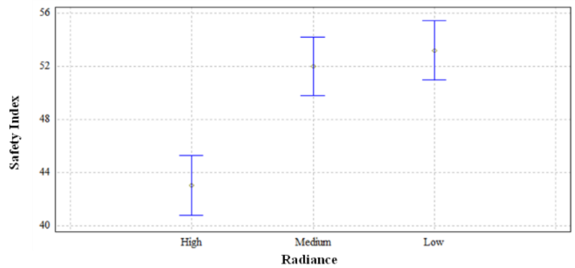

Figure 1. Multiple range test for means of safety index at various levels of radiance.

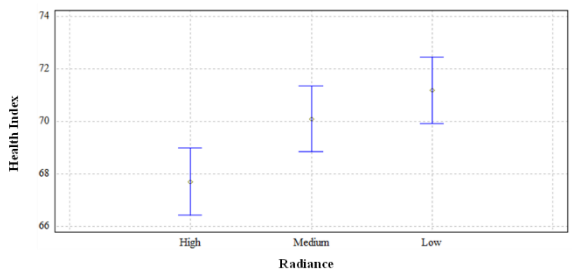

Figure 2.Multiple range test for means of health index at various levels of radiance.

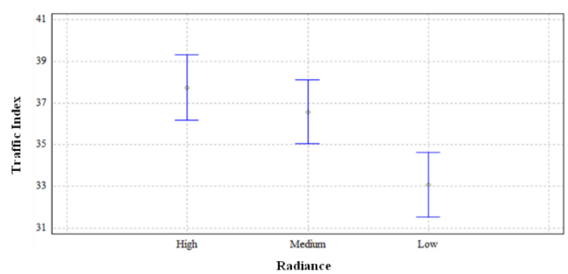

Figure 3.Multiple range test for means of traffic index at various levels of radiance.

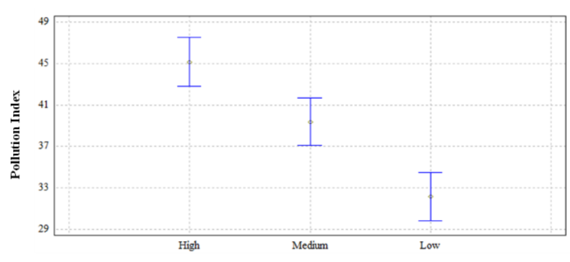

Figure 4.Multiple range test for means of pollution index at various levels of radiance.

Further Research

Future research could involve collection of additional and more granular data for radiance. Based central limit theorem, a much larger sample size could result in a normal distribution. Generalized linear and regression models can then be employed to quantify relationships between radiance and other attributes. Nevertheless, the results of this study should be replicated with data from other cities across the globe to generalize the findings.

Conflict of Interest

The author and research adviser certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest the subject matter or materials discussed in this manuscript.

Appendix 1 (Quality of Life Indices)

Quality of Life Index is a non-negative estimation of overall quality of life calculated with an empirical formula (Adamovic, 2023):

$$
\begin{aligned}
&Quality\ of\ Life\ Index \\
&= 100 + \left(\frac{Purchasing\ Power\ Index}{2.5}\right) - (Property\ Price\ to\ Income\ Ratio) \\
&- \left(\frac{Cost\ of\ Living\ Index}{10}\right) + \frac{Safety\ Index}{2} + \frac{Health\ Index}{2.5} - \frac{Traffic\ Index}{2} \\
&- Pollution\ Index * \frac{2}{3} + \frac{Climate\ Index}{3}
\end{aligned}
$$

Cost of Living and Purchasing Power indices are measured relative to New York City. Cost of life is an estimation of consumer goods prices including rent in a specific city. Purchasing Power shows relative purchasing power in buying goods and services in a specific city for the average net salary in that city. If domestic purchasing power is 40, this means that the inhabitants of that city with an average salary can afford to buy on an average 60% less goods and services than New York City residents with an average salary (Adamovic, 2023). Price to Income Ratio is the basic measure for apartment purchase affordability. It is calculated as the ratio of median apartment prices to median familial disposable income, expressed as years of income (Adamovic, 2023). The Safety, Health, Pollution indices are based on responses to the survey conducted by Numbeo.com (Adamovic, 2023). The Traffic Index is a composite index of work commute time, perceived commute dissatisfaction, CO_2 emissions and overall inefficiencies in the traffic system (Adamovic, 2023). The Climate index quantifies perceived likability of a city's climate (Adamovic, 2023). The interpretation of the various indices are noted in the table 5.

Table 5.Interpretation of Quality of Life related indices

Index	Interpretation
Quality of Life	Higher is better
Purchasing Power	Higher is better
Property Price to Income Ratio	Lower is better
Cost of Living	Lower is better
Safety	Higher is better
Health	Higher is better
Traffic	Lower is better
Pollution	Lower is better
Climate	Higher is better

Appendix 2 (Innovation Cities Index)

According to 2thinknow (2023) the Innovation Cities index for cities across the global is based on 162 indicators. The company claims that the indicators have been selected based on original studies, research, academic texts or established commercial principles. The indicators belong to one of 3 categories: 1) “Cultural Assets: Measurable sources of ideas (e.g. designers, art galleries, sports, museums, dance, nature, etc)”, 2) “Human Infrastructure: Soft and hard infrastructure to implement innovation (transport, universities, business, venture capital, office space, government, technology, etc.)” and “3) Networked Markets: Basic conditions and connections for innovation (location, tech, military, economies of related entities etc) - communication of innovation” (2thinknow, 2023)

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