Analysis of Significant Factors Influencing Light Pollution: Urbanisation and GDP Per Capita

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Abstract

In the modern world, light pollution has grown to become an increasingly serious issue, affecting the lives of plants and animals alike in major ways by altering their circadian rhythms. The purpose of the study was to find correlations between the amount of a nation's population affected by light pollution and demographic factors of that population. Through a quantitative approach, the research study sought to examine the impact of the following factors — population density, per capita income, literacy rate, forest cover, urbanisation — on the artificial brightness of an area. A regression analysis was conducted on the data for 178 United Nations Recognized Countries. The study found that the percentage of urban population and GDP per capita had a statistically significant impact on light pollution: the greater the percentage of urban population and the GDP per capita the more light pollution there was, at the probability level of $p<.01$. It was also found that in Indian cities, light pollution decreased with an increase in literacy rate, showing that education and awareness needs to be brought to the field. The results of this research study shows that human activity, particularly in the urban sector, exerts a strong impact on light pollution. Therefore, smart lighting, pollution-efficient lights, and streetlamps, etc. should be considered in urban planning and city design so that they can be implemented on a wide scale. This not only reduces light pollution, but also reduces energy consumption, thereby providing an economic incentive to prevent light pollution.

INTRODUCTION

Years ago, human beings lived according to the natural light in their environment [1]. They learnt to make the most of the day, where fruits and prey are more visible to them and slept through the night. Essentially, they conditioned themselves to sleep during the darkness that was related to the ambient light around them [1]. However, as more humans began to live in urban centres, in tandem with their reliance on artificial lighting during the night and the widespread deployment of light in these places, our human body's capability to differentiate night from day has been severely affected [2]. Continual exposure to high amounts of lighting, especially during the night, has been known to lead to major sleeping disorders, interference of melatonin production, and huge disruptions in the human circadian rhythm [3]. These often lead to major psychological damage to the victim, including, but not limited to, exhaustion, irritability, and in extreme cases anxiety, depression, and other long term psychological issues [4]. In other words, this interfering, polluting light is leading to some severe, unforeseen consequences, for human beings.

What is Light pollution? It is the excessive or inappropriate use of lighting, which is manifested in various forms [5]:

- **Light Trespass**: Unwanted light intruding into areas where it is not desired.
- **Glare**: Undesirable effect caused by the contrast between a bright, glaring light and a darker background.
- **Skyglow**: Brightening of the night sky by virtue of artificial or man-made lighting; and
- **Clutter**: Bright and excessive groups of light sources close together

The seeds of light pollution were first planted in the early 1900s with the rapid developments in commercial electricity, as well as the urban infrastructure leading to massive urbanization across the globe [6]. Today, across the world, hundreds of countries are affected by light pollution. Furthermore, as these urban clusters continued to modernize, they also continued to bring with them brighter and more frequent illumination. Apart from its adverse impact on humans' sleeping patterns and their performance, light pollution and artificial lights have also impacted on animals and ecosystems as a whole[6]. Birds that migrate using the sun and stars as methods of navigation can often get lost or stuck because of artificial lighting [7]. Nocturnal predators have a much easier time finding prey, who find it difficult to use darkness as a cover [8]. Artificial lights are disorientating for wildlife, greatly affecting their sleep cycles, or circadian rhythms [6-8]. Baby sea turtles can often get lost on their way to the ocean due to heavy beachside lighting, and insects tend to be attracted to artificial lights . As a result, the ecosystems have been affected in drastic ways[6].

Unfortunately, not many countries have put standards in place for efficient and effective lighting. Light pollution is heavily connected to energy misuse. Unnecessary or over illuminated indoor lighting installations also contribute to light pollution and sky glow, along with badly designed street lighting. Shielding light fixtures and cutting down on unnecessary indoor lighting would save on electricity, and in turn cost, while simultaneously reducing carbon emissions from electricity generation, with very few, if any repercussions [9]

METHODOLOGY

Research Aim and Research Approach

The research aim of this study was to evaluate the extent of the worldwide phenomenon of light pollution. More specifically, this research study sought to identify which of the demographic factors, specifically Gross Domestic Product (GDP) per capita, average population density, the percentage of population living in urban areas, and the percentage of land covered by forests, exerted an impact on the number of residents of a country living under significant light pollution and the extent of the impact. Essentially, significant light pollution refers to areas with over 688 $\mu cd/m^2$ of luminance. The investigation was confined to data gathered from the list of UN- recognised nations[10].

- Null Hypothesis: The factors described above have no effect on the percentage of the residents of the country living under high levels of light pollution.

- <u>Alternative Hypothesis</u>: The factors described above have an effect on the percentage of residents of the country living under high levels of light pollution.

These factors were identified as potential factors influencing light pollution in an exhaustive review of the literature:

- **GDP Per Capita**: This factor was likely to correlate with light pollution, due to the fact that countries with more expendable income can spend more on lighting and light installations. They are also likely to contain more cars, malls, roads, billboards, public displays, etc., all of which contribute to light pollution. Furthermore, localities with higher average incomes are likely to have more tax revenue to spend on the bright lighting of public areas.
- **Average Population Density**: Crowded regions, such as towns and cities, are more likely to contain brighter and numerous light sources than sparsely-populated areas, like farms, the forests, and deserts, with less people and thus a far lesser need for lighting.
- **Percent of Urban Population:** As urban areas are more likely to produce more light pollution than rural areas, due to more numerous light sources, this factor was also chosen.
- **Percentage of Forest Cover**: This factor is likely to be inversely proportional to light pollution produced, due to the fact that forested areas tend to be poorly lit due to a lack of human activity in those areas.

With regards to the dependent variable, the percentage of population living under light pollution was selected as a variable, instead of the average light pollution. It is a comparatively more relevant indicator of the impact of light pollution as populations are typically not evenly spread across a country.

Data Collection

Light pollution data were collected from Fabio et al.'s (2016) article, entitled "The New World Atlas of Artificial Night Sky Brightness" [11]. The remaining data for the countries were obtained from the World Bank development indicators database [12].

Data Analysis

A multiple regression analysis was utilized to analyse the data conducted using the data collected from the aforementioned sources and the percentage of people residing in high levels of light pollution as the dependent variable. Furthermore, a limited regression analysis was also employed with the statistically significant variables as the independent variables in order to derive a multiple regression equation that could be used to measure the precise impact of the statistically significant factors on the percentage of the population residing in high levels of light pollution.

RESULTS

In this section, all the results from the statistical analyses, as outlined in the "Description of Research Study" section, are presented, and examined in detail. The effects of the factors on the percent of population living under significant light pollution are discussed. The raw data for the study may be found in the appendix.

Results and Discussion

A regression analysis was conducted with the aforementioned dependent and independent variables, yielding the following results.

OVERALL FIT							
Multiple R	0.77931		AIC	1047.364769			
R Square	0.60733		AICc	1048.221911			
Adjusted R Square	0.59347		SBC	1069.597817			
Standard Error	18.9023						
Observations	177						
ANOVA				Alpha	0.05		
	df	*SS*	*MS*	*F*	*p-value*	*sig*	
Regression	6	93944.4	15657.4	43.82167701	4.4E-32	yes	
Residual	170	60740.7	357.298				
Total	176	154685					
	coeff	*std err*	*t stat*	*p-value*	*lower*	*upper*	*vif*
Intercept	-13.1369	4.50955	-2.91314	0.004059216	-22.0389	-4.23502	
2019 GDP Per Capita (2019 USD)	0.00019	6.8E-05	2.83684	0.00511037	5.8E-05	0.00032	1.21692
Pop/km2	0.00252	0.00235	1.07034	0.285985153	-0.00213	0.00716	1.06751
Land Area (km2)	1.1E-06	8.5E-07	1.27328	0.204656072	-6E-07	2.8E-06	1.30897
Population (2019)	-3.2E-09	1.1E-08	-0.30163	0.763303454	-2.4E-08	1.8E-08	1.27576
Urban Population %age	0.85853	0.0681	12.6075	3.74561E-26	0.7241	0.99295	1.23229
Forest Cover	-0.1327	0.06242	-2.12613	0.03493633	-0.25591	-0.00949	1.01414

Table 1: Regression Analysis of impact of factors on percentage of residents of a country living under significant light pollution.

Out of the six variables, two variables — Urban Population Percentage, GDP Per Capita - were found to be statistically significant in impacting the percentage of residents living under significant light pollution.

Urban Population Percentage: *b*=0.85853, *t* (170) =12.6075 (greater than critical *t* value of 1.654), *p*<.01.

GDP Per Capita: b=0.00019, t (170) =2.83684 (Greater than critical t value of 1.654), p<.01.

A multivariable regression analysis was conducted once more, with only the two statistically significant variables as independent variables, and the following results were obtained

OVERALL FIT							
Multiple R	0.76812254		AIC	1047.002282			
R Square	0.590012236		AICc	1047.23484			
Adjusted R Square	0.585299733		SBC	1056.530731			
Standard Error	19.09127892						
Observations	177						
ANOVA				Alpha	0.05		
	df	*SS*	*MS*	*F*	*p-value*	*sig*	
Regression	2	91266.08402	45633.04201	125.2014549	2.04676E-34	yes	
Residual	174	63418.98593	364.4769306				
Total	176	154685.0699					
	coeff	*std err*	*t stat*	*p-value*	*lower*	*upper*	*vif*
Intercept	-17.7783421	3.961028531	-4.48831459	1.30207E-05	-25.59619025	-9.96049	
2019 GDP Per Capita	0.0001998	6.73175E-05	2.968019972	0.003419638	6.69357E-05	0.000333	1.186502
Urban Population %:	0.883595018	0.067487218	13.0927758	1.0524E-27	0.750396073	1.016794	1.186502

Table 2: Regression Analysis impact of factors on percentage of residents of a country living under significant light pollution.

Significance:

The data shows that the income levels and urban population levels of a country correlate with the percent of population living under heavy light pollution. From this we can conclude that:

- Urban spaces need to manage their light levels more efficiently. They need to start taking light pollution into consideration when planning and designing roadways and development plans. Light efficient street lamps and lighting fixtures should be implemented.
- Areas with high levels of income tend to produce more light pollution. This could be because they have more expendable income to spend on consumption of energy for uses such as lighting fixtures.

To understand the analysis graphically, the two significant variables were plotted against light pollution

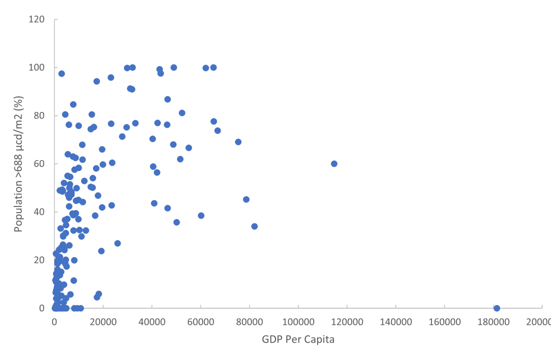

Figure 1: Scatterplot depicting GDP Per Capita vs Light pollution

It is apparent from the graph in figure 1 that majority of the nations follow a trend, but deviate further from the general trend as the GDP Per Capita increases.

The first area of note consists of countries with little measured light pollution, with all its nations having very few citizens residing under high levels of sky glow. This section tends to consist of remote locations, typically with low GDP per capita. The nations of this category appear to be nations who are remote or island nations (Solomon Islands, Samoa, Nauru, Grenada etc.), heavily forested (Guinea Bissau, Gambia, Liberia, Sierra Leone etc.), extremely mountainous (Nepal, Bhutan). In general, these nations have difficult terrain, which could explain the lack of urbanisation and light pollution.

A notable exception here is Liechtenstein, with one of the highest per capita GDPs in the world ($181402.8), yet not appearing to have any significant light pollution in its country. This may be due to the fact that light pollution education is well embedded in the nation of Liechtenstein, further showing that with the right measures, light pollution can be successfully combated [13].

The next notable region of the graph consists of nations with very low GDP Per Capita and a non-insignificant portion of the population living under serious light pollution. This is because they have developed and urbanized to some extent, however not to a high degree. They include the likes of Moldova, Namibia, Tajikistan, Democratic Republic of the Congo, Angola, Yemen, Guatemala and many more.

The rest of the graph shows a less clear trend; however it is clear that in general, higher income nations will have more of their population affected by light pollution. It appears that after a certain GDP Per Capita number, light pollution varies drastically from nation to nation. This category of nations vary greatly in their population demographics, means of income, and light pollution awareness, which could account for this great difference between the effects of light pollution on these nations.

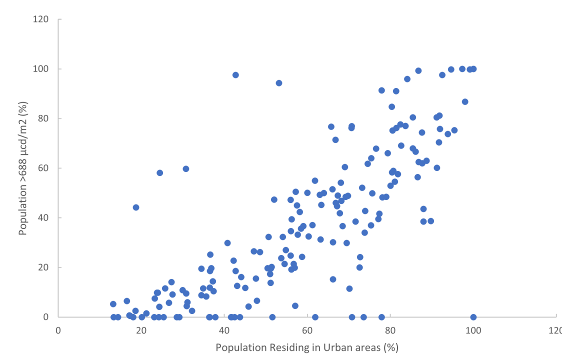

Figure 2: Scatterplot depicting Urban Population vs Light Pollution

It is apparent from figure 2, that as the Urban Population of a country increases, the amount of people residing under large amounts of light pollution increases similarly. This parallels the results found in the regression analysis in tables 1 and 2.

Some countries, however, deviate from this trend. Nauru, for example, has 100% of its population residing in urban areas. However, none of Nauru's over 10,000 residents live under any significant light pollution, perhaps because of Nauru's isolation and development levels [14, 15]. In Nauru, due to the small land area ($21km^2$), people are forced into living on the few major settlements on the island.

On the other corner of the plot, Egypt has extremely high light pollution levels despite having a relatively low urban population. This could be because even the residents of Rural Egypt are forced to live near the Nile River due to Egypt's geography [16], forcing even the non-urban residents to live under the skyglow produced by the cities near the Nile.

Four other countries deviate greatly from the general trend towards the top side of the graph. These are: St Lucia, Antigua and Barbuda, St Kitts and Nevis, and Trinidad and Tobago. Interestingly, all 4 of these nations are island nations, near each other in the Caribbean. They do not suffer from the isolation of Nauru, nor the lack of available land, and so this could be the reason for the complete contrast between these Caribbean nations and Nauru.

Towards the bottom of the graph, the major deviations come in the forms of nations with very few residents residing under heavy light pollution. This is due to their isolation or difficult terrain. The same pattern is also depicted by this group of nations in Figure 1.

From Figure 1 it is clear that there is a major distinction between the trends for lower income countries and higher income countries. Hence, a graphical analysis of ten Low Income Nations and ten High Income Nations was done.

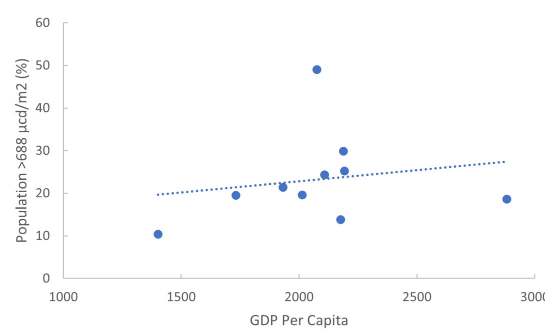

Figure 3: Graph Depicting GDP Per Capita vs Light Pollution for Developing Countries

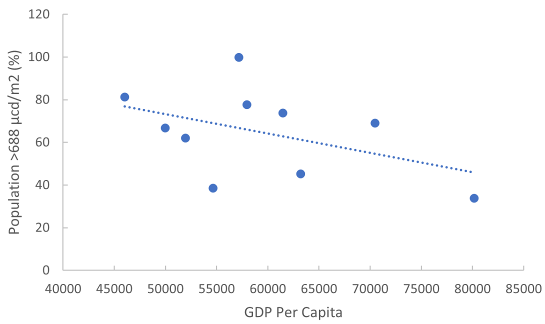

Figure 4: Graph Depicting GDP Per Capita vs Light Pollution for High Income Countries

As shown in Figure 3, there is a clear upwards trend when comparing the income levels of the developing nations to its light pollution. However, the exact opposite is found in Figure 4 while comparing the high income countries, which contrasts both the global trend and the above mentioned trend for developing nations.

From this we can infer that higher income countries have more expendable income to be utilized on commodities like night-friendly lights. This means that there is a need for work to be done in developing, low income countries.

Looking at one of these low income countries, India, it is clear that much work needs to be done even in its major urban areas. Here is a chart comparing the sky glow of 8 cities across the country [17,18].

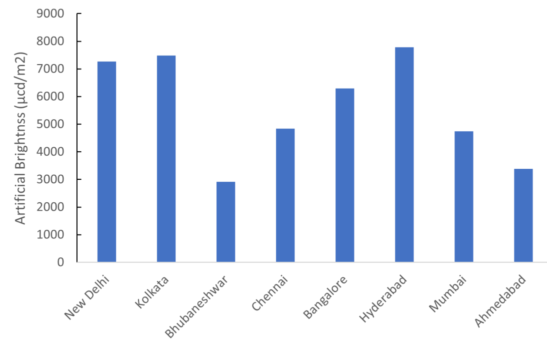

Figure 5: Graph Depicting Skyglow across Major Indian cities

As shown in Figure 5, the cities compared all show high levels of artificial brightness; however they vary in many aspects. A graphical analysis was done on these cities based on their population density in its urban areas and literacy rates.

The two factors which proved to be statistically significant globally were not chosen because the areas analysed were entirely urban areas, therefore the percent of urban population is 100% for all cities. GDP Per Capita was not considered because of the fact that no reliable estimates could be found for the same.

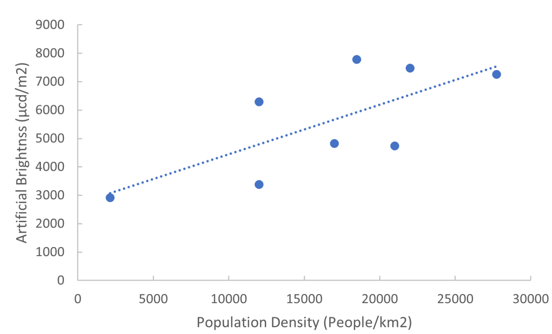

Figure 6: Graph depicting Population Density vs Skyglow for Indian Cities

The graph in Figure 6 shows that as the population density of a city increases, the artificial brightness of the city increases with it. This could be because of the fact that more individuals creating artificial lighting will increase the artificial brightness.

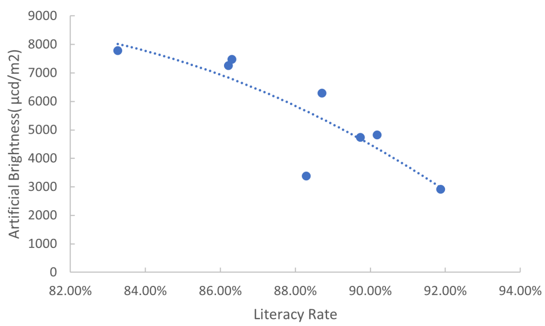

Figure 7: Graph depicting Literacy Rate vs Skyglow for Indian cities

The graph in Figure 7 shows that with a decrease in Literacy Rate, light pollution decreases. This shows that with better education comes a better understanding of light pollution and how to deal with it. Therefore, awareness is of utmost importance towards the reduction of light pollution.

CONCLUSION

The research paper attempted to find correlations between the amount of a nation's population affected by light pollution and demographic factors of that population by identifying factors that were correlated with the percentage of the population living under heavy light pollution.

In conclusion, it was determined that the percentage of the population of the country living under heavy light pollution was positively correlated with urban population and per capita GDP income. Average population density and forest cover did not show significant correlations. It was also determined that in Indian Cities, light pollution was positively correlated with the population density of the city, and inversely correlated with the literacy rate of the city.

This shows that it is absolutely essential to bring light pollution to the forefront during discussions about urban planning and city design. Smart lighting, pollution efficient lights and street lamps, etc. should be implemented. This not only reduces light pollution, but also reduces energy consumption, providing an economic incentive to prevent light pollution. It also shows that education and awareness programmes are essential to the fight against light pollution.

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