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Tracking Light Pollution: A Longitudinal Study Utilizing Two Methods

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Abstract

The Illuminating Engineering Society of North America (IESNA) and other groups have identified light pollution as an important outdoor lighting issue. Besides interfering with astronomical observations, research has uncovered negative effects on wildlife migration, marine life, star gazing and human health. Related issues include circadian rhythm disruption, melatonin suppression and cancer growth. In response to these threats, several European governments and American state legislatures have enacted legislation to curb light pollution. The main purpose of this longitudinal research project, based on data collected for the international Globe at Night program, was to measure light pollution levels at the same 20 sites in a small town in a Southern Midwestern U.S. state over a four year period. The research team members included University students and community member volunteers, supervised by University faculty members. Researchers visited sites at nighttime during the same month and lunar cycle each year and documented sky quality. One of two GLOBE at Night-approved data collection methods were used at each site: (1) manually comparing views of the constellation, Orion, to standardized star charts to determine Naked Eye Limiting Magnitude (NELM) or (2) using a Sky Quality Meter, which assigned magnitudes per square arcsecond (MPSAS) when energized and pointed at the night sky. Conversions allowed for results from both methodologies to be aligned in reporting. These observations were submitted to the GLOBE at Night worldwide data set. The research found evidence of light pollution at some of the sites. We also found that the mean light pollution increased significantly over the period of four years. In particular, NELM values dropped from 3.5 in 2009 to a 2.45 in 2012, which also marked the highest pollution levels over the period. Based on the results, it is evident that despite a sparse population of less than 50,000 people, this town showed changes in light pollution similar to the global trend. This study makes a meaningful contribution to light pollution research since previously only very limited topical research had been conducted in this geographic area. Light pollution mitigation efforts, including legislation, had increased in this area over time, rendering this work relevant to policy makers.

Keywords

Light Pollution, NELM, Outdoor Lighting

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1. Introduction

The term, *light pollution*, is a relatively recent addition to modern vocabulary. Some are becoming increasingly concerned with light pollution – wasted up-light streaming skyward, the glow of street lights intruding through bedroom windows, and the possible health, safety, welfare and environmental implications associated with the regular disruption of circadian rhythms [1, 2].

The term "light pollution" may be found in the dictionary, as "light pollution – *noun*; 1. unwanted or harmful light, as from bright street lights or neon signs; 2. *Astronomy.* artificial

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illumination of the sky that sets a limit on the faintness of stars that can be observed or photographed. Origin: 1970-75." [3]. Further, in 2009, the American Medical Association declared that some light exposure can be detrimental to human health [4]. [5] indicated that over the years, human activity has increasingly been illuminated, although it has long been understood that exposure to optical radiation has health benefits and risks [6]. Some have identified aesthetic, safety, and security issues as reasons for illumination. However, others have perceived some artificial lighting as disruptions of the natural light/dark cycles and a waste of energy. The terms, "light pollution", "light trespass", and/or "sky glow", have been coined. "Stray light from a security lighting installation may be considered to be light trespass by neighbors and a source of sky glow by others." [7]. In 2000, [8] indicated a need for light trespass research.

For over ten years, in an attempt to track light pollution, the GLOBE at Night program has collected sky brightness at night data, worldwide [9]. "The Globe at Night program is an international citizen-science campaign to raise public awareness of the impact of light pollution by inviting citizen-scientists to measure their night sky brightness and submit their observations." [10]. GLOBE at night is jointly sponsored by The National Optical Astronomy Observatory (NOAO); Centro de Apoyo a la Didáctica de la Astronomía (CADIAS), an Astronomy Teaching Support Center in Chile; and the International Dark-Sky Association (IDA), who "strives to preserve and protect the nighttime environment and our heritage of dark skies through quality outdoor lighting…and raises awareness about light pollution, its adverse effects, and its solutions". [11]

Astronomers are concerned about light pollution, because it prevents them from being able to see and study the stars. Light pollution is often created by man-made, electric lights and can be field measured at night by either of the following approaches, 1. comparing of visual observations of the stars in the sky with comparisons to star charts and assigning numerical ratings in Naked Eye Limiting Magnitude (NELM) [12] or 2. using a Sky Quality Meter, which assigns magnitudes per square arcsecond (MPSAS) [13, 14]. [28] reported that a SQM sky quality meter measurement indicates the amount of light falling on the meter's photocell in the units of magnitudes per square arc-second (MPSAS). A higher number indicates a darker sky with less light pollution. A lower number indicates a brighter sky with more light pollution. "A meter reading of 21.00 would indicate a very dark site, while a reading of 16.00 (MPSAS) would indicate a light polluted sky." [28]. A measurement of 16 MPSAS converts to 2.19 NELM. In 2007, near the beginning of the GLOBE at Night program, 8,491 observations were made by the GLOBE at Night participants in 60 countries worldwide [15]. Since then, annual reported observations have increased. Researchers, astronomers, physicians, citizens and students have raised light pollution concerns on global as well as local levels.

The researchers for the current study had hypothesized that light pollution exists at sites on and near the researcher's University campus in a southern mid-west town of less than 50,000 permanent inhabitants. Previously, at least one unsolicited complaint regarding light pollution at a student housing site on the University campus, has been recorded: "…I have to thank [the University] for the stadium; it provides a constant light at night that keeps me awake at all hours…" [16]. In the professional literature, the Illuminating Engineering Society of North America acknowledges that athletic facilities may produce light pollution and offers some suggestions for the implementation of ordinances that could curtail the times sports lighting may operate. "During post-curfew hours, lighting which is non-essential, such as that of sports facilities… could be extinguished…" [17].

In 2007, unsubstantiated anecdotal evidence from the University's small, off-campus observatory had pointed to increased light pollution as a detriment for physics students and faculty members who utilized the optical telescopes there. Optical telescope users who attempt to view starts at night are sometimes foiled by light pollution.

Six years later, in a nearby city, a lighting ordinance, whose… "major goal is to address light spillover from commercial properties onto residential properties…" was approved by the city council [18]. Lighting ordinances have become more common and attempt to reduce unwanted light in some areas. The [19] has published tips on how to have a lighting ordinance passed in a community.

Also in 2011, approximately eighty five miles from the University campus, a new zoning ordinance declared "…For projects that will likely impact nearby residential developments, a photometric plan (a point-by-point foot candle array in a printout format indicating the location and aiming of illuminating devices) will be required." [20]. A photometric plan would show the anticipated nighttime light level contributions from a new lighting installation [20].

Beyond athletic facilities, and neighbors' security lighting, advertising and retail operations have also previously been identified contributors to light pollution [21, 22, 23]. Car dealerships typically have included illuminated parking lots and outdoor signage which may provide high light levels, glare, and light trespass onto adjoining properties.

On and off-campuses, consideration of the relationships between light levels and potential crimes or security benefits

have been examined and discussed. Going against public opinion, which holds that higher light levels lower crime rates, The International Dark-Sky Association published an Information Sheet in 2000 entitled "Dark Campus Programs Reduce Vandalism and Save Money" [24]. The Information Sheet stated that turning off lights at night makes it easier to identify unusual activities on a campus. [25] presented examples of studies which seemed to show that crime may be correlated with an increase in light levels. Another publication, entitled Light Pollution Is A Safety and A Security Risk [26] explained that light pollution create conditions which may temporarily blind victims and give hiding criminals an advantage.

Researchers have "found that about 83% of the world's population and more than 99% of the U.S. and European populations live under light-polluted skies (that is, where artificial sky brightness at the zenith is >14 μcd/m^2)…" [27].

The purpose of the current research was to examine a range of sites on and near a southern mid-west United States of America's University campus to observe and document sky quality including any associated light pollution evidence. In consideration of this phenomenon, objectives of the current study included: to raise environmental design students' awareness of light pollution; to measure and document sky quality at different sites on and near a University campus; and to submit data to the GLOBE at Night program for inclusion in the international longitudinal data set. Data collection also provided researchers with an opportunity to participate in a longitudinal study with international implications.

2. Methodology

2.1. Study Sites and Data Collection

The research team consisted of undergraduate and graduate students, community volunteers and university faculty members at a large university in the Southern mid-west. One of these research team members taught an undergraduate course, Environmental Design, to interior design students which featured teaching modules focused on lighting design and lighting pollution. Students enrolled in this course were annually offered extra credit incentives to participate during the GLOBE at Night's program period. University faculty members from the instructors' college, some of whom were in the Department of Design, Housing and Merchandising or in the School of Hotel Restaurant Administration, also participated. The University faculty members and community volunteers were not provided with any incentives to participate.

After participating in annual training sessions on data collection procedures, the researchers visited 20 different outdoor sites which are identified in this study as site designations "A" – "T". The sites included retail and housing building types. Housing included multi-family units, dormitories, Greek fraternity houses and group housing for older adults. Viewing and data collection occurred between 9 p.m. and 11:59 p.m. in the Central Standard Time zone in the Spring of four consecutive years, 2009-2012). The research team adhered to the GLOBE at Night program's designated research period each year, usually an approximately 2 week window in March. Researchers only conducted the study on evenings which exhibited none of the following conditions: precipitation, overcast sky, or more than ¾ of the sky covered by clouds.

One of the following GLOBE at Night-approved methods of gathering data regarding light pollution were used: 1.) manual comparison of views of the constellation, Orion, to standardized star charts provided by NOAA to determine Naked Eye Limiting Magnitude (NELM) or 2.) Sky Quality Meter, which assigned magnitudes per square arcsecond (MPSAS) when energized and pointed at the night sky. The researchers referred to the methodology described in "Magnitude Charts for the Constellation Orion at 40N" [12] and "Using Sky Quality Meters to Measure Sky Brightness" [14]. The researchers recorded the latitude, longitude and cloud cover of each site. Viewers' use of eyeglasses and contact lenses was allowed but the use of telescopes and binoculars were prohibited.

2.2. Instruments

2.2.1. Manual Comparison of Orion to Determine NELM

Researchers documented sky quality by manually comparing their unaided views of the constellation, Orion, to star charts that represented Orion under various viewing conditions. The researchers utilized Magnitude Charts for the Constellation Orion at 40N from [14]. Viewing conditions (magnitude ratings) were measured on a scale of 1 to 7 ("1" indicating heavily light polluted skies with few stars visible, and "7" indicating "dark skies" (no pollution)). Members of the research team viewed Orion at the assigned site and rated the condition/level from the chart (See Figure 1) that best represented what they observed. Figure 2 shows student researchers gathering data in situ.

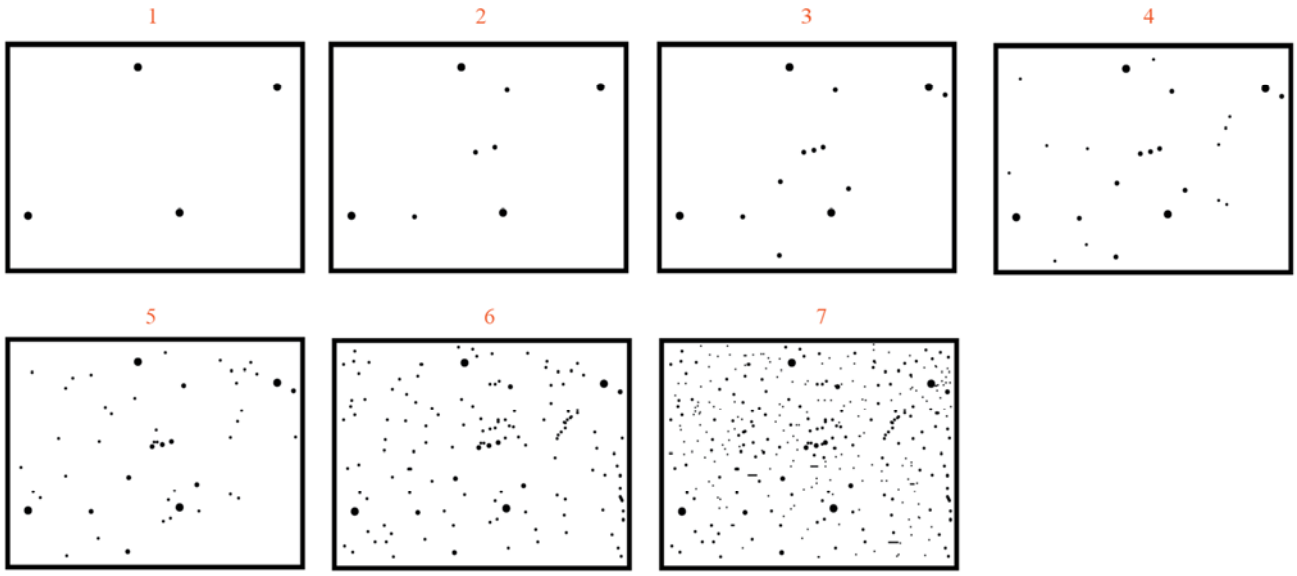

Figure 1. Schematic magnitude chart for the constellation Orion with highly polluted sky at "1" and least polluted at "7". (Image recreated from www.globeatnight.org).

2.2.2. Digital Measurements with Sky Quality Meter to Determine MPSAS

Some researchers utilized a Sky Quality Meter, which assigned magnitudes per square arcsecond (MPSAS) when energized and pointed at the night sky.

Figure 2. Data Collection routine by a member of the research team.

2.3. Data Analysis

Conversions were performed by the researchers to allow for the results from both sky quality measurement methodologies to be aligned and analyzed. The researchers converted the MPSAS data to the NELM format. The researchers utilized the "Conversion Calculator - MPSAS (B) to NELM (V) Systems" [29]. Refer to Table 1 for a summary of the NELM readings measured at the sites in the current study. A one-way ANOVA with repeated measures was performed on the collected data to determine if there was a significant difference in light pollution over the four year study period. The analyses were performed using SPSS 23.0.

3. Results

Based on the aforementioned measurement of 16 MPSAS or lower (converts to 2.19 NELM or lower) as evidence of light pollution, the researchers found evidence of light pollution at one half of the 20 sites (n=10, 50%). These ten sites, Site "A" (retail); "B" (multi-family residential); "C", "D" and "E" (fraternity houses); "F" (university dormitory); O, P, and Q (university multi-family residential); and "T" (retail car dealership) experienced measurable light pollution during at least one year of the study period. Refer to Table 1.

Table 1. NELM Magnitude by Site and Year (* refers to High Level of Light Pollution).

Site Designation	Type	NELM Magnitude by year			
		2009	2010	2011	2012
A	Retail	3	3	3	1*
B	Multi-family residential	6	3	3	1*
C	Fraternity house	3	6	1*	1*
D	Fraternity house	3	3	3	1*
E	Fraternity house	3	3	3	1*
F	University dormitory	4	4	2*	3
G	Older adult congregate living facility	4	4	5	3
H	Older adult congregate living facility	3	3	3	3
I	Older adult congregate living facility	4	4	4	4
J	Older adult congregate living facility	3	3	4	3
K	Older adult congregate living facility	3	4	3	3
L	Older adult congregate living facility	3	3	4	3
M	Older adult congregate living facility	3	3	4	3
N	Older adult congregate living facility	4	3	3	3
O	University multi-family residential	4	3	3	1*
P	University multi-family residential	3	3	3	1*
Q	University multi-family residential	3	3	2*	3
R	Single family residence	5	5	5	5
S	Neighborhood clubhouse	5	5	5	5
T	Retail - car dealership	1*	1*	1*	1*

Of the 80 total observations, there were fourteen observations (17.5%) of light pollution (2.19 NELM or lower) during the four year study period. One site, Site "T", retail car dealership, was consistently found to have a very high level of light pollution (1 NELM) during each annual visit (100%). Two sites, Site "R", single family residential, and Site "S" neighborhood club house were found consistently to have had no evidence of light pollution. The relatively dark sky measurements (5 NELM) were reported annually for each of the four years in the study (100%). Refer to Table 1.

Other sites appeared to have variability across years. Two of the 20 sites, Site "B" and "C", were found to have had the darkest sky measurements (6 NELM, n=2, 10%) which were recorded during the first year and second year of the study, respectively. A few of the sites (n=3, 15%) were found to have had a relatively dark sky of 5 NELM with a reported 9 observations (11%) over the four year study period. While Site "G" reportedly had 5 NELM in year 3 only, two of the sites, Site "R" and "S" reportedly measured 5 NELM for each of the four years.

On a scale of 1 (heavily light polluted) to 7 (dark skies, no pollution), the mean magnitude reading was calculated across the four years. The means across Sites "1" – "T" were found to vary from 1 - 5 NELM. Site "T" was found to have a mean of 1 NELM which was evidence of light pollution.

The mean across the four years, across all sites was 3.15 NELM which was not indicative of light pollution. Figure 3 shows the mean of NELM for all of the 20 sites.

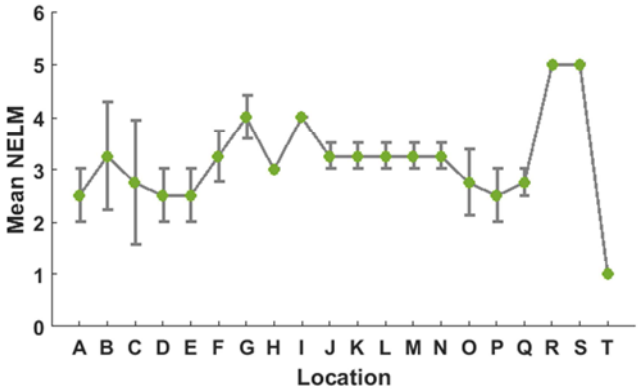

Figure 3. Mean NELM data by location (error bars indicate standard error of the mean).

The researchers submitted readings from all 20 sites to the GLOBE at Night worldwide data base, annually, for a total of 80 reported observations over the four year period. The mean NELM values for each year of the longitudinal study were as follows: Year 1, 3.50 NELM; Year 2, 3.45 NELM; Year 3, 3.20 NELM and Year 4, 2.45 NELM. (See Figure 4). To determine whether these changes in the NELM were statistically significant, a One-Way Analysis of Variance (ANOVA) with repeated measures was conducted. The confidence interval was chosen to be $\alpha = 0.05$. Mauchly's test of sphericity showed that that the assumption of sphericity was valid (p-value: 0.366) and the repeated measures ANOVA showed that there was a significant difference (p – value: 0.001) in light pollution over the four years. To further explore the differences, a post hoc analysis was performed using Bonferroni correction and the result showed that the

light pollution on Year-4 (2.45 NELM) was significantly different than Years-1 (p-value: 0.016), 2 (p-value: 0.016) and 3 (p-value: 0.033). In particular, the light pollution significantly increased in Year-4 compared to all the remaining years.

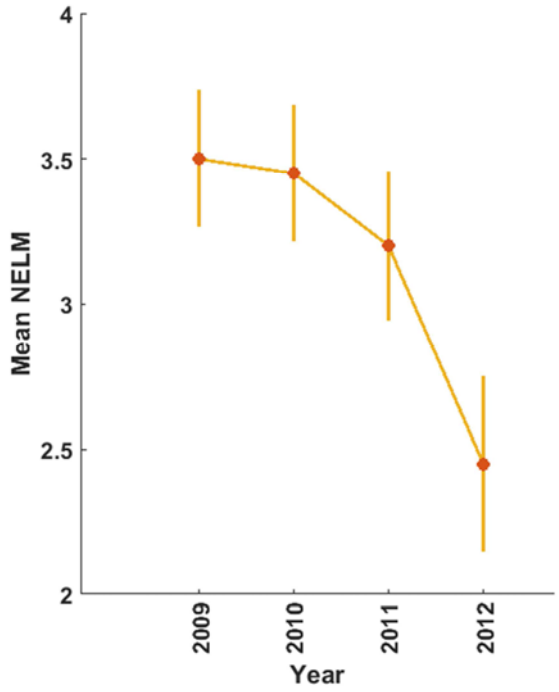

Figure 4. Mean NELM Data by Year (error bars indicate standard error of the mean).

Further, an online search by the researchers did not locate any current lighting ordinance in effect or under consideration for the study area.

4. Discussion and Conclusion

The manual comparisons of Orion under different sky conditions to the GLOBE at Night-provided star magnitude charts were found to be relatively simple for student researchers to understand and utilize. The charts were free to download and may be photo-copied. Since the manual method required no equipment acquisition or equipment usage in the field, it also provided an inexpensive way to collect data. The manual method could be simultaneously utilized by many researchers during the brief research periods. However, the judgment, reliability and visual acuity of observers utilizing this method may have resulted in faulty data.

The digital sky quality meter was found by researchers to be easier and faster to use than utilizing the Orion star magnitude charts since the meter utilized the "point and click" method. It may be assumed that the sky quality meter method was more reliable since an empirical measurement was generated by the device with no judgments required on the part of the data collectors. Sky quality meters were found to be readily available and relatively inexpensive (approximately $119.99 U.S.). However, the cost of the meters may be cost-prohibitive for some research groups to acquire, especially in multiple quantities. Recently, aps for smart phones have been developed which will also measure sky quality and may be even more convenient to use.

This study met its objectives to raise lighting design students' awareness of light pollution; to measure and document sky quality at different sites; and to submit data to the GLOBE at Night program for inclusion in the international longitudinal data set. Data collection also provided researchers with an opportunity to participate in a longitudinal study with international implications. The researchers were able to make a meaningful contribution to GLOBE at Night's international, longitudinal data set of light pollution and sky quality readings. Beyond the observations collected by the researchers, no other observations for the areas under consideration were found in the international data set for the period of the study. The research team found light pollution at some of the studied sites on and near a University campus in a town of less than 50,000 permanent residents during every year of the four year study period. This project filled a gap in the current light pollution knowledge for the studied area.

In the future, additional measurements could be made annually and comparisons over a longer time period at an expanded number of sites could generate more knowledge about the growth or waning of light pollution. Further studies, regarding the implications for health, safety, wellbeing and the environment, as influenced by light pollution and sky quality relative to all types of sites worldwide, are needed.

Limitations

The sites selected for the study constituted a convenience sample within or near the researchers' University campus. The total sample size of sites was relatively small. Some of the researchers were students whose cohort participated during only one of the four years of the study period. Thus, there was a variety of research team members submitting data throughout the research period.

The two instruments used to measure light pollution were very different. One of the instruments was subjective and one was empirical. At the time of data collection from one year to another, electric lights in the area of the considered sites may not have been operational (e.g., lamp burnout) or may simply have been temporarily turned off. Further, lighting may have been temporarily installed or energized (i.e., for a special event) at one or more of the considered sites during one or more of the data collection periods.

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