Comparing the Effects of Select Atmospheric Variables on Artificial Light Pollution at Night

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Abstract:

During the winter of 2023, a group of researchers from Crestwood High School in Dearborn Heights, Michigan, collected data in two specific locations to measure the amount of **light pollution** in suburban regions. Using the **Unihedron Sky Quality Meter (SQM)**, **Vernier Go Direct Weather Device**, and observational skills, the group recorded the **night sky brightness (NSB)**, various **atmospheric parameters**, and ground/weather conditions, respectively. The Unihedron SQM measured NSB in **magnitudes per arcsecond^2**. The collected data from the Vernier Weather Device was then compared with atmospheric data from a research-grade **Weather Network HD CCD Video Camera (Weather Station)** located on the roof of the school building. Atmospheric protocols collected and compared between the Vernier Weather Device and the Weather Station included **barometric pressure**, **relative humidity**, and **air temperature**. Lastly, the researchers recorded weather conditions, including precipitation, such as snowfall. The data mentioned above was collected each day at approximately two hours after sunset from 20 November 2023 to 19 December 2023. Comparing trends in NSB with those in atmospheric data allowed the group to correlate the relationship between light pollution and weather conditions. Furthermore, the usage of both the Vernier Weather Device and the Weather Station allowed for the testing of the accuracy of the Vernier Weather Device. Moving forward, the researchers intend to share and analyze the collected data with local environmentalists and community members. Additionally, the group recommends the usage of the Vernier Weather Device by citizen scientists around the world for atmospheric data collection.

Research Questions:

The following research questions guided the researchers' investigation of the impact of certain atmospheric and meteorological variables on light pollution around a suburban high school campus:

1. How do different atmospheric meteorological variables, such as air temperature, altitude, and barometric pressure, affect the intensity of artificial light pollution?
2. How do specific weather conditions, such as snow, affect the intensity of artificial light pollution?
3. Can inexpensive, compact, and portable weather devices like the Vernier Go Direct Weather Device effectively and accurately collect atmospheric protocols such as temperature, humidity, and air pressure?

Null Hypotheses:

1. Atmospheric and meteorological variables like air temperature, humidity, and barometric pressure do not affect artificial light pollution.
2. Specific weather conditions, such as snow, do not affect the intensity of artificial light pollution.
3. Vernier Go Direct Weather Device atmospheric measurements can be utilized effectively and accurately by students and other citizen scientists as an inexpensive medium to collect weather-related data.

Introduction and Review of Literature

Artificial light pollution refers to changes in the natural level of the nightscape produced by excessive artificial light sources (Azman 2019). There has been a rapid increase in light pollution within the last few decades (Azman 2019). Notably, due to the reflecting ability of clouds, light can be seen tens of kilometers away from the light source, meaning light pollution is a widespread issue not only in entirely urban and suburban areas but even surrounding regions. In fact, between 2011 and 2012, the average night sky brightened by 9.6% (Impey 2023).

Furthermore, according to the London Natural History Museum, night skies are becoming "around 10% lighter each year" (Ashworth 2023). The issue of light pollution most commonly manifests itself in the form of "skyglow," which is the combination of artificial light at night (ALAN) and atmospheric scattering, which is the diffusion of light due to suspended atmospheric particles (Gaston 2023). The increase in artificial light pollution in the form of skyglow over the years has resulted in various negative impacts, including harming human health, disturbing wildlife behavior, and obstructing the view of astronomical bodies.

For example, in Dearborn Heights, Michigan, the location of the research site, a large majority of households light up their homes at night using LED and incandescent light bulbs. This action is a common practice worldwide, significantly contributing to the increase in light pollution and, therefore, the adverse effects on plants, animals, and even humans. Specifically, a brief duration or low intensity of light at night can cause physiological and behavioral reactions in many plants, inhibiting photosynthesis (Wei 2023). Additionally, nocturnal animal species are expected to be most vulnerable to artificial light. Specifically, adult moth populations have been declining in many parts of central Europe due to moths' tendency to fly toward sources of light, including artificial light, which causes them to die of "sheer exhaustion" from not being able to escape the light, or the heat of the light itself (Boyes 2020). Additionally, in humans, disruption of the circadian rhythm, the internal 24-hour day-night clock affecting multiple physiological processes, is linked to several medical disorders in humans, including depression, insomnia, cardiovascular disease, and cancer, says Paolo Sassone-Corsi, chairman of the Pharmacology Department at the University of California, Irvine (Chepesiuk 2009).

Moreover, atmospheric variables, including air temperature, relative humidity, and barometric pressure, have been proven to affect the intensity and impact of artificial light pollution on the environment. For instance, particulate air pollution in the form of aerosols can intensify light pollution (Czaplicka 2020). Organic compounds and inorganic carbon-graphite compounds such as soot particles, sulfate aerosols, and nitrate aerosols resulting from chemical transformations of sulfur and nitrogen oxides have strong properties of reflection of light, resulting in the scattering of light (Czaplicka 2020). This results in the source of the artificial light being spread across an even larger area, intensifying the consequences of the artificial light at night. Additionally, low-pressure systems lead to cloudiness, wind, and precipitation, while high-pressure systems indicate calmer weather, as seen on the weather news each evening. In these low-pressure systems, the associated cloudiness can lead to an increased severity of light pollution, as the high albedo of clouds can result in artificial light being reflected toward the surface (Kocifaj 2020).

This preliminary research is vital to preventing the future extinction of multiple species as a result of the significant increase in the use of artificial lights. Understanding the effects of different atmospheric variables on the severity of light pollution will allow future research studies to examine how this artificial light pollution impacts certain species directly. With the decreasing costs associated with the efficiency of LED lights, many homes in Dearborn Heights and other urban/suburban areas globally are installing lights around their home for aesthetic benefits. However, they do not consider the environmental consequences, such as a decrease in the variety of plants and animal species (Hölker 2021).

Researching and measuring the impact of a variety of atmospheric conditions on the intensity of light pollution will allow for the presentation and education of this critical topic to local

communities, whether this be through informational webinars, community events, or student leadership meetings. This data will allow the research group to make an impact and open numerous opportunities for research, including an analysis of the decrease in certain organisms due to the excessive use of artificial light in suburban neighborhoods.

Materials and Method:

Figure 1 and Figure 2. Research Sites. The image on the left is a satellite view of a research site in front of Crestwood High School (42°19'17"N 83°17'33" W). The image on the right is a satellite view of a research site at the practice field of Crestwood High School (42°19'16"N 83°17'40" W).

Figure 3 and Figure 4. Vernier Go Direct Weather Device. The image on the left shows the Vernier Go Direct Weather Device that was used to take most of the data. The image on the right shows a Dearborn Heights researcher taking data using the device.

Figure 5 and Figure 6. Sky Quality Meter Device. The image on the left shows the Sky Quality Meter that was used to measure the luminance of the night sky. The image on the right shows a Dearborn Heights researcher taking sky-quality measurements.

Figure 7. Location of Weather Network HD CCD Video Camera Relative to Ground Level. The figure above shows the research-grade Weather Station located on top of the school building in Dearborn Heights, Michigan.

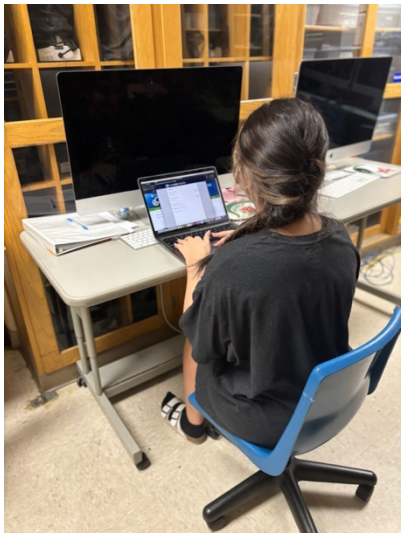

Figure 8. Uploading Research Data to GLOBE Website. The image above shows the Dearborn Heights researcher inputting the data into the GLOBE database.

Before the start of the study, researchers in Dearborn Heights, Michigan, collaborated with their GLOBE advisor and NASA Scientist Marilé Colón Robles to help determine possible protocols for taking measurements as well as how to limit the scope of the study. For example, the group decided that measurements would be recorded approximately two (2) hours after the projected sunset time for 21 days. Further, each group of data from the Vernier Go Direct Weather Sensor was collected over a span of 60 seconds at a height of approximately one (1) meter above the ground. The Unihedron Sky Quality Meter (SQM) readings were taken from five (5) spots around the reading site in a 10-meter radius and 1 meter off the ground, with an effort to minimize variables that might interfere with the measurement.

The researchers then recorded select atmospheric data using a Vernier Go Direct Weather Device over a four-week period from November to December of 2023. The Vernier device was connected to a wind attachment to monitor wind direction and speed. The data collected included air temperature, relative humidity, and barometric pressure. Additionally, a Unihedron Sky

Quality Meter was utilized to take SQM readings. The data collected using the Vernier device and SQM were compared to answer Research Question (1) regarding whether different atmospheric meteorological variables affect the intensity of artificial light pollution. Also, cloud types and unusual weather conditions were recorded for reference. Since clouds are not considered a GLOBE protocol, the research team took the initiative to find an alternative way to determine cloud type at night. The team decided to use the school's Weather Station HD CCD video camera to observe the clouds since they are not clearly visible to the human eye. The Weather Station allowed the researchers to identify these clouds more accurately and collect atmospheric data using GLOBE-acceptable protocols.

The sites used for this investigation were the front of Crestwood High School– exact location of latitude 42°19' 17" N and longitude 83°17' 33" W– and the soccer/football practice field lot– exact latitude 42°19' 16" N and longitude 83°17' 40" W. In addition, the data collected using the Vernier device was compared to the data collected by the stationary Weather station to determine the Vernier device's accuracy level.

Data Summary:

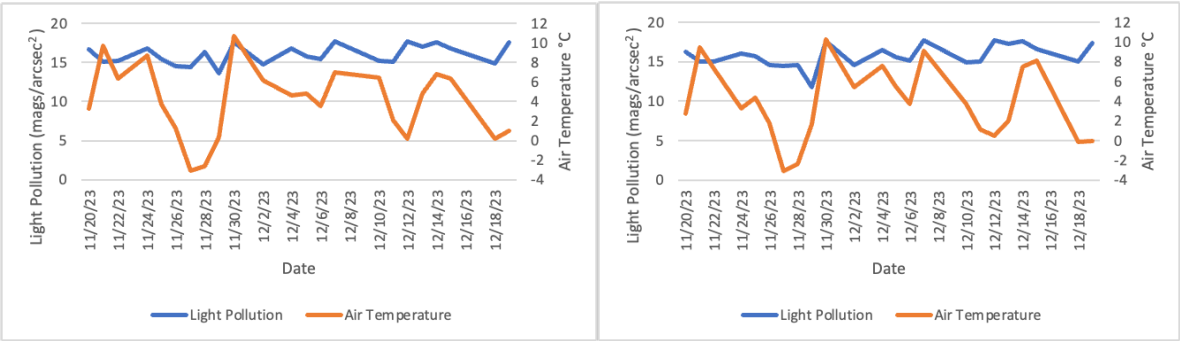

Figure 9 and Figure 10. Light Pollution vs Air Temperature. The line graph on the left shows the comparison of light pollution and air temperature in the front of the school, while the graph on the right shows that of the practice field. Light pollution shows little variation between the two locations, as well as little variation between each day. In contrast, air temperature fluctuates

from day to day with the most dramatic drop being on 11/28/2023. Although a relationship was expected between the two, the research shows that in these locations, there is little to no relation between light pollution and air temperature.

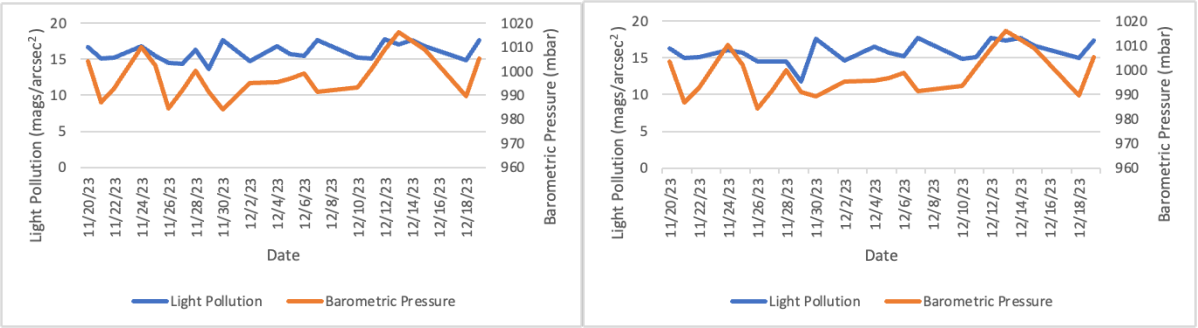

Figure 11 and Figure 12. Light Pollution vs Barometric Pressure. The line graph on the left shows the comparison of light pollution and barometric pressure in the front of the school, while the graph on the right shows that of the practice field. Both the light pollution and barometric pressure show little to no variation between locations, but barometric pressure fluctuates slightly from day to day. The graphs show little to no relationship between light pollution and barometric pressure.

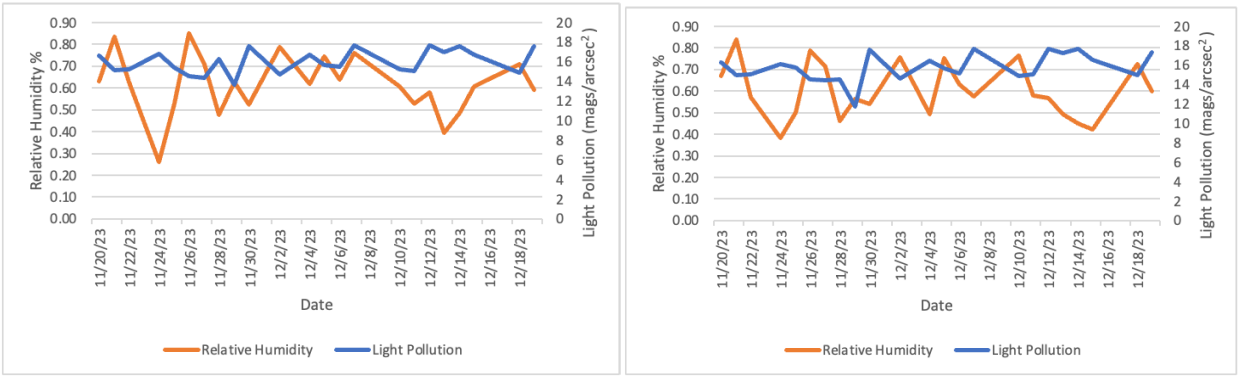

Figure 13 and Figure 14. Light Pollution vs Relative Humidity. The line graph on the left shows the comparison of light pollution and relative humidity in the front of the school, while the graph on the right shows that of the practice field. There is some variation in relative humidity between locations and a significant amount of variation in each location from day to day. Light pollution and relative humidity appear to have an inversely proportional relationship.

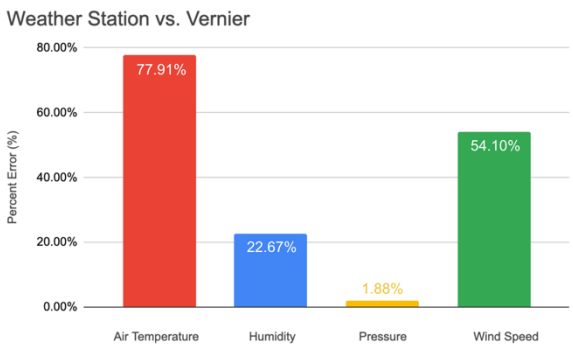

Figure 16. Weather Network HD CCD Video Camera vs Vernier (Dearborn Heights). The graph above shows the percentage error of air temperature, humidity, pressure, and wind speed between the Weather Station and the Vernier Go Weather Direct Device in Dearborn Heights, Michigan. Air temperature and wind speed have high percent errors of about 77% and 54%, while humidity has a percent error of approximately 20%. Pressure has the lowest percent error, hardly reaching 2%.

Discussion

The researchers both confirm and reject certain conditions within the first null hypothesis, which states that atmospheric and metrological variables do not affect artificial light pollution. Specifically, the data show that the atmospheric variables of air temperature and barometric pressure do not affect artificial light pollution. As shown by the data in Figures 9, 10, 11, and 12, the amount of light pollution measured in mags/arcsec2 fluctuates irrespective of the change in air temperature and barometric pressure. Additionally, the atmospheric variable of humidity is shown to have a significant, inverse relationship with the amount of light pollution present at any given point, as illustrated in Figures 13 and 14. Each peak of relative humidity in the atmosphere is coupled with a divot in light pollution. This conclusion is contradictory to common findings regarding the relationship between relative humidity and light pollution, likely because most light pollution observations are collected in the summer, where haziness due to humidity causes an increase in light pollution. This same principle may not apply to relative humidity in the

winter, as relative humidity is measured by absolute humidity compared to air temperature. Therefore, relative humidity is higher in the winter because the air temperature is lower.

Furthermore, we reject the second null hypothesis, which states that snow, among other weather conditions, does not significantly affect light pollution. In fact, during a snowstorm in Dearborn Heights on December 12, 2023, the data illustrated a peak in light pollution, demonstrated at that date's location on each figure above. This relationship is likely because the snowstorm resulted in an increase in cloud coverage and the reflection of light off precipitation particles.

Finally, the researchers reject the null hypothesis that the Vernier Go Direct Weather Device cannot be used effectively and accurately. It was concluded that the Vernier Go Direct Weather Device can, in fact, be used accurately and effectively, despite the significant percentage error demonstrated between the Vernier Go Direct Weather Device in Figure 15. While there does appear to be a significant difference between the air temperatures and wind speeds measured by the Vernier Go Direct Weather Device and the Weather Station, this discrepancy can be explained by the fact that measurements taken by the Vernier Device were taken 1 meter off the ground. At the same time, the Weather Station is located on top of the Crestwood High School building, which is several meters off the ground. This difference in altitude, coupled with the fact that a windbreak surrounds the collection locations, can account for the high discrepancy in air temperature and wind speed between the two devices. Additionally, the over 20% percent error in humidity can be explained by a multitude of factors, including human error when conducting the measurements. Lastly, the percentage error in pressure is negligible, which signifies that the Vernier Go Direct Weather Device accurately collects pressure measurements.

Conclusion

The researchers concluded that select atmospheric parameters such as humidity, as well as specific weather conditions like snow, can significantly impact the intensity of artificial light pollution at night in suburban regions. A relatively strong, inversely proportional relationship was recorded between humidity and light pollution, with every increase in humidity corresponding to a decrease in light pollution and vice versa. Additionally, the highest peak in light pollution was recorded on the date when a snowstorm hit the Metro-Detroit area, demonstrating the directly proportional relationship between snow precipitation and the intensity of artificial light pollution. This result was most likely due to the high albedo of snow, as snow can increase the intensity of light pollution by reflecting and scattering light sources, which enhances their reach and visibility at night. Due to this property of snow, the impact of artificial light pollution is exacerbated by reducing the visibility of the night sky and impacting respective organisms. In contrast, air temperature and barometric pressure were found to have little to no effect on the trend of light pollution from day to day. While air temperature and pressure can influence the dispersion and absorption of light in the atmosphere, the impact is relatively small and does not directly contribute to the intensity of light pollution at night.

Furthermore, using the inexpensive, compact, and portable Vernier Go Direct Weather Station will allow other students across the globe to take moderately accurate atmospheric measurements to help mitigate the gaps in current data due to the inaccessibility of atmospheric variable measuring devices. Moreover, this device will open opportunities for collaboration between student scientists worldwide, breaking down barriers caused by socioeconomic-related struggles and uniting student researchers in a collaborative effort to better understand the effects of certain

atmospheric variables on the intensity of natural and artificial phenomena on a local and global scale.

In future studies, this research may be expanded to locations across the globe to allow for an expanded comprehension of the impact of atmospheric conditions on the intensity of artificial light pollution at night. Additionally, for future reference, similar data should be collected over extended periods and span more than one season to draw more correlations between weather and the intensity of artificial light pollution at night. Also, to ensure that differences in elevation are accounted for, ground-level data should be taken simultaneously with daily reports from a Weather Station to have the highest accuracy and applicability of the data. Finally, working with other student researchers and mentors in the STEM field provided a unique and fulfilling experience for every single researcher and opened opportunities for them to pursue studies related to this research, including an analysis of the decrease in certain organisms due to the excessive use of artificial light in suburban neighborhoods.

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Badges:

I Make An Impact

The researchers hope to receive the esteemed “I Make An Impact” badge for the impact their data had on their local community. They collected data from two sites adjacent to Crestwood High School, a facility surrounded by households, and the researchers hope that their findings will allow their local community to determine how atmospheric conditions are impacting the intensity of light pollution, and how to go about improving this. The sites chosen by the researchers are surrounded by homes, the majority of which are constantly illuminated by LED and incandescent lightbulbs. This likely contributes to the existing light pollution in the community, and by utilizing the researchers’ findings, they can understand how atmospheric

conditions can intensify this pollution as well. The researchers intend to share this data at the local Dearborn Heights Watershed Commission to understand the implications of the data and the necessary actions thereafter.

I Am A STEM Professional

The researchers hope to receive the prestigious "I Am A STEM Professional" badge for their collaboration with Marilé Colón Robles of NASA Langley. The group members met with Ms. Robles via Zoom on 18 September 2023 for nearly an hour. At this meeting, Ms. Robles provided much-needed guidance regarding the scope and impact of the group's data. Specifically, in collaboration with Ms. Robles, the group members were able to properly set boundaries around their research project, as well as understand the significance of light pollution on affected communities. Additionally, with Ms. Robles' direction, the group was able to decide on which specific atmospheric parameters to measure in addition to the methods used in the data collection.

I Am A Data Scientist

The researchers hope to receive the esteemed "I Am A Data Scientist" badge for their collection, organization, and analysis of atmospheric and light pollution at night data. For twenty-three days, the researchers collected and compared data from two separate locations, including the soccer/football practice field and the front of the school. This data was then compiled into Microsoft Excel and converted into graphs. The information provided by these graphs allowed the researchers to identify any relationships or correlations between the variables, allowing them to draw conclusions between atmospheric variables and light pollution. The researchers hope that

by using their findings, they will be able to draw inferences that can be applied to broader atmospheric protocols in the future.

I Am A STEM Storyteller

The researchers hope to receive the "I Am A STEM Storyteller" badge for their creation of a public Instagram account that provides information regarding the effects of artificial light pollution at night to viewers and allows them to follow the researchers as they collect data and fabricate their GLOBE project. The account (@alan.dbh) details many of the researchers' experiences through posts and stories, allowing viewers the ability to follow the team's journey and learn more about the process of conducting GLOBE research. Additionally, the researchers intend to continue to educate the community about their findings and possible solutions to light pollution in the community.