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Assessing Winter Holiday Air Quality: Preliminary Insights Towards Establishing a Baseline Air Pollutant Measurement Study in Lancaster, Pennsylvania

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Abstract

Air pollution represents one of the gravest threats to human health globally, with profound implications for life expectancy and quality of life. Greenstone and Hasenkopf (2023), reported that reducing global $PM_{2.5}$ air pollutant to meet World Health Organization's (WHO) guidelines could potentially add 2.3 years to average human life expectancy, based on the Air Quality Life Index's (AQLI) 2020 state of the air report. Our preliminary study employed the use of an Air Quality Monitoring Station for Millersville Atmospheric Research and Aerostat Facility to collect real-time data on various air pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), carbon monoxide (CO), and Ozone (O_3). Results showed that $PM_{2.5}$ and CO readings were above the World Health Organization's Air Quality Guidelines. Relative humidity and atmospheric pressure accounted for high levels of those air pollutants ($PM_{2.5}$ and CO).

keywords: air pollution, particulate matter ($PM_{2.5}$), public health, Lancaster city

Introduction

Air pollution poses a significant threat to public health worldwide, with particulate matter ($PM_{2.5}$) emerging as a major concern due to its adverse health effects on respiratory, cardiovascular, reproductive, and central nervous system (Manisalidis et al., 2020). According to Greenstone and Hasenkopf (2023), reducing $PM_{2.5}$ to meet World Health Organization's (WHO) guidelines could potentially increase average human life expectancy by 2.3 years. The health impact of $PM_{2.5}$ is comparable to that of smoking, being more than three times as detrimental as alcohol use and unsafe water, exceeding five times the harm caused by transport injuries like car crashes, and more than seven times as damaging as HIV/AIDS (Greenstone and Hasenkopf (2023)). $PM_{2.5}$ exposure has also been strongly linked to various ocular diseases, further emphasizing the need for effective air quality management (Wang et al., 2019). The city of Lancaster, Pennsylvania, faces challenges in maintaining clean air, particularly due to agricultural activities coupled with emissions from vehicles and industrial activities, as highlighted in the recent State of the Air report by the American Lung Association (2022). Despite some improvements, concerns persist, especially regarding particle pollution and ozone levels, which pose both immediate and long-term health risks to humans (Kelishadi & Poursafa, 2010). To address these concerns, Millersville University's Earth Science

Department initiated a preliminary study to assess air pollution levels in Lancaster city, focusing on traffic-related pollutants during the winter break of 2023. This study serves as a precursor to a larger project aimed at establishing a baseline air pollution measurement in Lancaster and assessing its impact on public health during the summer 2024.

Methodology

Our preliminary study utilized an Air Quality Monitoring Station equipped with state-of-the-art instruments to monitor weather conditions and collect real-time data on various air pollutants, including $PM_{2.5}$, PM_{10}, nitrogen oxides (NOx) and ozone. These instruments include Aethalometer AE43, Nano-Scan SMPS Nanoparticle Sizer, 2B Technology: Ozone Analyzer Monitor-Model 202, Nitric Oxide Monitor; Optical Particle sizer and a Vaisala Beacon Weather Transmitter (WXT). The monitoring station, located behind the Farm and Home Center on Arcadia Road, continuously monitored air quality from Route 30. During the study period, data was collected from December 23rd to December 27th, 2023. For data management, The Air Quality Monitoring Station at the Millersville Atmospheric Research and Aerostat Facility employs a systematic approach to manage recorded measurements. Data is continuously collected and securely uploaded to a cloud storage system using FileZilla, a reliable file transfer protocol (FTP) client. Python scripts are utilized to automate the extraction of data from the cloud server, leveraging the FileZilla application programming interface (API). The extracted data is processed and analyzed using the R programming language, benefiting from its robust statistical capabilities and data visualization tools.

Results

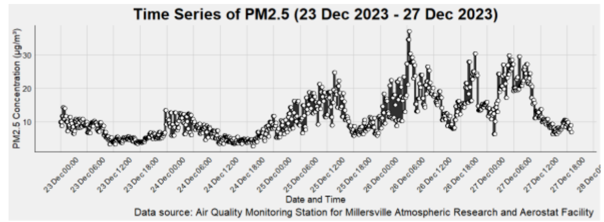

Figure 1 illustrates the notable increase in $PM_{2.5}$ concentrations on December 25th and 26th, coinciding with the Christmas holiday period. These elevated levels highlight the impact of increased activities, such as holiday travel and traffic congestion, increased industrial demands, and celebratory events like fireworks, on air quality during festive periods.

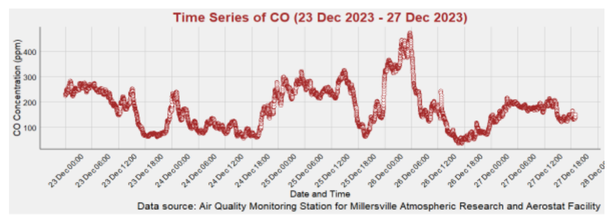

Figure 2. shows a significant rise in CO levels on December 25th and 26th, corresponding to the day and the day after Christmas. The observed increase suggests heightened emissions from various sources, including increased vehicular traffic, combustion activities from industries, and festive activities like cooking, contributing to deteriorating air quality during this period.

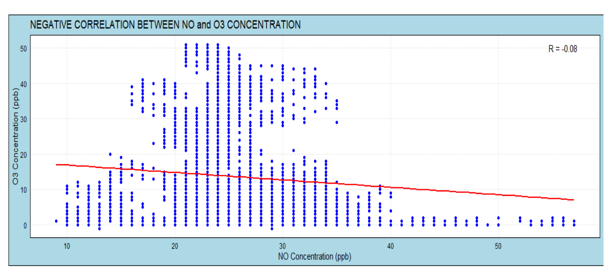

Figure 3 shows an unusual negative correlation between nitrogen oxide (NO) and ozone (O_3) levels. Contrary to expectations, excess nitric oxide (NO) reacts with ozone (O_3) to deplete ozone levels, known as the Titration Effect. This can occur particularly in areas with high NO emissions relative to VOCs (volatile organic compounds), which are also involved in ozone formation ((Li et al., 2013). Though the correlation coefficient is very weak (R = -0.08), more analysis needs to be done to confirm this phenomenon.

Titration Effect Equation: $NO + O_3 \rightarrow NO_2 + O_2$

Discussion

During our study period, we compared air pollutant concentrations to the World Health Organization's (WHO) 2021 Air Quality Guidelines (AQG) and found that CO and $PM_{2.5}$ levels exceeded recommended values. For instance, while the AQG 24-hour average for $PM_{2.5}$ is 15 µg/m³, our study recorded slightly higher values of 15.010417 µg/m³. This discrepancy could be attributed to various factors contributing to elevated pollutant levels during the Christmas season.

Increased emissions from industrial activities due to increase demand, heightened holiday travel and commuting, and congestion in urban areas are all contributing factors to elevated pollutant levels. Additionally, combustion of fuels for heating and celebratory events featuring fireworks displays may have further increased pollutant emissions, surpassing AQG thresholds. Fluctuations in meteorological conditions, such as relative humidity and atmospheric pressure, also played a significant role in exacerbating air quality concerns. Our study recorded a mean relative humidity of 82.28%, higher than normal levels recommended by the National Oceanic and Atmospheric Administration (NOAA n.d.). Elevated relative humidity enhances the formation of secondary pollutants, such as ozone and particulate matter. Studies, such as the one conducted by Park et al. (2018), have also indicated that under high-pressure systems, pollutants tend to be trapped and accumulate near the ground troposphere, particularly in urban environments. This phenomenon occurs due to reduced vertical mixing in the atmosphere under elevated atmospheric pressure conditions. Consequently, this leads to reduced vertical dispersion and dilution of air pollutants, exacerbating air quality concerns. This finding aligns with our observations, as our preliminary study recorded an average atmospheric pressure of 1014.14 hPa, slightly higher than the normal atmospheric pressure of 1013.25 hPa. The elevated atmospheric pressure likely contributed to the heightened levels of CO recorded during the study period.

The research also observed a weak negative correlation between ozone (O_3) and nitrogen oxide (NO) concentrations, with a correlation coefficient (R = -0.08). This weak correlation suggests that there may be other factors influencing the relationship between ozone and NO during the study period. The observed inverse relationship between ozone and NO aligns with findings from previous studies, indicating the complex interplay between these pollutants in atmospheric chemistry (Kelly and Gunst, 1990; Sillman et al., 1990). One factor contributing to this inverse relationship is the titration effect, where NO reacts with ozone, leading to its removal from the atmosphere (Tonse et al., 2008). This chemical reaction can decrease ozone levels, particularly in areas with high NO emissions relative to volatile organic compounds (VOCs), which are also involved in ozone formation. Additionally, reductions in NO emissions may result in less ozone depletion, and potential ozone levels to increase, as observed in urban areas (Jacob et al., 1995; Hanna et al., 1996). However, the negative correlation observed in our study suggests that other factors, such as variations in atmospheric conditions or local emission sources, may have masked the relationship between ozone and nitrogen oxide during the study period. Further investigation is needed to understand the precise mechanisms underlying these interactions and their implications for air quality management.

In conclusion

Our study underscores the impact of holiday activities on air quality, particularly with elevated CO and PM2.5 levels during the Christmas season. Comprehensive monitoring and management strategies are essential to safeguard public health, especially in urban areas prone to air quality degradation during festive periods. This requires a multifaceted approach considering meteorological conditions and targeted pollution control measures.

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