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Pollution Variability in Urban Environments (PVUE)

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Abstract

Pollution Variability in Urban Environments (PVUE) is a student-led research project focusing on urban air pollution. The goal of the project was to gather air quality data, specifically, ozone and particulate matter concentrations, from across the urban landscape in cities across Pennsylvania (PA). The measurements were then compared to each other and to the data collected at the PA Department of Environmental Protection (DEP) monitoring sites. The research team also recorded meteorological data (temperature, pressure, and wind) to assess biases in measured pollution variability due to weather factors. These ozone and particle measurements were obtained using an ozone monitor, and two particle sizers. Weather data was gathered via handheld and vehicle-mounted instruments. The data collected from June to October 2021 were processed, analyzed, and put into a format allowing for transfer into Geographic Information System (GIS) software. Data extracted from the 2019 American Community Survey was also transferred into GIS. This data provided information on housing density, population density, and median income for the areas where the PVUE team gathered measurements. Overlays of these data fields were used to search for correlations between these different variables to see whether they support the hypothesis that low-income and high population density neighborhoods within cities experience higher concentrations of ozone and particulate matter, both of which are known to have adverse health effects.

Air quality is an important environmental factor that affects those living in medium and high-density communities. Poor air quality is known by many different health agencies to be linked to respiratory problems such as bronchitis and increased rates of asthma and COPD, as well as cardiovascular problems such as high blood pressure and heart attacks. However, due to various limiting factors, the air quality data gathered from urban environments often only comes from one or two locations per city and may not be representative of pollution concentrations elsewhere within that city's air shed. In the Commonwealth of Pennsylvania, most of these measurement sites are operated by the Pennsylvania Department of Environmental Protection, otherwise known as the DEP. Allegheny and Philadelphia counties have their own

agencies responsible for air quality, meaning that the DEP does not gather pollution data in the cities of Pittsburgh and Philadelphia.

There are a few reasons why we questioned the representativeness of the data collected by these agencies. As previously mentioned, most cities throughout PA only have one or two different measurement sites. Additionally, most of these sites are not located in dense areas of their respective cities due to property ownership issues as well as the fact that they take up too much physical space to be placed in dense urban areas. Furthermore, meteorological conditions such as temperature and wind direction, both of which are known to have effects on pollutant concentrations, are not always the same in these dense urban areas as they are where the air quality measurement sites are located.

Pollution Variability in Urban Environments, henceforth referred to as PVUE, is a project which aims to test the representativeness of the official air quality measurements taken by the DEP and local agencies. PVUE looked at seven cities across Pennsylvania: Lancaster, York, Harrisburg, Reading, Allentown, Pittsburgh, and Philadelphia. Hyperlocal measurements were taken at multiple locations in each of the cities except for Philadelphia. (Measurements were initially planned to be taken in Philadelphia, but the team found the city's air monitoring network to be expansive enough to not warrant collecting additional data.) These measurements, taken by the PVUE team, were then averaged in such a way which allowed them to be compared with official measurements taken during the same time. Weather data was also collected at each location to allow any variations in conditions to be considered.

Methodology

The methodology for PVUE falls into two main categories: field methodology and data analysis methodology. The reason for separating the two categories is that both methodologies are equally complex, just in different ways. Field methodology involves planning data collection (such as choosing instruments and measurement sites), collecting data in the field, and then preparing it for analysis. Data analysis methodology encompasses everything done with the data after it is collected and imported from the instruments.

Field Methodology

PVUE's field methodology has not been uniform throughout the entire project. The team was forced to make changes to both instrumentation and procedures due to time constraints, equipment failures and malfunctions, and COVID-19 protocol. However, throughout all these changes, the integrity of the data collection process was upheld to the highest standards possible. After the seven cities were decided upon, multiple sites in each city were chosen based on factors such as building density, proximity to potential sources of pollutants such as highways, and whether the area was commercial, residential, or industrial. Since PVUE aimed to look at the extent to which urban pollution variability affects humans, most of the sites in each city were in residential areas. The locations of official government air quality equipment were also considered, using recent documentation and information from the DEP and local agencies, and a measurement site was put at each of these locations.

In the case of Philadelphia, the PVUE team decided there was no need to obtain additional measurements due to the current network of monitoring equipment. The city's air quality measurements are taken by the City of Philadelphia Air Management Services. The agency has a large network of monitoring sites spread throughout the city, and the PVUE team

determined that the existing network was similar enough to the network of measurements that the team planned to be taken in other cities. Therefore, it made sense to obtain data from that network to use for the project and focus data collection efforts on the other six cities.

The pollutants that PVUE aims to measure are ozone (O_3) and particulate matter (PM). The DEP measures PM in two sizes, $PM_{2.5}$ and PM_{10}, which signify 2.5µm and 10µm diameters, respectively. One µm

Fig. 1
From Left to Right, Top to Bottom: TSI Optical Particle Sizer, TSI Scanning Mobility Particle Sizer, 2B Technologies Ozone Monitor, 2B Technologies Nitric Oxide Monitor (discontinued use after Lancaster)

(pronounced micrometer, sometimes shortened to micron) is equal to one millionth of a meter. The project also initially aimed to gather data on Nitrous Oxide (NO) concentrations, however due to equipment issues during data collection efforts in Lancaster, the decision was made to focus only on ozone and PM measurements for the rest of the cities. Pollutant data was collected using three instruments powered by batteries. These instruments were a 2B Technologies Model 202 Ozone Monitor that relies on photo-absorption to measure ozone, a TSI Model 3330 Optical Particle Sizer (OPS) which measures particles from 0.3µm to 10µm, and a TSI Model 391000 Scanning Mobility Particle Size Spectrometer (SMPS) which measures particles from 10nm to 420nm (0.010µm to 0.42µm) [Fig. 1].

Weather data (temperature, pressure, wind speed, and wind direction) was gathered through one of two methods. The first method employed was a Kestrel 5000 handheld environmental meter [Fig. 2], with measurements recorded at either a five- or ten-minute interval. Wind direction was determined by a compass and wind flag. This method saw use in Lancaster and Harrisburg. The second method, which saw use in York, Reading, Allentown, and Pittsburgh, used a modified Texas Weather Instruments WLS-8000 weather station

Fig. 2
Left: Kestrel 5000 Handheld Environmental Meter
Right: Modified TWI WLS 8000 mounted on a vehicle

mounted to the roof of a vehicle [Fig. 2]. This system can either be powered by the vehicle's electrical system or by external batteries. For PVUE, the system ran on external battery power so that vehicle exhaust would not contaminate the pollutant measurements.

At each site, the air quality instruments were placed on a cart and shaded by an umbrella to keep the batteries from overheating in the summer sun, similar

to the setup seen in [Fig. 1]. Measurements were taken for half an hour at each site in Lancaster, and for an hour in every other city. The reason behind this is that the use of nitrous oxide monitoring equipment was stopped after Lancaster, allowing for longer battery lives for the remaining instruments. The battery capacity that the team had allowed for between three and four different one-hour long measurements to be taken before the batteries needed to be recharged. This meant that for most cities, measurements had to be spread out over a two-to-four-day period. The number of days needed to obtain measurements in each of the cities depended on the total number of sites in that city, as well as the time needed to travel back and forth from Millersville.

Data from the air quality instruments was transferred to a computer in two ways. For the ozone monitor, data was transferred directly to a laptop in the field. For the PM equipment, data was saved from the instrument to a USB flash drive, where it was then transferred to a computer. Weather data was stored internally on the WLS 8000's data logger, which is too old to interface with modern computers. Once back in Millersville, the logged data was brought up on the logger's display unit, and each data point was manually transferred to a spreadsheet. This process caused a few problems, as the data logger needed to undergo repairs after returning from Pittsburgh, and during repairs, all the weather data from that city was lost. For the weather data measured via the Kestrel 5000, measurements were recorded in a notebook and then transferred to a spreadsheet once the team returned home. After all the ozone, PM, and weather data was transferred from the instruments, the focus shifted to data analysis.

Data Analysis Methodology

After all the data had been transferred from the instruments, the process of data analysis could begin. Pollutant data was geometrically averaged to align with the top of every hour, as the measurements taken by the DEP and the Allegheny County Health Department are reported at the top of each hour. This allowed for a comparison to be made between the local measurements taken by PVUE and the official measurements taken by government agencies. The difference in those two measurements is the variability. A large variability meant that the official government measurements were not very representative of the area, while a small variability meant the opposite. The PVUE team was also able to obtain five-minute interval data from the DEP, which had been planned to be used to provide more accurate comparisons than the hourly data, however, there was not enough time before publication to run those new comparisons.

Weather data was averaged across the entire hour, or half hour in the case of Lancaster. This data was also put into five-minute running averages to show any change in conditions over the measurement period. Those measurements were then compared against official measurements taken by nearby automated surface observing stations (ASOS) and surface observation maps.

Air quality and weather data were then imported into GIS, where they were plotted on a map of each city. Data on population and housing density, as well as income, were obtained from the 2019 American Community Survey, and overlaid on these maps in GIS [Fig. 3]. Doing this helped the PVUE Team to determine whether areas of low-income and high-density populations, which are determined using the data from the 2019 American Community Survey, experience higher levels of pollution compared to

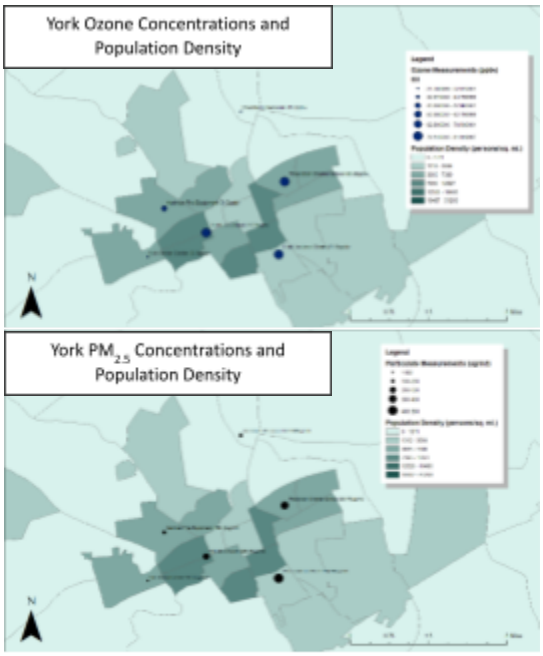

Fig. 3
Top: York ozone concentrations with population density
Bottom: York PM 2.5 concentrations with population density

surrounding areas, and whether measurements taken by the DEP and local health agencies are representative of these levels. Additional calculations were made to determine how correlated the pollutant concentrations were with the population density, housing density, median income, and wind speed data.

Observations and Findings

The results of the data analysis process have been somewhat surprising. The team found that for each city the project focused on, there is no statistically significant correlation between ozone concentrations and the parameters of median income, housing density, population density, and wind speed [Fig. 4]. $PM_{2.5}$ measurements also showed a lack of any significant correlation to those same metrics as well.

There are a few possible reasons for the lack of any clear correlation with ozone and $PM_{2.5}$ data. One possibility is that PVUE was not as extensive as it would have needed to be in order to show any sort of

Fig. 4
Correlations between Ozone concentrations and Population Density, Housing Density, and Median Income for all sites

correlation. Having multiple sets of instruments deployed at multiple sites simultaneously over long periods of time would have been the most optimal method of collecting data. However, doing this just wasn't feasible for a project as small as PVUE. Another possibility is that there isn't any true correlation between ozone and $PM_{2.5}$ concentrations and the parameters that were previously mentioned. The only way to know for sure would be to conduct a larger, more comprehensive study in the future.

As for the representativeness of the DEP monitoring sites, the hypothesis that these sites don't obtain representative measurements held true. The differences between ozone and $PM_{2.5}$ concentrations measured by the DEP and concentrations measured by the PVUE Team were very stark. For example, DEP ozone measurements in Lancaster fluctuated

between 20-60 ppbv (parts per billion volume) during daylight hours, while PVUE measurements at one site were above 70 ppbv, and measurements at multiple other sites were above 60 ppbv. Additionally, DEP $PM_{2.5}$ measurements in York peaked around 70 $\mu g/m^3$, while PVUE measured $PM_{2.5}$ concentrations between 200-500 $\mu g/m^3$ at multiple sites. That said, these variations don't seem to correlate with any specific parameter, as was previously mentioned. However, the fact that there is any sort of variability shows that the DEP's measurements are not representative of the actual concentrations within these cities, which aligns with part of PVUE's initial hypothesis.

Conclusions

Current analysis shows that there is no discernable correlation between dense, low-income neighborhoods and ozone and $PM_{2.5}$ concentrations. However, data did show that there are significant variations between pollution concentrations at PA DEP measurement sites and concentrations within their respective cities. Even without being able to show any correlations between pollutant concentrations and population metrics, showing that PA DEP measurements are not representative of pollutant levels at multiple locations in urban areas is still very significant. These findings are even more significant when considering that PVUE had several setbacks, such as equipment issues and having to work around COVID-19. Time constraints also limited the length of time spent taking measurements at each site. Considering all this, the PVUE Team was able to produce valuable conclusions about urban pollution variability. PVUE also demonstrated that there is a need for a larger, more comprehensive project that would be able to either confirm or disconfirm PVUE's findings. Most importantly, PVUE has helped to bring attention to an area that has not received much attention and research.

References

-Data on population density, housing density, and median income was obtained from the 2019 American Community Survey

-Official pollutant measurements for the cities of Lancaster, York, Harrisburg, Reading, and Allentown were obtained from the Pennsylvania Department of Environmental Protection

-Official pollutant measurements for the City of Pittsburgh were obtained from the Allegheny County Health Department

-Official pollutant measurements for the City of Philadelphia were obtained from the City of Philadelphia Air Management Services