Monitoring Personal Exposure to Air Quality Gradients while Biking on an Elevated Urban Trail

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Monitoring Personal Exposure to Air Quality Gradients while Biking on an Elevated Urban Trail

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ABSTRACT Air pollution is a major global health concern, specifically as it relates to the human exposome. The EPA criteria pollutants, including particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO₂), and NOₓ can have severe impacts on respiratory and cardiovascular health, particularly in populations with chronic illnesses such as asthma, those facing economic hardships and individuals who frequently spend time outdoors, such as bicyclists and runners. To understand the impact of air pollution on human health, it is essential to assess personal exposure. This study aimed to investigate personal exposure to air pollution levels while biking along a former elevated railway, now urban trail, in Chicago, Illinois due to the east trailhead’s proximity to the I-90 highway, a significant source of PM, NOₓ, CO, and CO₂. Ozone (O₃), a secondary air pollutant, was also monitored, but was not statistically analyzed. During summer months of 2022, portable sensors were attached to a bike rack for data collection, and GPS-captured datasets were analyzed for statistical significance between longitude, which describes the location along the east-west path, and criteria air pollutants using linear regression in RStudio. The findings from the linear regression analyses revealed that longitude had a significant, strong positive association with carbon monoxide across three datasets, making longitude an appropriate predictor. However, CO₂, PM₁, PM₂.₅, and PM₁₀, only showed a significant association with longitude on one day. O₃ concentrations displayed sudden increases near the west trailhead on four out of six collection datasets observed. These spikes consistently exceeded 50 ppb, indicating a persistent source of ozone. Further investigation is necessary to understand the reason for the variation in significance of the criteria air pollutants and the potential source of ozone.

INTRODUCTION

Air pollution is an environmental challenge that affects the health of all people. The air quality on any given day can influence how long people should stay outdoors. The effects of air pollutants...
on mortality worldwide are well documented with over 4.2 million deaths occurring due to outdoor air pollution exposure annually (World Health Organization, 2021); certain populations of people are more vulnerable and/or susceptible to air pollution exposure due to economic hardships or chronic diseases such as asthma (World Health Organization, 2021). In the United States, the EPA criteria pollutants are carbon monoxide, nitrogen oxide, nitrogen dioxide, ground-level ozone, lead, particulate matter (PM), and oxides of sulfur (CDC, 2021). Particulate matter is an air pollutant on the micrometer level that can vary in diameter denoted by a subscript. Most health impact studies focus on PM$_{2.5}$, particulate matter with a diameter less than 2.5 µm. Depending on concentration levels emitted by vehicular engine combustion, it can be extremely harmful to respiratory and cardiovascular health both in short-term and long-term exposure (Anderson et al., 2011; US EPA, 2021). Tropospheric ozone, a secondary air pollutant, is created when oxides of nitrogen (NO$_x$) and volatile organic compounds (VOCs) react with sunlight (hv) to produce oxygen radicals (HOx and RO2, respectively) that form ozone (O$_3$) (Figure 1).

**Formation of Ground-Level Ozone**

![Formation of Ground-Level Ozone](https://via.library.depaul.edu/depaul-disc/vol12/iss1/8)

**Figure 1.** Tropospheric ozone diagram (Zhang et al., 2019)

Common air pollutant sources in Chicago due to fuel combustion from heavy vehicles and trucks include PM$_{2.5}$ and NO$_x$, while ozone, a precursor of chemical reactions with sunlight due to fuel combustion, is produced as a secondary pollutant (C.A.R.B., n.d.). With over 55% of NO$_x$, 10% of PM$_{2.5}$ emissions being directly caused by the transportation sector due to emissions from vehicles and other forms of transportation (US EPA, 2022b), and 84% of particulate matter in the 2.5-10 micrometer range are emitted from natural primary sources (Querol et al., 2001), the need to understand the spatial distribution of air quality as it relates to the human exposome will continue to grow (Figure 2). One study by Guo et al. (2018) found that rush hour and daytime periods are most representative of true exposure levels of commuters when compared to the average concentration means of a diurnal cycle. While there are many advanced instruments used to measure air pollution concentrations for air quality monitoring, the current methods to monitor individual exposure while a person commutes are lacking. Using networks of fixed sensors deployed around an area of study is a common method to measure air pollution concentrations for air quality as used by Schneider et al. (2017). Portable sensors are more suited for personal exposure monitoring as they are spatially continuous in collecting instant air quality data of commuting individuals, especially in the scarcity or absence of location dependent air quality sensors (Milton & Steed, 2006). Most personal exposure studies directly measure on or near major roads whereas fewer studies focus on urban trails. One study showed the effectiveness of portable air pollutant sensors as it relates to locomotive and vehicular commuting/transportation (Motlagh et al., 2021). Motlagh et al. (2021) was able to correctly identify changes of air pollution using portable air pollution sensors; however, bicycling was not one of the methods of commuting used in the study. Ziter et al. (2019) conducted a study in which they attached a sensor to a bicycle to test the effects of impervious surface structures and tree canopy on air temperature in Madison, Wisconsin. While the method to measure air temperature was successful, our study aims to use low-cost portable sensors to assess the exposure of air pollutants along the Bloomingdale trail, (also known as the 606), a 2.7-mile bike/walking trail in the City of Chicago. The Interstate 90 intercontinental freeway is directly across and overlooks the east trailhead of the Bloomingdale Trail where many heavy vehicles and trucks exhaust emissions of interest.
Figure 2. Overview of link between vehicle-emitted air pollutants and human exposure. This conceptual model illustrates the relationship between air pollutants from vehicles and their impact on the human exposome. The portions within the green outline are the central theme of this study, examining the connections between air pollutants and human exposure.

\[
\begin{align*}
NO + O_3 & \rightarrow NO_2 + O_2 \quad (1) \\
NO_2 + h\nu & \rightarrow NO + O \quad (2) \\
O + O_2 & \rightarrow O_3 \quad (3)
\end{align*}
\]

Ozone (O\(_3\)) is known to be quenched by nitrogen oxide (NO), when in the vicinity of NO emissions from vehicles (Equation 1). As NO\(_2\) undergoes photodissociation (Equation 2), the atomic oxygen produced from the previous reaction would reform ozone (Equation 3), stabilizing ozone levels further away from the source of emissions towards the west trailhead.

In our study, the urban trail follows an east to west path (Figure 3). The east trailhead is closer to the source of emissions that are of interest to the study, specifically, PM, carbon monoxide, and carbon dioxide. This study area offers an opportunity to conduct east to west and west to east gradient measurements of air pollutants, allowing for observations of their spatial behavior with respect to distance from the emissions source. We expected to see a quenching effect of ozone near the source of emissions, which is closest to the east trailhead. Spatially, the presence of ozone was predicted to have a “lag-effect”. This is because ozone that naturally occurs nearby vehicular sources is converted to NO\(_2\) by NO emissions. The further away from the source of NO emissions, in this case, west of the I-90, we can expect to see higher concentrations of ozone. It was hypothesized that using the data collected from air sensors while bicycling, PM\(_2.5\), PM\(_1\), PM\(_{10}\), carbon monoxide, and carbon dioxide concentrations increase as distance to the east trailhead decreases. Ozone was predicted to not have a simple linear relationship due to its chemistry and spatial behavior outlined previously.
METHODS

Overview

Air pollution gradients were measured while bicycling using two portable sensors attached to a bike rack along a trail that used to be an elevated railway in Chicago, Illinois. Repeated days were recorded during the summer months. Using the GPS functionality of the sensors, the datasets were analyzed in RStudio using linear regression to test the statistical significance and relationship between air pollutants and longitude on the trail.

Data Collection

The area of study was the Bloomingdale Trail (606), a 2.7-mile walk/bike trail in the City of Chicago, Illinois, where the east trailhead is near the Interstate 90 intercontinental freeway, a significant source of PM$_{2.5}$ and NO$_x$ emissions (Figure 3). The sensors recorded repeated days during late June and September, when the trail was used the most by commuters and pedestrians. Measurement days occurred 21 times, approximately 2-3 times weekly between June 4th – July 6th, and 1-3 times weekly between July 27th – September 6th, along with one final repeat day on September 26th. Each measurement day consisted of 2-3 roundtrip gradient measurements starting at the east trailhead to the west trailhead. The sensors included on a roundtrip were a PAM (Personal Air Quality Monitor, 2B Technologies) sensor, which is a portable air pollutant sensor capable of recording primary pollutants, (PM, CO, CO$_2$) and a POM (Personal Ozone Monitor, 2B Technologies) sensor, which is a portable sensor capable of measuring ozone (O$_3$). GH (PA-II, Purple Air) was a PM2.5 sensor initially used during test runs until the PAM sensor could be acquired for future measurements. All sensors were attached to a bike rack using zip ties. Prior to the start of a measurement day, each device was turned on.

Figure 3. Study area location. The map is annotated with latitude and longitude decimal degree markers and depicts the boundaries between several Chicago neighborhoods. The highlighted red path outlines the route of the Bloomingdale Trail, marked by two pin icons at either end to indicate the trailheads. The blue path highlights the location of the I-94 highway.
and allowed to “warm up” (calibrate) for 20-25 minutes. The approximate time it took for the devices to warm up was spent preparing and verifying all necessary items were accounted for (5 minutes), commuting to the trail (8 minutes), and taking field notes upon arrival (1 minute). After the warm-up period, the sensors were set to capture sample data which was recorded on a SD card inside the PAM device and recorded on internal storage of the POM device. The PAM recorded at 10 second intervals and the POM recorded at 5 second intervals. (Note: the SD card slot for the PAM sensor broke during (08/04/2022) and was unable to record data via SD card. Using the cellular capability, the PAM sensor recorded and uploaded data to the 2B tech proprietary cloud system). The gradient measurements were tracked using GPS included with both instruments while biking from the east trailhead to the west trailhead. GH device kept 4 repeated samples that were not analyzed. Due to the SD card for the PAM device being lost during a collection day on 08/04/2022, 11 repeated samples were kept (Table 1). The POM device kept 20 repeated samples. Data collected after a measurement period were logged to a device for analysis using RStudio.

Statistical Analysis

A linear regression analysis, a statistical method to model the relationship between a dependent variable and an independent variable was conducted to examine air pollutants (dependent variable) as a function of longitude (independent variable). Linear regression also allowed us to measure the strength of the relationship between the two variables. Longitude is an appropriate variable because the longitudinal values on the x-axis of a scatterplot (from left to right) aligned with the coordinates for the trail from west to east. Based on the positive or negative slope, it was possible to assess the relationship with an air pollutant concentration with respect to the east trail head due to its proximity to the source of emissions. The aim of the study was not to develop a comprehensive model that explains air quality, but to test the presence of a significant relationship between air quality and longitude along the Bloomingdale trail. An F-test was also used to determine statistical significance of the relationship between air pollutants and the regression coefficients. All tests were evaluated at an $\alpha < 0.05$.

<table>
<thead>
<tr>
<th>Date</th>
<th>Operational Sensors Used</th>
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<tbody>
<tr>
<td>2022-06-24</td>
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</tr>
<tr>
<td>2022-06-29</td>
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<tr>
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<td>-</td>
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<td>POM</td>
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<tr>
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<tr>
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<td>PAM</td>
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<tr>
<td>2022-09-06</td>
<td>PAM</td>
</tr>
<tr>
<td>2022-09-23</td>
<td>POM; PAM</td>
</tr>
<tr>
<td><strong>Total Samples</strong></td>
<td><strong>GH: 4; POM: 20; PAM: 11</strong></td>
</tr>
</tbody>
</table>

Table 1. Sensors Used in repeated measurements. This table lists the types of sensors used during each measurement cycle. Yellow highlighting indicates instances of data loss that were unable to be recovered.
RESULTS

PM1

The linear regression analysis for PM1 data collected did not indicate that longitude is significant in its relationship with PM1 concentrations in most cases (Figure 4). On 8/11/2022, three roundtrip gradient measurements were collected and were not significant (p = 0.0831, R2 = 0.018, F-stat = 3.038 on 1 and 168 DF). The concentrations remained stable throughout the entire trip, never exceeding past 7 ug/m3. On 8/16/2022, three roundtrip gradient measurements were collected, and the results indicate concentration levels are significant in its relationship with longitude (p = 0.0454, R2 = 0.014, F-stat = 4.038 on 1 and 293 DF). However, the longitude only explains a small proportion of the variance. Data collected on 8/25/2022 showed the concentration levels of PM1 for one roundtrip gradient measurement not to be significant (p = 0.424, R2 = 0.0081, F-stat = 0.6456 on 1 and 79 DF). The concentrations on this day were higher comparatively than other repeated days with concentrations exceeding past 20 ug/m3.

PM2.5

Likewise, the linear regression analysis for PM2.5 data collected did not indicate that longitude is significant in its relationship with PM2.5 concentrations in most cases (Figure 4). The results from the linear regression analysis for PM2.5 data collected did not indicate that longitude is significant in its relationship with PM2.5 concentrations collected on 8/11/2022 (p = 0.144, R2 = 0.013, F-stat = 2.152 on 1 and 168 DF); concentrations remained low and consistent. On 8/16/2022, the gradient measurements indicated statistical significance (p = 0.018, R2 = 0.019, F-stat = 5.618 on 1 and 293 DF), but only explained a small proportion of variance. On 8/25/2022, the roundtrip gradient measurement collected were extremely noisy with concentration levels exceeding 27 ug/m3; however, this was not considered statistically significant (p = 0.251, R2 = 0.017, F-stat = 1.336 on 1 and 79 DF). The concentration levels appeared stable and consistent in the first two repeat days, but there was more noise and greater outliers on the third repeat day.

PM10

Similarly, the linear regression analysis for PM10 data collected did not indicate that longitude is significant in its relationship with PM10 concentrations in most cases (Figure 4), only 08/16/2022 showed a statistical significance in the relationship between longitude and PM10 concentrations (p = 0.0165, R2 = 0.019, F-stat = 5.819 on 1 and 293 DF); while outside the scope of the study, the strength indicates other variables still need to be considered in the relationship. The other two datasets did not indicate any significant relationship between longitude and PM10 concentrations (p = 0.13, R2 = 0.0133, F-stat = 2.284 on 1 and 168 DF; p = 0.379, R2 = 0.013, F-stat = 1.053 on 1 and 79 DF). The concentration levels for 08/11/2022 never exceeded 8 ug/m3, but the concentration values for 08/25/2022 were extremely inconsistent and exceeded 28 ug/m3.

CO

Conversely, the relationship between longitude and CO concentrations observed in the datasets were statistically significant (p < 0.0001, R2 = 0.35, F-stat = 88.87 on 1 and 168 DF; p <0.0001, R2 = 0.47, F-stat = 260.3 on 1 and 293 DF; p < 0.0001, R2 = 0.42, F-stat = 56.4 on 1 and 79 DF, respectively (Figure 5). The results of the linear regression analysis showed a strong positive relationship between longitude and CO concentrations for the datasets. The low p-values and high R-squared values indicate that longitude is a strong predictor of CO concentrations in the data.
Figure 4. 3x3 panel of 9 linear models plotting longitude as a function of PM1, PM2.5, and PM10 over three repeated measurements in descending order of date, respectively. The blue line added to all plots represents the trendline and assists with seeing the relationship. The shaded area represents the confidence interval.
Figure 5. Linear model of longitude and CO over three repeated measurements in descending order of date. The blue line added represents the trendline and assists with seeing the relationship. The shaded area represents the confidence interval.

Figure 6. Linear model plotting longitude as a function of CO₂ over three repeated measurements in descending order of date. The blue line added represents the trendline and assists with seeing the relationship. The shaded area represents the confidence interval.
The linear regression analysis for CO₂ data collected did not indicate that longitude is significant in its relationship with CO₂ concentrations in most cases (Figure 8). The relationship between longitude and CO₂ concentrations observed in the datasets was statistically significant in the dataset of 8/16/2022 ($p = 0.013$, $R^2 = 0.021$, F-stat = 6.229 on 1 and 293 DF); while outside the scope of the study, the strength indicates other variables still need to be considered in the relationship. The other two datasets were not statistically significant for 8/11/2022 ($p = 0.2987$, $R^2 = 0.0064$, F-stat = 1.086 on 1 and 168 DF) and 8/25/2022 ($p = 0.1077$, $R^2 = 0.032$, F-stat = 2.647 on 1 and 79 DF). The low p-value and R-squared value for the 8/16/2022 dataset indicates that longitude is a significant predictor of CO₂ concentrations.

Ozone

The merged ozone data collected on various dates (07/06/2022, 08/04/2022, 08/11/2022, 08/16/2022, 08/25/2022, 08/30/2022) showed that the ozone concentration was within standard concentrations along most of the trail from the east trailhead moving westward (Figure 9). However, near the west trailhead there was a sudden increase in ozone levels, exceeding 50 ppb, on four of the collection dates (07/06/2022, 08/04/2022, 08/11/2022, 08/16/2022). This spike in ozone was consistent in the same longitude coordinate at different dates, potentially exhibiting a consistent source of high ozone production.

**DISCUSSION**

This study reveals longitude is an appropriate variable to assess air pollutants concentrations of the Bloomingdale trail. All the results for data collected on 8/16/2022 indicated that longitude was statistically significant in its relationship with PM₁, PM₂.₅, and PM₁₀ concentrations, which supported the hypothesis. The peaks were most notable closer to the east trailhead, specifically in between the -87.69 and -87.68 longitude coordinates. Statistically significant, strong positive trends were observed in all the analysis testing done on CO and longitude, thus supporting the hypothesis.
The relationship was clear in every dataset that the initial spikes were always significantly observed closest to the east trailhead, where the source of emissions were likely from the interstate. The results for CO\textsubscript{2} reflected similar patterns as the PM data where solely 8/16/2022 CO\textsubscript{2} was significant in its relationship with longitude, supporting the hypothesis. Although, difficult to pinpoint, spikes in CO\textsubscript{2} appeared relatively more eastward on the first roundtrip, and seemed to stabilize, with spikes occurring at a lower scale closer to the east trailhead. Further investigation would need to be conducted to reveal the exact reason for such fluctuations when an emissions source such as an interstate is so closely positioned to the east trailhead.

Gradient measurements continue to be a sound method for personal exposure monitoring and can often yield different results depending on the type of mode chosen. Adams et al. (2001), in one of the experiments in their study, showed how bicyclists can monitor their personal exposure using portable sensors; however, variations in exposure data can increase depending on factors such as location, biking distance, and seasonal/climate factors, which can be factors considered for a similar study in the future.

Upon qualitative observation of merged Ozone data from: 07/06/2022, 08/04/2022, 08/11/2022, 08/16/2022, 08/25/2022, 08/30/2022, which plots ozone concentrations against longitude of the trail, spikes were noticed in one specific area closer to the west trailhead that could not be explained by the photochemical production alone. It is possible the source of these high ozone levels could be from a local industrial source. Electrical discharge from generators and machinery could also result in oxygen molecules splitting to atomic oxygen which can lead to direct ozone production. Further investigation is needed to determine the source of these high ozone concentrations.

One possible explanation could be the emissions from the nearby Pulaski industrial corridor. The Natural Resource Defense Council (NRDC) aggregated 11 environmental factors and 6 demographic factors sourced from the EPA Environmental Justice Screen (EJScreen) database to create an index of Environmental Justice graded by census tract on a choropleth map (Figure 8). The rectangular black box on the map indicates the approximate area of the Bloomingdale trail. The top left corner of the highlighted area shows the nearby Pulaski industrial corridor, which is positioned closely to the west trailhead, where the spikes of ozone were observed.

The threshold for ozone according to EPA criteria air pollutant standards is 70 ppb for an 8-hour average, 9 ppm for an 8-hour average of carbon monoxide, 35 ug/m\textsuperscript{3} for a 24-hour average of PM2.5, and 150 ug/m\textsuperscript{3} for a 24-hour average of PM10 (US EPA, 2022b). While interesting to observe with data collected from this study, it would not be accurate to meaningfully compare any of our measurements with national averages set by the EPA for any criteria pollutant data we collected because it was not collected based on hourly averages.

The potential benefits of community science in the context of this study are numerous. Key benefits include education, public engagement, and collaboration with community members in the three Chicago neighborhoods the Bloomingdale trail travels through. Community members can gain experience on the scientific method by engaging in the data collection and analysis process while also learning about air pollutants and their impacts. For example, air sensors can be accessed through programs such as US EPA Region 5 air sensor loan program for particulate matter sensors in the Midwest (US EPA, 2022c).
Figure 8. Choropleth map showing the Environmental Justice Index graded by census tract, using 11 environmental factors (PM2.5, O3, air toxic cancer risk, Diesel Particulate Matter, Air Toxics Respiratory Hazard Index, Air Toxics, Cancer Risk, Lead Paint Indicator, Traffic Proximity, Proximity to Superfund (National Priority List) Sites, Proximity to Risk Management Plan Facilities, Proximity to Treatment Storage Disposal Facilities, Wastewater Discharge Indicator) and 6 demographic factors (Low income, Minority percentage, Less than high school education, Linguistic isolation, Children under age 5, Adults over age 64) from the EPA Environmental Justice Screen (EJ Screen) database. The Bloomingdale trail's general region is indicated by the rectangular black box (Geerstma, 2018).
Engaging members of the community can increase data collection to gain a more comprehensive understanding of the relationship between air pollutants, specifically ozone, along the trail. Zhang et. al (2019), highlights how elevated ozone levels in short-term exposure may pose health risks as it can cause reduced lung function, coughing, and irritation. This poses a risk to frequent users of trails such as bicyclists and runners as the combined stress of exercise and inhalation could lead to adverse health effects, particularly for those with preexisting conditions such as asthma.

Another specific benefit of community based participatory research is the opportunity to collaborate with Chicago-based environmental justice organizations such as the Chicago Environmental Justice Network (CEJN). Community organizers who do advocacy work could benefit from collaboration because of the immediate and transparent access to data collected that is of particular interest/concern to residents. The findings from this work could be accessed and used by community organizers to make informed decisions and verify their own observations regarding concerns with air pollution. This could then incentivize proper reporting to appropriate agencies such as the Chicago City Council and alderpersons that represent community members.

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REFERENCES


US EPA. (2021). *Basic Information about NO2*. https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects


US EPA. (2022b, April 5). *NAAQS Table*. US EPA. https://www.epa.gov/criteria-air-pollutants/naaqs-table


