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Spatial and Temporal Analysis of $PM_{2.5}$ Concentrations in Chicago Along the Lakefront Trail Using Wearable Air Quality Sensors

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ABSTRACT Mass urbanization and transportation practices have resulted in high amounts of air pollution. Air pollution can have detrimental effects on human health causing respiratory issues as well as other health complications. Certain areas of cities experience more exposure to air pollution which can also cause them to have more health issues and lower life expectancy. These areas are often associated with disinvestment and minoritized communities of color. This research explores patterns of air quality related to environmental justice areas using low-cost wearable air quality monitoring sensors attached to a bicycle. Data was collected along the Lakefront Trail stretching from Irving Park Road to 43rd Street. We hypothesized that pollutant concentrations would be higher further south due to larger presence of areas identified as having poor environmental justice metrics. Since wind direction could have an influence on pollutant concentrations along the Lakefront Trail, that variable was also considered. Data was collected at the same time of day on twelve different days over the summer into fall of 2023. The data were split into three zones along the Lakefront Trail: North, Loop, and South. CO_2 levels were significantly higher along the north section of the trail and there was no significant difference between $PM_{2.5}$ levels between the North and South sections of the trail. Both these findings did not support our hypothesis. Wind direction also did not have a significant impact on the pollutant concentrations. We speculate that other factors might influence lakefront pollution concentrations. Future research should investigate additional factors, such as local traffic patterns and industrial activities, that might influence pollutant concentrations along the Lakefront Trail.

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INTRODUCTION

The impact of air pollution in Chicago on public health is very severe. Respiratory issues as well as other health concerns can be caused or exacerbated by air pollutants. Air pollution is a prevalent problem in the developing urban landscape and has major impacts on public health. These pollutants cause damage to our respiratory systems and are responsible for premature deaths as well as other health complications including asthma and lung diseases (EPA, 2022). The most common and dangerous pollutants are referred to as the criteria pollutants, which include ground-level ozone, particulate matter, carbon monoxide, lead, sulfur dioxide, and nitrogen dioxide (EPA, 2022). Criteria air pollutants were created to define six principal pollutants in the Clean Air Act which was last amended in 1990 and establishes standards for these criteria pollutants that have been deemed harmful to public health and the environment (EPA, 2023). Particulate matter is described as fine inhalable particles and 2.5 is the maximum diameter of the molecule in micrometers (EPA, 2022). Ozone is comprised of three oxygen atoms and in its ground form is harmful towards human health (EPA 2022). Carbon dioxide is one of the main products of burning fossil fuels and is used as a tracer for fossil fuel combustion in this research (EPA, 2022). These pollutants are deemed hazardous for human health by the USEPA. The sources for these pollutants are mainly from the process of fossil fuel combustion which is used in industrial centers and for transportation purposes. The spatial pattern of air pollution and its health impacts are still not completely understood in Chicago. This research will assist in filling some of those gaps. The impacts of air pollution disproportionately affect certain demographics of people. Minoritized communities experience higher levels of air pollution due to practices like red lining in the past, which denied predominantly Black neighborhoods credit on mortgages as well as other issues - making the process of finding housing more difficult for them. This practice resulted in these low-income neighborhoods being located near industrial centers that produce large quantities of pollution. (Jones, 2016, Jephcote et al., 2012). This also means that they experience more adverse health impacts from the higher concentrations of pollutants. These findings may also play a role in future policies regarding the urban landscape and city-wide Particulate Matter (PM) 2.5 concentration standards. The disproportionate levels of $PM_{2.5}$ concentrations in different communities could highlight the environmental injustice occurring in our urban landscape. New innovations for monitoring air quality have become more prevalent in recent years. These new low-cost mobile sensors have been used in multiple studies and have been shown to be able to collect more data over a wider area than the previously used ground stations (Leung et al., 2019, Morawska et al., 2018). Ground stations are still an excellent way of measuring air quality because they allow for long term data collection in a single area to see how pollutions levels fluctuate. These ground stations are inadequate for monitoring air quality over a wide area to measure spatial changes in air quality. Wearable sensors can account for this and have been used to monitor air quality along trails and along major roads (Marquart et al., 2021, Kane et al., 2022). Attaching these sensors to a bicycle and using it as our method of data collection allows us to simulate personal exposure of others using the Lakefront Trail in Chicago. Breathing at a faster rate can also increase exposure to possible pollutants. Using a bicycle also allows for an effective method of spatially collecting data without creating more pollution. Access to financial assistance also contributed to the decision of using the mobile sensor instead of purchasing multiple sensors to place along the trail. It also would have been difficult to guarantee the sensors along the trail wouldn't have been stolen after leaving them in a public area for a long time. Using this method of a mobile sensor, $PM_{2.5}$ and CO_2 concentrations will be analyzed to show if communities experience disproportionate levels of exposure. This information will be vital to other disciplines which are responsible for the development of the urban landscape. It could impact architecture and civil engineering practices by changing their procedures to minimize impact on air quality. This study could also impact political decisions by demanding changes for these communities that are disproportionately affected by environmental dangers. Our hypotheses for this experiment were $PM_{2.5}$ concentrations will be higher along the south side communities due to more pollution sources and more industrialized neighborhoods on the Lakefront Trail (Figure 1). $PM_{2.5}$ concentration may change depending on latitudinal wind direction. Concentration will be stronger when the prevailing winds are from the west (from the land and pollution sources) and the concentration will be lower when winds are from the east (from the lake). Riding on the Lakefront Trail was determined to be the safest option due to lack of biking infrastructure on major roads further west. Riding along those roads could have provided more impactful data, however for the safety of the researcher the Lakefront Trail was determined to be a better option.

METHODS

Methodology Overview

Our hypothesis was tested by measuring CO_2 and $PM_{2.5}$ concentrations along the Lakefront Trail using wearable sensors attached to a bicycle. The trail was split into three zones based on latitude so a latitudinal difference could be observed. After collecting the data along the Lakefront Trail between Irving Park and 43rd Street, the means and standard error of each zone's pollutant concentrations were calculated and then compared. Wind data was also used to determine if that influenced the pollutant concentrations.

Air pollution data was collected with two different mobile sensors (Model POM Serial #1196 and model PAM Serial #1161, 2B Technologies, Broomfield, CO). One focused on collecting particulate matter and carbon dioxide while the other collected ozone. These devices were attached to the back of a bicycle using a rack and fasteners. It was also necessary to turn the instruments on early and give them time to warm up before use. This can be done by turning them on inside and allowing them to run overnight before use. The Lakefront Trail in total stretches 29 kilometers but for this experiment only a portion of the trail was used. The section of the Lakefront Trail used for this study was from Irving Park Road to 43rd Street (Figure 2). The GPS in the devices were used to record the locations of each data point along the trail. 12 days of data collection were done stretching through the summer into the early fall and each ride was done at the same time of day in the early mornings between 7am to 10am. After collecting data, the readings were split into sections labeled North (N), Loop (L), and South (S) to determine spatial differences. The averages of the CO_2 and $PM_{2.5}$ data were collected for each zone along the trail as well as the standard error. Further statistical analysis was done to examine the air pollution data between the different sectors on the trail. A t-test was done to compare the north and south sections for both CO_2 and $PM_{2.5}$, considering each ride as one paired observation. The environmental justice map was used to help determine where to ride to along the trail (Figure 1). The wind data was found using the Midwest Regional Climate Center (MRCC) and to consider our idea about how wind could have an effect on the pollutant concentrations we compared the difference between the north and south sections based on whether the prevailing wind direction for that day was from the east or from the west. A t-test was also done to determine if the impact of wind direction was statistically significant.

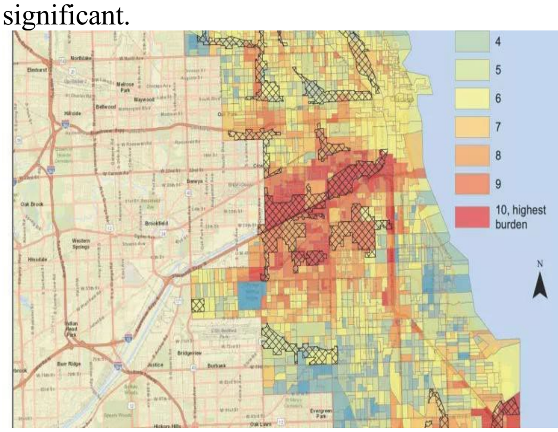

Figure 1. Environmental justice map of Chicago from NRDC. Burden is referring to different factors combined to determine total impacts.

Figure 2. Path of data collection taken for each sample. North=Blue, Loop=Green, South=Red.

RESULTS

The high-frequency data from each ride shows that pollution spikes depended on mobile sources and the spikes were not consistent between the north and southbound data collection routes (Figure 3). The averages for CO_2 and $PM_{2.5}$ are shown in Figures 4 and 5. The variance of $PM_{2.5}$ concentrations is very high between the different data days (Figure 5). The CO_2 concentrations follow a more consistent pattern with the north section of the trail having higher values. There is also less variation by day in CO_2 concentrations compared to $PM_{2.5}$ concentrations (Figure 4). In Figure 4 the data on 9/7 is very low which was caused by the rainy weather that day. When subtracting the North – South means of $PM_{2.5}$ concentrations there is very low variation between the two zones. The standard error bar is also relatively big showing the high variance by day of the concentrations (Figure 6). When doing the same thing for CO_2 there is a much larger difference when subtracting the two means of the North and South zones. This outcome indicates a significant difference between the two zones' CO_2 concentrations (Figure 7). The variation based off wind direction for CO_2 was high for both offshore and westerly prevailing winds, which indicates there is no significant difference for CO_2 concentrations based off which direction the prevailing winds are from (Figure 8). There was little variation for $PM_{2.5}$ concentrations based off the prevailing winds' direction, indicating there is no significant difference for $PM_{2.5}$ concentrations based off prevailing wind direction (Figure 9). The t-tests done for this study indicate there is no statistically significant $PM_{2.5}$ concentrations for the North and South sections of the Lakefront Trail. However, there was a statistically significant difference between the CO_2 concentrations between the North and South sections of the trail. The t-test has a p-value of 0.001. The p-value for the $PM_{2.5}$ t-test was 0.4, meaning there is no significant difference. The t-test based off wind data that was taken from the Midwest Regional Climate Center showed there was no statistical significance that the prevailing wind direction was having an effect on the pollutant concentration values for both $PM_{2.5}$ and CO_2. The p value for the CO_2 t-test for wind direction was 0.41 and the p value for the $PM_{2.5}$ test was 0.675. Thus, wind direction did not significantly affect the observed North-South difference.

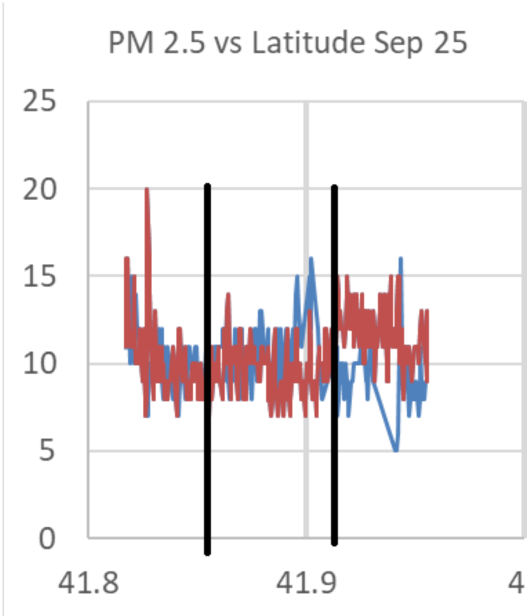

Figure 3. $PM_{2.5}$ values for a single sample showing southbound in red and the northbound trip in blue. Vertical black lines indicate different sections of the Lakefront Trail. The largest spikes that are shown highlight the exposure to certain vehicles near the Trail. The section on the right of the graph is the North Section of the Trail, and the South Section of the Trail is the left most portion of the figure.

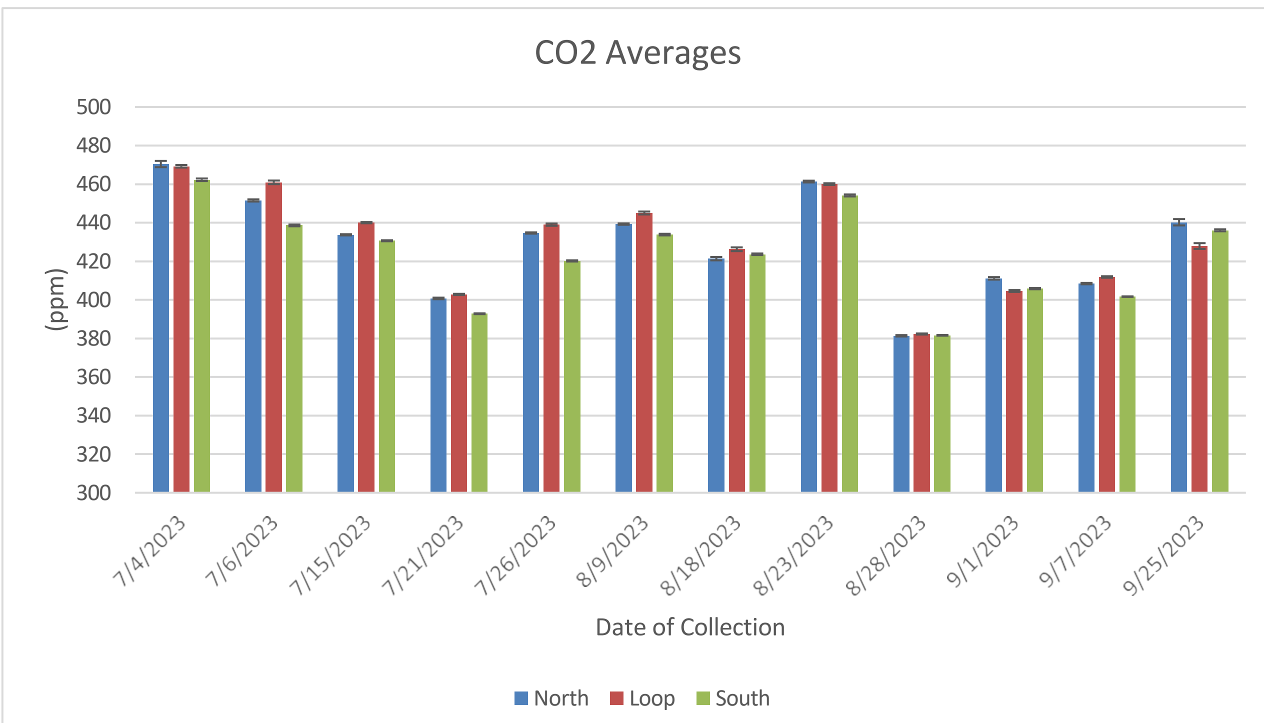

Figure 4. CO_2 Averages

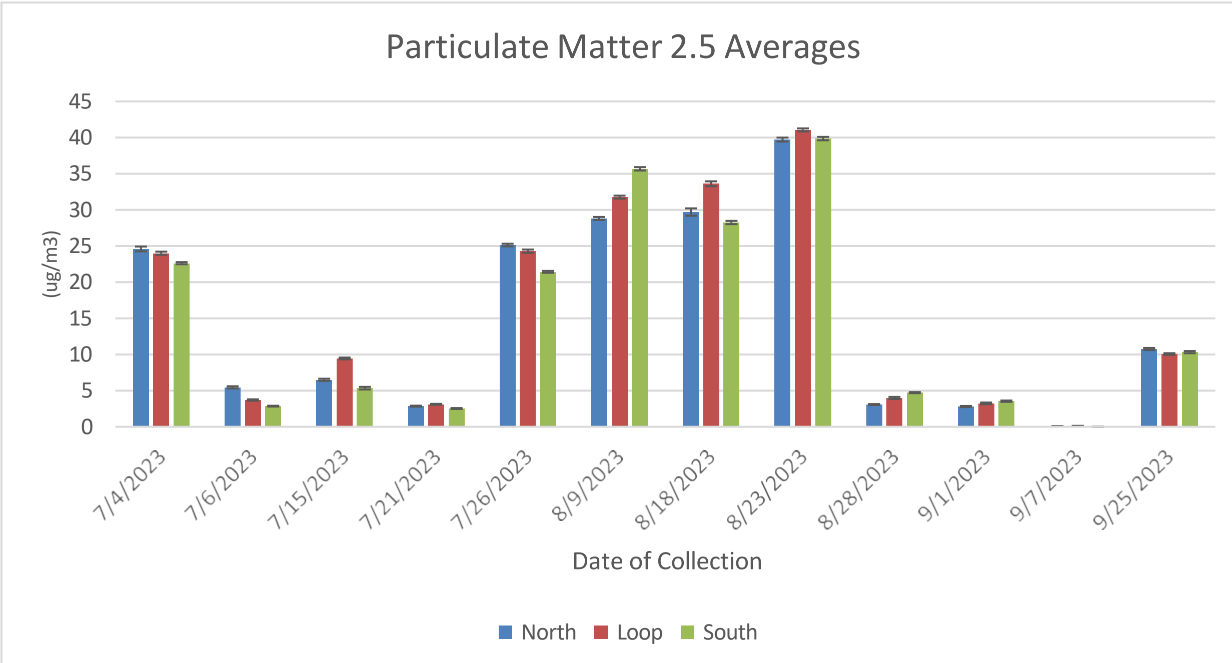

Figure 5. $PM_{2.5}$ averages; the error bars represent the standard error.

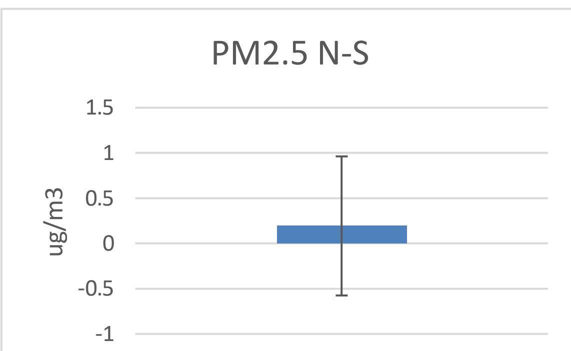

Figure 6. The difference between all North and South $PM_{2.5}$ averages including the standard error bar.

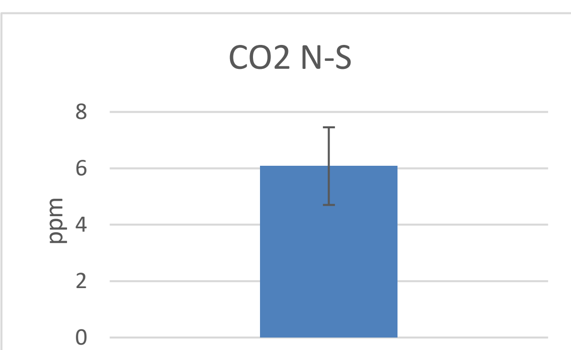

Figure 7. The difference between all North and South CO_2 averages including the standard error bar.

N-S Averages for CO_2

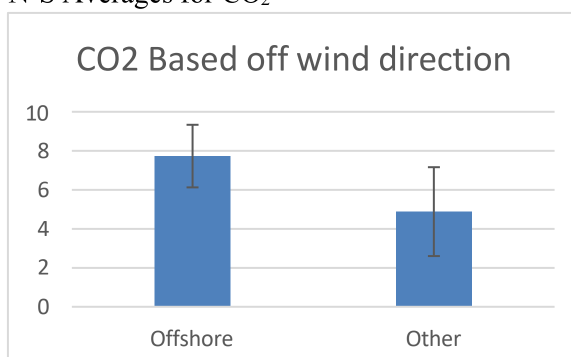

Figure 8. CO_2 differences based off wind direction. Offshore is Easterly Winds, and other is Westerly Winds.

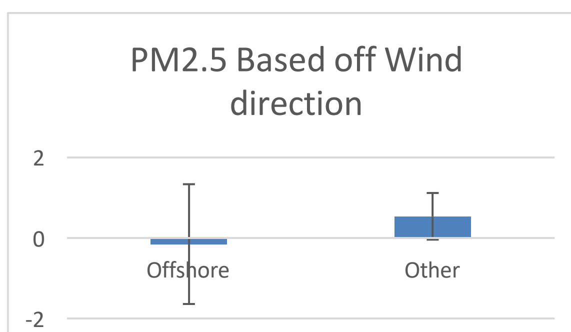

Figure 9. $PM_{2.5}$ differences based off wind direction. Offshore is Easterly Winds, and other is Westerly Winds.

DISCUSSION

When analyzing the difference between the $PM_{2.5}$ concentrations between the North and South sections of the trail we cannot reject the null hypothesis. This study was important due to how it can highlight potential health risks to certain communities along the Lakefront Trail. Also, a main use of the trail is exercise for people, where breathing heavily harmful pollutants can have an even greater effect on you. This is another reason why evaluating pollutant concentrations along the trail is important. We speculate that our original hypothesis would be correct for communities on the south side near industrial centers; however, there aren't communities with those industrial centers near the trail. We also speculate that pollutant concentrations are higher in south side communities further west of the trail. In Figure 1 the environmental justice map of Chicago shows many neighborhoods adversely affected by environmental factors that are not near the Lakefront Trail. We speculate CO_2 is higher in the North section because of higher traffic flow near the Lakefront Trail in this section. The Trail is also in closer proximity to Lakeshore Drive in the north section of the trail compared to other sections. Rain absorbs the particulate matter particles from the air which is what caused the values for $PM_{2.5}$ to be so low on 9/7, while CO_2 was unaffected by the weather (Tian et al., 2021). Wind direction for both $PM_{2.5}$ and CO_2 did not have a significant impact altering the concentrations based off prevailing wind direction. This study shows the Lakefront Trail area has healthy levels of PM2.5 but the North section of the trail has higher levels of CO_2. CO_2 is used as a tracer in this study for combustion of fossil fuels that can have adverse effects on human health. Also highlighted by this study is the variability between different days' air quality. Fluctuations make it difficult to accurately assess the air quality which is why a large sample size was needed to observe the air quality over many different days. Another possible influence that could have affected the data were the wildfires occurring over the summer of 2023, when the smoke blew south from Canada to Chicago. No data collection days were done when air quality was noticeably affected however it could have influenced the data. The ozone data collected in this experiment will be used by Dr. Potosnak in contribution to the work he has been doing about ozone concentrations. Overall, this study has shown that air quality in Chicago is adequate for an urban center. $PM_{2.5}$ concentrations do not come close to unhealthy levels in any of the samples. This result indicates there is no threat to public health based off air quality along the Lakefront Trail.

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