

**COMMUNITY EXPOSURE TO
PARTICULATE MATTER AND ITS
IMPACT FOR STUDENTS AND
RESIDENTS NEAR A
CONSTRUCTION
ASPHALT PLANT: A CASE STUDY**

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Abstract:

Particulate matter (PM) consists of various small particles in the atmospheres that have been associated with many deadly diseases. PM_{2.5} and PM₁₀ are different sized respirable particles that can penetrate the lungs and increase risk of cardiovascular problems and respiratory illness. Exposure to particulate pollution tends to cause lost income from work absence, students' absences from school, hospital admissions as well as emergency and doctor room visits.

Although asphalt plants are an important industry, they emit many pollutants, including PM_{2.5} and PM₁₀, during the production processes that are dangerous. Wells Cargo is an asphalt plant in Las Vegas located to the immediate north of Spring Valley High School. Spring Valley High School

(SVHS) students and nearby neighborhoods observe dust fumes frequently and are often forced to stay in their houses. As a result, air quality in the area is of concern to the residents' and students', which led to widespread protests from students and residents in the community.

This study sought to examine community exposure to particulate matter near Wells Cargo, to assess the short- and long-term health risks, and to examine the contributions from Wells Cargo. A year-long air quality monitoring was conducted at SVHS that simultaneously measured PM_{2.5}, PM₁₀, wind speed, and wind direction in real-time in order to evaluate daily and annual pollution levels against air quality standards and how the pollution levels vary with wind conditions. In addition, we established a control site at the immediate north of Wells Cargo.

Between December 1, 2018 and May 31, 2019, the average PM_{2.5} and PM₁₀ concentrations are 6.2 µg/m³ and 11.6 µg/m³, respectively, measured at SVHS, with the maximum 24-hour average of 14.9 µg/m³ and 50.0 µg/m³. There have been no exceedances to the EPA air quality standards. One-way ANOVA analysis shows that PM_{2.5} and PM₁₀ concentrations depend ($p < 0.001$) on wind speeds and wind direction. Higher PM levels occur during higher wind speeds and with northeasterly or southwesterly winds. There were appreciable differences when the school is upwind or downwind of Wells Cargo. The contributions from Wells Cargo are estimated to be 0–1 µg/m³ and 2–8 µg/m³ for PM_{2.5} and PM₁₀, respectively, during windy events.

Overall, the air quality at SVHS and its surroundings is in compliance with the EPA standards. Although there is no indication of immediate threat to the public, actions should be taken to reduce PM emissions from the plant to reduce health risks for the most sensitive populations. Air quality alerts should be generated for high wind conditions so community and school personnel can take necessary protection.

Introduction

Everybody has to breathe air to survive. The air we breathe is fundamental to our health yet we live in a world where it is often polluted. Air pollution is currently a public health concern and is accountable to major health risks. It is estimated that ambient air pollution is responsible for 4.2 million annual premature deaths globally (WHO, 2018) and World Health Organization estimated that every year, 6.4 million (1 in 9 deaths) people die due to adverse effect of exposure to poor air quality (WHO, 2018).

Outdoor air pollution is not just caused by activities from major industries it is also caused from wastes produced by human and animals (Manisalidis, et. al., 2018). Such polluted air has the tendency to travel and spreads to a wider area and affects the lives of many. The polluted air we breathe has both acute and chronic hence of impacts. According to the latest World Health Organization (WHO) database air pollution has worsened 8% between 2006 and 2008 that cause eye irritation, skin diseases and various

long-term consequences such as cancer (Pope et al., 2006).

Air pollutants include particulate matter (PM). PM_{2.5} and PM₁₀ are respirable particles less than 2.5 and 10 micrometers in diameter, respectively. Research shows that they have the ability to travel from the lungs into the bloodstream and cause various cardiovascular problems including death (Donaldson et al., 2005). Children and older adults are most susceptible to this exposure (Pope et al., 2006)

The United States Environmental Protection Agency (EPA)'s Office of Air Quality Planning and Standards (OAQPS) has set standards for PM pollutants as part of the National Ambient Air Quality Standards (NAAQS) (U.S. EPA, 2015). Currently, the standards for PM_{2.5} and PM₁₀ particles are 35 µg/m³ and 150 µg/m³, respectively, on 24-hour average. EPA monitors PM in two sizes (i.e., PM_{2.5} and PM₁₀) due to their different health effects.

In the Las Vegas metro area, the Clark County Air Quality Department (CCAQD) is responsible for maintaining the air quality-monitoring network.

The primary source of PM cities is road transportation and power plants (Chen et al., 2002; 2007; 2012). The level of PM exposure is affected by factors including the amount of pollutants that are emitted into the environment, weather and season (Madureira et al., 2012). Among other parameters, particle size is a huge factor causing health problems (Dockery, 2009). Under normal circumstances tiny particles that are inhaled have the potential to quickly travel into our lungs to cause short-term and long-term complications. Coarse particles that are inhaled have the tendency to deposit in our nose and throat, causing breathing problems (Atkinson et al., 2010). A visual comparison of PM_{2.5} and PM₁₀ particle size and where they deposit in human airways are illustrated in Figure 1(a) and 1(b).

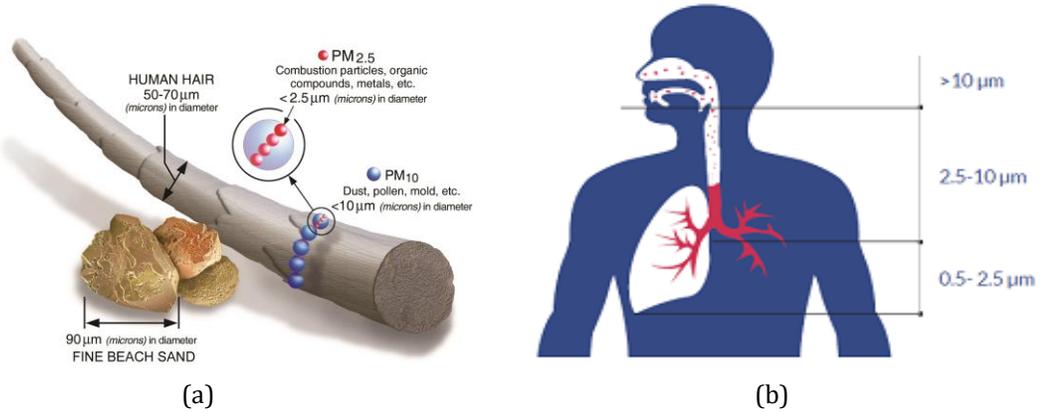


Figure 1. Illustration of (a) PM_{2.5} and PM₁₀ sizes compared to human hair and beach sand and (b) where particles deposit in human airway by their size.

Source: https://www.epa.gov/sites/production/files/2016-09/pm2.5_scale_graphic-color_2.jpg

According to U.S Census Bureau, the population of Las Vegas metropolitan area is about 2.3 million as of 2017. Las Vegas air quality is among the worst in the nation for ground-level ozone (O₃), the colorless gas that causes smog (American Lung Association (ALA), 2019) and Las Vegas is ranked 13th metropolitan area for O₃ pollution, making it among the worst in the nation (ALA, 2019).

Asphalt plants are an important industry to cities, counties and states. These plants mix gravels and sands with crude oil to make asphalt for highways, parking lot, and paved roads. Wells Cargo is a family owned asphalt company in Las Vegas that started as one truck operation in Sierra, Nevada in

1935 (Wells Cargo, 2018). The construction company owns and operates the existing plant in Spring Valley at the corner of Spring Mountain Road and South Tenaya Way. Wells Cargo provides services to the city of Las Vegas including comprehensive soil structuring, soil conditioning to surface preparation, asphalt mixes, which includes recycled asphalt (Wells Cargo, 2018).

Today, residential communities and schools surround Wells Cargo. The release of dust is causing air in the area to be polluted (Madureira et al., 2012). The air quality in the area is of concern to residents and students at nearby Spring Valley High School (SVHS) (Miller, 2019). Air pollution related diseases

in the neighborhood range from asthma attacks to lung damage. Currently it is reported that more than 300 students in the Spring Valley High School (SVHS) have asthma. Despite the fact that the community is concerned and protested, Wells Cargo was granted permission to add a second plant for Project Neon (Murray, 2019, para. 2). Project Neon is the largest freeway infrastructure in Nevada.

This study seeks to examine community exposure to particulate matter near Well Cargo. A

year-long air quality monitoring was conducted at SVHS that measured $PM_{2.5}$, PM_{10} , wind speed, and wind direction in real-time in order to evaluate daily and annual pollution levels and how the pollution levels vary with wind conditions. In addition, a control site was established at the immediate north of Wells Cargo. Comparing concurrent PM measurements from the two sites helps understand whether exposure is influenced by being upwind or downwind of Wells Cargo.

METHODOLOGY

In October 2018, we established air quality monitoring at SVHS ~50 m south of Wells Cargo (Figure 3). The school has a student population of about 3000 (Clark county, 21018). Other than Wells Cargo, residential communities to its east, south, and west surround SVHS. There are no other major point sources of pollution within 1 km of the school. Two large open lands (with sandy surface) located ~1 km to the west and southwest of SVHS may be dust sources. The site is 4 km from the nearest highways.

To evaluate the contribution from Wells Cargo, we established a control site in the backyard of a residential house at Derby Rd. in January 2019. The site is ~200 m to the north of Wells Cargo and is ~1 km from SVHS (Figure 3). The Derby site can serve as the urban background for the SVHS site to evaluate how Wells Cargo adds to air pollution levels during northeasterly winds, and vice versa during southwesterly winds.

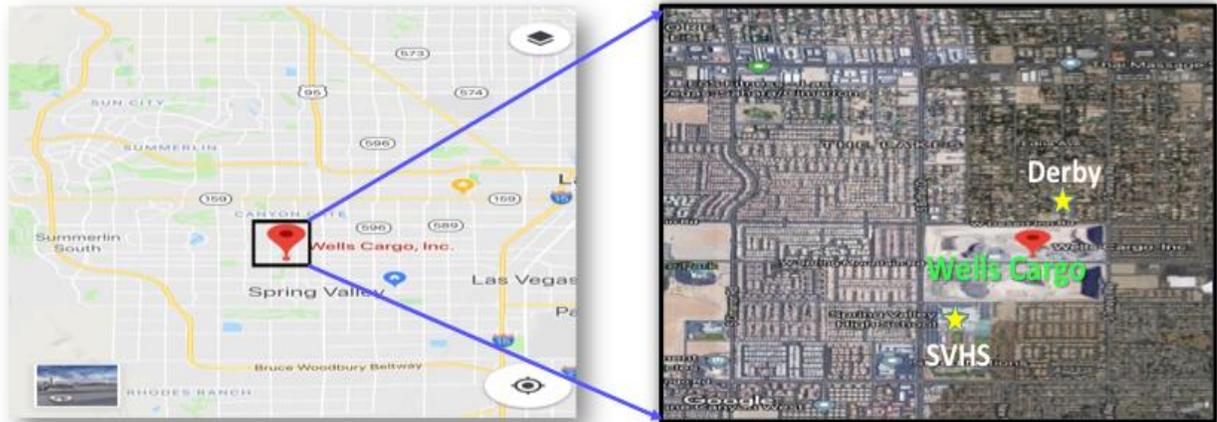


Figure 3. The map indicates location of two monitoring sites, SVHS and Derby, relative to the Wells Cargo plant in Las Vegas. Both sites are within 200 m from the Wells Cargo.

PM monitoring methods

Multiple technologies were used to acquire air quality data at the SVHS and Derby sites. PM_{10} and $PM_{2.5}$ were collected by NFRM (air quality samplers (ARA Ins., Eugene, OR) at SVHS. NFRM is able to complete 24-hour sampling periods utilizing battery power. Three NFRM samplers were installed on the rooftop of SVHS (Figure 4a). Each

sampler can collect $PM_{2.5}$ or PM_{10} filter sample and simultaneously measure and log real-time (every 5 minutes) sampling parameters such as flow rate as well as wind speed, wind direction, ambient temperature, and air pressure. Teflon-membrane filters were used to collect the $PM_{2.5}$ and PM_{10} deposits for subsequent analysis of particle mass and

metal composition (e.g., lead, cadmium, and mercury). The other NFRM collected PM_{10} on quartz-fiber filters for analysis of organic carcinogens such as polycyclic aromatic hydrocarbons. The filters sampled for 24 hours every 3rd day starting October 20, 2018 and following the U.S. EPA $PM_{2.5}$ sampling schedule. All the PM mass and chemical analysis were conducted by Desert Research Institute (DRI) scientists (Watson & Chow, 2017).

All NFRM samplers are equipped with a PM sensor that measures both $PM_{2.5}$ and PM_{10} using a light-scattering technique and logs the data every 5 minutes. While the sensor provides real-time data for evaluating short-term exposure, it needs to be calibrated constantly against $PM_{2.5}$ and PM_{10} concentrations from filters. Calibration factors were determined from the ratio of sensor and filter results for corresponding 24-hour periods. Throughout the monitoring period there were several occasions where there were missing data due to malfunction of the sensors including battery and downloading issues with the monitors or even sometimes the sensors not recording anything or indicating zeros. In general, 24-hour averaged data from the sensors are

considered reliable because of the constant calibration, while the hourly and sub-hourly data can be more uncertain.

To complement real-time PM measurement for addressing the second and third hypotheses in the Objectives of the Study, two Criteria Pollutant Sensors (SCI 608, Sailbri Cooper Inc., Beaverton OR) were installed at the SVHS site and started measurements on January 26, 2019 (Figure 4b). SCI sensors measured PM_{10} , $PM_{2.5}$, CO, NO_2 , SO_2 , and O_3 simultaneously at 5-minute intervals. They were factory calibrated before deployment and require collocated calibration against EPA certified monitors every 2-3 months. Since CCDAQ operates an EPA-certified site at the Jerome Mack Middle School (JMMS), the two SCI sensors were moved to JMMS between 3/1/2019 and 3/21/2019 for calibration. After the calibration, they were relocated back to SVHS and the Darby site. Further calibrations were conducted between 5/9/2019 and 5/17/2019 and between 8/6/2019 and 8/23/2019, when both sensors were moved to JMMS. Engineers from Sailbri Cooper Inc conducted all calibrations.



(a)



(b)

Figure 4. Illustration of (a) NFRM and (b) SCI 608-air quality monitors at the SVHS and Darby site, respectively.

PM monitoring schedule

Figure 5 shows the timeline of air quality measurements at both the SVHS and Darby sites. Our study focuses on real-time $PM_{2.5}$ and PM_{10} data

measured during the first six months (December 1, 2018 – May 31, 2019).

| Site | Measurements\Month | 2018 | | | 2019 | | | | | | | | | | |
|-------|-------------------------------|------|----|----|------|---|---|---|---|---|---|---|---|----|--|
| | | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| SVHS | PM on Filters (every 3rd day) | | | | | | | | | | | | | | |
| | NFRM 5-min PM | | | | | | | | | | | | | | |
| | NFRM 5-min Wind | | | | | | | | | | | | | | |
| | SCI 5-min PM | | | | | | | | | | | | | | |
| Darby | SCI 5-min PM | | | | | | | | | | | | | | |

Figure 5. Timeline of air quality measurements at SVHS and Darby. Blue shades include the periods where data are available. The period (December, 2018 – May, 2019) used for this thesis is highlighted in bold box.

Statistical analysis

Air quality data (December 1, 2018 – May 31, 2019) were downloaded from the equipment, organized and cleaned, and then submitted for statistical analysis. To be consistent, our analysis was mainly based on the SCI 5-minute PM data since they are calibrated against the EPA certified measurements at JMMS. Wherever necessary, they were supplemented with the NFRM 5-min PM data calibrated against 24-hour filter measurements. Short- (24-hour) and long- (weekly to six-month) term PM_{2.5} and PM₁₀ concentrations at SVHS were calculated to compare with the relevant EPA standards for testing the 1st hypothesis.

A one-way ANOVA analysis was conducted to examine PM_{2.5} and PM₁₀ concentration levels grouped by wind direction or wind speed at the SVHS site. This tested whether wind direction (WD) or wind speed (WS) led to significantly different PM concentrations, addressing our 2nd and 3rd hypotheses. In this study, the SPSS software was used to conduct statistical analysis. A p-value of 0.05 was used; Additionally, we calculated the difference between PM concentrations at the SVHS and Darby under different wind directions to determine how much enhancement is caused when winds originate from the Wells Cargo plant.

RESULTS

Temporal Variations

A twenty-four-hour average PM_{2.5} and PM₁₀ concentration at the Spring Valley High School between December 1, 2018 and May 31, 2019 was observed. The data show a maximum of 16.86 µg/m³ (December 18) and 50.0 µg/m³ (April 9) for PM_{2.5} and PM₁₀, respectively, well below the 24-hour NAAQS of 35 and 150 µg/m³ (U.S. EPA, 2015). For the six-month average (December 1, 2018 to May 31, 2019), PM_{2.5} concentration was 6.2 µg/m³, which was below the annual NAAQS of 12 µg/m³. There were no EPA standards to compare with the six-month PM₁₀ concentration of 11.6 µg/m³ measured at the SVHS site.

Excel was used to sort out the data by week and calculate weekly averages for both PM_{2.5} and PM₁₀ as well as the maximum and minimum daily means for each week. Figures 6 and 7 show the temporal trend of weekly particulate matter. PM_{2.5} concentrations appeared higher in winter than in spring, with the exception of March 24-26, 2019 (Week 17). Over the course of the research levels of PM_{2.5} occasionally exceeded the EPA annual standard but not the 24-hour standard (Figure 6). The highest and lowest weekly PM_{2.5} is 12.3 µg/m³ (Week 3) and 2.8 µg/m³ (Week 10), respectively, varying by a factor of 4.3.

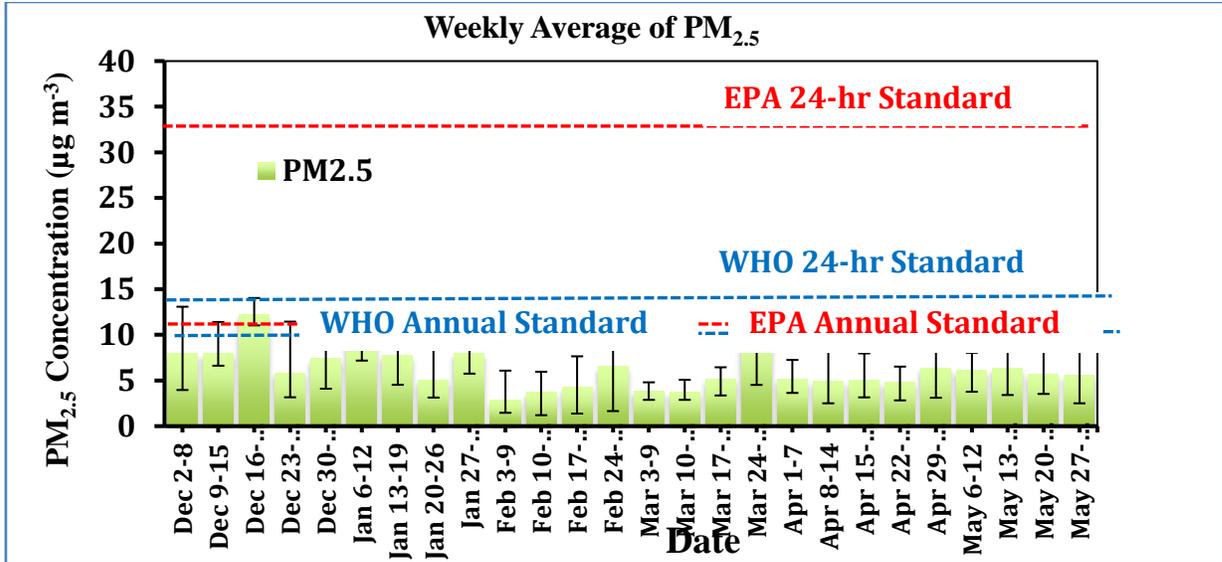


Figure 6. Weekly average of PM_{2.5} concentrations at the Spring Valley High School with error bars indicating the lowest and highest 24-hour average concentrations within the week

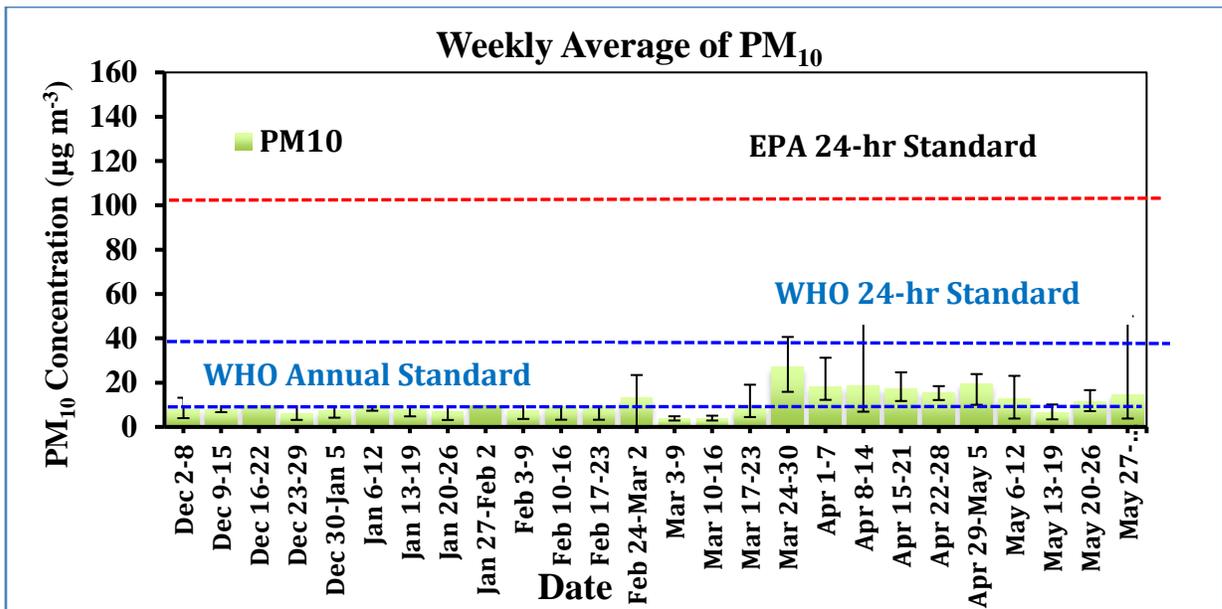


Figure 7. Weekly average of PM₁₀ concentrations at the Spring Valley High School with error bars indicating the lowest and highest 24-hour average concentrations within the week

Weekly average PM₁₀ concentrations varied by a factor of 5.6, from 4.8 µg/m³ (Week 14, March 3–9) to 27.1 µg/m³ (Week 17, March 24–30). In

contrast to PM_{2.5}, PM₁₀ concentrations were generally higher in spring than in winter suggesting different sources. Over the monitoring period none of weekly PM₁₀ were higher than the EPA 24-hour standard. However, the WHO guideline for annual and 24-hour PM₁₀ concentration is 20 and 50 µg/m³,

respectively (WHO, 2006). There have been at least 2 days in spring (March 24-30) where PM₁₀ concentrations reached the WHO guideline level.

PM Concentration and wind speed

Strong winds may re-suspend dust particles previously settled on the surface and/or on soil piles at construction sites. In order to evaluate how PM levels at SVHS vary by wind speed, we separated wind speeds (5-minute data) into six groups and summarized PM_{2.5} and PM₁₀ statistics within each group (Table 2). There 26,003 5-min data from the SCI sensor at SVHS used for this analysis. We followed a conventional grouping scale – the first two groups correspond to no wind (WS = 0) and calm wind (0 < WS ≤ 0.6 m s⁻¹) conditions, followed by light air (0.6 m s⁻¹ < WS ≤ 2 m s⁻¹), light breeze (2 m s⁻¹ < WS ≤ 4 m s⁻¹), gentle breeze (4 m s⁻¹ < WS ≤ 7.5 m s⁻¹), and moderate breeze (WS > 7.5 m s⁻¹). The frequency of each group (i.e., sample size) decreases

with increasing wind speed, with no wind, calm wind, light air, light breeze, gentle breeze, and moderate breeze occurring 33.8%, 25.4%, 23.8%, 13.8%, 3.1%, and 0.1% of the time, respectively.

Average PM_{2.5} and PM₁₀ concentrations of each WS group were calculated along with the standard deviations to help us examine how spread out PM concentrations are from the respective means. The standard errors for both PM_{2.5} and PM₁₀ generally increases from low-wind to high-wind groups, as the “moderate breeze” group with WS greater than 7.5 m s⁻¹ and the smallest sample size (24) has the highest standard error followed by the “gentle breeze” group with WS between 4 and 7.5 m s⁻¹ that has the second smallest 811 samples.

| Wind Speed | Sample Size | Average | | | Average | | |
|--------------|--------------|---------|--------------|-----------|---------|-----------|--------------|
| | | PM2.5 | S. Deviation | Std Error | PM10 | Std Error | S. Deviation |
| WS = 0 | 8779 | 6.60 | 4.73 | 0.05 | 16.71 | 0.17 | 16.09 |
| 0 < WS < 0.6 | 6598 | 5.09 | 3.28 | 0.04 | 13.51 | 0.15 | 12.01 |
| 0.6 < WS < 2 | 6191 | 4.76 | 3.18 | 0.04 | 13.97 | 0.16 | 12.71 |
| 2 < WS < 4 | 3600 | 4.80 | 3.53 | 0.06 | 16.03 | 0.32 | 19.15 |
| 4 < WS < 7.5 | 811 | 5.57 | 5.94 | 0.21 | 21.67 | 1.07 | 30.44 |
| 7.5 < WS | 24 | 6.35 | 8.11 | 1.62 | 35.75 | 12.27 | 61.33 |
| Total | 26003 | | | | | | |

Table 1. Statistics of PM_{2.5} and PM₁₀ concentrations for 6 distinct WS groups.

We then plotted the average PM concentration by WS group, with WS on the x-axis and PM_{2.5} and PM₁₀ concentration on the y-axis (Figure 9). Although there appear to be a wide distribution of PM concentrations within each WS group, both mean PM_{2.5} and PM₁₀ concentrations show a U-shape dependence on wind speed.

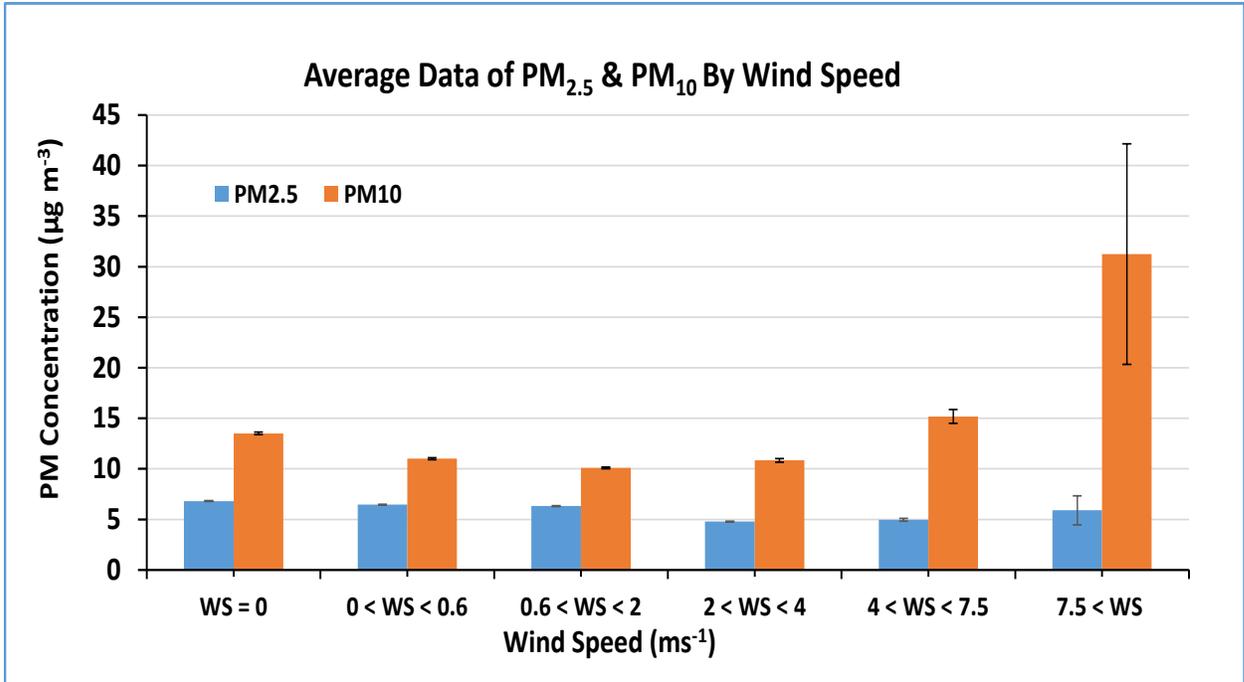


Figure 8. Average PM_{2.5} and PM₁₀ concentrations by WS group.

PM concentration and wind direction

In order to compare PM_{2.5} and PM₁₀ concentrations at SVHS under different wind directions we categorized the wind directions (WD) into nine groups. The first corresponds with no wind (WS = 0), and the other eight groups correspond with winds from eight directions each separated by 45°: North (WD < 22.5° or WD > 337.5°).

among all the WD groups. The most frequent WD is Southwest, with 2664 (10.2%) records corresponding to 202.5° < WD < 247.5°, while the least frequent WD is East, with 67.5° < WD < 112.5° captured in 1095 (4.2%) records. PM_{2.5} and PM₁₀ concentrations vary with wind direction.

26,003 five-minute data were used for this analysis. There are 8779 (33.8%) records with no wind (WS = 0), which is the largest sample size

| Wind Direction | | Sample Size | Average | | | Average | | |
|--------------------|---------|--------------|---------|--------------|-----------|---------|--------------|-----------|
| | | | PM2.5 | S. Deviation | Std Error | PM10 | S. Deviation | Std Error |
| WD=0 | No Wind | 8780 | 6.63 | 4.73 | 0.05 | 16.77 | 16.13 | 0.17 |
| WD < 22.5 | N | 2405 | 4.63 | 3.45 | 0.07 | 14.34 | 14.37 | 0.29 |
| 22.5 < WD < 67.5 | NE | 2444 | 5.75 | 4.08 | 0.08 | 17.37 | 15.42 | 0.31 |
| 67.5 < WD < 112.5 | E | 1095 | 6.07 | 3.63 | 0.11 | 15.39 | 10.80 | 0.33 |
| 112.5 < WD < 157.5 | SE | 1721 | 5.72 | 3.70 | 0.09 | 14.19 | 10.13 | 0.24 |
| 157.5 < WD < 202.5 | S | 2480 | 4.38 | 2.92 | 0.06 | 12.17 | 0.23 | 0.23 |
| 202.5 < WD < 247.5 | SW | 2664 | 5.53 | 3.69 | 0.07 | 17.45 | 20.52 | 0.40 |
| 247.5 < WD < 292.5 | W | 1985 | 5.31 | 2.81 | 0.06 | 14.84 | 13.20 | 0.30 |
| 292.5 < WD < 337.5 | NW | 2429 | 3.87 | 4.08 | 0.08 | 13.52 | 20.89 | 0.42 |
| Total | | 26003 | | | | | | |

Table 2: Statistics of PM_{2.5} and PM₁₀ concentrations for 9 distinct WD groups.

Northeasterly ($22.5^\circ < WD < 67.5^\circ$) and southwesterly ($202.5^\circ < WD < 247.5^\circ$) produced higher PM₁₀ concentrations (17.4 ± 15.4 and $17.5 \pm 20.5 \mu\text{g}/\text{m}^3$, respectively) than no-wind conditions ($16.8 \pm 16.1 \mu\text{g}/\text{m}^3$). This is consistent with a stronger

effect of winds on PM₁₀ than PM_{2.5}. Lower PM₁₀ concentrations were also found during southerly winds ($12.2 \pm \mu\text{g}/\text{m}^3$) and northwesterly winds ($13.5 \pm 20.9 \mu\text{g}/\text{m}^3$), as was observed for PM_{2.5}.

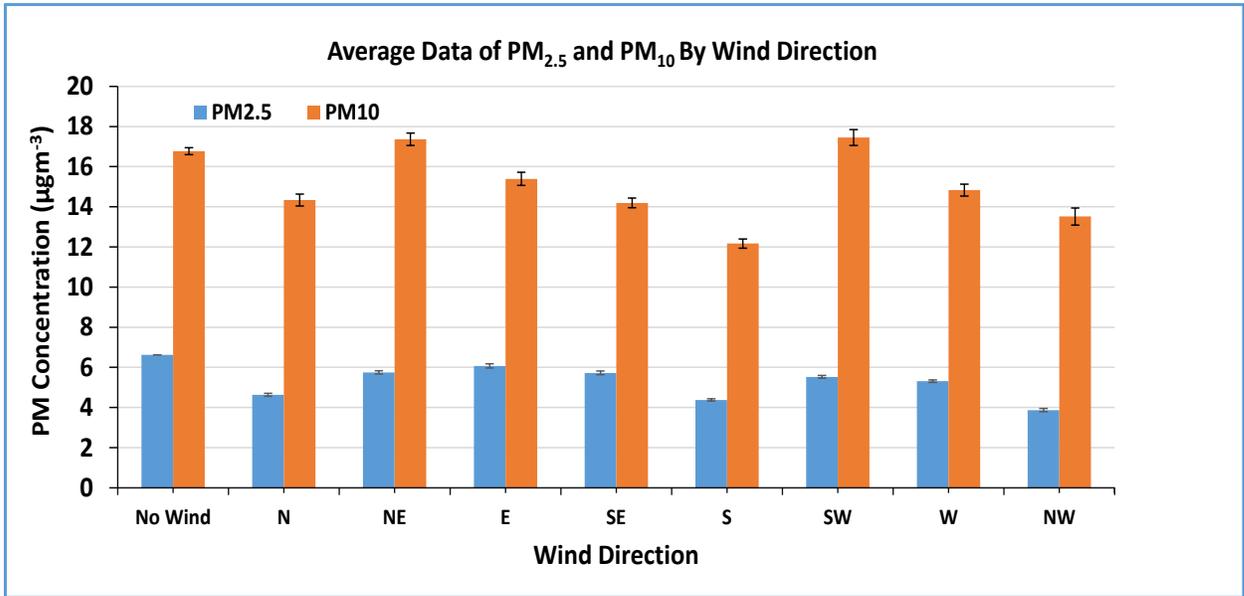


Figure 9. Both PM_{2.5} and PM₁₀ concentrations vary with wind direction. The NE and SW transport as well as no-wind conditions produce higher PM levels.

Since Wells Cargo is located northeast of SVHS, we expect to see high PM concentrations during northeasterly winds. It is interesting to find that PM₁₀ concentrations are relatively high during

both northeasterly winds and the opposite southwesterly winds. Possibly there are other sources located southwest of SVHS, thus increasing the PM₁₀ level during southwesterly transport.

Estimates of PM contributions from Wells Cargo

When PM measurements are available at both SVHS and Darby (Figure 5), it offers the opportunity to evaluate contributions from Wells Cargo. The PM enhancements were calculated by subtracting PM_{2.5} or PM₁₀ concentrations at Darby from those simultaneously measured at SVHS. They were then grouped by wind direction in a manner similar to Section 3.2. WD in Figure 10 plots the average PM enhancements and standard errors.

When the air is calm (no wind), SVHS measured an average PM_{2.5} concentration similar to

Darby but a slightly higher PM₁₀ concentration (by $\sim 1.2 \mu\text{g}/\text{m}^3$). The PM₁₀ enhancement must result from sources very proximate to the site, and is consistent with the shorter distance between SVHS and Wells Cargo than between Darby and Wells Cargo.

With winds, the differences between SVHS and Darby PM levels varied dramatically with wind direction (Figure 10).

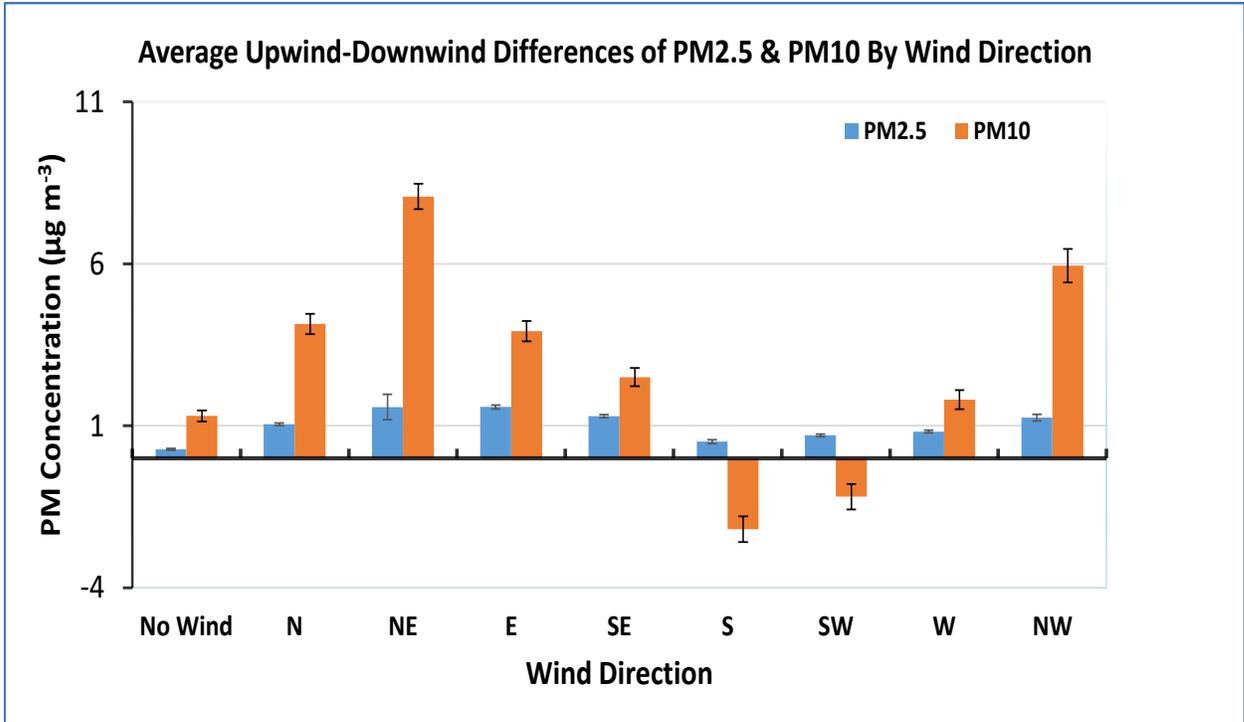


Figure 10. Differences of PM_{2.5} or PM₁₀ between SVHS and Darby (i.e., SVHS minus Darby) by wind direction.

Statistical analysis and hypotheses testing

One-way ANOVA analysis was conducted to compare mean PM_{2.5} and PM₁₀ concentrations between different wind groups. For WS, the mean PM_{2.5} and PM₁₀ differences are both significant at the 0.05 levels among groups (between-group $p < 0.001$). Table 3 and 4 shows the paired p-values for PM_{2.5} and PM₁₀, respectively.

The one-way ANOVA analysis also shows a significant difference in mean PM_{2.5} and PM₁₀ concentrations across all WD groups (between-group $p < 0.001$). Mean PM_{2.5} and PM₁₀ concentrations between WD group pairs are compared in Table 5 and

6. For PM_{2.5}, the “no wind” and “northwest” wind conditions differ significantly from all other groups. These two groups have the highest and lowest mean PM_{2.5} concentrations, respectively.

The difference between SVHS and Darby (PM_{2.5} and PM₁₀) varied with WD, as shown in Figure 10. The one-way ANOVA analysis also shows a significant difference across all WD groups with a between-group p value < 0.001 .

| WS Group | No Wind | Calm Wind | Light Air | Light Breeze | Gentle Breeze |
|-----------------|---------|-----------|-----------|--------------|---------------|
| Calm Wind | 0.000 | | | | |
| Light Air | 0.000 | 0.000 | | | |
| Light Breeze | 0.000 | 0.000 | 0.995 | | |
| Gentle Breeze | 0.000 | 0.947 | 0.000 | 0.000 | |
| Moderate Breeze | 1.000 | 0.791 | 0.287 | 0.318 | 0.877 |

Table 3. Paired p-values for comparing mean PM_{2.5} concentrations between WS groups. Insignificant results ($P > 0.05$) are highlighted.

| WS Group | No Wind | Calm Wind | Light Air | Light Breeze | Gentle Breeze |
|-----------------|---------|-----------|-----------|--------------|---------------|
| Calm Wind | 0.000 | | | | |
| Light Air | 0.000 | 0.759 | | | |
| Light Breeze | 0.130 | 0.000 | 0.000 | | |
| Gentle Breeze | 0.000 | 0.000 | 0.000 | 0.000 | |
| Moderate Breeze | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 4. Paired p-values for comparing mean PM₁₀ concentrations between WS groups. Insignificant results (P > 0.05) are highlighted.

| WD Group | No Wind | N | NE | E | SE | S | SW | W |
|----------|---------|-------|-------|-------|-------|-------|-------|-------|
| N | 0.000 | | | | | | | |
| NE | 0.000 | 0.000 | | | | | | |
| E | 0.000 | 0.000 | 0.421 | | | | | |
| SE | 0.000 | 0.000 | 1.000 | 0.388 | | | | |
| S | 0.000 | 0.410 | 0.000 | 0.000 | 0.000 | | | |
| SW | 0.000 | 0.000 | 0.538 | 0.005 | 0.808 | 0.000 | | |
| W | 0.000 | 0.000 | 0.008 | 0.000 | 0.046 | 0.000 | 0.675 | |
| NW | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 5. Paired p-values for comparing mean PM_{2.5} concentrations between WD groups. Insignificant results (P > 0.05) are highlighted

| WD Group | No Wind | N | NE | E | SE | S | SW | W |
|----------|---------|-------|-------|-------|-------|-------|-------|-------|
| N | 0.000 | | | | | | | |
| NE | 0.735 | 0.000 | | | | | | |
| E | 0.122 | 0.666 | 0.012 | | | | | |
| SE | 0.000 | 1.000 | 0.000 | 0.572 | | | | |
| S | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | | | |
| SW | 0.646 | 0.000 | 1.000 | 0.009 | 0.000 | 0.000 | | |
| W | 0.000 | 0.983 | 0.000 | 0.991 | 0.950 | 0.000 | 0.000 | |
| NW | 0.000 | 0.679 | 0.000 | 0.031 | 0.914 | 0.071 | 0.000 | 0.130 |

Table 6. Paired p-values for comparing mean PM₁₀ concentrations between WD groups. Insignificant results (P > 0.05) are highlighted.

DISCUSSION

PM_{2.5} and PM₁₀ are respirable particles that can penetrate the lungs and increase risk of cardiovascular problems and respiratory illness, among other health issues.

We conducted air quality monitoring for one year at SVHS and a control site that simultaneously measured PM_{2.5}, PM₁₀, wind speed, and wind direction in real-time (5-minute interval) in order to

evaluate daily and annual pollution levels against EPA air quality standards and how the pollution levels vary with wind conditions.

Between December 1, 2018 and May 31, 2019, the average PM_{2.5} and PM₁₀ concentrations are 6.2 µg/m³ and 11.6 µg/m³, respectively, measured at SVHS, with the maximum 24-hour average of 14.9 µg/m³ and 50.0 µg/m³. There have been no

exceedances of EPA air quality standards. $PM_{2.5}$ levels were higher in winter than spring while PM_{10} were higher in spring than in winter. The results suggest that $PM_{2.5}$ and PM_{10} concentrations depend significantly on wind speed and wind direction. Higher PM levels appear to occur during higher wind speeds and are associated with northeasterly or southwesterly wind direction. There were appreciable differences when the school is upwind or downwind of Wells Cargo, as compared with the control site. Based on the difference between SVHS and Darby measurements, we estimate that the contributions from Wells Cargo are 0–1 $\mu\text{g}/\text{m}^3$ and 2–8 $\mu\text{g}/\text{m}^3$ for $PM_{2.5}$ and PM_{10} , respectively, during windy events. However, there could be other dust sources around the SVHS besides Wells Cargo that also contributed to PM during windy events.

Our research has a few limitations, and time constraint is among them because we were not able to present the whole 1-year data, which would have provided a better picture. Another limitation to this work is that there are substantial missing data as shown in Figure 5. Some equipment were not ready during the first couple months of the project, and there were times that sensors were down.

Our study showed that the PM concentrations around the asphalt plant for both short-term and long-term exposure do not pose immediate threats to the community because there were no violations to the U.S. EPA air quality standards. However, the asphalt plant does increase the short-term and long-term exposure of schoolchildren and community to PM air pollution, especially during windy conditions. Actions should be taken to reduce PM emissions from the plant to reduce health risks for the most sensitive populations. Air quality alerts should be issued for high wind conditions so community and school personnel can take necessary protections. There can be many other ways to examine community exposure to particulate matter, which we will try in future. Future works include among the following; examining the health outcomes of students and residents near the asphalt plant. Moreover, to help investigate the impact of Wells Cargo near a school and resident's area it is essential to have a control group, a school that is exactly similar but in different location away from contraction. Having a school serve as a control will allow us to minimize the effect of all variables except the independent variable.

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