PM$_{2.5}$ Air Quality Trends at Mark Keppel High School

For Asian Pacific Islander Forward Movement

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Participating Organizations

About the Roberts Environmental Center

The Roberts Environmental Center (REC) is a student-staffed research institute at Claremont McKenna College. The REC's mission is to identify, publicize, and encourage practices that achieve social and economic goals through sustainable means. REC student analysts research real-world environmental issues from broad perspectives, considering science, economics, and policy. The Natural Sciences team at the REC focuses on bridging science and policy, while also making findings accessible to the public.

About the Asian Pacific Islander Forward Movement

Asian Pacific Islander Forward Movement (APIFM) is a non-governmental organization (NGO) that focuses on including the Asian Pacific Islander community in public health matters within the San Gabriel Valley. Our research partnership follows the community-based participatory research (CPBR) approach, which equitably involves community members, organizational representatives, and academic researchers. Among APIFM's primary goals is advocating for environmental justice and including youth participants.

Acknowledgments

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Abstract

In partnership with the Asian Pacific Islander Forward Movement, this report aims to help Mark Keppel High School (MKHS) identify air quality trends and implement solutions for minimizing harmful health effects due to poor air quality. $PM_{2.5}$ data from March 2018-February 2019 for four PurpleAir sensors was converted to its air quality index (AQI) and analyzed for trends by hour, day of the week, and month. For students at MKHS, their respiratory system is not fully developed and thus prolonged exposure to $PM_{2.5}$ and AQI > 50 is associated with asthma and other respiratory diseases. On weekdays, the morning rush hour, 6 AM-10 AM, has a greater association with higher AQI values than the evening rush hour, 4 PM-7 PM. Air quality is worse in the summer (67 days of AQI > 50) and better in the winter (32 days of AQI > 50). Closer proximity, less than 330 ft, to the San Bernardino Freeway makes air quality significantly worse on all days of the week, and it is notably worse 5 AM-5 PM. To control harmful health effects due to air quality, MKHS students should limit outdoor activity during 8 AM-10AM, especially on Wednesdays. Further analysis of factors associated with air quality trends is needed to create policies that will improve air quality.

Introduction

Air pollution causes serious adverse health effects, such as asthma, respiratory disease, and cancer, and is responsible for 6.4 million deaths per year.[1,2] Particulate matter, the main contributor to air pollution, is made of small airborne particles that are a product of burning fossil fuels. The primary contributors are automobiles and industrial facilities.[3] Particulate matter can be classified into two categories: coarse particulate matter that is less than 10 micrometers in diameter (PM_{10}) and fine particulate matter that is less than 2.5 micrometers in diameter ($PM_{2.5}$). $PM_{2.5}$ is of particular concern due to the particles' abilities to penetrate deep into the lungs. Exposure to $PM_{2.5}$ is associated with respiratory and cardiovascular health effects. Respiratory effects include asthma, lower respiratory tract infections, and even lung cancer. Cardiovascular diseases include hypertension, myocardial infarction, and stroke.[4] Due to its direct correlation with adverse health effects, it will be the metric by which air quality is analyzed for this report. At-risk populations, including children, the elderly, and those with heart or lung disease, are especially prone to the adverse health effects of poor air quality.[5] The respiratory system is not fully developed until the ages of 20-25 so exposure to harmful pollutants like $PM_{2.5}$ could cause permanent damage.[6] Additionally, the rate of children with asthma in Los Angeles is 9% which represents a large, extremely vulnerable population to poor air quality.[6,7]

Mark Keppel High School, located in Alhambra, CA, was built less than 100 feet from the San Bernardino Freeway. As a result, the high school students are constantly exposed to elevated levels of $PM_{2.5}$ due to nearby traffic and parents or guardians idling cars at the school drop-off and pick-up locations.[8] APIFM has provided PurpleAir sensors, small sensors that continuously measure air quality levels, to various organizations within the cities of Monterey Park and Alhambra, California, including Mark Keppel High School. PurpleAir sensors are relatively inexpensive compared to other air quality sensors while still being highly accurate and thus are ideal for large community-based data collection projects.[9]

The goal of this project is to analyze air quality trends across time and geographical location at Mark Keppel High School. Although the full effects of automobile pollution are difficult to determine, this report achieves a quantitative estimate based on the available data collected from four PurpleAir sensors. The data was examined across the hour of the day, day of the week, and month. Utilizing air quality guidelines outlined by the Environmental Protection Agency (EPA), patterns regarding the health effects of certain air quality levels were discovered and documented. The information has been synthesized for distribution to MKHS administration, parents or guardians of students, and members of the community of Alhambra. This analysis aims to be informative for school officials and community members with regard to administrative and scheduling decisions. For example, decisions regarding outdoor sports practice and recess times can now be scheduled considering air quality at specific times.

Methodology

Data Collection

Mark Keppel High School is located in Alhambra, CA. The school property is approximately 500,000 square feet and located 500 feet from the San Bernardino 10 Freeway. There are four outdoor PurpleAir sensors located on Mark Keppel High School grounds: SCAP 1, 3, 4, 5 (Figure1).

Figure 1. Aerial view of Mark Keppel High School acquired from Google Maps. Yellow dots indicate the location of the four PurpleAir sensors on campus. Sensors are named SCAP 1, 3, 4, 5 based on their ID number in the PurpleAir database. SCAP 1 is 179 ft. from the San Bernardino Freeway; SCAP 3 is 397 ft. from the San Bernardino Freeway; SCAP 4 is 490 ft. from the San Bernardino Freeway; SCAP 5 is 328 ft. from the San Bernardino Freeway. Blue squares indicate athletic facilities: basketball court (A), open field (B), tennis court (C), track (D), baseball field (E).

PurpleAir sensors collect data about particulate pollutant matter that is less than 2.5 micrometers ($PM_{2.5}$), 10 micrometers (PM_{10}) and 50 micrometers (PM_{50}) in diameter approximately every 30 seconds through two channels attached to the sensor. Additionally, they collect humidity and temperature values during these timestamps. These measurements are recorded through two separate channels and uploaded to purpleair.com, a public database. Publically available data from purpleair.com/sensorlist was downloaded for the sensors located on Mark Keppel High School for the time period March 13, 2018-February 28, 2019. Data from March 1-March 12, 2018 was not available. The data was downloaded as .csv files and values from channel A were used to perform analysis.

Data Analysis

All data analysis was performed in RStudio. The RStudio coding base was obtained from Ashley Collier-Oxandale, South Coast Air Quality Management District (AQMD) Air Quality Specialist, and modified as follows. Data time stamps were first changed from Coordinated Universal Time (UTC) to the appropriate local time: Pacific Standard Time (PST) or Pacific Daylight Time (PDT). $PM_{2.5}$ values from March 13, 2018 - February 28, 2019, were formatted to display hourly, daily, weekly, and monthly $PM_{2.5}$ averages. The averaged $PM_{2.5}$ values were converted to Air Quality Index (AQI) values using the following equation:

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \tag{1}$$

Where I is the air quality index (AQI), C is the pollutant concentration (μg/m³), C_{low} is the concentration breakpoint that is $\leq C$, C_{high} is the concentration breakpoint $\geq C$, I_{low} is the AQI breakpoint corresponding to C_{low}, and I_{high} is the AQI breakpoint corresponding to C_{high}. For example, a $PM_{2.5}$ concentration of 50 μg/m³ has a corresponding AQI of 137 (Table 1). Averaged AQI values were used for all following analyses and graphics as AQI is unitless and an easier metric for categorizing health impacts. AQI values greater than 500 were determined to be unreasonable outliers and were deleted from the dataset.

Table 1. The relationship between $PM_{2.5}$ concentrations ((The World Air Quality Project 2016; United States Environmental Protectio...) μg/m³) and AQI categories. Breakp[10,11]

24-hr $PM_{2.5}$ (μg/m³)	AQI Values	AQI Categories	Cautionary Statements	Health Implications
0-12.0	0-50	Good	None	Air quality is considered satisfactory, and air pollution poses little or no risk
12.1-35.4	51-100	Moderate	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.	Air quality is acceptable; however, for some pollutants, there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
35.5-55.4	101-150	Unhealthy for Sensitive Groups	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
55.5-150.4	151-200	Unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
150.5-250.4	201-300	Very Unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.	Health warnings of emergency conditions. The entire population is more likely to be affected.
Greater than 250.5	Over 300	Hazardous	Everyone should avoid all outdoor exertion	Health alert: everyone may experience more serious health effects

Results and Discussion

Data Validation

All the sensors were collecting data on a daily basis, except for SCAP 1 where there was a short pause from mid-January 2019 to late February 2019. Moreover, SCAP 2 was not active throughout the data collection period; all of the data utilized for analysis was taken from SCAP 1, 3, 4, and 5 during the period of time indicated in Figure 2. Supporting the conclusion of the AQMD PurpleAir report 2018-2019, PurpleAir sensors are a reliable and complete source of data collection for $PM_{2.5}$ values over time.[9]

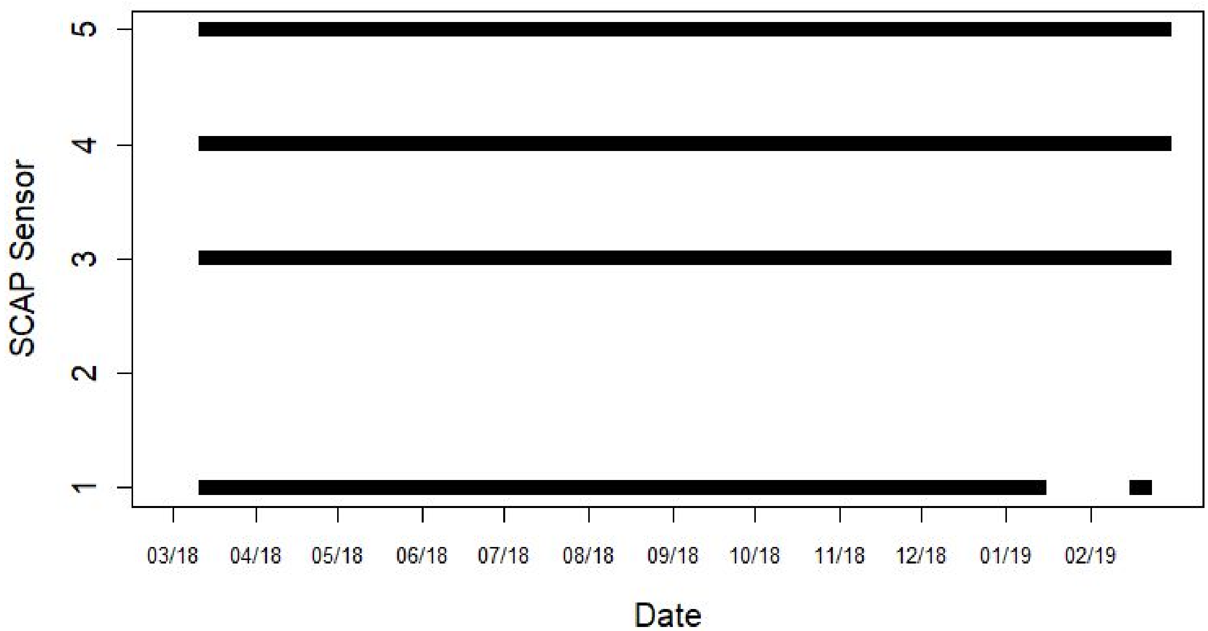

Figure 2. Completeness plot for SCAP 1, 3, 4, and 5 sensors. Data was collected from March 2018 until February 2019. All the sensors were collecting data on a daily basis, except for SCAP 1 where there was a short pause from mid-January 2019 to late February 2019.

AQI Trends

Figure 3 demonstrates the hourly average AQI levels for all four sensors throughout the data collection period. The AQI level averaged every five minutes varies greatly throughout the data collection period, making Figure 3 hard to interpret. However, this time series plot reveals significant AQI spikes that may be hidden by the analyses which are averaged across longer time periods of hour, day, or month. There are occasional significant spikes, the most severe of which occurs at the beginning of July, corresponding with particulate matter from the 4th of July fireworks. In a 2015 nationwide study, the average daily $PM_{2.5}$ concentration on July 4 was 42% higher than the national average on any other day.[12] The spikes in $PM_{2.5}$ were the greatest between 9 and 10 PM on July 4. Moreover, the air quality trends on July 4 were the same when the holiday fell on a weekend as opposed to a weekday.[12] This yearly degradation of air quality on July 4 is due not only to firework emissions but also to charcoal cooking and vehicle emissions.[4]

While the average AQI across the whole data collection period is in the "Moderate" category (AQI 51-100), the AQI does reach the "Unhealthy for Sensitive Groups" (AQI 101-150) and "Unhealthy" (AQI 151-200) category (Figure 3).

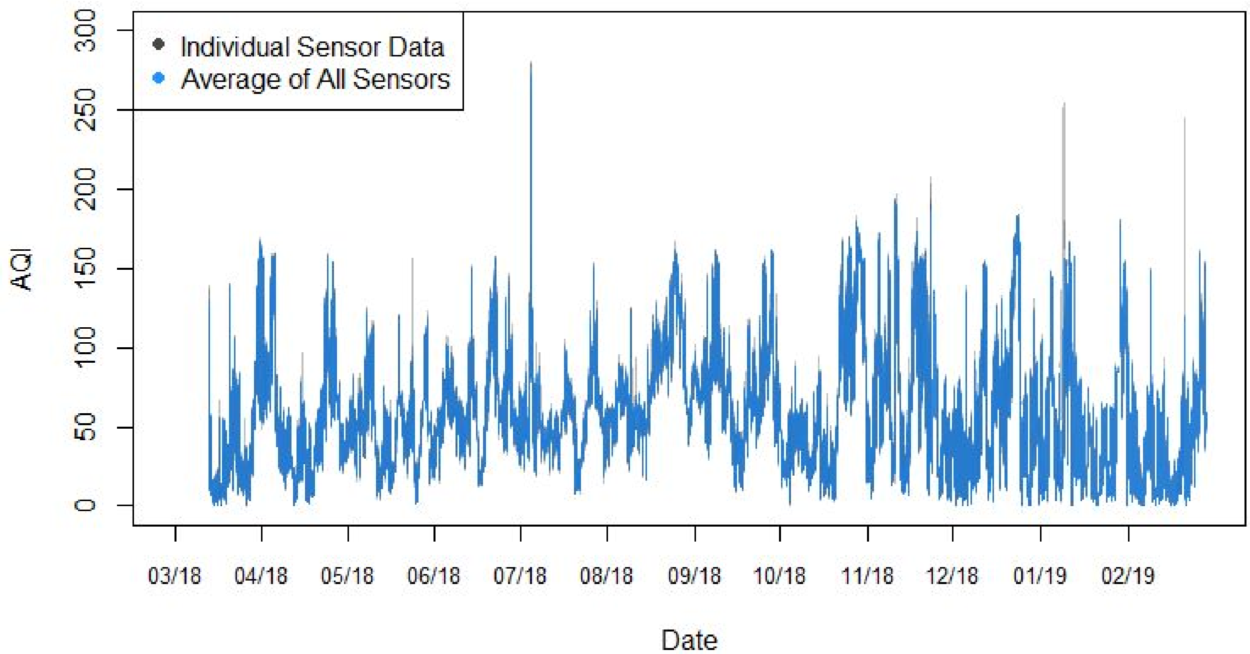

Figure 3. AQI values from March 2018 through February 2019 taken every five minutes from the four PurpleAir sensors on Mark Keppel High School's campus. The blue line indicates the average AQI across all sensors and the grey lines indicate the average AQI for each individual sensor.

Across the days of the week, there is a gradual decline in AQI levels after approximately 10 AM, reaching their lowest points at around 5 PM and then gradually rising again corresponding to the evening rush hour (Figure 4a,b). For weekly trends by the hour, there is a spike to a 75 AQI value on Tuesday, Wednesday, and Thursday between the hours of 6 AM-10 AM (Figure 4a). Other weekdays also demonstrate a smaller spike to 65 AQI during the morning hours, but it is most pronounced on Tuesday, Wednesday, and Thursday at 8 AM, likely corresponding to the morning rush hour. Saturday and Sunday do not demonstrate as much fluctuation in AQI level but do show more consistently steady elevated AQI levels when compared to the weekdays. Traffic trends on the San Bernardino Freeway near MKHS were obtained from Google Maps. The morning rush hour, in which traffic peaks at 8 AM on weekdays, has a greater association with higher AQI values than the evening rush hour, in which traffic peaks at 6 PM on weekdays. This is further examined in the hourly plot, which displays a spike in AQI values at 8 AM (Figure 4b). The consistent decrease in AQI at 5 PM on both weekends and weekdays suggests that the afternoon rush hour does not have a strong detrimental effect on the air quality.

Comparing SCAP 1 to the other sensors, average AQI for SCAP 1 from 5 AM to 5 PM is statistically significantly higher than the other three sensors, as indicated by the SCAP 1 shaded region not overlapping with the shaded regions of the other sensors (Figure 4b). Moreover, since the 95% confidence intervals of SCAP 1 do not overlap with those of the other three sensors, the AQI trend across days of the week is consistently statistically significantly higher than the other three sensors (Figure 4d). SCAP 1 is the closest sensor to the San Bernardino Freeway, and this proximity to the freeway may be a contributing factor for its higher AQI trend. Air quality is significantly worse within 330 ft of freeways than it is further away.[13] SCAP 1 is 179 ft from the freeway and the only sensor significantly less than 330 ft away. Thus, closer proximity to the freeway yields a higher risk of exposure to $PM_{2.5}$ from automobile emissions. Moreover, 90% of cancer risk from air pollution in Southern California is attributed to automobile emissions.[14]

The AQI by month exhibits a trend of alternating increasing and decreasing values between months (Figure 4c). This monthly variation is largely unexplained. However, during the spring and summer months (March-August) there is an overall increase in AQI values with the average AQI values beginning to drop in September (Figure 4c). The high AQI value of 88 for SCAP 1 in January does not align with the AQI values of 50 for the other three sensors. This may be attributed to the shorter data collection time period for SCAP 1 during the month of January since SCAP 1 stopped collecting data for late January (Figure 2). Disregarding the high AQI of SCAP 1 in January (Figure 4c), the air quality is the worst in the summer through early winter (June-December); our seasonal trend follows the California statewide trend.[15] The higher AQI in April-October may also associate with the season of high ozone levels which is during the same months in the greater Los Angeles area.[15] Ozone is a different air pollutant from $PM_{2.5}$, and these two pollutants are the top two pollutant types in the U.S.[16]

Air quality for community members at MKHS may be worse during the beginning of the week (Tuesday-Wednesday) and on Sunday (Figure 4d). The range, or difference between the maximum and minimum, for AQI among day of the week per sensor is at max 5: SCAP 1 min = 69, max = 64, range = 5; SCAP 3 min = 56, max = 59, range = 3; SCAP 4 min = 56, max = 60, range = 3; SCAP 5 min = 57, max = 60, range = 3. The max range for AQI among hour is 30 (SCAP 1 min = 45, max = 75, range = 30; Figure 4b) and the max range for AQI among month is 43 (SCAP 1 min = 37, max = 80, range = 43 disregarding inaccurate January AQI; Figure 4c). While AQI does vary among the day of the week (Figure 4d), the magnitude of the variation is not as large as the variation among hour or month (Figure 4b,c). Thus, the variation and trends for AQI by hour and month have a greater impact on health effects than those for AQI by day of the week.

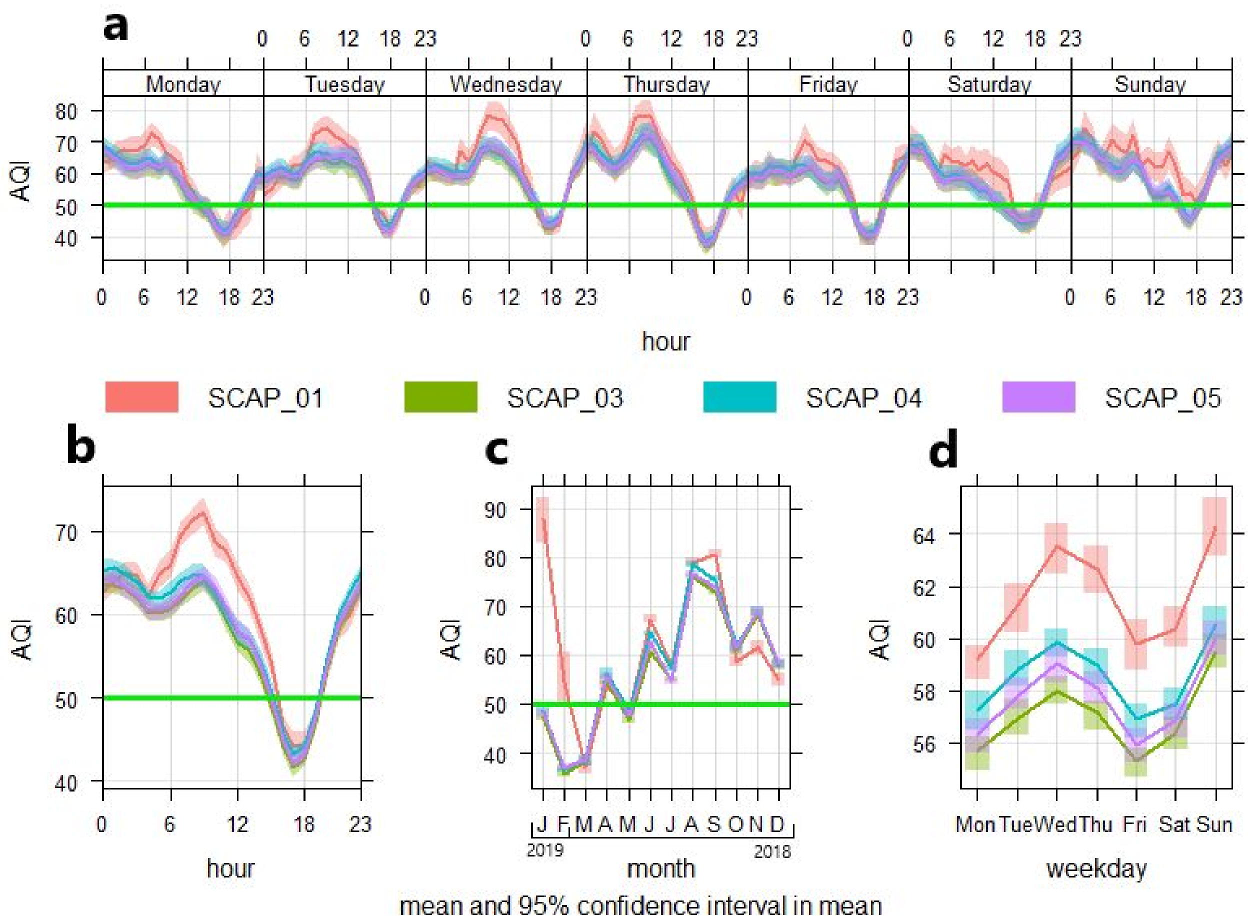

Figure 4. AQI trends for four sensors (SCAP 1, 3, 4, 5) by time for March 2018-February 2019. Horizontal green line represents the AQI separation between "Good" (AQI = 0-50) and "Moderate" (AQI = 51-100). Light shaded regions represent the 95% confidence interval for each sensor's AQI means. **a-b**, AQI variation by the hour (**b**) and by the hour for each day of the week (**a**). **c**, AQI variation by month, with January-February 2019 plotted before March-December 2018. **d**, AQI variation by day of the week.

Similar to the interpretation of Figure 4c, the calendar in Figure 5 indicates that average AQI levels per day were higher in late summer to the fall season (August-December). The data suggests that it would be optimal to be active outside when AQI is "Good" during mid-March, mid-April, mid-May, early October, early December, early and mid-January, and early and mid-February. AQI is in the "Unhealthy" range on days corresponding to holidays. Holidays are associated with heavier vehicle traffic and increased particulate matter from outdoor activities involving emissions, such as fireworks or barbeques. October 28 and 29 are in close proximity to Halloween on October 31; November 11 is Veterans Day; December 23 and 24 are in close proximity to Christmas on December 25. Contrary to expectation, July 4 and January 1 have relatively low AQI despite the tendency to have fireworks during those holidays. Thus, the AQI spike during July 4 in the time series plot (Figure 3) is not sustained long enough for the spike to influence the daily average.

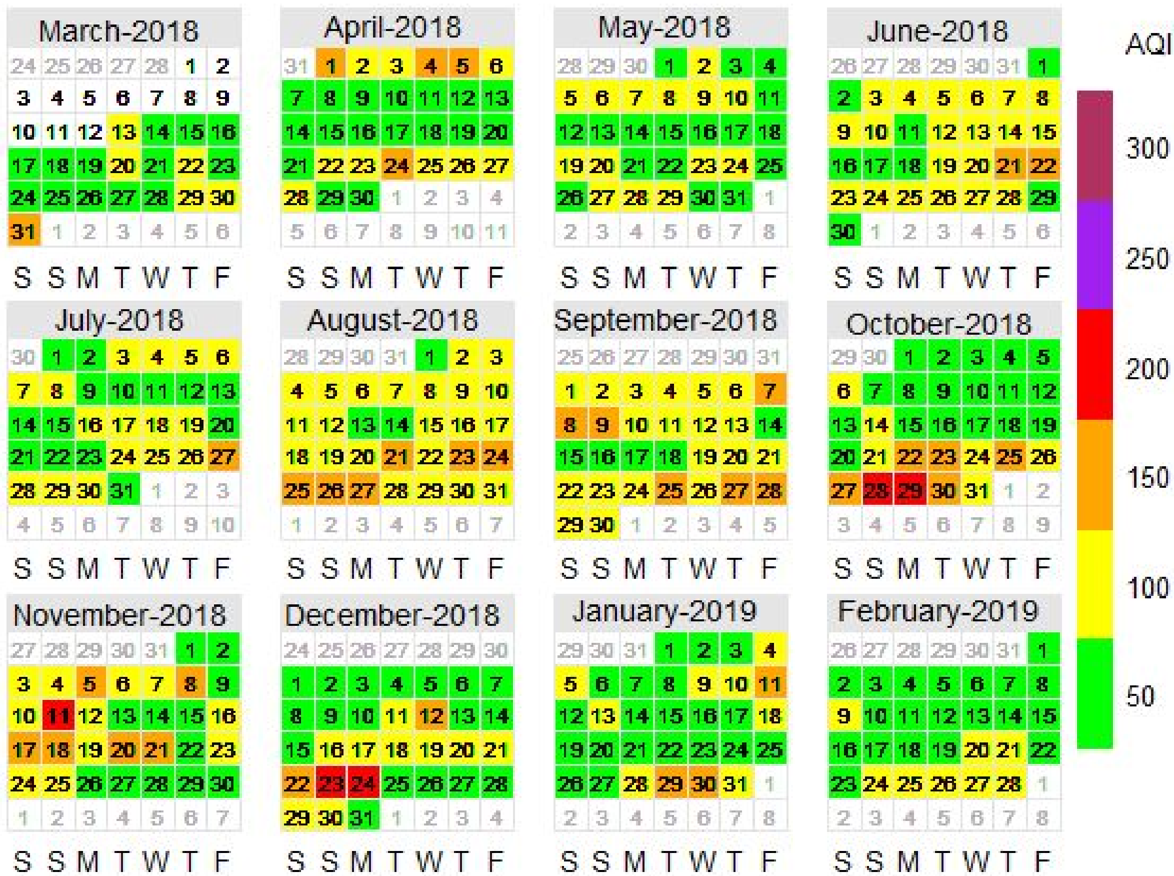

Figure 5. The calendar indicates the mean AQI among all sensors per day from the months of March 2018-February 2019. Color corresponds to air quality for that day (AQI of 1-50 "Good" is green; 51-100 "Moderate" is yellow; 101-150 "Unhealthy for Sensitive Groups" is orange; 151-200 "Unhealthy" is red).

Figure 6 quantifies Figure 5 by displaying the number of days within each AQI category by month. Summing the number of days per month with AQI over 50, which indicates that the air quality is "Moderate," "Unhealthy for Sensitive Groups," or "Unhealthy," summer months of June-August have 67 days; fall months of September-November have 56 days; winter months of December-February have 32 days; spring months of March-May have 33 days (Figure 6). Summer has the worst overall air quality while winter has the overall best air quality. November is one of the worst air quality months with 12 days of "Good," 11 days of "Moderate," 6 days of "Unhealthy for Sensitive Groups," and 1 day of "Unhealthy." In comparison, February has the best air quality with 20 days of "Good" and 8 days of "Moderate."

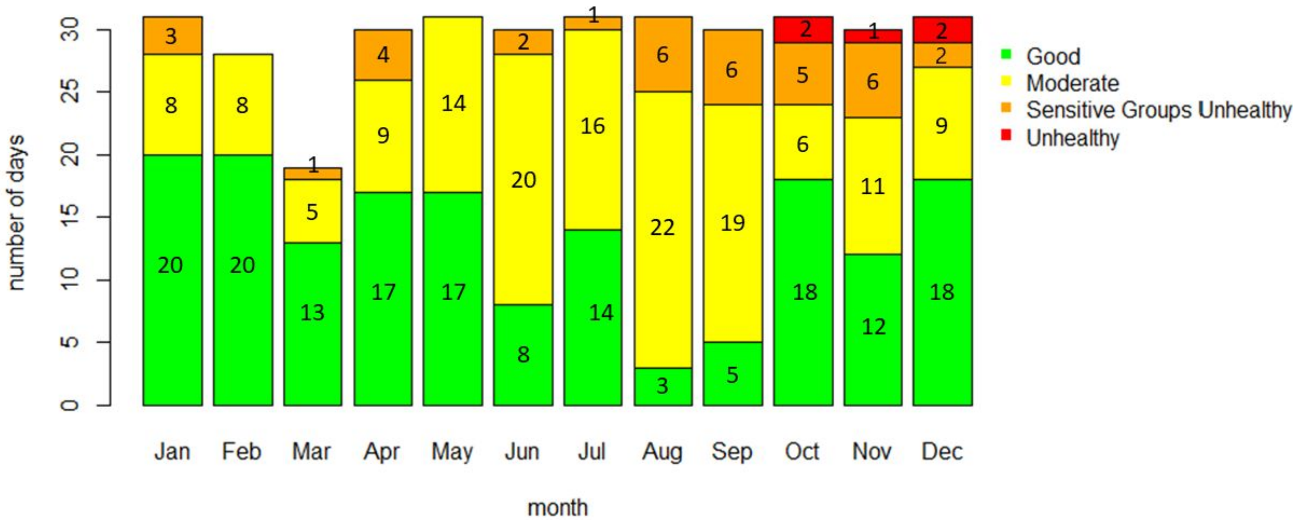

Figure 6. Number of days within each AQI category for the months of March 2018-February 2019. Color corresponds to average air quality for that day (AQI of 1-50 "Good" is green; 51-100 "Moderate" is yellow; 101-150 "Unhealthy for Sensitive Groups" is orange; 151-200 "Unhealthy" is red). March has incomplete data since data collection started on March 13, 2018.

Solutions for Monitoring Air Quality and its Effects

Students at MKHS are under the age of 20 and thus their respiratory system is not fully developed.[6] They are sensitive to the health effects of poor air quality in the "Unhealthy for Sensitive Groups" category of AQI 101-150. Poor air quality has more severe health effects on people who are physically active or have a respiratory disease. Students who have both prolonged outdoor exertion and a respiratory disease such as asthma will be impacted by the air quality in the "Moderate" category of AQI 51-100. Thus, solutions for monitoring air quality and its effects are twofold:

1. Monitor the health effects of air quality. Do not change the air quality but minimize the harmful health effects.
2. Monitor air quality. Improve overall air quality, which will consequently decrease harmful health effects.

Controlling Health Effects

Given the current air quality trends, the first solution aims to modify student behavior in order to minimize susceptibility to harmful health effects. Students should avoid outdoor exertion during peak periods of poor air quality. Outdoor sports practice and physical education classes should be scheduled during lower AQI periods of 4 PM-6 PM and not during higher AQI periods of 8 AM-10 AM (Figure 4a,b). Wednesday is a particularly bad day for AQI; Wednesdays should be reserved for indoor practices (Figure 4d). Summer months generally have worse air quality than winter months (Figure 6). Even though warmer weather in the summer encourages outdoor activity, students should take precautions to the current air quality conditions. Moreover, outdoor activities should be hosted at least 330 ft away from the freeway.[13] During the morning rush hour traffic of 6 AM-10 AM, students should avoid practicing on the tennis courts, track, and baseball field which are closer to the freeway. The basketball courts and the open field are further from the freeway and thus more preferable for physical activity (Figure 1).

Another approach to the first solution is to relocate athletic facilities further from the freeway. While this is the most impactful solution, it is not a practical solution due to the financial and legal constraints of MKHS. Thus, the proposed approach to change the timing of outdoor activity is the overall preferred solution to monitor the health effects due to air quality at MKHS.

Improving Air Quality

The second solution involves actions to improve air quality and decrease overall AQI. In order to improve air quality, we need to know what factors are associated with the observed air quality trends. Factors associated with poor air quality may include closer proximity to the freeway, increased vehicle traffic, more idling cars, and a shorter distance from a park. Further analysis by the REC Natural Sciences Team on these factors will provide evidence and insight for creating policies that aim to improve air quality at MKHS.

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