

# QUANTIFICATION OF METAL CONCENTRATIONS IN PARTICULATE MATTER COMING FROM TRANSIENT AIR POLLUTION IN SOUTHERN CALIFORNIA: FIREWORKS AND WILDFIRES

A Thesis By

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## Abstract:

Particulate matter exposure, both long-term and short-term, has been linked to an increased risk of negative health effects on humans. Exposure to particulate matter with a diameter of less than 2.5 micrometers (PM<sub>2.5</sub>), is especially dangerous, as particles can penetrate deep into the lungs and bloodstream. The composition of particulate matter is what makes it toxic to humans. There are consistent sources of particulate matter, such as vehicular emissions and there are transient sources, like fireworks and wildfires. Both consistent and transient sources are known to emit heavy metals in particulate matter. Heavy metals in the ambient air are known to be extremely toxic and some carcinogenic. Metal pollutants like lead, chromium and arsenic are heavy metals emitted into ambient air are extremely dangerous for human exposure. This study investigates the effects of transient sources of particulate matter air quality, specifically examining firework activity, during July 4<sup>th</sup>, 2024, and wildfires during January 2025. The firework activity was monitored in three different sites in Southern California. This study focuses on quantifying the concentrations of metals in PM<sub>2.5</sub>. Air samplers with a PM<sub>2.5</sub> inlet (Access Sensors Technology, UPAS v2+) were used to collect particulate matter onto 37 mm mixed cellulose ester (MCE) filters. Filters were then extracted in nitric acid and metals were quantified using inductively coupled plasma-optical emission spectroscopy (ICP-OES, Agilent 5800). Results showed elevated concentrations for strontium and barium along with other metals during firework activity. During wildfire activity, increased concentrations in lead and chromium were observed in addition to other metals.

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# CHAPTER 1

## INTRODUCTION

### Particulate Matter

The air we breathe is made of a mixture of gases, such as nitrogen and oxygen, water vapor, and solid or liquid particles suspended in the air. These tiny particles carried in the atmosphere come in various forms, they can be very small liquid droplets or solid particles, and are called particulate matter (PM) [1]. A suspension of particles in the atmosphere is called an aerosol. PM can be emitted into the atmosphere from both natural and anthropogenic (due to human activity) sources. Some examples of natural processes that generate aerosol particles into the atmosphere are sea spray, mineral dust events, and wildfires. Human activity plays a large role in the emission of particulate matter. Sources such as fossil fuel combustion from cars and factories, fireworks, and agricultural pollution are all anthropogenic emitters of particles [2]. These sources are usually categorized into primary or secondary sources. Primary sources result from the direct emission of PM into the air, for example wildfires or fuel combustion. Secondary sources of particles are not from particles emitted directly into the atmosphere, but instead these particles are formed in the atmosphere through a series of photochemical reactions [3].

The presence of PM or aerosols in the atmosphere has great effects on the Earth's climate. Our climate is affected by several factors like sunlight or gases in our atmosphere, but the presence of aerosol particles plays an important role. The direct effect of aerosols describes the ability of a particle to absorb and/or scatter incoming solar radiation back in all directions, thus affecting Earth's climate [4]. Lighter colored particles are known to have a negative radiative forcing because they scatter the visible light that hits them, having a cooling effect on the climate. Darker colored particles have positive radiative forcing because although they also scatter light, they can absorb and re-emit visible light, increasing the temperature of the Earth's climate [5].

When studying particulate matter, atmospheric chemists focus on two characteristics: size and chemical composition. PM comes in various sizes, categorized on the micrometer scale from 0.1-100

$\mu\text{m}$ . Within this range, PM is categorized in the following way:  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{PM}_1$  etc. These categories represent particles of a specific diameter in size [1], [6]. For example, in  $\text{PM}_{10}$ , particles have a diameter of 10  $\mu\text{m}$  or smaller, while  $\text{PM}_{2.5}$  includes particles smaller than 2.5  $\mu\text{m}$ . In this work, we focus on  $\text{PM}_{2.5}$ , particles with a diameter of 2.5  $\mu\text{m}$  or smaller.

PM in the atmosphere has adverse effects on human health. The size of PM is important to study because it can determine the severity of its health effects on humans. Larger PM ( $\text{PM}_{10}$ ) are small enough to enter the body through nasal and oral passages reaching the trachea and bronchi. Particles of  $\text{PM}_{2.5}$  or smaller penetrate deeper into our lungs reaching the bronchioles and alveoli, eventually these particles diffuse into the bloodstream and throughout our bodies [6].

Exposure to these particles whether for long or short periods of time can lead to detrimental human health effects. According to the World Health Organization (WHO), in 2024 exposure to outdoor air pollution led to 4.2 million premature deaths globally and 3.8 million from indoor air pollution, specifically from  $\text{PM}_{2.5}$ , with the greatest numbers coming from South-East Asia [7]. Long-term, or chronic, exposure of  $\text{PM}_{2.5}$  can cause lung cancer [8], cardiovascular diseases [9] and even reproductive issues, such as premature births. Even short-term exposure to  $\text{PM}_{2.5}$  may affect individuals with weaker immune systems such as children, the elderly, and immunocompromised individuals causing an increase in asthma, cardiovascular diseases, skin irritations, and strokes [10].

### **Detrimental Health Effects Caused by Particulate Matter**

Several health organizations have shown that  $\text{PM}_{2.5}$  can cause premature deaths and therefore reduce the life expectancy over the global population. Apte et al. (2016) quantified the global impact of ambient  $\text{PM}_{2.5}$  on life expectancy and found that exposure to  $\text{PM}_{2.5}$  led to a global life expectancy decrement[11]. Life expectancy decrement is defined as a decrease/shortening of life expectancy due to different risk factors such as tobacco use, cancer, water sanitation and air pollution. This study also compared the life expectancy decrements of different risk factors to those of all air pollution and

specifically from ambient PM<sub>2.5</sub>. The life expectancy decrement from all air pollution globally was 1.65 years. From the life expectancy decrement of all air pollution, PM<sub>2.5</sub> contributed to 1.03 years out of the total 1.65. This means that PM<sub>2.5</sub> is the highest contributor to life expectancy decrement in all air pollution. The study compared those decrements to the life expectancy decrement of lung cancer and that of tobacco use which were 0.41 years and 1.82 years, respectively. This shows that air pollution is potentially more harmful to human health than lung cancer [11]. When compared to tobacco use, even non-smokers would have approximately the same life expectancy decrement as smokers from just breathing what is found in the atmosphere. The study also looked at the life expectancy decrement for 182 different countries. Those with higher levels of pollution, for example, China, India, and parts of Africa, had higher life expectancy decrements caused by PM<sub>2.5</sub> [11].

The World Health Organization (WHO) reduced the acceptable annual mean concentrations of PM for PM<sub>10</sub> and PM<sub>2.5</sub> in 2021 from the first levels established in 2005 after evidence showed that air pollution affects health at lower concentrations. The annual mean concentrations in 2005 were 20 µg/m<sup>3</sup> for PM<sub>10</sub> and 10 µg/m<sup>3</sup> for PM<sub>2.5</sub> and since 2021 have been reduced to 15 and 5 µg/m<sup>3</sup> respectively [12]. These guidelines are placed to help reduce the number of particles found in the atmosphere and potentially reduce the life expectancy decrement [12]. Lin et al. (2025) conducted a study on life expectancy gains ascribed to PM reduction in China [13]. This study took the new WHO guidelines and determined how much life expectancy would increase with the decreased concentrations of PM<sub>2.5</sub> in the ambient air. Reducing PM<sub>2.5</sub> to the new threshold of 5 µg/m<sup>3</sup> was shown to contribute to a 4.07-year average life expectancy gain in China. This study shows promising results for China, a country with a very high pollution problem. If these guidelines were to be followed globally, over time the life expectancy decrement of 1.82 years should decrease [12], [13].

Ambient PM<sub>2.5</sub> exposure has also been linked to causing preterm births. A preterm birth is the delivery of a baby before the fetus has reached the full 37-weeks of pregnancy. A study by Malley et al. (2017) determined the global estimate of preterm births caused from maternal PM<sub>2.5</sub> exposure in



2010[14]. Globally, the number of preterm births caused by PM<sub>2.5</sub> exposure was 2.7 million. The countries with higher percentages of preterm births were countries with extremely poor air quality in parts of Africa and South-Asia[14]. Preterm births can be caused by several risk factors, but Malley et al. noted a pattern where countries that had worse air pollution had more preterm births. The countries with less air pollution due to stricter air quality regulations showed a lower percentage of preterm births from PM<sub>2.5</sub>. The results of the Malley et al. study are consistent with those of the Apte et al. (2016) study that looked at life expectancy decrements, showing the adverse effects of PM<sub>2.5</sub> exposure on humans.

Studies have also shown that exposure to PM<sub>2.5</sub> has also been linked to brain damage, specifically increasing the risks of dementia and Alzheimer's disease[15], [16], [17]. A study conducted by Calderon-Garcidueñas et al. (2021) studied the impact of PM<sub>2.5</sub> exposure on the central nervous system[15]. In this study, they examined the brain tissue in children living in Mexico City, a highly polluted city due mostly to vehicular emissions. From their observations they saw lesions in the white matter of the brains of children living in highly polluted areas of Mexico City in contrast to those of children living in less polluted areas. These lesions are features that are usually linked to individuals with early onset Alzheimer's disease[15]. Another study by Livingston et al. in 2024, focused on dementia prevention and intervention. In this study they reported that reducing air pollution was linked with improved brain cognition and reduction in dementia. This was done by looking at the different levels of pollution in different regions and correlating those with the number of dementia cases in each area. They determined that with every 1 µg/m<sup>3</sup> increase of PM<sub>2.5</sub> exposure, more cases of dementia were seen globally[16]. These studies indicate a link between PM<sub>2.5</sub> exposure and various negative health effects on humans. If the WHO guidelines for particulate matter are implemented strictly around the globe, this would lead to a potential increase in human life expectancy [11], decrease in preterm births[14], and reduced brain damage in humans[15], [16], [17].

## Metals in Particulate Matter

Atmospheric chemists, as previously mentioned, focus on two characteristics of particulate matter: size and chemical composition [1]. PM size determines where particles travel throughout the body causing many adverse health risks, as mentioned in the previous section [10]. However, the chemical composition of these particles is what makes them toxic. PM contains potentially toxic compounds including, but not limited to, heavy metals, brown and black carbon, inorganic ions and biological particles. In this study, we focus on heavy metals found in PM<sub>2.5</sub>[18]. Particulate-bound heavy metals are emitted from both natural and anthropogenic sources. Metals that are naturally emitted into the atmosphere come from sources including sea-spray, volcanic ash or wildfires. Metals that are emitted anthropogenically come from fossil fuel combustion, fireworks, industrial or agricultural pollution, and transportation sources such as tire and brake wear, for example[2], [18]. Recently, particles due to wildfires occurring at the wildland urban interface (WUI) in Los Angeles were shown to contain lead, for example, due to burning of structures that contained leaded paint[19].

Not all metals that are found in the atmosphere adversely affect humans, but heavy metals like lead (Pb), arsenic (As), and chromium (Cr) that are found in PM are potentially toxic to human health and the environment. The metals are contained in particles being inhaled by humans and, depending on the size, can travel from the respiratory system to different parts of the body[20]. Metals found in PM<sub>2.5</sub> can travel throughout the capillaries in the lungs and into the blood stream. The accumulation of these metals in the body poses potentially toxic effects on human life. Metals have been shown to cause different diseases including cancers, neurological damage and cardiovascular diseases[21].

Arsenic (As) is a carcinogenic metal that is found in the air, water, food and soil. Upon entering the human body, arsenic can be absorbed into different chemical forms, each with varying levels of toxicity[22]. Arsenic is associated with causing multiple types of cancer such as lung, bladder, kidney, skin and liver cancers. It has also been linked with causing preterm births, as previously mentioned in the Malley et al. study [14]. Arsenic can also lead to metabolic diseases, like diabetes. It disrupts insulin

production by affecting the beta-cells in the pancreas, causing diabetes and eventually leading to liver problems[22].

Lead (Pb) is another heavy metal that is extremely toxic and has very strict guidelines imposed by the Centers for Disease Control and Prevention (CDC) to reduce concentrations as much as possible[23]. Pb can come from many sources including the burning of materials that contain lead such as leaded paint, solder, plastic cables, and some cookware leading to coming from anthropogenic sources [24]. Exposure to lead can affect multiple systems of the body and is very harmful specifically to young children and women. When lead enters the body in the form of particulate matter, it travels to the brain, kidneys, liver and bones. Short term exposure to lead can cause comas and seizures, specifically in children [25], [26]. Long term exposure to Pb has shown severe physiological changes in the brain, such as reductions in brain volume and gray matter. In women, Pb that is stored in the bones can be released into the blood during pregnancy and affect the fetus [27]. This can increase the chances of premature newborns (born before 37 weeks) where the newborns suffer from neurological diseases. In children, Pb can have very serious consequences such as impaired cognitive development. The United States Centers for Disease Control (CDC) has defined lead poisoning in children as any blood concentration greater than 10  $\mu\text{g/dL}$  [23]. In 2017, Hauptman et al. the studied effect of different blood levels of Pb on the nervous system of children. Children with blood Pb concentrations as low as 5  $\mu\text{g/dL}$  were seen to have decreased intelligence quotient (IQ), problematic behavior and reduced cognitive function. Children with levels ranging between 5-10  $\mu\text{g/dL}$  started having decreased auditory function and even some reproductive issues [26]. Children with levels above the CDC level of greater than 10  $\mu\text{g/dL}$  were seen to be more likely to suffer from gastrointestinal problems, convulsions and loss of muscle control [23], [26].

Another metal found in the atmosphere is chromium. Chromium has two oxidation states, Cr (III) and Cr (VI), depending on which kind of state it is in, it can be potentially dangerous for humans. Cr (III) is a stable metal that is found in plants, animals and humans, supporting the body's metabolism.

However, Cr (VI) is a less stable metal and is very toxic to humans, classified as a carcinogenic metal. It is emitted from welding and industrial processes [29]. Exposure to Cr (VI) can cause serious complications in humans like asthma, bronchitis and different cancers such as lung, kidney, and urinary cancer [29].

Heavy metals in the atmosphere are not only a hazard to human health, but they also pose toxic effects on the environment. When metal-containing particles are emitted into the atmosphere, they travel different distances depending on their size. Larger PM like PM<sub>10</sub> travel shorter distances due to their larger size whereas smaller PM like PM<sub>2.5</sub> travels much longer distances [1], [2], [21]. As these particles/metals travel in the atmosphere, they eventually sink down from the atmosphere potentially harming the environment. These metals may contaminate lakes, soil, and other ecosystems through deposition [30].

There are two kinds of deposition that lead to the contamination of different ecosystems, wet and dry deposition. Wet deposition is when the atmosphere loses particles through rainfall, meaning that the metals in the atmosphere are flushed down into the ground by rain [31]. Dry deposition is when particles sink into the ground without rainfall. When these metals accumulate in water sources and soil, the whole ecosystem is being contaminated. Plants growing in metal-contaminated soil, become contaminated with these toxic metals which can lead to lower percentages of seed germination and plant growth[30]. Heavy metals also affect algae, promoting the production of certain toxic algal products [32]. The algal products can cause oxygen depletion in the water and can lead to the death of many aquatic organisms like fish. When the plants, water sources and fish are contaminated, the marine animals consuming them ingest these toxins as well. Animals like cattle and humans consume the plants, drink the water and consume the fish, ingesting these metals into their bodies [33]. The presence of PM poses a threat on human health through direct inhalation from the atmosphere and through ingestion from the contaminated food chain.

## **Vehicular Emissions**

Metals in PM are a common pollutant in the near-road environment. The near-road environment is defined as the environment surrounding major roadways such as freeways and highways where pollutants coming from traffic, specifically from vehicles, affect air quality[34]. Heavy metals are one of the many pollutants that are released into the atmosphere by vehicles. Vehicles are heavily used globally, therefore being a chronic source of metals found in PM[35]. When studying the near-road environment, there are two types of vehicular emissions that need to be considered, tailpipe emissions and non-tailpipe emissions. Tail-pipe emissions are any particles coming from fuel combustion of vehicles like gasoline or diesel[35]. Because the chemical composition of fuels is different, each fuel can emit different kinds of metals into the air. Tail-pipe emissions not only lead to heavy metal production but also the production of pollutants like carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>)[36].

Non-tailpipe emissions are all the sources of pollutants coming from vehicles that are not coming from tailpipe emissions or fuel combustion. These sources are mainly coming from brake wear, tire wear and road dust resuspension[36], [37]. Similarly to how different fuels may introduce different metals into the atmosphere, different non-tailpipe emissions produce various metals as well. Brake wear is known to release metals like iron (Fe), copper (Cu), antimony (Sb) and barium (Ba). Tire wear is known to release metals like zinc (Zn), chromium (Cr) and lead (Pb)[37]. Road dust resuspension occurs when vehicle tires drive over dust and soil on roads which “picks-up” or resuspends particles into the atmosphere. Some common metals that are emitted from road-dust resuspension are silicon (Si), calcium (Ca), aluminum (Al) and potassium (K). In this work, we will discuss how some heavy metals in our samples are coming from non-tailpipe emissions.

Lopez et al. (2023) investigated the metal composition of ambient PM<sub>2.5</sub> and PM<sub>10</sub> from non-tailpipe emissions in Southern California, specifically two highly traffic freeways, I-5 Anaheim and I-710 Long Beach[37]. To identify the elements in the PM samples an X-ray fluorescence (XRF) system and a medium-volume PM sampler were used. The PM samples were collected on Teflon and quartz

fiber filters from both upwind and downwind sides of both freeways. The most abundant metals found were Fe and Si from both freeways and both PM<sub>2.5</sub> and PM<sub>10</sub>. Previously mentioned, Fe is released from brake wear and Si is released from road dust resuspension. The study also looked at how metal concentrations vary throughout the day, with higher concentrations peaking during morning and evening rush hour. The higher concentrations during rush hour were due to the increased number of vehicles on the freeways and the increased amount of dust found on the roads, specifically during the morning rush hour. Lower concentrations were seen in weekend data in comparison to weekdays, consistent with vehicles as the major source of this pollution.

From the Lopez et al. study[37], a related study by Chen et al. (2023) developed a question of which non-tailpipe emissions contribute more to the emission of PM<sub>2.5</sub> and PM<sub>10</sub> particles[38]. To answer this question, they used source apportionment which is defined as a process of identifying types of particles that contribute to air pollution. They found that from both freeway sites (I-5 and I-710) and two size fractions, PM<sub>2.5</sub> and PM<sub>10</sub>, road dust resuspension had the highest fraction of contribution, followed by brake wear and tire wear. The source apportionment model also showed that there was a higher percentage of road dust resuspension metals found in PM<sub>10</sub> particles than PM<sub>2.5</sub>, this indicates that road dust resuspension emissions are composed of a significant fraction of coarse particles[38]. These two studies focused on non-tailpipe emissions and are showing that these emissions play a much larger role in the release of metals into the air than tail-pipe emissions do.

### **Firework Emissions**

Fireworks are used to celebrate different holidays and traditions worldwide. However, firework combustion results in poor air quality because it leads to an increase of PM, heavy metals and polycyclic aromatic hydrocarbons (PAHs) in the atmosphere[39]. Fireworks are a transient source of pollutants, because they are only used during celebrations, therefore there is little chronic exposure to pollutants directly from fireworks. However, the concentrations of particles during these events are extreme. During firework celebrations, large crowds tend to surround these areas, putting people at risk of

exposure to large numbers of PM even if just for short periods of time[39], [40]. As mentioned before, even short-term exposure to particulate matter can have adverse health effects on humans [2].

In the United States, specifically in Southern California, the South Coast Air Quality Management District has stated that during Independence Day celebrations, July 4<sup>th</sup> and July 5<sup>th</sup> are among the worst air quality days of the year [41]. Seidal et al. (2015) studied the air quality during Independence Day, specifically looking at the effects of fireworks on PM<sub>2.5</sub> concentrations[42]. The study aggregated PM<sub>2.5</sub> concentrations from over 315 monitoring sites in the United States from the years 1999-2013. During those 14 years, the hourly measurements of non-firework days had an average PM<sub>2.5</sub> concentration below 14  $\mu\text{g}/\text{m}^3$ , whereas those of July 4<sup>th</sup> reached above 30  $\mu\text{g}/\text{m}^3$ , with the highest concentrations occurring around 9 to 10 pm[42]. This large-scale study however has some drawbacks due to their inability to localize firework air pollution zones at a fine spatial scale.

Another study, Mousavi et al. (2021), investigated time-resolved PM<sub>2.5</sub> concentrations from PurpleAir sensors to identify spatial hotspots and county-level trends of PM<sub>2.5</sub> coming from firework emissions in California during 2019 and 2020[43]. The PurpleAir monitoring network consists of relatively low-cost air pollution devices. The county-level trends of PM<sub>2.5</sub> concentrations for July 4<sup>th</sup> were observed with high, moderate and low concentrations. Figure 1 shows the hourly PM<sub>2.5</sub> concentrations of three different counties in Southern California. In Figure 1a, in Los Angeles County, an increase of 5-10 times more PM<sub>2.5</sub> concentration was seen from 7pm to 12am on July 4<sup>th</sup> compared to the same time period from July 5<sup>th</sup>. Figure 1b in Orange County shows the increase of PM<sub>2.5</sub> concentration during this time was three times higher where those in Figure 1c, Riverside County, saw a minimal increase in PM<sub>2.5</sub> concentration.

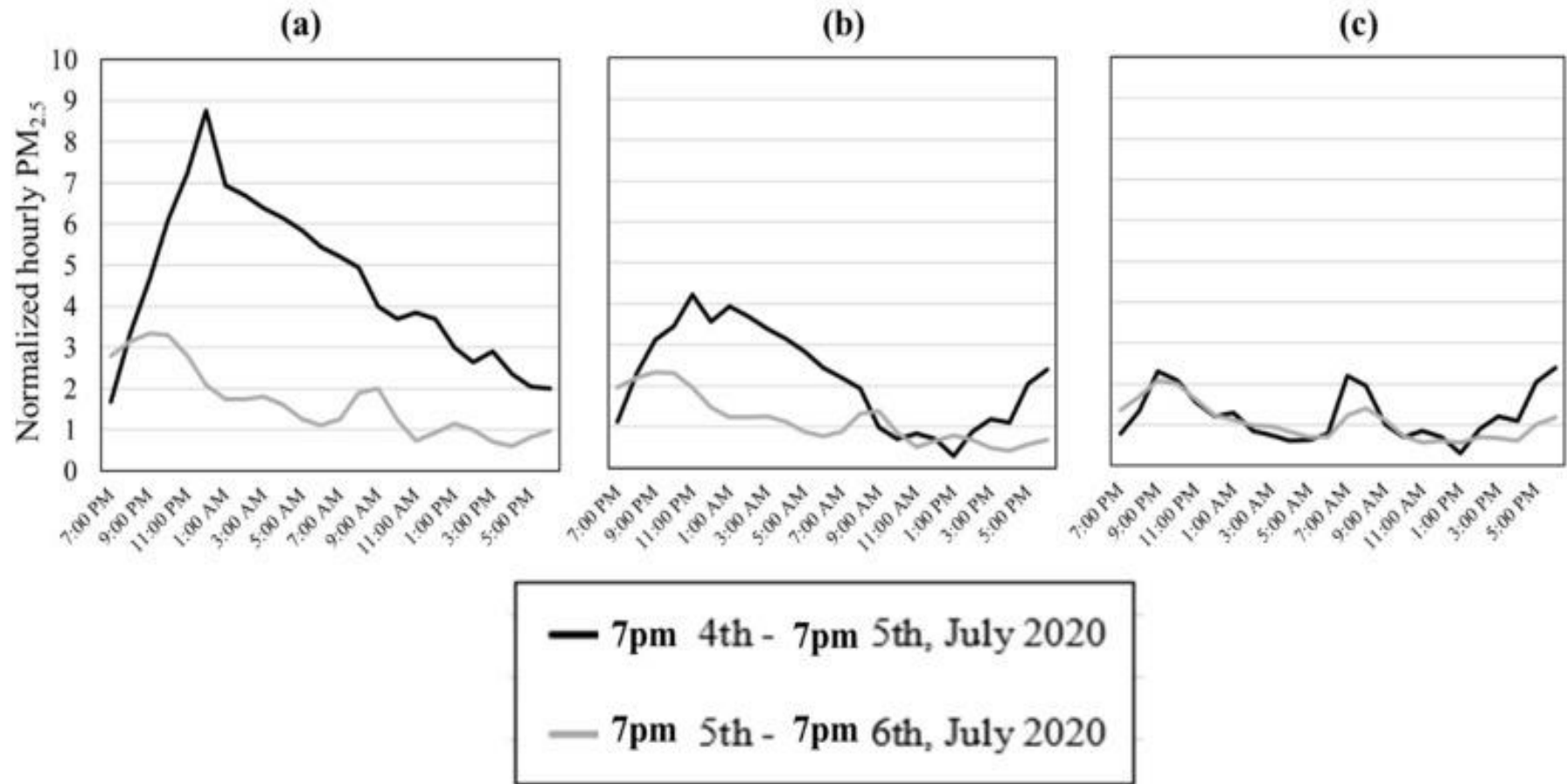


Figure 1. Hourly averages of  $PM_{2.5}$  concentrations from July 4th to July 5th of 2020 in (a) Los Angeles County (high impact), (b) Orange County (moderate impact) and (c) Riverside County (low impact)[43].



In the same study[43], they looked at the spatial distribution of daily PM<sub>2.5</sub> concentrations to identify firework-related PM<sub>2.5</sub> hotspots. Hotspots were identified as any area with a PM<sub>2.5</sub> concentration higher than 11 µg/m<sup>3</sup>. The spatial distribution showed that Southern California metropolitan areas suffered from greater air pollution during the July 4<sup>th</sup> and 5<sup>th</sup> than northern areas. Sensors deployed in Los Angeles County showed PM<sub>2.5</sub> concentrations of greater than 38 µg/m<sup>3</sup> while other southern counties showed concentrations of 22 µg/m<sup>3</sup> or lower. In northern counties, concentrations ranged between 5-15 µg/m<sup>3</sup>. Figure 2 shows the spatial distribution of PurpleAir PM<sub>2.5</sub> measured daily during July 4<sup>th</sup> and 5<sup>th</sup> in both 2019 and 2020. Firework hotspots in Southern California were identified in Los Angeles County, San Bernardino County and San Diego County in both years. In Northern California, San Francisco County and Sacramento County were labeled as cold spots. In this study, Mousavi et al. were able to reveal peaks and hotspots using the PurpleAir sensors to determine the PM<sub>2.5</sub> concentrations at a fine temporal and spatial resolution therefore showing that previous research using large scale measurements may be misrepresenting PM<sub>2.5</sub> exposure due to inability of using fine temporal resolution[43].

As mentioned previously, the chemical composition of particulate matter is what makes it toxic [1], [2], [10], [15]. Fireworks are a distinctive source of metal-containing PM [40], [41]. This is because different components of fireworks emit different kinds of pollutants. Metals in fireworks are usually found the oxidizing component, ignitors and in the colorants[44]. Studies have shown that during firework activity, metals such as strontium (Sr), barium (Ba), copper (Cu), aluminum (Al), lead (Pb) and chromium (Cr) increase greatly in the atmosphere[44], [45]. Cu is used in fireworks to emit the blue and purple colors. Sr is used for red colors, Ba for green and Al for silver. Some other metals that are found in the atmosphere during firework activity like Pb and Cr, come from the ignitor and propulsion of the fireworks respectively[45], [46]. Firework emissions are therefore releasing heavy metals in the form of PM which can potentially cause adverse effects on the population in these areas.

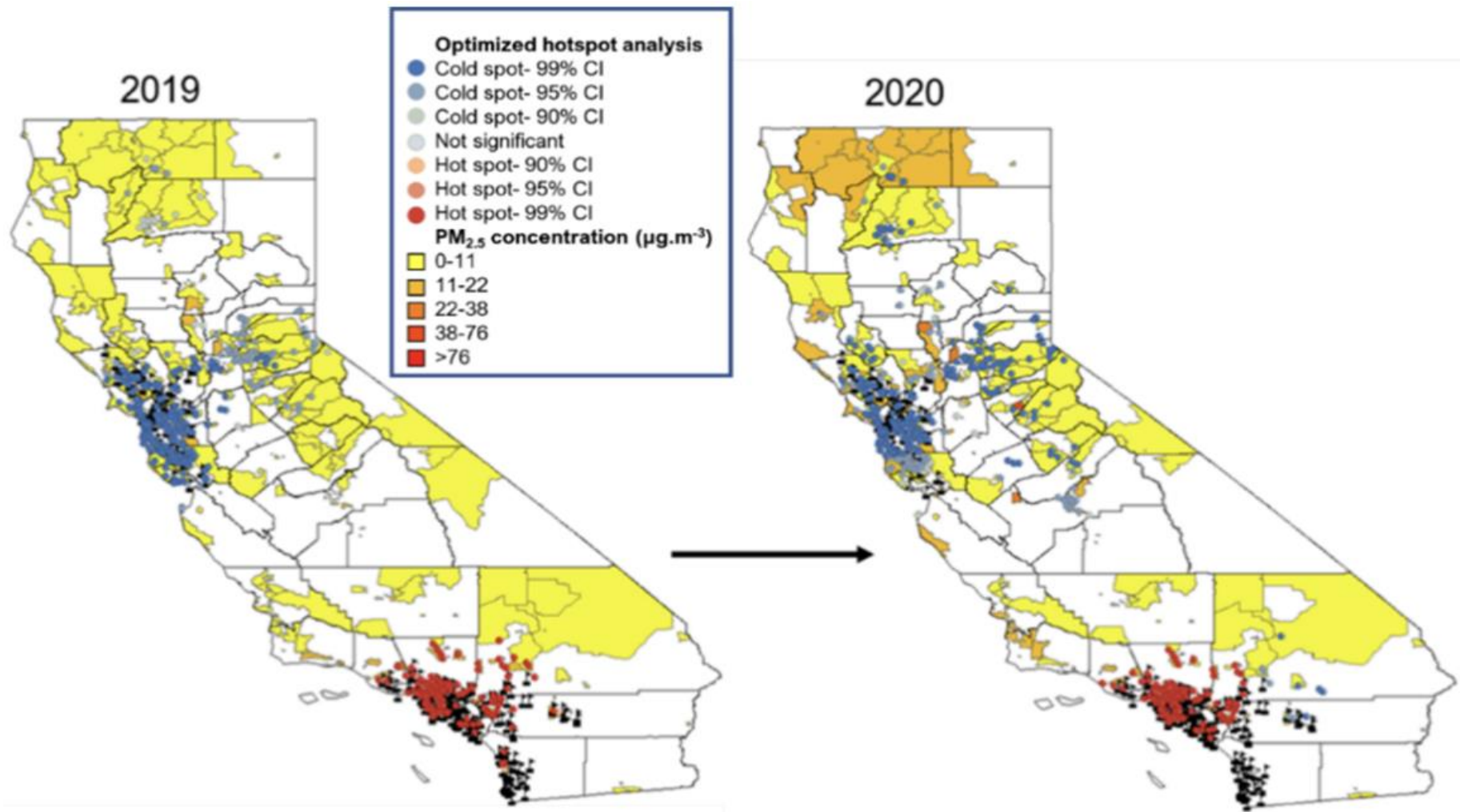


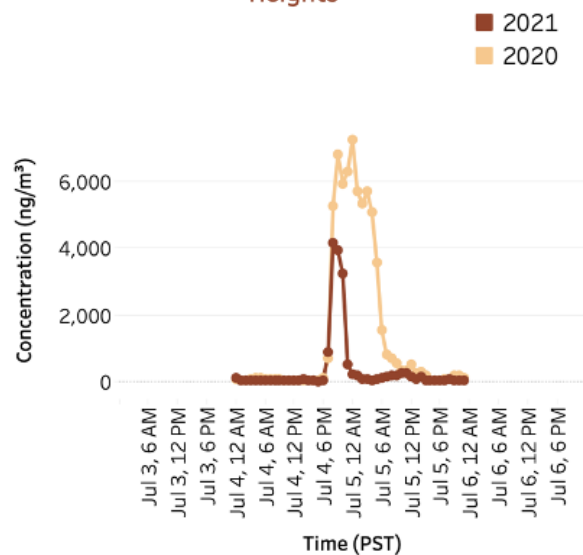
Figure 2. Spatial hotspot analysis for PM<sub>2.5</sub> concentration across California during July 4th and 5th of 2019 and 2020[43].

In Mousavi et al. (2021),  $PM_{2.5}$  concentrations increased greatly during the firework activities in California, but their work did not measure the chemical composition of these particles[43]. In 2021, the South Coast Air Quality Management District (SCAQMD) reported heavy metal concentrations in PM attributed to fireworks during July 4<sup>th</sup> in Southern California[41]. The data that was released was from two different locations: Paramount and Boyle Heights. SCAQMD compared the hourly concentrations of copper and total chromium for Boyle Heights for the years 2021 and 2020, whereas in Paramount, the instrument was not functioning during 2020, therefore they took compared their 2021 results to those of 2019, 2018 and 2017.

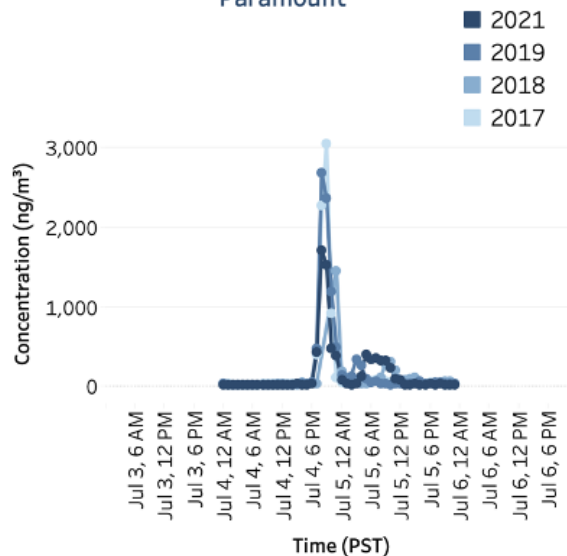
Figure 3 shows the concentrations for both Cu and total Cr from data collected on early July 4<sup>th</sup> to July 6<sup>th</sup>. In both locations an increase in concentration of both metals was seen July 4<sup>th</sup> at 6 pm through 6 am of July 5<sup>th</sup>. Concentrations of Cu in both locations were lower in 2021 than in other years, which may be due to the COVID-19 pandemic.

Although a large increase in the concentration of Cu is observed during July 4<sup>th</sup>, 2021, lower concentrations of Cr were also seen in 2021 than in other years. Cr concentrations reached around 80 ng/m<sup>3</sup> in Paramount and around 400 ng/m<sup>3</sup> in Boyle Heights. Both locations are in the Los Angeles basin, 18-21 km apart. This indicates that location variability even in short distances can play a large role in the collection of particles. This variability may be due to wind speed, wind direction, number of fireworks used in the area, and the proximity the detectors were to the local fireworks. Particulate pollution varies from location to location and therefore shows that air quality can be different from one neighboring community to the other[41], [43].

Hourly Concentrations of TSP Cu (Copper) in Boyle Heights



Hourly Concentrations of TSP Cu (Copper) in Paramount\*



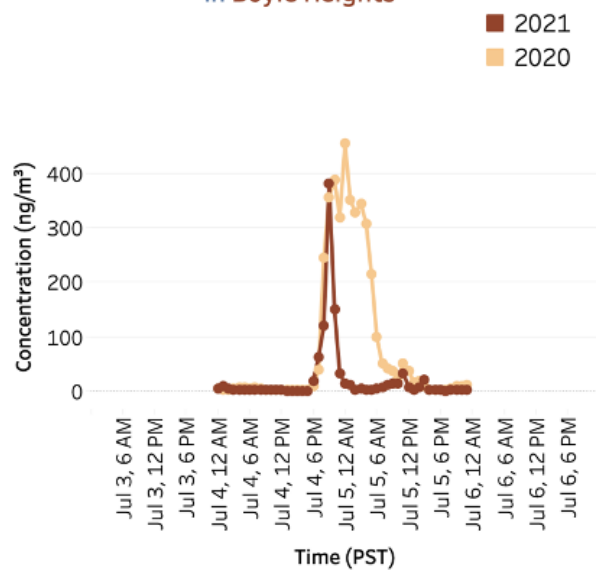
(a)

(b)

(c)

(d)

Hourly Concentrations of TSP Cr (Total Chromium) in Boyle Heights



Hourly Concentrations of TSP Cr (Total Chromium) in Paramount\*

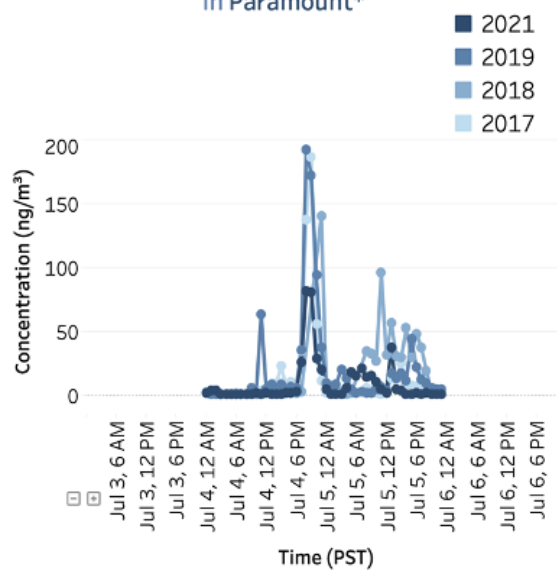


Figure 3. Hourly concentrations of Cu and Cr for July 4<sup>th</sup> in Southern California from Boyle Heights (red) and Paramount (blue).

In another study conducted in North China, Hao et al. (2020) investigated the chemical characteristics of different trace metals found in PM<sub>2.5</sub> from fireworks during the Spring Festival (February 2016). The study consisted of collecting daily samples of PM<sub>2.5</sub> before, during and after the

Chinese Spring Festival on high volume air sampler[47]. The trace elements were determined using inductively coupled plasma mass spectrometry (ICP-MS). From their samples, they saw a large increase in  $PM_{2.5}$  levels with an average of  $57.70 \mu\text{g}/\text{m}^3$  during the Spring Festival. On three days of the festival period (Figure 4), the average  $PM_{2.5}$  levels surpassed those of the Chinese National Ambient Air Quality Standard ( $75 \mu\text{g}/\text{m}^3$ ) with the maximum level reaching  $371 \mu\text{g}/\text{m}^3$  during Chinese New Year.

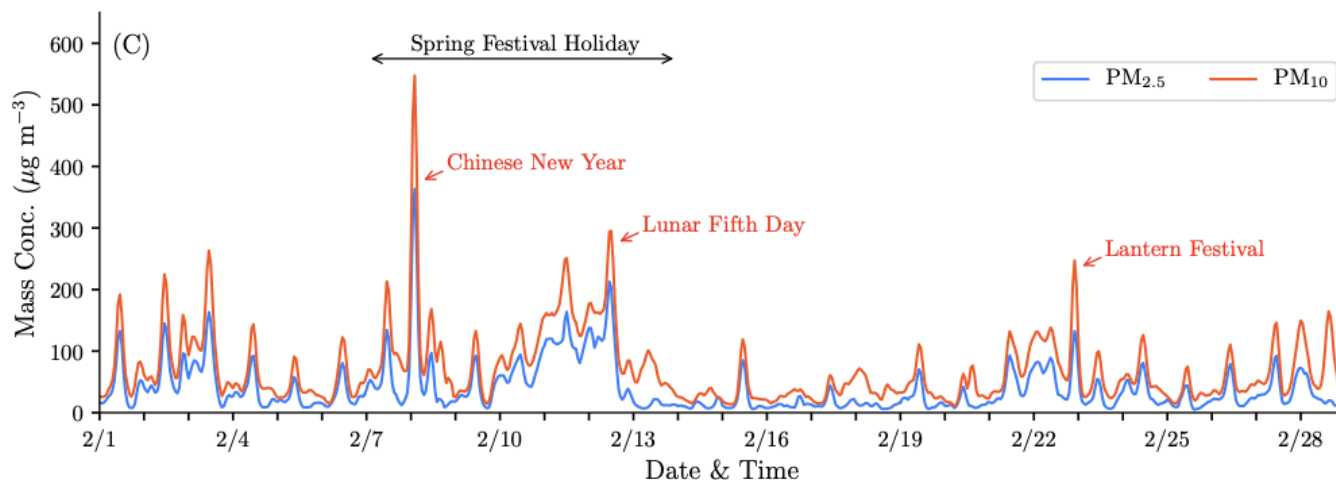


Figure 4. Time series of mass concentration of  $PM_{2.5}$  (in blue) and  $PM_{10}$  (in red) measured during the Spring Festival in North China[47].

Hao et al. (2020) also looked at the concentration of trace elements emitted from the fireworks. In Figures 5a and 5b, a scatter plot of mass concentrations are shown for each metal respectively. They noticed potassium (K) and aluminum (Al) were the most abundant elements in  $PM_{2.5}$ , where K concentrations increased to 16.78 times more than those before the Spring Festival and Al increased 6.90 times. As mentioned before fireworks are made of oxidizing agents, colorants and other parts that lead to the emission of different metals into the atmosphere[39], [44], [45]. Al and K are emitted greatly by other sources into the atmosphere, but the observed increase during the Spring Festival indicate that they are being released by part of the firework components. K compounds are commonly used as oxidizing agents in fireworks and aluminum is used as an additive or colorant in fireworks[39], [46], [48]. Known tracers of fireworks such as barium and strontium were also monitored during the Spring

Festival. Ba and Sr increased by a factor of 27.99 and 23.75, respectively. These two tracers are emitted from firework colorants, where they make the green and red colors in fireworks[46].

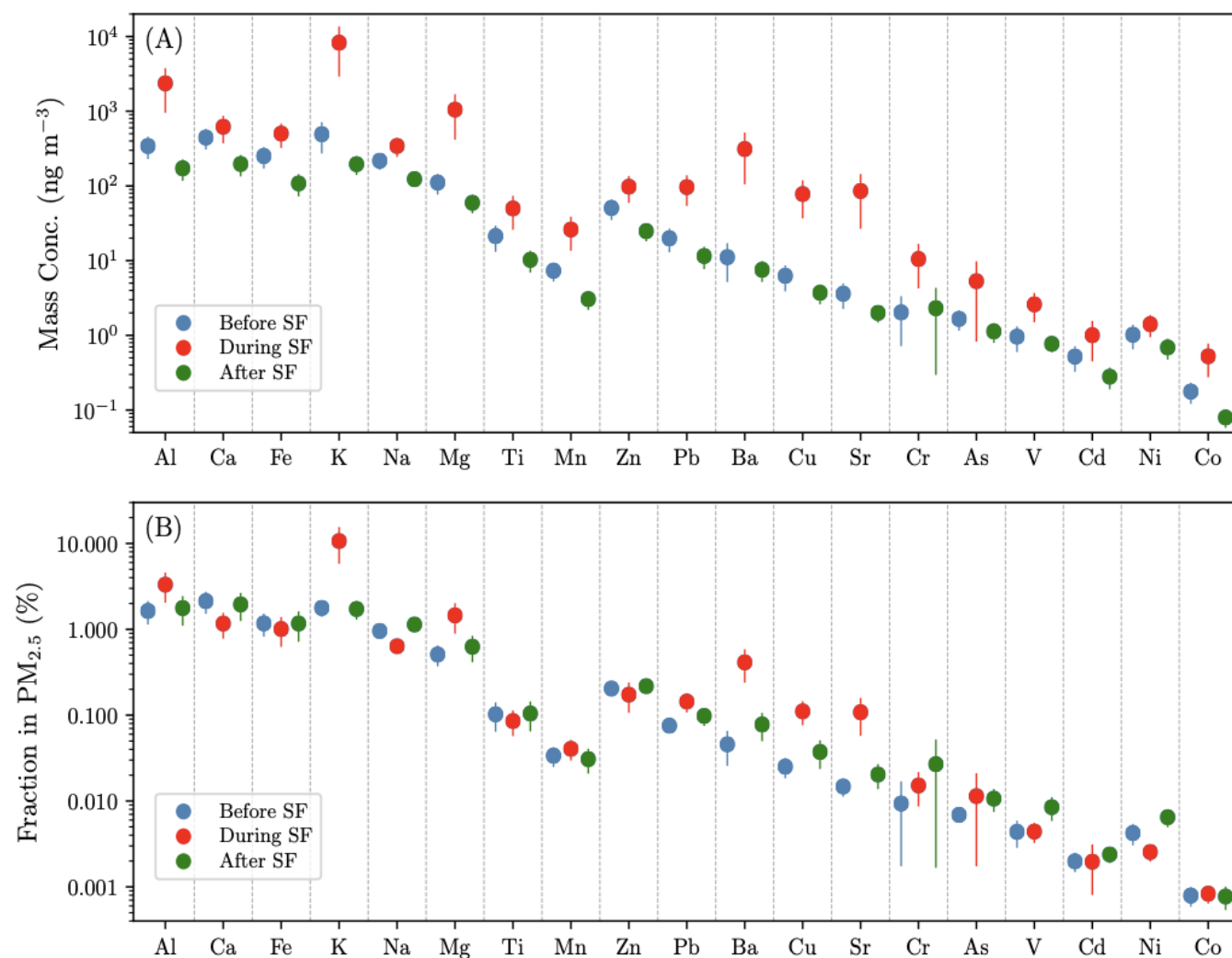


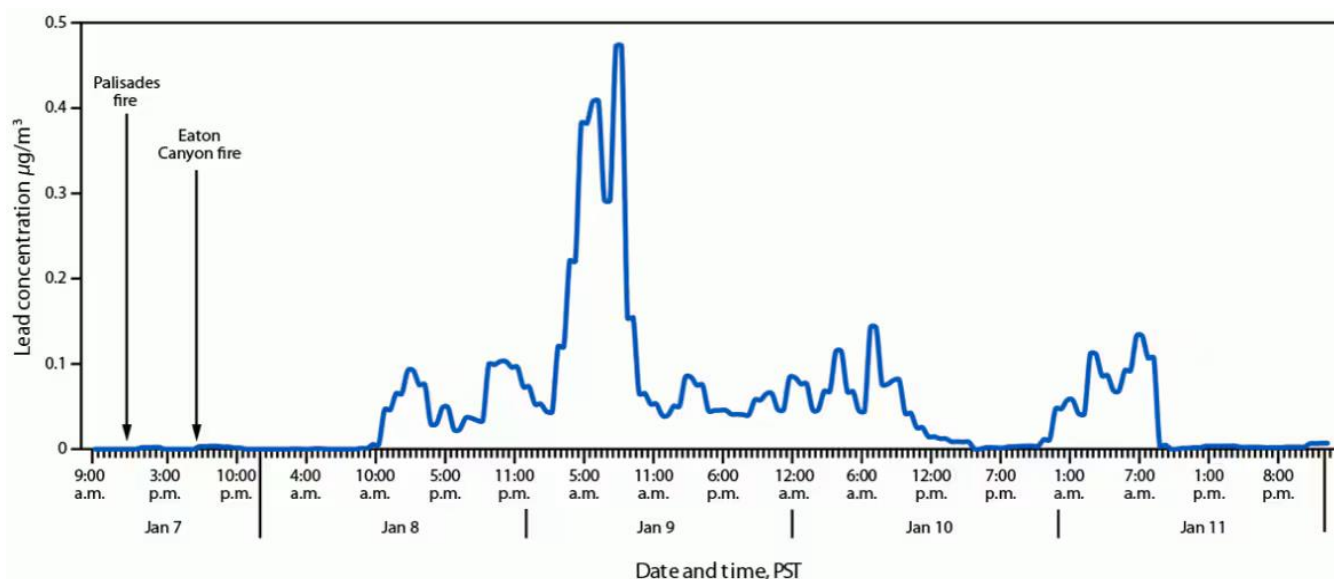
Figure 5. Scatter plots of (A) mass concentrations and (B) mass contributions in PM<sub>2.5</sub> of trace metals[47].

### Wildfire Emissions

Wildfires are a natural source of emitting particles into the atmosphere [1]. From wildfires various heavy metals are released into the air like lead (Pb), arsenic (As) and chromium (Cr VI). These metals are usually released from the burning of infrastructure, soil and vegetation but can also be emitted by fire suppressants[49]. Many commercial fire suppressants have been tested for metals and have shown high levels of toxic metals in them, all being released into the environment when used[50].

A wildfire, like firework emissions, is a transient source of pollutant, or a short-term pollutant. Wildfires not only emit metals in PM but also emit other pollutants like black carbon, carbon dioxide and methane[49].

During the 2025 Los Angeles urban fires (Eaton and Palisades fires), Baliaka et al. (2025) measured the concentration of airborne PM<sub>2.5</sub> Pb emitted during the fires[19]. The group collected hourly measurements of PM<sub>2.5</sub> lead recorded during and after the wildfires using Xact 625i and EDXRF (Energy Dispersive X-ray fluorescence) from the ASCENT site in Pico Rivera. The ASCENT site is approximately 14 miles away from the Eaton Fire. Before the fires started (Jan 2-6), the ASCENT site was recording an average of 0.00068  $\mu\text{g}/\text{m}^3$  of PM<sub>2.5</sub> Pb (Figure 6). During the wildfires (Jan 8-11), the average Pb concentration increased to 0.077  $\mu\text{g}/\text{m}^3$ , almost 100 times higher than the levels before the fires started, with the highest level of PM<sub>2.5</sub> Pb recorded to be 0.5  $\mu\text{g}/\text{m}^3$ .



*Figure 6.* Hourly measurements of Pb concentrations from ASCENT site in Pico Rivera during the January 2025 Los Angeles wildfires.

Baliaka et al. suggest the high amount of Pb being released is due to the burning of older infrastructure containing leaded paint and leaded pipes[19]. The Environmental Protective Agency (EPA) standard for Pb over a 3-month period is 0.155  $\mu\text{g}/\text{m}^3$ , the wildfire recorded higher levels of lead

over a few days. Most studies of Pb and the negative effects it has on health are from chronic exposure of lead. There are very few studies that look at the negative effects of Pb being in the atmosphere for short periods of time, like during a wildfire.

After the same urban fires of 2025, Kleeman et al. (2025) measured airborne Cr (VI) nanoparticles in cleanup zones of the Los Angeles fires in March 2025[51]. Cascade impactors were used to collect samples of PM<sub>10</sub> from both Altadena and Pacific Palisades cleanup zones and were analyzed using ICP-MS. The PM<sub>10</sub> concentrations of Cr (VI) averaged to  $13.7 \pm 6.2$  ng/m<sup>3</sup>. This average was compared to the Occupational Health and Safety Administration (OSHA) workplace level of 2500 ng/m<sup>3</sup> [51]. The levels found in these areas did not exceed the OSHA 8-hour exposure workplace levels meaning that cleaning up the zone is still considered safe over an 8-hour period and no further action needs to take place. The Cr (VI) concentration levels were measured in these zones because Cr is an element that can cause cancer. Kleeman et al. (2025) were also interested in understanding if people living in these zones were at high risk of developing any health effects. The EPA's screening level for cancer from Cr (VI) in indoor air is less than 0.1 ng/m<sup>3</sup>. Although measurements were done outdoors, homes in the area are exposed to the air exchange with the outdoors putting residents in this area at risk of inhalation of these toxic particles and potentially affecting their health adversely[51].

### **Research Description**

The studies presented above described three different types of heavy metal emissions: vehicular emissions, firework emissions and wildfire emissions. The studies on vehicle emissions show the number of heavy metals are released into the atmosphere from both non-tailpipe and tailpipe vehicular emissions. In the Lopez et al. (2023) [38] and Chen et al. (2023)[38] studies, it was observed that Fe and Si were the most abundantly released metals from the near-road environment. Their studies also showed that non-tailpipe emissions, specifically road dust resuspension, played a much larger role in metal concentrations found in PM<sub>2.5</sub>, respectively. In this thesis, we will also be discussing how the near-road environment plays a significant role in the emission of PM<sub>2.5</sub> and heavy metals. This information will be



used to further understand our firework data, by determining which metals are coming from vehicular emissions and which are from fireworks.

The studies on fireworks, showed that although fireworks contribute to a short term release of pollutants into the atmosphere, the pollutants that are emitted are much more concentrated and harmful than the long-term exposure of pollutants that we breathe in every day[39], [40], [44], [45]. Not only do the dangerously large number of particles emitted by fireworks into the atmosphere cause a huge threat to human health, but the heavy metals contained in the particles pose an additional one. The data released from SCAQMD during 2021 in Boyle Heights and Paramount showed that July 4th and 5th produce some of the worst air quality in southern California due to the burning of fireworks[7], [41]. Their study also showed the importance of location variability and how metal concentrations differed greatly from two locations that were approximately 20 km apart. The Mousavi et al. (2021) study indicated that the Los Angeles area was a firework hotspot, and that southern California was saw a huge increase in PM<sub>2.5</sub> concentrations during Independence Day[43]. Since the SCAQMD data only looked at two locations and proved the importance of location variability, and the Mousavi et al. (2021) [44] study showed that Los Angeles County is a firework hotspot, this inspired us to look deeper into the Los Angeles area. In this work, we will be further exploring the effects of fireworks during Independence Day. Our work will consist of determining the concentrations of heavy metals found in PM<sub>2.5</sub> in different locations within southern California.

In this thesis, we focused on determining the impact of Independence Day fireworks on air quality in three different locations: Fullerton, Downey, and California State University, Fullerton (CSUF) in 2024. The goal of this study was to look at ambient particulate concentrations of different metals in PM<sub>2.5</sub> and to see how much location variability affects these concentrations. The hypothesis of this first study is that we will see a large increase in PM concentrations and in metals like strontium, barium and lead, specifically during July 4<sup>th</sup>. The increase in concentration of these metals poses a potential threat on public health, therefore we are determined to spread public awareness on this matter.

In this thesis, we will also be discussing wildfires, particularly the same wildfire mentioned in the literature above: the Los Angeles 2025 Eaton and Palisades urban fires. We were interested in observing the effects the wildfires had on surrounding areas of the fire, specifically looking at the Downey area. Wildfires in the wildland-urban interface are a producer of heavy metals in the atmosphere, so being in near proximity to one sparked inspiration to determine the concentration of metals that would be emitted from these wildfires in  $PM_{2.5}$ . Our data collected will be compared to the data collected in the above literature by Baliaka et al. (2025) [19] and Kleeman et al. (2025)[51].

One major difference between our study and the literature study is the type of instruments being used to collect our samples. All the literature studies mentioned above are using very costly instruments and our research will be using low-cost sensors. Low-cost sensors have a price range of around tens to hundreds of dollars, making them affordable to use by the public, whereas the regulatory instruments used in most industries have a price range of around a hundred thousand to a million dollars. Regulatory instruments are used in larger industries and by state and federal agencies, which means they are of very high quality. The price of low-cost sensors makes them more accessible, but they are lower in quality because there is variability between the instruments which requires more testing and verification to obtain more accurate results. In our work, we co-located each of the same instrument together before collecting our firework activity data, to ensure our instruments are not providing different results. Once this was verified, we were able to separate each sensor and collect our data in multiple locations. The low-cost sensors are also much smaller in size making them portable whereas regulatory instruments are very large. The portability of the low-cost sensors make them have higher spatial resolution than those regulatory instruments. As we can use multiple instruments to collect data in multiple locations, which is what we will do in our work. Regulatory instruments tend to measure only in specific locations as they are not as easy to move around. In our research we used two types of low-cost air sensors, the ultrasonic personal air sampler (UPAS v2+, Access Sensor Technologies), and the solar-powered Modulair PM device by QuantAQ (we will be calling it QuantAQ).

Our metal concentrations were collected on filters using the UPAS v2+. The metals collected on the filters were then extracted and analyzed for metal quantification using inductively coupled plasma emission spectroscopy (ICP-OES). Total PM, wind speed and direction, and gas concentrations were determined using the QuantAQ. Our data from both devices are then compared to the data provided by SCAQMD for PM concentrations.

Chapter 2 of this thesis will go over the instruments used for collecting and analyzing our samples, the sampling sites and digestion processes. Chapter 3 will report the data collected from the firework activity and wildfires and discuss the implications of our results on our research goals. Chapter 4 will provide a conclusion summarizing the goals of our research and our findings.

## CHAPTER 2

### MATERIALS AND METHODS

#### Experimental Protocol

##### Sampling Devices and Location

Particles of PM<sub>2.5</sub> were collected using an ultrasonic personal air sampler (UPAS v2+, Access Sensors Technology). The UPAS v2+ is a portable instrument with a rechargeable battery that can be carried around with an individual as they collect sample (Figure 7). It provides data that is useful for understanding spatial-temporal aspects of ambient exposure. To detect PM, the UPAS v2+ includes an aerosol sensor called Sensirion SPS30 sensor which detects and measures the concentration, size and type of particle suspended in the air. The UPAS is composed of several parts, starting with piezoelectric pump, a cyclone inlet, and a filter cartridge. To collect samples, the pump brings air into the instrument at a rate of 1 L min<sup>-1</sup>, where it reaches the cyclone inlet. The cyclone inlet then separates the particles entering by size, controlling which sized particles enter the filter cartridge. Upon entering the cyclone inlet, the particles undergo tight turns, any particles that have a diameter greater than 2.5 µm will have large inertia leading to them hitting the walls of the cyclone and falling to the bottom, such that these particles do not enter the filter cartridge. Particles with diameters 2.5 µm or smaller, will have smaller inertia and will be able to go through the tight curves of the cyclone without hitting its walls eventually reaching the filter cartridge. The filter cartridge contains a 37 mm diameter mixed cellulose ester (MCE) filter (with pores of 0.8 µm) which collects the particles of PM<sub>2.5</sub> or smaller. To avoid contamination when measuring a sample, the filter cartridge and cyclone inlet is cleaned with 1% nitric acid before and after each sampling. Once sample collection was complete, filters were stored and labeled in sterilized petri dishes at room temperature. The variability of low-cost sensors was taken into consideration before collecting our data. Each UPAS v2+ used was co-located before the firework measurements in the lab to make sure that the data collected on each instrument agreed with each other.

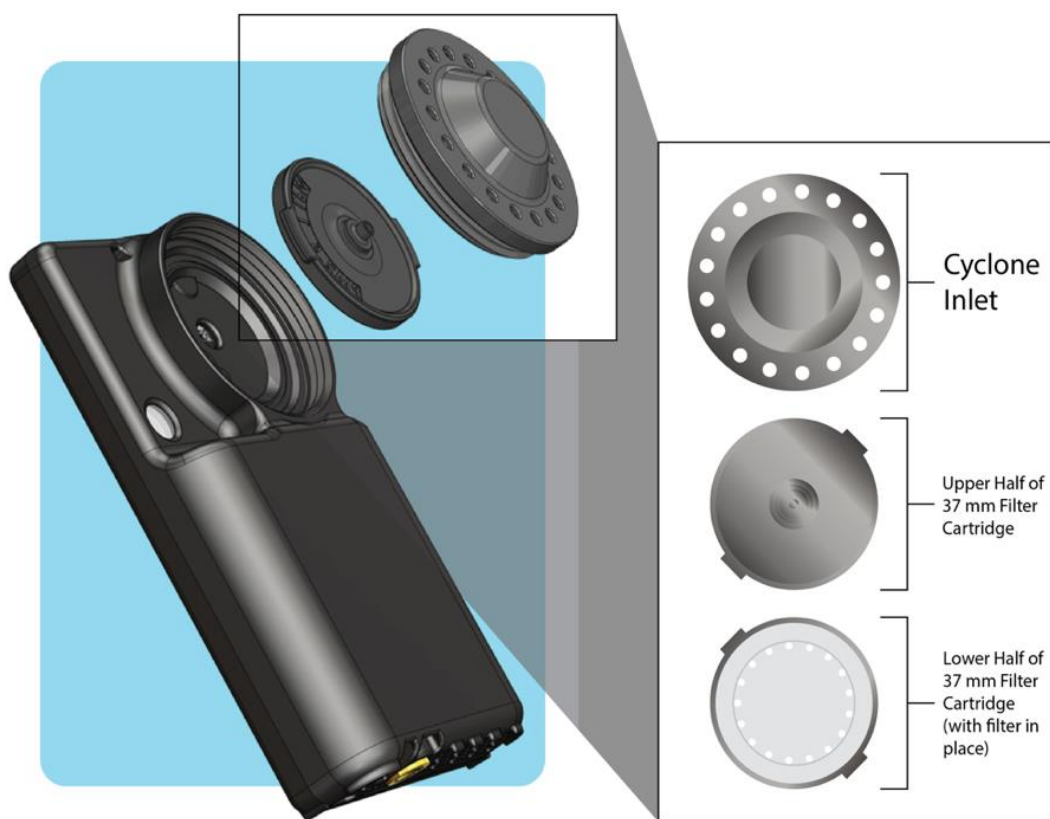


Figure 7. Ultrasonic Personal Air Sampler (UPAS) v2+ Schematic

The Modulair PM QuantAQ (Figure 8) is another instrument that was deployed with the UPAS v2+ for intercomparison of PM concentrations. It was used to provide real-time particulate matter concentrations from PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub>. It also provides wind speed, wind direction and concentrations of four gas-phase pollutants: carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO<sub>2</sub>) and ozone (O<sub>3</sub>). Each Quant-AQ was co-located to each other before collection of data, similarly to the UPAS v2+ sensors to verify that the instruments are collected the same data. Each UPAS v2+ used during the 2024 firework measurements was co-located with a QuantAQ instrument, for data intercomparison and the data was also compared to the 2024 data reported by SCAQMD. A QuantAQ sensor was deployed on the campus of California State University-Fullerton, (CSUF) as well. The CSUF sensor was deployed on the roof of the first floor of Dan Black Hall on the southwest corner of the building, such that the predominant wind direction (from the southwest) would not be affected by the building.



*Figure 8.* Image of ModuAir PM by QuantAQ sensor

In this work, two UPAS v2+ samplers along with two QuantAQ sensors were deployed in two different locations for the collection of PM<sub>2.5</sub> heavy metals during the 2024 Independence Day fireworks: residential Downey and residential Fullerton. Figure 9a shows the locations of the deployed sensors and SCAQMD monitoring sites located nearby. A third QuantAQ was deployed during the same time at CSUF without a UPAS v2+ sampler. The data collected by the UPAS v2+ and QuantAQ sensors from residential Downey and residential Fullerton were compared to those recorded by SCAQMD sites in Compton and Anaheim respectively. This intercomparison was done to understand how efficiently the low-cost sensors (UPAS v2+ and QuantAQ) detect particulate matter.



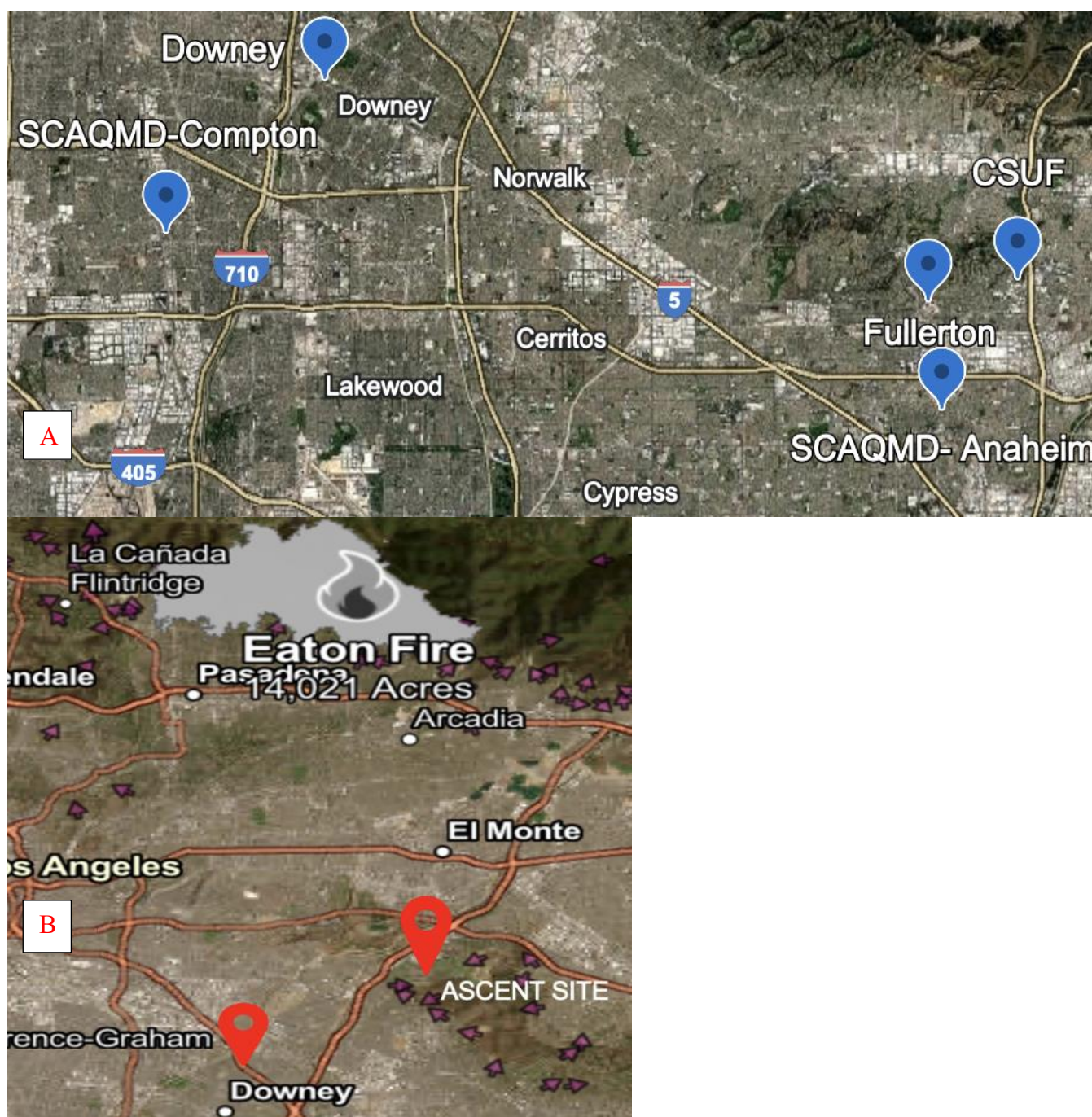


Figure 9. Sampling locations for PM<sub>2.5</sub> during (A) July 1<sup>st</sup> -6<sup>th</sup> 2024 in residential Downey, CSUF, residential Fullerton, SCAQMD-Anaheim and SCAQMD-Compton. (B) January 9<sup>th</sup>-21<sup>st</sup> in residential Downey and ASCENT- Pico Rivera.

The UPAS v2+ sampler was also used during the 2025 Los Angeles wildfires in residential Downey and the data collected was compared to data recorded by the ACSCENT site (Atmospheric

Science and Chemistry mEasurment NeTwork) operated by Georgia Institute of Technology at the SQACMD in Pico Rivera (Figure 9b).

Sampling periods for July 2024 and January 2025 data are summarized in Tables 1 and 2, respectively. 24-hr sampling periods were used before and after July 4<sup>th</sup> (July 1<sup>st</sup>-July 3<sup>rd</sup> and July 5<sup>th</sup> (noon)- July 6<sup>th</sup>). These 24 hr. sampling periods were considered as control samples where there was no firework activity. 6-hr sampling periods were taken on July 4<sup>th</sup> (during firework activity) through early July 5<sup>th</sup>. 24-hr sampling periods were used during control days to help increase sensitivity and limit error on days that did not have firework activity. For each sampling period, the UPAS v2+ inlet was cleaned and replaced with a new MCE filter.

Table 1. Sampling Periods for July 4<sup>th</sup> 2024 Measured on UPAS v2+

Date	Start Time (Local)	Duration (in minutes)
7/1/24	11:45 am	1120
7/2/24	11:50 am	1440
7/3/24	11:50 am	1408
7/4/24	12:00 pm	325
7/4/24	5:55 pm	381
7/5/24	12:00 am	351
7/5/24	6:00 am	310
7/5/24	12:05 pm	1439
7/6/24	12:00 pm	1440



Table 2. Sampling Periods for January 2025 Measured on UPAS v2+

Date	Start Time (Local)	Duration (in minutes)
1/9/25	8:00 AM	1440
1/10/25	8:00 AM	1440
1/11/25	8:00 AM	1440
1/12/25	8:00 AM	1440
1/13/25	8:00 AM	1440
1/14/25	8:00 AM	1440
1/15/25	8:00 AM	1440
1/16/25	8:00 AM	1440
1/17/25	8:00 AM	1440
1/18/25	8:00 AM	1440
1/19/25	8:00 AM	1440
1/20/25	8:00 AM	1440
1/21/25	8:00 AM	1440
1/22/25	8:00 AM	1440
1/23/25	8:00 AM	1440

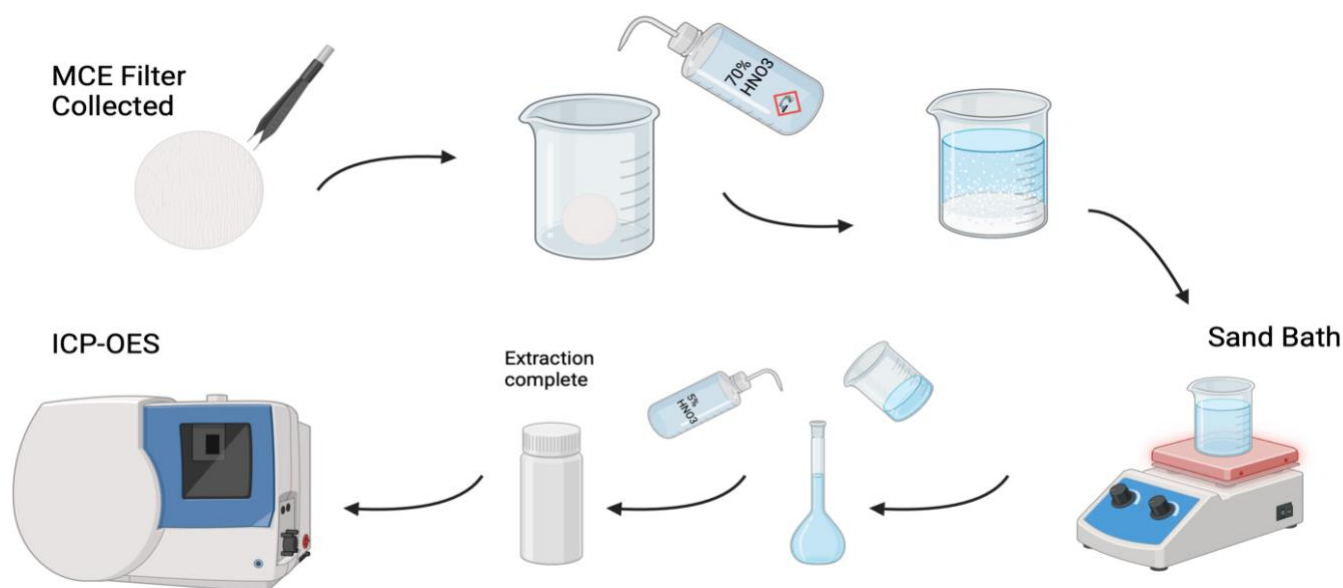
### Sample Preparation and Extraction

When the total sampling period for the event was concluded, the filters collected were prepared for analysis (Figure 10). All glassware was thoroughly cleaned and conditioned before digestion using 70% trace metal grade nitric acid to prevent metal contamination within the glassware. No metal tools or instruments were used during the digestion to prevent metal contamination in the sample.

All MCE filters were digested using a modified version of the NIOSH Manual of Analytical Methods, Method 7300. This hot acid digestion method prepares the sample to be used for inductively coupled plasma-optical emission spectroscopy (ICP-OES). Each filter was placed in a 50 mL beaker

with 10mL of 70% nitric acid covered with a watch glass and set aside for 30 minutes at room temperature. A sand bath was prepared with the hot plate heated to 120°C. Each beaker, covered with a watch glass was placed in the sand bath for 30-60 minutes until all the nitrogen dioxide (NO<sub>2</sub>) brown gas has disappeared. The temperature was raised to 150°C for 10 minutes. The flasks were then removed and cooled to room temperature for approximately 30 minutes.

The metals collected from the filters were extracted into the solution and the solution was quantitatively transferred into a 25 mL volumetric flask. The volumetric flask was then filled to the line with Nanopure water. To store the metal-containing solutions, the solutions were transferred into sterile plastic storage bottles tested for trace metal analysis (Trace metal grade, Fisher Scientific). Once the metal extraction was completed, the solutions were prepared for ICP-OES analysis to quantify and identify the metals found in the samples.



*Figure 10.* Filter digestion and Metal Extraction using a modified version of NIOSH Manual of Analytical Methods, Method 7300.

### Analytical Instrumentation

After metal extraction was complete, the solutions were analyzed for metal quantification using ICP-OES, (ICP-OES 5800, Agilent Technologies). ICP-OES is an analytical instrument for the

identification of elements within a sample down to the parts per billion (ppb) concentrations and is specifically very well-suited for the identification of certain heavy metals. It is also used for measuring metals because it samples several matrices like air, soil/sludges, and water. Some limitations of ICP-OES involve operational costs and routine maintenance. The instrument requires frequent replacement of its different components. Despite some limitations, ICP-OES is an effective instrument because of its ability to detect multiple elements simultaneously.

The ICP-OES instrument has three main components: sample introduction system, inductively couple plasma (ICP), and the optical emission spectrometer (Figure 11). The sample introduction system consists of a peristaltic pump and tubing, a spray chamber with nebulizer and torch with injector tube. The nebulizer converts the liquid sample entering through the peristaltic pump to a fine aerosol. The aerosols enter through the spray chamber and only smaller sized droplets are directed into the injector tube, larger droplets are removed and drained from the system. Once the aerosols enter the injector tube, they will meet the inductively coupled plasma. The plasma excites the atoms of the liquid sample promoting them from a ground state to an excited state. The plasma is created by passing a current through a cooled induction copper coil creating a magnetic field. This magnetic field allows for the excited electrons to move in a circular motion. Simultaneously, a flow of argon gas enters through the torch and is ionized. The argon ions collide with the electrons forming an extremely hot plasma at the end of the torch. The high temperatures within the plasma excite electrons within the atoms. When the electrons return to the ground state, light is emitted at specific wavelengths depending on the atom and are directed to the spectrometer for measurement. In the spectrometer, the emission lines are separated using a high-resolution dispersion grating. These emission lines are detected using a photosensitive detector which converts the light energy into electrical energy. This electrical energy is an absorbance that will be measured by the software of the instrument and allow for the detection of the elements within the sample.

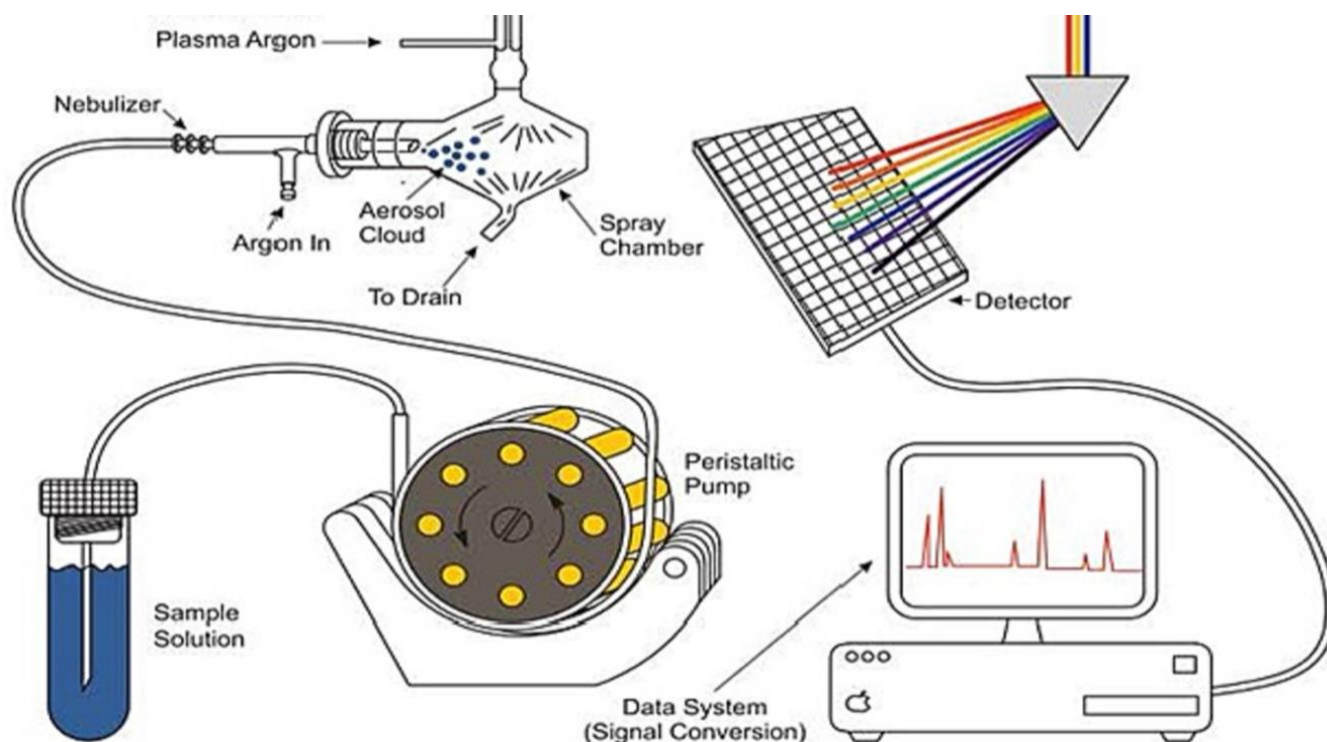


Figure 11. Schematic diagram of ICP-OES components.

Each element has a specific limit of quantification therefore for precise results, proper calibration should be used when using ICP-OES. Some detection limits used in this study for ICP-OES were taken from a review article by Douvris et al. 2023 shown in Table 3[52].

An internal standard of 1 part per million (ppm) of scandium in a solution of 5% nitric acid was used in this research, where all the emission intensities were normalized to the scandium signal. Internal standards are used for ICP-OES to correct for matrix effects, monitor instrument variability, such as fluctuations in plasma or nebulizer efficiency, and overall interferences. We used scandium in this research because it has very low concentration in particulate matter and because it was the internal standard recommended by the manufacturer of the instrument. The internal standard was continuously flowing into the sample line prior to entering the plasma. Standardized signals from the sample solution were determined by using the measured signal intensity of the ICP-OES for that element dividing that by the signal intensity of the scandium internal standard.

Table 3. Detection Limits for Metals Using ICP-OES (Douvris et al. 2023[52])

Element	Detection limit (ppb)
K	1
Ca	0.05
Mg	0.04
Na	0.5
Ag	0.6
As	1
Cr	0.2
Mn	0.1
Pb	1
Zn	0.2

To determine the metal concentrations of each sample solution from the ICP-OES, we performed the necessary data analysis. Standard solutions of known concentrations for our metals of interest were prepared using a stock multi-element standard from Agilent (multi-element quality control standard, Part Number: 5190-9418). From the dilution of the 100-ppm stock solution we obtained the following concentrations for our standards: 20 ppb, 40 ppb, 60 ppb, 80 ppb, 100 ppb, 200 ppb, 500 ppb ( $\mu\text{g L}^{-1}$ ). We also prepared a blank of 5% nitric acid which represented 0 ppb of metal concentration. Using these known concentrations, we were able to make calibration curves for each metal of interest. To determine the unknown concentrations of metals found in our UPAS filters, we take the extracted solution and place it in the ICP-OES. The different metals give signal intensities that are then compared to the calibration curve of the known standard. To determine the total concentration of each metal that was pulled from the atmosphere using the UPAS, the concentrations obtained from the ICP-OES are converted from  $\mu\text{g L}^{-1}$  of 25 mL sample solution to  $\text{ng m}^{-3}$  in the ambient air using Equation 1:

$$\begin{aligned}
 &\text{Total concentration of each metal collected from air} = \\
 &\text{Concentration of metal in solution } \left( \frac{\mu g}{L} \right) \times \text{total volume of solution (L)} \times \\
 &\text{total volume of air sampled (L)} \times \frac{1000 \text{ ng}}{1 \mu g} \times 0.001 \frac{m^3}{L} \quad (1)
 \end{aligned}$$

Where the concentration of digestion solution is the total concentration obtained from the ICP-OES in ppb, the total volume of solution is 25mL or 0.025L, total volume of air sampled is calculated by multiplying the total time UPAS v2+ sampler collected particles by the UPAS v2+ flow rate (1L min<sup>-1</sup>).

## CHAPTER 3

### RESULTS AND DISCUSSION

In this chapter, we will report and discuss the results of the July 2024 fireworks and the January 2025 wildfires studies. For the July 2024 fireworks, we are reporting the results of measured concentrations of ten metals found in ambient particulate matter collected from the UPAS v2+/ICP-OES during July 1<sup>st</sup> to July 6<sup>th</sup> in residential Downey and Fullerton. We will also report the total concentrations of PM<sub>2.5</sub> measured by the UPAS v2+ (in Downey and Fullerton), total concentrations of PM<sub>1</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> from the QuantAQ (in Downey, Fullerton and CSUF), and compare the PM<sub>2.5</sub> concentrations to those measured by SCAQMD during the July 2024 fireworks.

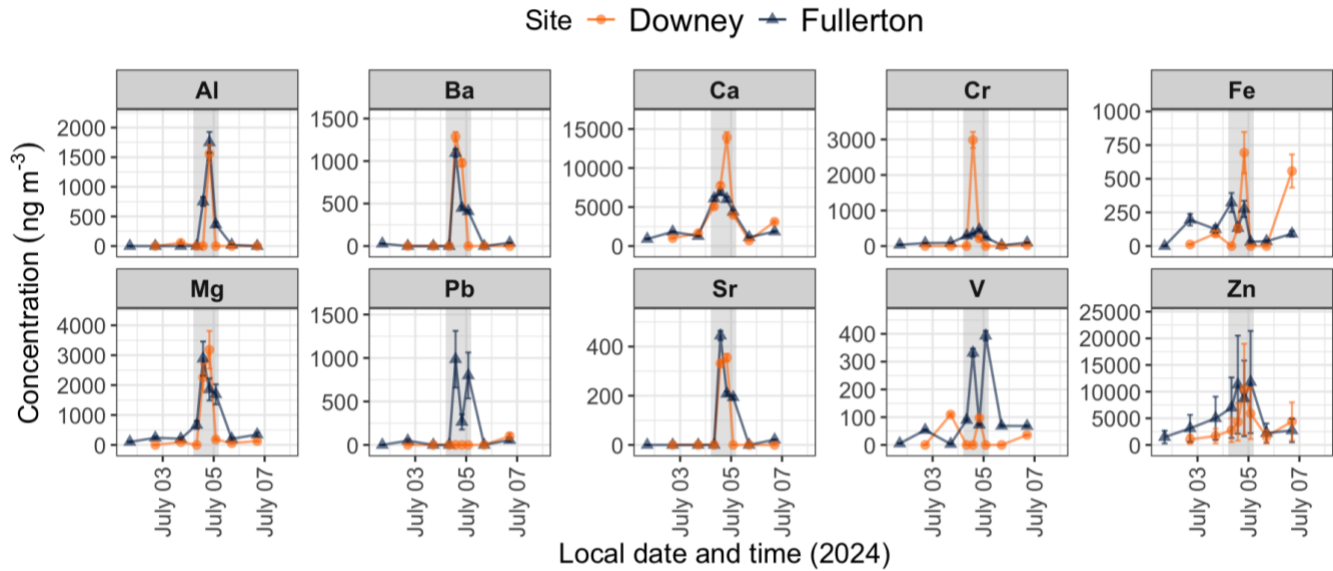
For the 2025 wildfires, we are reporting seventeen metals found in ambient particulate matter using the same instruments during January 9<sup>th</sup> to 20<sup>th</sup> in Downey. We will also report the total concentrations of PM<sub>2.5</sub> measured by the UPAS v2+ (in Downey and Fullerton), total concentrations of PM<sub>1</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> from the QuantAQ (in Downey, Fullerton and CSUF), and compare the PM<sub>2.5</sub> concentrations to those measured by SCAQMD during the July 2024 fireworks.

#### JULY 4<sup>TH</sup> 2024 Fireworks Results

##### Metal Concentrations from UPAS v2+

Figure 12 shows PM<sub>2.5</sub> concentrations of 10 selected metals were obtained from both residential Downey and Fullerton during the July 4<sup>th</sup>, 2024, sampling period. In both locations, before firework activity began, concentrations of all metals were relatively low at near 0 ng/m<sup>3</sup> or below limit of detection. During the firework activity, we see a large increase in concentration signal for all the metals and then the concentration decreases after the firework activity ends. In both sites, before the firework activity, we see concentration signals for calcium (Ca), aluminum (Al), zinc (Zn), and iron (Fe). The concentrations before firework activity are coming from vehicular emissions and other sources. From the Lopez et al. (2023) and Chen et al. (2023), we know that Zn and Fe are both markers of the near-road environment, specifically non-tailpipe emissions coming from tire wear and brake wear

respectively[37], [38]. Ca is a very prevalent metal found in the atmosphere, usually coming from sea-spray, road-dust resuspension and even from construction[33], [35]. Al can come from vehicle emissions, dust, and from firework activity[46], [47], [48]. Tables 4 and 5 show the firework activity sampling days, times and concentrations of some select metals in Downey and Fullerton, respectively.



*Figure 12.* PM<sub>2.5</sub> concentrations of 12 individual metals measured using the UPAS v2+ air sampler from July 1<sup>st</sup> – July 7<sup>th</sup>, 2024. The shaded area represents the time period when high fireworks use is expected (6:00 PM July 4<sup>th</sup> – 6:00 am July 5<sup>th</sup>).

Before the firework activity, we also notice a negligible amount of barium (Ba), strontium (Sr), lead (Pb), and chromium (Cr). From previous firework studies in the literature, we know that Ba and Sr are emitted from firework activity[44], [45]. During the firework activity on July 4<sup>th</sup>, approximately around 6:00 pm, we observe an increase in the concentration of all the metals found in PM<sub>2.5</sub> in both locations. This indicates that fireworks are contributing to the emission of metals into the atmosphere. We specifically see a large increase in the concentration of Ba (~ 1000 ng/m<sup>3</sup>), Sr (~500ng/m<sup>3</sup>) and we see large increases of Ca (~9000 ng/m<sup>3</sup>) and Zn (~10000 ng/m<sup>3</sup>) in both Downey and Fullerton (See Tables 4 and 5). These elevated concentrations are seen from July 4<sup>th</sup> and continue through the morning of July 5<sup>th</sup> and then are seen at negligible concentrations again on July 6<sup>th</sup>. Our data is therefore showing that fireworks lead to a large increase in concentration of metals in particulate matter.



Table 4. Sampling Days, Times, Duration and Select Metal Concentrations in Samples of residential Downey During Firework Activity.

Date	Start Time (PST)	Sample Duration (mins)	Barium Concentration (ng/m <sup>3</sup> )	Strontium Concentration (ng/m <sup>3</sup> )
7/1/24	11:45 am	1120	Below LOD	6
7/2/24	11:50 am	1440	Below LOD	Below LOD
7/3/24	11:50 am	1408	Below LOD	Below LOD
7/4/24	12:00 pm	325	Below LOD	Below LOD
7/4/24	5:55 pm	381	1307	362
7/5/24	12:00 am	351	989	371
7/5/24	6:00 am	310	Below LOD	Below LOD
7/5/24	12:05 pm	1439	Below LOD	Below LOD
7/6/24	12:00 pm	1440	Below LOD	Below LOD

Each location also brings its own variability throughout the sampling period. In Downey, we see a large increase in total Cr signal during the firework activity but a very slightly increase in Fullerton, this however is believed to be an outlier. In Fullerton, we see a large increase in signal for lead whereas we see almost no change in signal in Downey. This likely an effect of location variability and depends on the kinds of fireworks that may have been used in each area. Not all areas sell the same kinds of fireworks, and each firework can be made with different materials leading to the production of different metals.

Table 5. Sampling Days, Times, Duration and Select Metal Concentrations in Samples of residential Fullerton During Firework Activity.

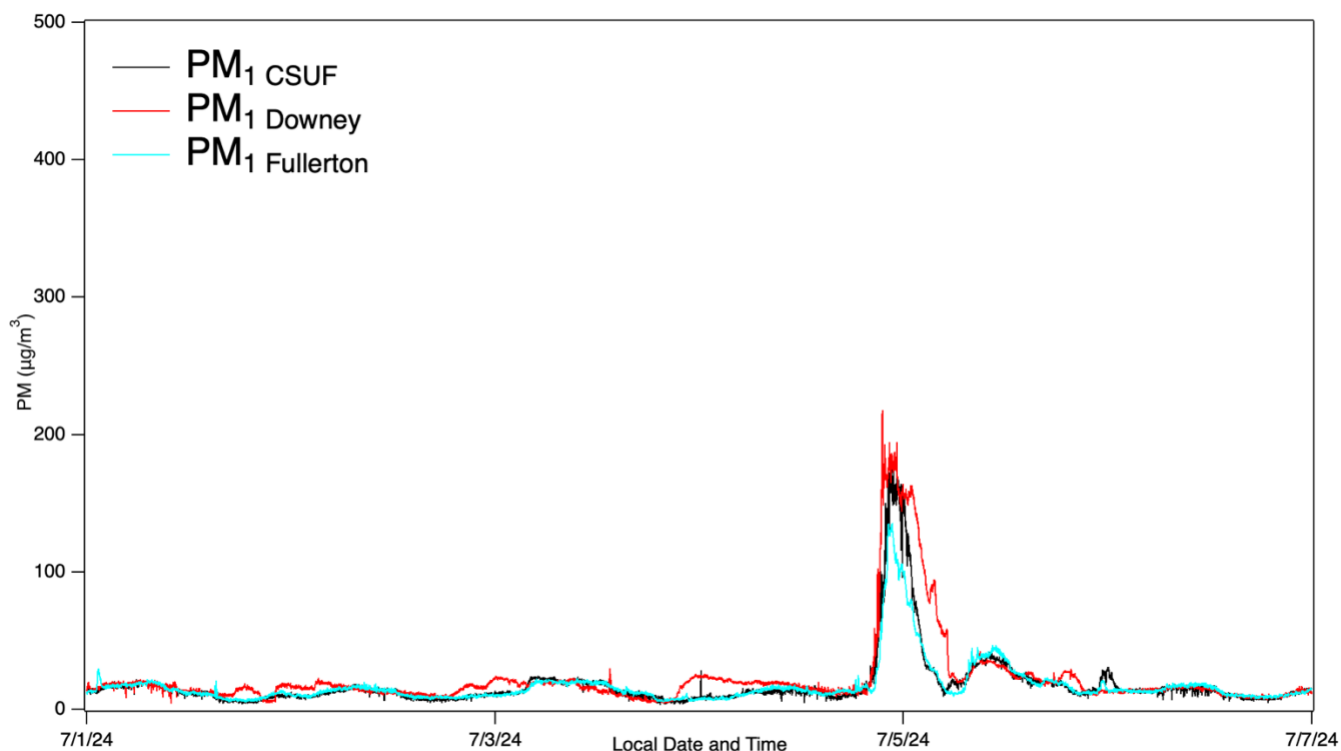
Date	Start Time (PST)	Sample Duration (mins)	Barium Concentration (ng/m <sup>3</sup> )	Strontium Concentration (ng/m <sup>3</sup> )
7/1/24	11:45 am	1120	28	Below LOD
7/2/24	11:50 am	1440	Below LOD	Below LOD
7/3/24	11:50 am	1408	Below LOD	Below LOD
7/4/24	12:00 pm	325	Below LOD	305
7/4/24	5:55 pm	381	Below LOD	Below LOD
7/5/24	12:00 am	351	1094	450
7/5/24	6:00 am	310	447	208
7/5/24	12:05 pm	1439	Below LOD	194
7/6/24	12:00 pm	1440	38	21

### QuantAQ Particulate Matter Data

For instrument intercomparison, we also collected PM data using the Modulair PM QuantAQ system from July 1<sup>st</sup> to July 7<sup>th</sup>, in three locations, residential Downey, residential Fullerton and CSUF. Measurements from the QuantAQ were taken continuously for PM<sub>1</sub>, PM<sub>2.5</sub> and PM<sub>10</sub>, to better understand in which PM level we see the largest increase due to firework activity. The data is shown in Figures 13, 14, and 15, respectively.

In Figure 13, PM<sub>1</sub> concentrations are shown for all three locations. From July 1<sup>st</sup> to July 3<sup>rd</sup>, we see minor fluctuations in the concentration of PM<sub>1</sub> in all three locations with concentrations below 50 µg/m<sup>3</sup>. This could be PM<sub>1</sub> being emitted from the near-road environment, construction or even lawnmowing in the area. Increased PM<sub>1</sub> signals were observed from late July 4<sup>th</sup> through the morning of July 5<sup>th</sup> (during firework activity) in all three locations. Another slightly increased concentration was observed again on July 5<sup>th</sup> in the late afternoon in all three locations, and a few increases in data

specifically in Downey and CSUF during the night of July 5<sup>th</sup>. Beyond this day, the concentrations in all three locations decreases to almost zero post firework activity.



*Figure 13.* QuantAQ data for concentrations of PM<sub>1</sub> measured in residential Downey (red), residential Fullerton (cyan) and CSUF (black) during the week of July 4<sup>th</sup>.

In Figures 14 and 15, PM<sub>2.5</sub> and PM<sub>10</sub> concentrations collected from the QuantAQ are shown for all three locations. Similar patterns that are seen in Figure 13 are seen in Figures 14 and 15, where increased concentration of PM<sub>2.5</sub> and PM<sub>10</sub> are seen during the firework activity from July 4<sup>th</sup> through the morning of July 5<sup>th</sup> and then a second increase seen during the afternoon of July 5<sup>th</sup>. We also see the same small increased signals in Downey and CSUF as well.

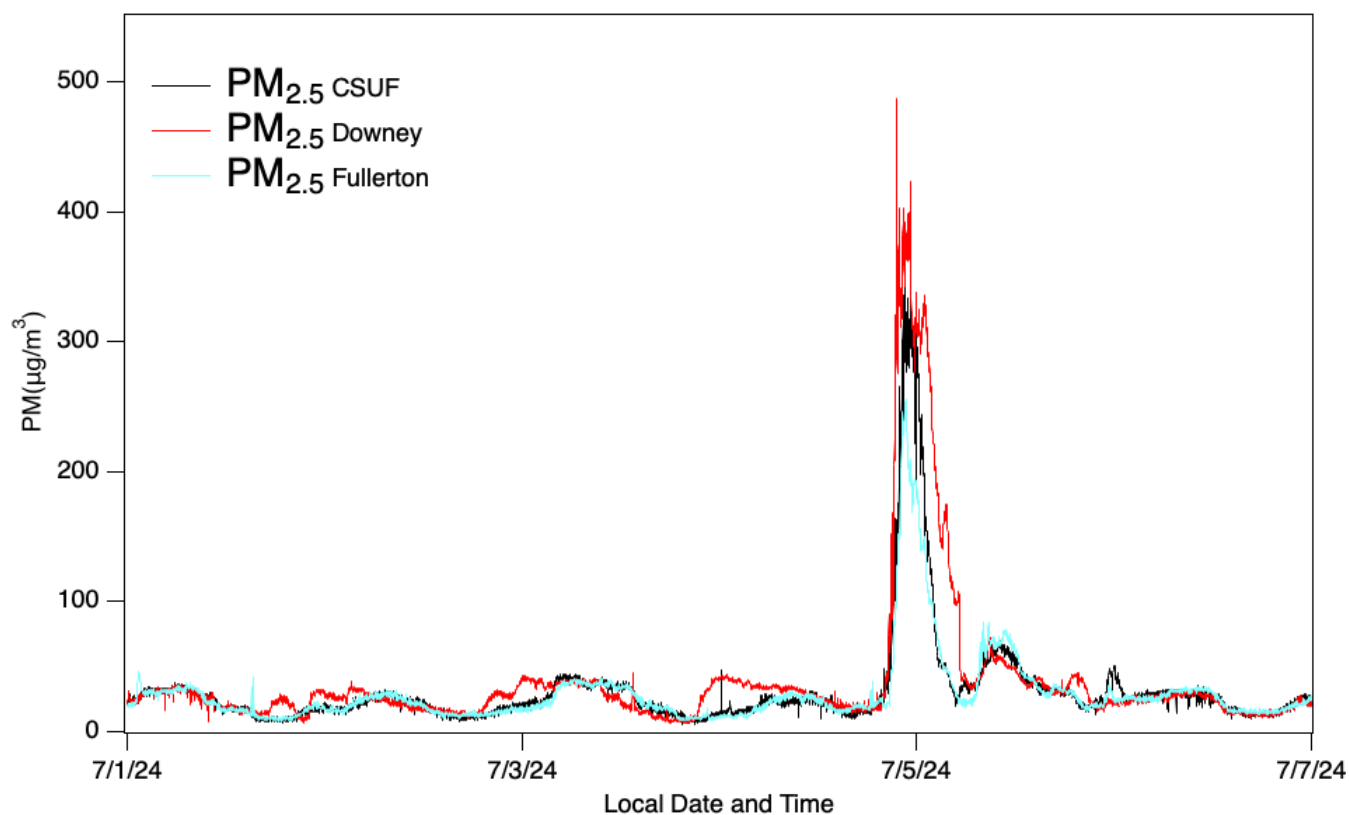


Figure 14. QuantAQ data for concentrations of PM<sub>2.5</sub>, measured in residential Downey (red), residential Fullerton (cyan) and CSUF (black) during the week of July 4<sup>th</sup>.

Figures 13, 14 and 15, all show a similar pattern in the concentrations of PM<sub>1</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> measured by the QuantAQ. In all three figures, it is notable that the Downey location (red) has the highest concentration of PM, followed by CSUF (black) and then residential Fullerton (cyan). However, during the second increase of PM concentrations (late afternoon of July 5<sup>th</sup>), we see that residential Fullerton has higher concentrations of PM, followed by CSUF and then Downey. This may be due to location variability, wind direction and wind speed which could be transporting firework particles from other areas over the QuantAQ sensors.

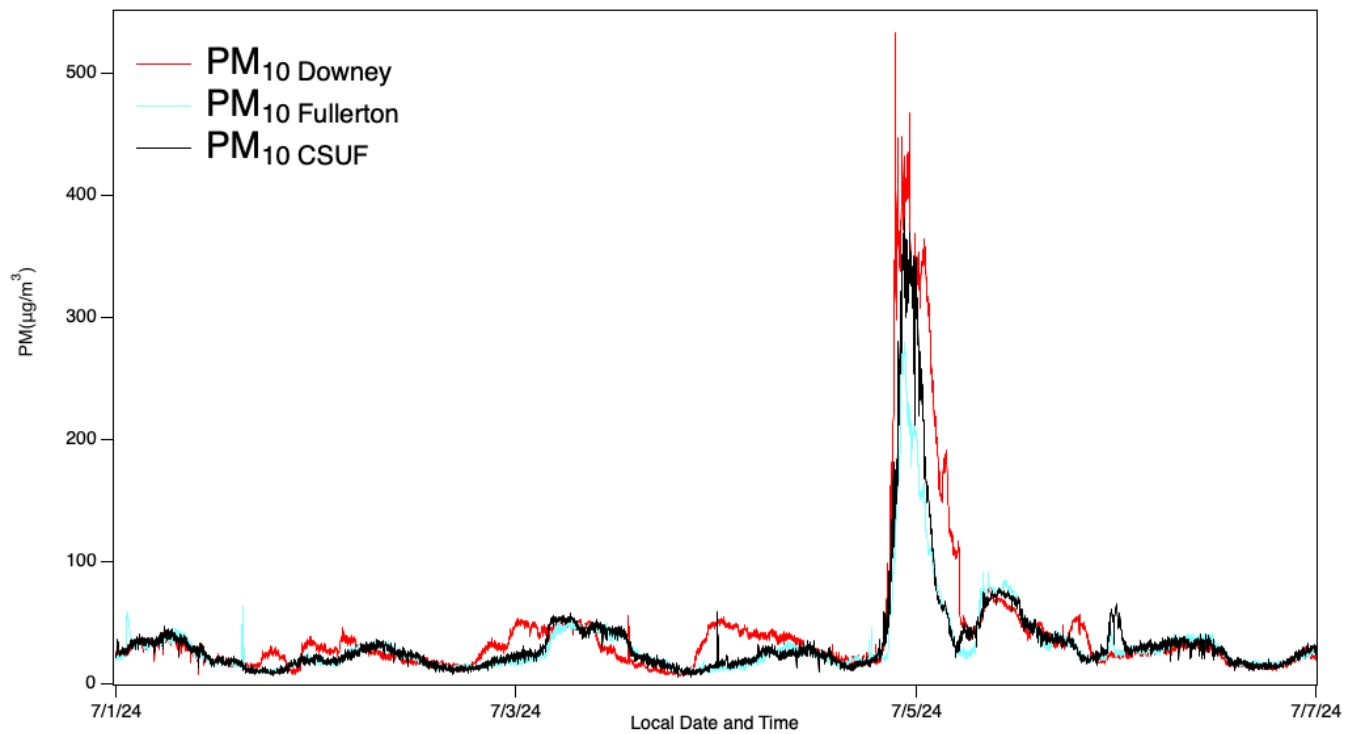
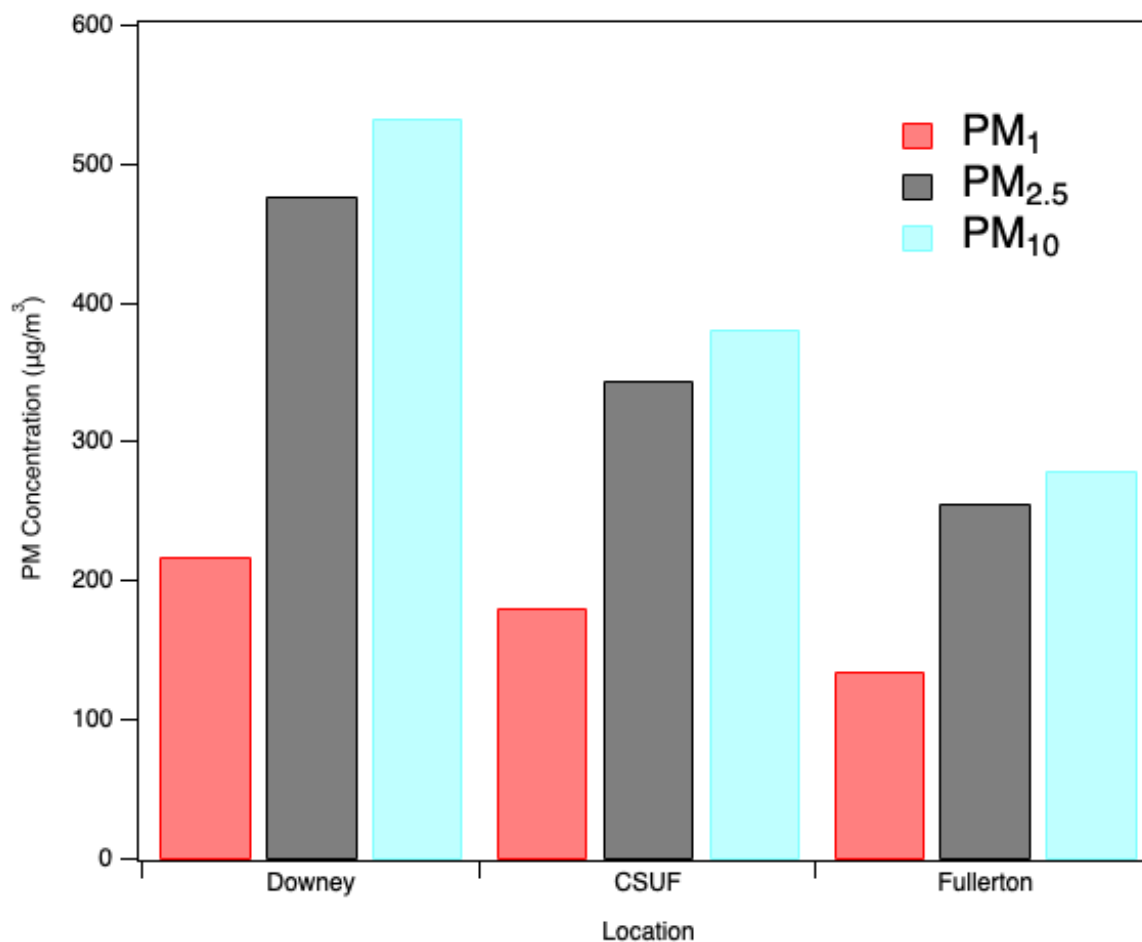


Figure 15. QuantAQ data for concentrations of PM<sub>10</sub> measured in residential Downey (red), residential Fullerton (cyan) and CSUF (black) during the week of July 4<sup>th</sup>.

Figure 16 compares the maximum concentration of PM<sub>1</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> in all three locations during the firework activity. The concentration of PM<sub>10</sub> (blue) in all three locations is the highest with the Downey location measuring of 550 µg/m<sup>3</sup>, compared to CSUF of 380 µg/m<sup>3</sup> and Fullerton of 290 µg/m<sup>3</sup>. The PM<sub>2.5</sub> (black) concentration is the second largest and the PM<sub>1</sub> (red) is the least. Particulate matter is categorized according to its size, as mentioned in the introduction chapter. PM<sub>10</sub> represents the particulate matter of diameter 10µm or less, which therefore includes PM<sub>2.5</sub> and PM<sub>1</sub>. PM<sub>2.5</sub> is any particulate matter of diameter 2.5 µm or less, therefore including PM<sub>1</sub>. Therefore, it seems intuitive that the PM<sub>10</sub> concentrations would be the highest, as it includes the data measured for PM<sub>2.5</sub> and PM<sub>1</sub>. The difference between the values would represent the additional mass within that respective size fraction.



*Figure 16.* Maximum PM concentrations measured by QuantAQ in three locations: residential Downey, CSUF and residential Fullerton during the week of July 4<sup>th</sup>. Each bar graph represents the maximum concentration of PM (PM<sub>1</sub> (red), PM<sub>2.5</sub> (black), PM<sub>10</sub> (blue)) measured in each location.

### **Intercomparison of PM<sub>2.5</sub> Concentrations Between UPAS v2+, QuantAQ and SCAQMD**

The PM<sub>2.5</sub> concentrations measured in Downey and Fullerton using the UPAS v2+ and QuantAQ compared to those measured by SCAQMD sensors in two sites Compton (to compare with Downey data) and Anaheim (to compare with Fullerton) are shown in Figures 17 and 18. Figure 17 shows a time series of PM<sub>2.5</sub> concentrations for each sensor during the week of the fireworks. All three sensors were in good agreement, following the same pattern where the highest concentrations of PM<sub>2.5</sub> were seen in the evening of July 4<sup>th</sup> to the morning of July 5<sup>th</sup> and then another small peak seen during the afternoon of July 5<sup>th</sup>.

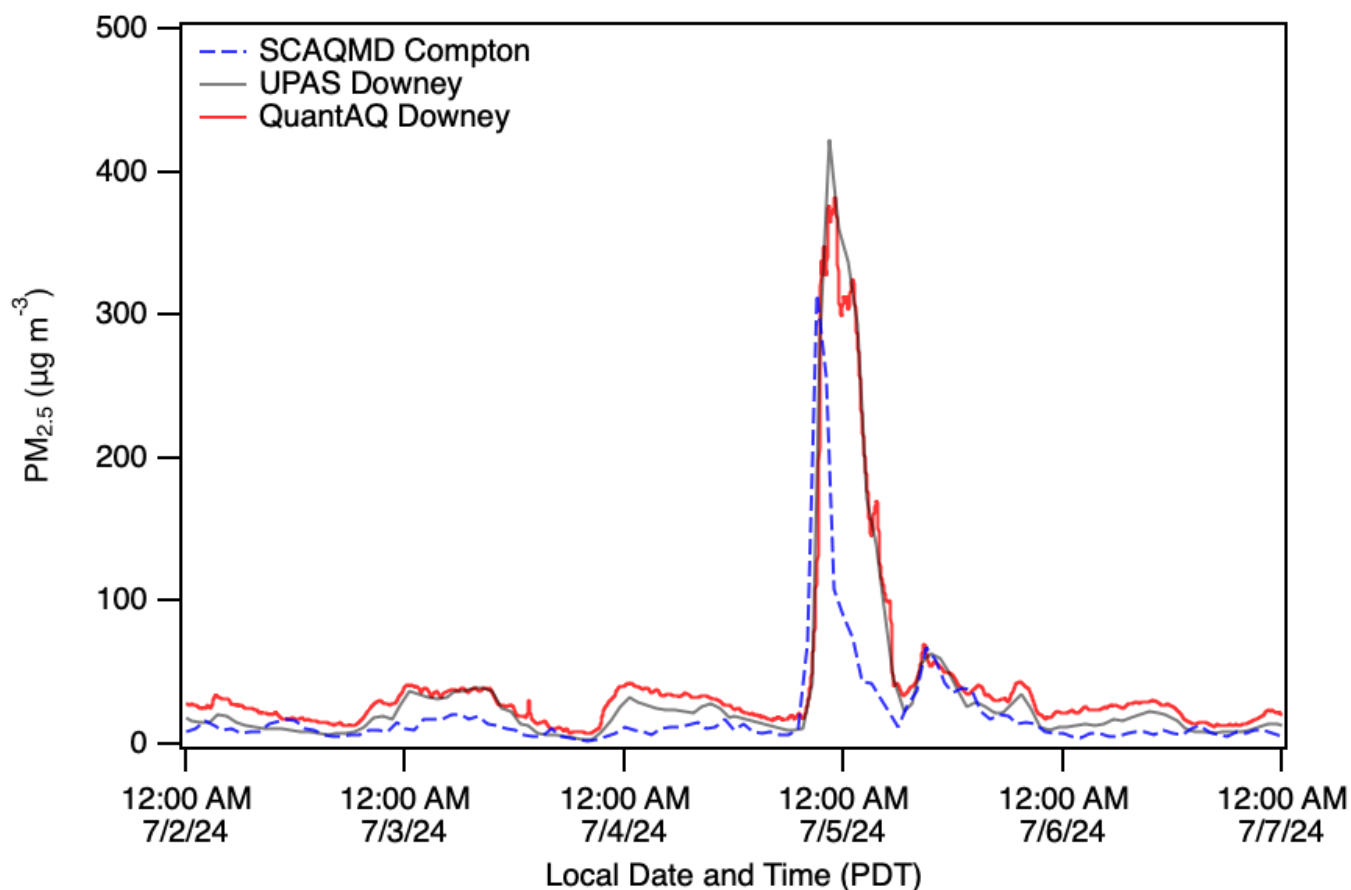


Figure 17. Total PM<sub>2.5</sub> data recorded by UPAS v2+, QuantAQ in residential Downey and SCAQMD Compton site during the week of July 4<sup>th</sup>, 2024.

Figure 18 shows similar value patterns between each sensor. This shows that the low-cost sensors (UPAS v2+ and QuantAQ) are reliable sensors for detection of particulate matter. We do see a slight deviation in the SCAQMD curve in comparison to the QuantAQ and UPAS v2+ curves in both Downey and Fullerton. This may be due to time-averaging in the SCAQMD data from the site itself leading to slight shifts in the time data. The SCAQMD sites are also in different cities than Fullerton and Downey, so location variability must be taken into consideration as well. This means, that the firework emissions may have started slightly before in the cities of the two SCAQMD locations or the wind speed and direction could have played a role in the particle transportation.

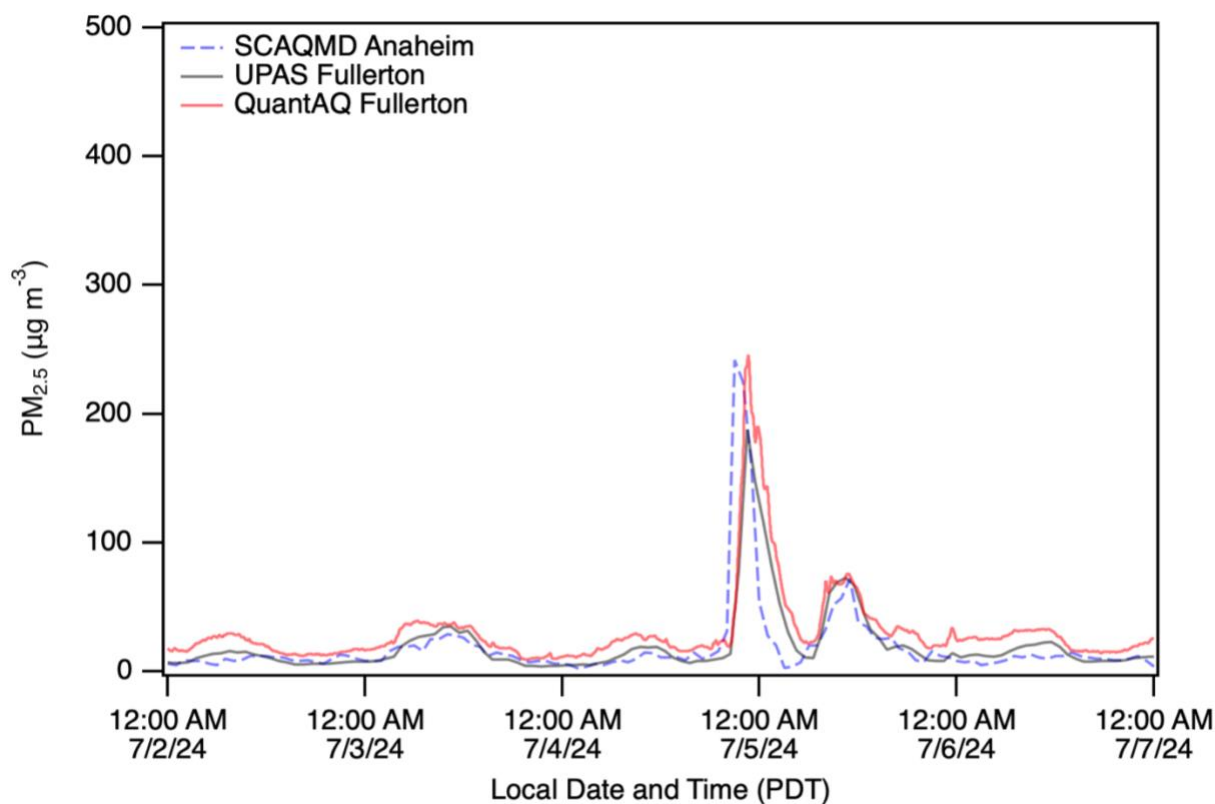


Figure 18. Total PM<sub>2.5</sub> data recorded by UPAS v2+, QuantAQ in residential Fullerton and SCAQMD Anaheim site during the week of July 4<sup>th</sup>, 2024.

### January 2025 Wildfires Results

24-hour measurements of PM<sub>2.5</sub> concentrations of seventeen metals were collected and analyzed during the 2025 Los Angeles wildfires from January 9<sup>th</sup> through 20<sup>th</sup> shown in Figure 19. The 2025 Los Angeles wildfires began on January 7<sup>th</sup> and according to the Baliaka et al. (2025) study[19], during the first week of January (Jan 2<sup>nd</sup>-6<sup>th</sup>) their measurements showed an average Pb concentration of 0.00068 µg/m<sup>3</sup> in Pico Rivera. We began collecting our data on January 9<sup>th</sup>, when the fires were at its strongest and the Baliaka et al. study measured a Pb concentration of 0.5 µg/m<sup>3</sup> on January 9<sup>th</sup> [19] (Figure 4). In our data, we see very intense signals for many metals including, lead (Pb), magnesium (Mg), silver (Ag), calcium (Ca), zinc (Zn) and iron (Fe). Again, many of these metals are already prevalent in the atmosphere, and are emitted from different kinds of sources like vehicular emissions, sea-spray etc. However, Pb is a metal that has been highly reduced globally and rarely seen in the atmosphere over the past decades due to its adverse effects on human health[23], [26], [30].



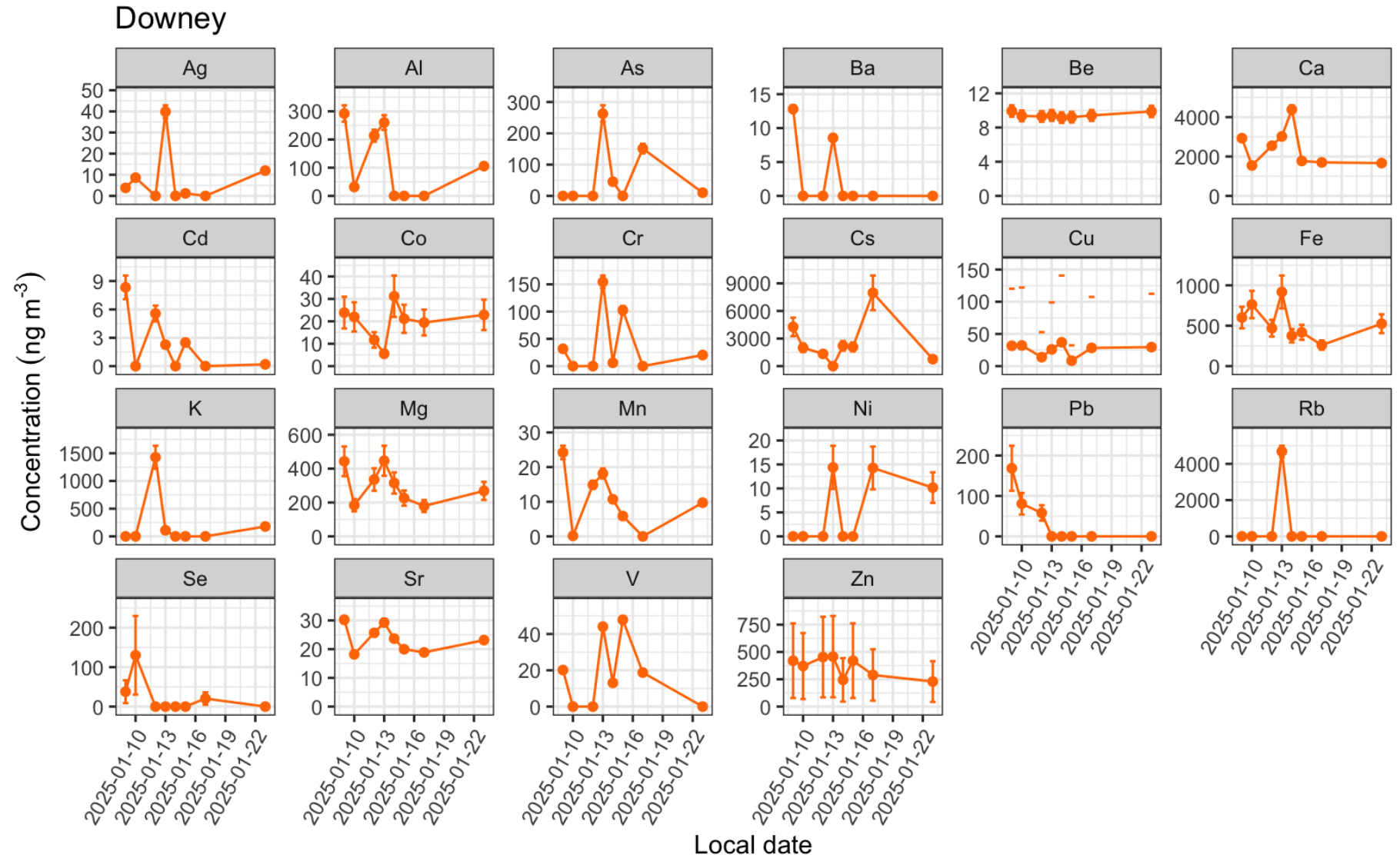


Figure 19. PM<sub>2.5</sub> concentrations of 17 individual metals measured using the UPAS v2+ air sampler from January 9th – 20th during the 2025 Los Angeles wildfires.

On January 9<sup>th</sup>, the Los Angeles wildfires were at their peak strength and the Downey data show an increased signal in Pb of approximately 165 ng/m<sup>3</sup> or 0.165 µg/m<sup>3</sup>. As the wildfires were contained, the concentration of Pb decreased back to almost negligible values after January 13<sup>th</sup>. The Downey data also show high concentration signals of As and total chromium (Cr III and Cr VI) around January 13<sup>th</sup> both of which are common metals emitted from wildfires. Both As and Cr (VI) are released during wildfires but are also released after wildfires. Studies have shown that arsenic can be released during the burning of pesticides, soil, fire suppressants and industrial materials[22], [53]. These particles can become prevalent in the atmosphere after wildfires as well, as they settle in soil and dust, which could be why we see a large increase in As on the 13<sup>th</sup> instead of on the 9<sup>th</sup> like Pb [30], [53]. Cr (VI) is also a common metal released during wildfires, through the combustion of wood, soil and also fire suppressants[30], [54]. It is also seen to be at its highest concentration on the 13<sup>th</sup>, and that is because studies have shown Cr (VI) remains in the ash and soil after wildfires, so upon cleaning the fire zones, these concentrations increase[51], [54]. The concentrations of As and total Cr reached approximately 260 ng/m<sup>3</sup> or 0.260 µg/m<sup>3</sup> and 155 ng/m<sup>3</sup> or 0.155 µg/m<sup>3</sup>, respectively. Unlike Pb, As and Cr lingered in the atmosphere longer until around January 16<sup>th</sup>. Potassium (K) is another metal and is the second most abundant metal that was released during the wildfires. This is because K is a very common marker for biomass burning[55]. We see the K increase largely from January 10<sup>th</sup> to 13<sup>th</sup> with concentrations reaching around 1500 ng/m<sup>3</sup>. Rubidium (Rb) was the most abundant metal released with the highest concentrations showing on January 13<sup>th</sup>. Rb is a trace element that is found in vegetation and soil, during combustion of these materials it is released into the atmosphere in the form of particulate matter[56].

### **Fireworks Discussion**

The South Coast Air Quality Management District (SCAQMD) has reported that in the United States, specifically in Southern California, July 4<sup>th</sup> fireworks cause the worst air quality of the year [41]. As we mentioned before, fireworks are a transient source of pollutants but during this short period of time, the pollutants that are emitted can pose dangerous effects on human health, specifically those with

weaker immune systems. In 2021, SCAQMD conducted a study of how fireworks affected air quality, specifically looking at PM<sub>2.5</sub> particles emitted by fireworks in Paramount and Boyle Heights [41]. In that study, they looked specifically at two metals emitted by the fireworks, Cu and Cr (Figure 3). Cu concentrations measured at an average of 4000 ng/m<sup>3</sup> and 1800 ng/m<sup>3</sup> in Boyle Heights and Paramount respectively. Cr concentrations measured at an average of 390 and 80 ng/m<sup>3</sup> respectively. The SCAQMD data showed that location affects air quality and although they looked at PM and metals in some areas of the Los Angeles basin, they did not have a report on Fullerton and Downey. Mousavi et al. (2021)[43] used PurpleAir sensors to determine which areas in California were hotspots for fireworks, determining that Southern California had many firework hotspots (Figure 2).

In our study we wanted to determine the effects of July 4<sup>th</sup> fireworks on trace metals found in PM<sub>2.5</sub> in Southern California, specifically in Fullerton and Downey. Our results showed that there was an increased amount of Al, Ca, Ba, Sr and Zn during the fireworks. From Hao et al. (2020), we have seen that Al was one of the most abundant metals present in the atmosphere during the Spring Festival fireworks (Figure 5). Ca, Zn, Al and Mg were the most abundant metals present in our samples during the fireworks (Figure 12). Again, Ca and Al are emitted into the atmosphere from many sources, but we do see that fireworks play a large role in their increase as well. Ca, like K explained in Hao et al. (2020), is emitted by fireworks from the oxidizing agents used in them, Mg is emitted by the colorant materials used and Al from the silver sparkles[47]. We also focused on looking at Ba and Sr metals because they are tracers for firework activity, and we see an increase in their concentration during the July 4<sup>th</sup> firework activity, showing that their main presence in the atmosphere is indeed due to fireworks. In both Fullerton and Downey, we saw Ba and Sr increase by a factor of 1000 and 400 respectively during the firework activity (Figure 12). Our study is not only showing that firework activity increases metal concentrations, but it is also further reinforcing that Southern California has multiple hotspots for firework activity consistent with Mousavi et al. (2021)[43] and that the Los Angeles Basin emits a large amount of metals from the July 4<sup>th</sup> fireworks.

The increase of metals in the atmosphere is due to an increase of metal-containing particles in the atmosphere. The QuantAQ data shows a large increase in  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$  concentrations during the firework activity in all three sites. We saw concentrations of  $PM_{2.5}$  specifically reach around 300-500  $\mu g/m^3$  during the firework activity which drastically exceeds the daily EPA limit of 35  $\mu g/m^3$  [57]. Our results showed that location plays a large role in the concentration of PM, with Downey having the largest emission of PM followed by CSUF and residential Fullerton. Interestingly, race/ethnicity and socioeconomic roles play a large factor in PM emissions, and we see that in our data. In a study conducted by Masri et al. (2023), race and ethnicity were found to be the biggest predictor for July 4<sup>th</sup> PM emissions in Southern California [58]. The study was specifically conducted in Orange County, California and showed that areas with higher Hispanic populations had higher PM emissions than in areas with lower Hispanic populations. Another study by Tessum et al. (2021) points out a trend showing that PM emissions are much higher in areas of non-white Americans, and that this trend is seen consistently no matter the city, or state and no matter the socioeconomic status [59]. In our study, Downey had higher PM emissions than Fullerton and it also has a higher Hispanic population than Fullerton does [60], further validating the results of both Masri et al. (2023) and Tessum et al. (2021). The large increase of metal and PM emissions in the atmosphere can cause detrimental health effects on civilians exposed to it. Fireworks are a transient source of particles, but even particles found in the atmosphere for a short term can lead to health problems to those exposed to it. To reiterate some dangers of short-term exposure to PM, people can have heart attacks, asthma attacks and even strokes. This means that non-white Americans (specifically children and the elderly) and areas of lower socioeconomic status are also more susceptible to developing certain diseases due to their exposure to higher levels of PM and metals. Our results show the importance of monitoring the air quality during firework activity of Independence Day in different locations and shows that low-cost monitors can be used as reliable sources to monitor the air quality.

## Wildfires Discussion

Wildfires are a natural and transient source of emitting particles into the atmosphere [1]. From wildfires various heavy metals are released into the air like lead (Pb), arsenic (As) and chromium (Cr VI). Pb is the most monitored metal due to its detrimental health effects on children specifically [23], [24], [26]. During the 2025 Los Angeles fires, Baliaka et al. (2025) measured concentrations of PM<sub>2.5</sub> Pb emitted before during and after the wildfires from the ASCENT site in Pico Rivera (Figure 6). Before the fires they recorded an average of 0.00068  $\mu\text{g}/\text{m}^3$ . During the wildfires, the average Pb concentration increased almost 100 times higher than the levels before the fires started, with the highest level of PM<sub>2.5</sub> Pb recorded as 0.5  $\mu\text{g}/\text{m}^3$ . The Environmental Protective Agency (EPA) standard for Pb over a 3-month period is 0.155  $\mu\text{g}/\text{m}^3$  [19]. The concentrations of PM<sub>2.5</sub> Pb that were emitted during the wildfire clearly reached potentially dangerous levels. These levels and those of the EPA limit are not measured on the same time scale, but we do see the large increase in lead in the atmosphere over a short period of time during the wildfire activity.

In our study, we wanted to understand how the concentration of different PM<sub>2.5</sub> metals would be affected by the Los Angeles wildfires of 2025 using a low-cost instrument (UPAS v2+) in Downey. We noticed a great increase in concentration of many metals, indicating that wildfires do play a role in the emission of metals found in the atmosphere. Specifically, we noticed a large increase in concentration of Pb, As and total Cr. Our PM<sub>2.5</sub> Pb concentrations measured a maximum of 165  $\text{ng}/\text{m}^3$  or 0.165  $\mu\text{g}/\text{m}^3$ . Our Pb values followed the same pattern that the Baliaka et al. (2025) study observed in Pico Rivera, indicating that our low-cost sensor was a credible instrument to take our measurements. We may not have seen concentrations that were as high as those in the Baliaka et al. study, but we must remember that location variability like wind direction and wind speed, and the different instruments used to take the measurements also play a role in the results. Our results showed a large increase in the concentration of Pb in just a couple of days, indicating that people located in the Downey area were in the plume of the wildfires and were exposed to all the contaminants that come from urban wildfires.

The Baliaka et al. (2025) study only reported PM<sub>2.5</sub> Pb concentrations, but we noticed from our data that PM<sub>2.5</sub> total Cr concentrations increased greatly up to 155 ng/m<sup>3</sup> and that its largest concentration was a couple days after the wildfires. Interestingly, Kleeman et al. (2025) looked at airborne Cr (VI) particles in cleanup zones of the Los Angeles fires up until March 2025[51]. This is because Cr (VI) particles remain in the ashes of the fire zones, the wind or when cleaning these zones can lead to an increase of Cr (VI) particles in the atmosphere[51], [54]. The PM<sub>10</sub> concentrations of Cr (VI) collected during this study averaged to  $13.7 \pm 6.2$  ng/m<sup>3</sup>. Our data, unlike Kleeman's is looking at total Cr levels during the active wildfire. We are unsure how much of our total Cr is Cr (VI), but it is a very common metal emitted during wildfires, so we are assuming that a fraction of the Cr is in the form of chromium (VI). The interesting part we see is that the total Cr lasts a longer time in the atmosphere than Pb or other metals, and in the Kleeman et al. (2025) study they were studying Cr levels caused by the wildfires in March 2025, long after the wildfires ended. This suggests that Cr indeed, lasts a long time in the atmosphere even in areas that were not directly affected by the fire but still within the plume like Downey. Our data have shown us, that our low-cost sensor (UPAS v2+) is a reliable source to monitor air quality during wildfires.

## CHAPTER 4

### CONCLUSION

Particle pollution is a dangerous issue that is only increasing in our communities. It has been proven repeatedly to increase the risk of health effects in humans, specifically the young and elderly. Chronic and acute exposure to PM both are associated with causing detrimental effects on humans. Chronic exposure to PM can shorten life expectancy, cause pre-term births, and increase the likelihood of developing many kinds of cancers. Acute exposure to PM can increase heart problems, cause asthma attacks and even strokes for people who have weaker immune systems. The composition of the particles found in PM are what cause these health risks. Some particles may be toxic upon inhalation and lead to dangerous consequences on people exposed to them. There are many sources that emit PM into the atmosphere whether natural or anthropogenic. Some sources that emit PM are constant emitters like vehicular emissions, and some are transient emitters like firework activity and wildfires. These types of PM emitters release heavy metals into the atmosphere that become incorporated into the PM.

Firework activity is known to decrease air quality and largely increase the concentration of PM in the atmosphere, specifically increasing the concentration of many toxic gases and metals. The different parts of that make up fireworks emit different kinds of metals into the atmosphere like lead (Pb), strontium (Sr), barium (Ba) etc. In the United States, Independence Day (July 4<sup>th</sup>) is the day with the worst air quality recorded yearly due to the large number of fireworks used on that day[41], [43], [61]. This means that the concentration of particulate matter and metals recorded during Independence Day are at extremely high levels. Fireworks as mentioned before are a short-term emitter of pollutants, but these pollutants reach dangerously high concentrations during very short periods of time, which could cause harmful effects on humans. Previous studies have shown large variability and different concentrations in metals found in PM during different firework events. There are many causes for this variability such as location variability, wind speed and direction, the number and types of fireworks used as many fireworks used have different components leading to different metals emitted into the

atmosphere. Because of these variables, multiple measurements of firework activity are needed to accurately understand how metal concentrations are affected during firework events.

Wildfires are a natural source of particle emissions and like firework emissions are a short-term source. Many studies have shown that during wildfires, not only the fire itself is emitting metals and particles into the atmosphere but also types of fire suppressants, biomass burning and the burning of infrastructure. Some common metals emitted during wildfires are Pb, As and Cr (VI). During wildfires, the air quality is monitored, and some studies focus on monitoring the Pb concentrations found in particulate matter to see how areas surrounding the fires were affected by them. Again, location variability plays a large role in the concentrations of metals found in particulate matter. This can depend on how close or far one is from the plume, the direction the fire is heading, how large the fire is, and meteorological conditions. Because of these factors, it is important to understand that a single measurement of metals emitted during wildfires cannot be representative of all wildfires and we need multiple measurements from several locations to describe wildfire emissions.

The aim of this thesis was to quantify metal particulate matter emissions due to transient sources using low-cost sensors. Our first transient source was firework activity during the July 4<sup>th</sup> celebrations during 2024. In this scenario, we focused on understanding and observing how location variability can affect our PM emissions. Our study involved three locations, residential Downey, CSUF and residential Fullerton. We looked at quantifying total PM emissions, comparing PM<sub>2.5</sub> concentrations using low-cost sensors like UPAS v2+ and the QuantAQ Modulair and comparing to measured concentrations by SCAQMD. Metal concentrations of PM from fireworks were quantified from measurements in the residential Downey and Fullerton areas. This study is important because it is not only important to measure air quality during firework activity (specifically July 4<sup>th</sup>), but also to spread awareness to the public on how fireworks contaminate the environment they live in.

Our study on firework activity focused on how location variability in areas of Southern California affects metal concentration in PM and the measured total PM emissions from fireworks. Our



data showed significant increases in  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$  during the firework activity using the QuantAQ sensors, where most of those particles were classified as  $PM_1$ , followed closely by  $PM_{2.5}$ , with  $PM_1$  being the size that has greater risk of affecting human health. Metals found in  $PM_{2.5}$  during this period were collected by the UPAS v2+ on a filter, where the metals would then be measured and analyzed using ICP-OES. During the firework period, we noticed significant increases in  $PM_{2.5}$  heavy metals, mostly seeing a large increase in Ba and Sr which are both firework tracers. We also noticed a significant increase in metal concentrations of Ca, Zn, Pb and Cr, depending on the location of the fireworks. Location variability played an important role on the metal measurements indicating the importance of monitoring air quality during firework activity in several locations. Comparison of our PM emission results to those of the QuantAQ and SCAQMD showed that our low-cost sensors are providing credible results for the public to monitor air quality.

Using these sensors and samplers has its pros and cons. The fact that they are low-cost sensors means that they are affordable to be used by a wider scope of people wishing to monitor the air quality surrounding their area. They are also small and compact making them easy to use in many settings, for example, placing them in your backyard or front porch. However, these low-cost sensors and samplers have some limitations. The UPAS v2+ for example, can only collect 1 liter of air per minute whereas samplers used in studies like the Baliaka et al. or the SCAQMD sites can sample up to 1000 liters of air per minute. Collecting more air per minute means higher flow rate which means it can allow shorter sampling periods and improve detection limits for low-level concentrations. Our results in comparison follow similar patterns to those of the SCAQMD site but there is not a way to be sure that these samplers are collecting the same as more powerful samplers unless further studies are made. In our research, the point of using these UPAS v2+ and QuantAQ sensors is to stay on a low budget and understand how these low-cost sensors work, which means we only have a few sensors and samplers that are used for collecting measurements. If we wanted to look at this research in a wider scope, we would need more samplers and sensors to collect at multiple sites under different circumstances.

The second transient source of PM this study focused on was wildfires. Here, the focus was solely on quantifying the concentrations of metals in PM<sub>2.5</sub> emitted during the wildfires in residential Downey. The data reported concentrations of multiple metals but focused on Pb and total Cr. This is because Pb and Cr (VI) are carcinogenic metals that are commonly emitted during wildfires. During the Los Angeles wildfires in 2025, Downey was not directly affected by the fires, but this study was interested in seeing if Downey was in the wildfire plume and investigate how air quality in the area would be affected. By conducting this study, we are providing valuable information on how air quality is affected in areas that are prone to wildfires or are adjacent to those areas. Again, although wildfires are not a chronic source of metals in PM, they lead to an increase of carcinogenic metals in the atmosphere. Using the UPAS v2+, we were able to monitor the air quality in residential Downey, and we saw increased concentrations of Pb and total Cr. Pb levels during the week of the wildfires largely increased during the wildfires up to concerning amounts. These high concentrations of Pb can lead to significant health risks, if exposed to even during acute exposure. The concentrations of Cr during the week of the wildfires also increased significantly during the fires and lasted a longer period in the atmosphere than lead did. This indicates the importance of monitoring the air quality during wildfires. Cr (VI) is usually emitted during wildfires with its toxic characteristics can lead to many health issues, specifically in people with weaker immune systems.

It is important to continue the research on transient sources of metals in PM and to monitor the air quality affected by these metals because of their harmful effects on human health. Most studies focus on the sources that lead to chronic exposure of metals and other toxic particles found in PM, but these transient sources are also leading to extremely high levels of toxic metals in the atmosphere.

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