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The Invisible Threat: Tracking Air Quality Across UC Merced

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The Invisible Threat: Tracking Air Quality Across UC Merced

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Abstract

Fine particulate matter (PM2.5) exhibits pronounced spatial variability even across the scale of a university campus and readily infiltrates the lungs and bloodstream, exacerbating respiratory and cardiovascular health burdens. Recognizing this heterogeneity is essential for accurately characterizing exposure, particularly for the student population that may be unaware of its adverse impacts. The San Joaquin Valley, home to UC Merced, remains out of compliance with federal PM2.5 and ozone standards and has received an F grade from the American Lung Association. However, campus air quality is monitored by only one fixed PurpleAir sensor at the Science and Engineering 2 Building (SE2), which may not capture local PM2.5 variability. To address this gap, we undertook a mobile monitoring campaign during the 2025 spring term using a handheld EXTECH VPC300. Hundreds of geo-referenced readings were gathered along walkways, parking areas, construction zones, and other busy sites, then compared with daily values from the fixed PurpleAir sensor. The handheld and PurpleAir measurements exhibited similar day-to-day and weekly trends, indicating that the fixed PurpleAir unit effectively captures overall temporal variations in PM2.5. Midweek elevations compared to weekends likely reflect increased campus activity, such as traffic, construction, and maintenance. However, the fixed PurpleAir sensor cannot capture elevated PM2.5 near parking areas and construction zones detected by the handheld device. These findings suggest that while a single monitor can track general trends, a distributed network of low-cost sensors is needed to capture local exposure differences and guide targeted mitigation for the UC Merced community.

Keywords: *PM2.5, air quality monitoring, spatial variability, mobile monitoring, PurpleAir*

Introduction

Air pollution remains a significant public health concern, particularly when it involves fine particulate matter (PM2.5), which refers to airborne particles with a diameter of 2.5 micrometers or smaller that can penetrate deep into the lungs and enter the bloodstream (World Health Organization, 2025). Due to their minute size and reactive chemical nature, PM2.5 particles can cross cell membranes and disrupt normal physiological processes, contributing to widespread harm across multiple organ systems (Brook et al., 2010). Chronic exposure to elevated PM2.5 levels has been linked to respiratory disease, cardiovascular disease, cancer, and other adverse health outcomes (Chowdhury et al., 2018; National Institute of Environmental Health Sciences, 2025; Pope et al., 2002; Sangkham et al., 2024). These health risks are particularly concerning in regions where fine particulate concentrations remain persistently high, exposing residents to levels that exceed both national and global health guidelines (World Health Organization, 2021). The San Joaquin Valley, home to the University of California (UC) Merced, consistently ranks among the most polluted regions in the United States and continues to fall short of federal air quality standards (United States Environmental Protection Agency, 2025). The American Lung Association likewise gave the San Joaquin Valley an overall “F” grade for particle pollution and a “C” for ozone, underscoring the region’s ongoing struggle to meet clean air benchmarks (American Lung Association, 2025).

Regional air quality observations offer important insights into pollution trends, but they often mask local variation that can significantly affect exposure levels (Beckerman et al., 2013). Air quality can fluctuate sharply over short distances because of differences in traffic flow, construction activity, outdoor activities, and the distribution of open green spaces (Eeftens et al., 2012). Understanding these local fluctuations is critical for evaluating air quality in sensitive environments such as university campuses, where students and staff spend much of their day outdoors. At UC Merced, campus air quality is currently tracked by a single PurpleAir sensor positioned at the Science and Engineering 2 (SE2) building (PurpleAir, 2025a). PurpleAir sensors are low-cost optical monitors that estimate real-time PM2.5 concentrations using light scattering technology (PurpleAir, 2025b). Although these sensors are effective for detecting regional trends, a single fixed monitor may not capture the spatial variability in exposure across the UC Merced campus, limiting its ability to reflect localized fluctuations in air quality.

To address this limitation, a campus-wide air monitoring campaign was conducted during spring 2025. PM2.5 levels were recorded at several outdoor campus locations, including pedestrian walkways, parking lots, construction zones, and open green areas, using a handheld particle counter. These measurements were compared with data from the stationary PurpleAir sensor. Two analyses were performed: one examining the temporal variability between the handheld and PurpleAir measurements from February to May 2025, and another comparing their weekly PM2.5 trends. Together, these comparisons evaluate how well a single PurpleAir sensor reflects broader campus air quality conditions and whether a denser monitoring network may be needed to capture localized variations in PM2.5 exposure.

Methods

Data Collection

A mobile air quality sampling campaign was conducted across the UC Merced campus during spring 2025 to assess spatial variability in fine particulate matter (PM2.5). The EXTECH VPC300 Particle Counter (see Fig. 1), a portable laser-based optical device for measuring PM2.5, was used to collect airborne particle counts and environmental parameters (FLIR, 2025). The instrument measures particles across several size thresholds (0.3, 0.5, 1.0, 2.5, and 10 µm) and simultaneously records air temperature (AT), dew point (DP), relative humidity (RH), and wet-bulb temperature (WB) (EXTECH Instruments, n.d.).

Before each measurement, the protective cap on the metal intake cylinder was removed to allow air sampling. The device was powered on, allowing for stabilization for several seconds before initiating a 20-second sampling period using the “Run” function. During each cycle, air was drawn through the optical chamber, and particle counts were displayed on screen at the conclusion of the measurement. The results were then recorded manually in a data table that included the date, time, geographic coordinates, and environmental conditions at the sampling site (see Fig. 2). After recording, the device was powered off and recapped to prevent contamination or dust intrusion.

Figure 1. EXTECH VPC300 Handheld Particle Counter: *Portable laser-based optical device used to measure particle counts (0.3–10 µm) and environmental parameters for assessing spatial variation in campus air quality.*

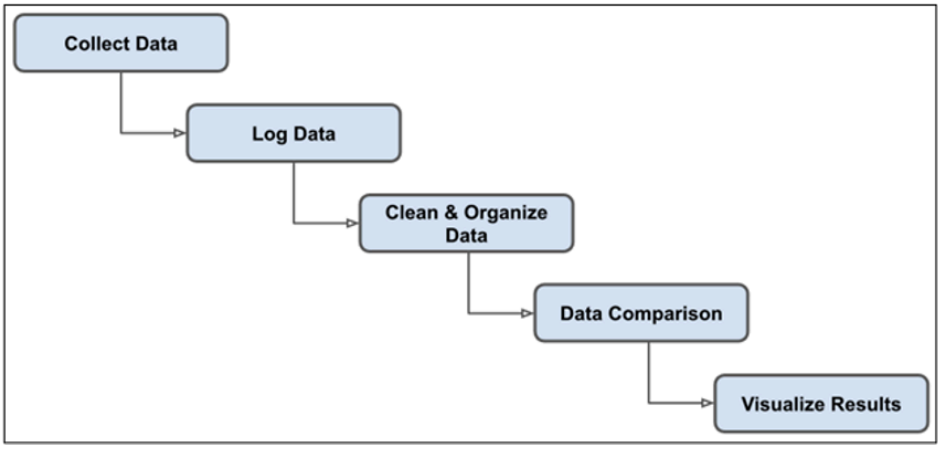

Figure 2. Overview of the Monitoring Campaign Data Workflow: *Illustrating the process of data collection, logging, cleaning, comparison, and final visualization for the monitoring campaign from inception to completion.*

Sampling Locations

Sampling locations were selected to represent diverse outdoor campus environments, including pedestrian walkways, parking lots, classroom exteriors, construction areas, and open green spaces (see Fig. 3). Each data point was geo-tagged using smartphone GPS and paired with a photographic record of the immediate surroundings to capture contextual information such as visible dust, vehicular activity, or wind exposure. Measurements were collected twice daily during 8:00–8:30 a.m. and 6:00–6:30 p.m., from February 16 to May 8, 2025, to capture morning and evening conditions and assess diurnal variation in PM2.5.

Figure 3. Map of PM2.5 Sampling Locations Across the UC Merced Campus: *Pinned map showing the locations of air quality sampling points across the UC Merced campus, created using Python and Folium. Each red marker represents a site where fine particulate matter (PM2.5) measurements were collected during the spring 2025 monitoring campaign.*

Data Processing and Analysis

Raw data from the handheld device was compiled and cleaned for organization and basic statistical checks. Geo-referenced data points were imported into mapping software to visualize PM2.5 intensity across campus zones and to identify recurring hotspots such as areas near vehicle traffic or construction sites. Temporal analyses examined day-to-day variation and recurring evening or midday peaks. Figures depicting location-specific concentration gradients were produced using Matplotlib to provide interpretable spatial and temporal visualizations.

Comparison with Fixed Monitoring Data

The mobile particle count data was compared against daily PM2.5 concentration averages from UC Merced's fixed PurpleAir sensor located at the Science and Engineering 2 (SE2) building. PurpleAir sensors employ light-scattering technology to estimate particulate matter concentration in micrograms per cubic meter ($\frac{\mu g}{m^3}$)(see Fig. 4). The comparison focused on temporal alignment, ensuring that handheld measurements were analyzed alongside the same-day PurpleAir averages to identify trends in magnitude and fluctuation. Because no standardized equation exists to convert raw particle counts into concentration without assumptions about particle size and density, no such conversion was applied. Instead, emphasis was placed on relative differences and spatial contrasts across the campus environment. To support this comparison, the data from both sources were processed to highlight key trends and facilitate a qualitative comparison across the datasets.

Figure 4. PurpleAir Sensor Serving as the Fixed Monitoring Site at UC Merced: *The PurpleAir PA-II-SD sensor (ID 163173) functions as the campus's fixed monitoring site. Left: device with internal optical particle counters exposed. Right: field installation on the exterior of SE2 providing real-time PM2.5 data for comparison with handheld EXTECH VPC300 measurements.*

Results

The goal of this analysis was to evaluate whether a single fixed monitor at the Science and Engineering 2 (SE2) building can adequately represent campus-wide air quality patterns. To address this question, temporal and spatial comparisons were made between the handheld EXTECH VPC300 measurements and the SE2 PurpleAir sensor data collected during spring 2025.

Overall temporal patterns

As shown in Figure 5, the handheld EXTECH VPC300 and the fixed SE2 PurpleAir unit exhibited broadly similar fluctuations in PM2.5 across the February to May 2025 period. Peaks and troughs occurred on roughly similar dates, indicating that both instruments tracked day-to-day variation in ambient air quality conditions.

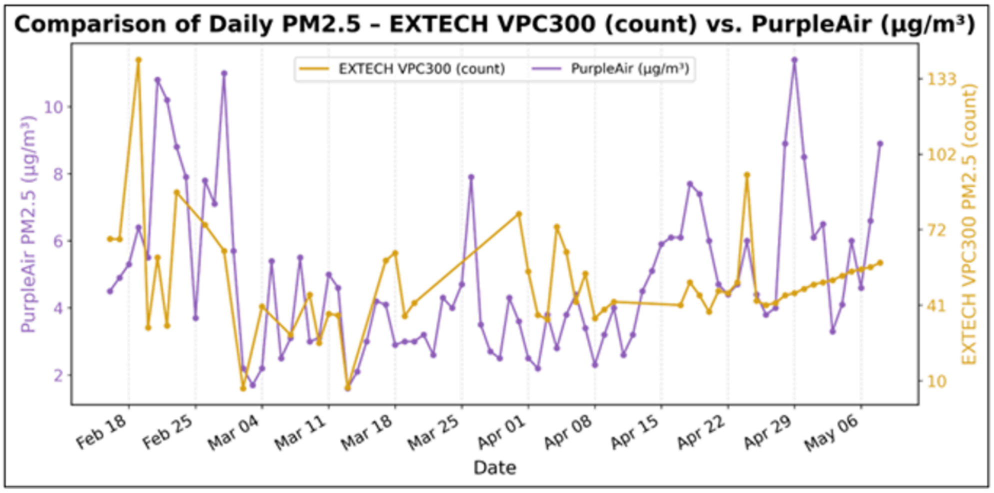

Figure 5. Daily PM2.5 patterns from a handheld EXTECH VPC300: *(particle count; gold) and the Science and Engineering 2 (SE2) PurpleAir monitor (*$\frac{\mu g}{m^3}$*; purple), February–May 2025.*

Absolute values differed, with the handheld device generally reporting lower magnitudes than the fixed monitor. Because the datasets are reported in different units and were compared using visual normalization scaling rather than a calibration transfer, these magnitude differences are interpreted cautiously. Taken together, the alignment in timing suggests that the single fixed sensor captures regional temporal patterns, whereas the handheld series provides complementary information on local variability.

Day of week variation and microenvironments

Aggregation by weekday revealed a consistent midweek elevation and lower weekend levels (see Fig. 6). Field notes documented greater campus activity during weekdays (vehicular flow, construction, and grounds maintenance) and reduced activity on weekends. While this study was not designed to attribute causality, the pattern is consistent with activity-related influences on short term PM2.5. When comparing sites with the handheld counter, lower values were observed in open landscaped areas, whereas higher values appeared near parking lots and construction zones. Taken together, these contrasts indicate microenvironmental heterogeneity that a single fixed sensor may not fully represent; a background monitor can reflect overall trends but may not capture campus variability.

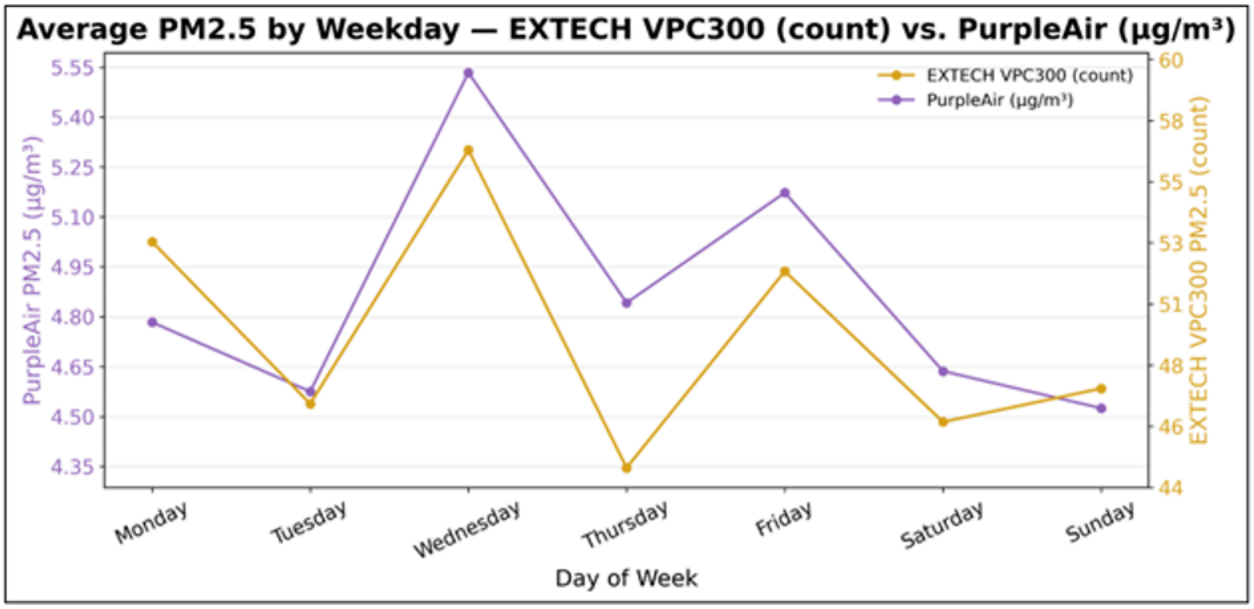

Figure 6. Average PM2.5 by weekday from the handheld EXTECH VPC300: *(particle count; gold) and the PurpleAir monitor (*$\frac{\mu g}{m^3}$*; purple).*

Discussion

This study examined whether one fixed PurpleAir sensor can represent air quality across a dynamic university campus. Figure 5 shows that while the PurpleAir monitor located at the Science and Engineering 2 (SE2) building and the handheld instrument exhibited similar fluctuations in PM2.5 levels, with their peaks and troughs occurring on comparable dates. This rough alignment indicates that a single fixed sensor can capture general trends in air quality over time, reflecting broad patterns in environmental conditions such as weather changes and regional pollution levels. At the same time, weekday patterns and site comparisons pointed to local heterogeneity: higher values near parking areas and construction zones and lower values in open landscaped spaces. Together, these findings suggest that a single fixed sensor is informative for trend detection but insufficient for characterizing spatial variation in exposure across campus.

Interpreting the results within this frame yields two conclusions. First, the SE2 PurpleAir monitor appears adequate for signaling campus-level shifts in PM2.5, identifying days when overall conditions improve or deteriorate. The approximate concordant timing of peaks and troughs supports its use as a background indicator. Second, the handheld series revealed reproducible microenvironmental differences tied to human activity and site context. Midweek elevations compared with weekends align with changes in traffic, construction, and maintenance schedules, and higher values near parking and work zones suggest short-duration plumes that a background site may mute. For students and staff who move between areas adjacent to campus roadways, major pedestrian routes, building perimeters, and open landscaped spaces, these short-duration increases are relevant for exposure management even when the background monitor indicates moderate conditions.

Implications for the study question and public health

Collectively, these observations indicate that one fixed PurpleAir monitor can reflect overall temporal trends but is unlikely to characterize on-campus variability in exposure nor its magnitude. Although this analysis is qualitative and does not involve a mass-based conversion, the concordance in patterns across instruments, together with the weekday gradients, supports the practical value of mobile sampling for identifying times and places where exposure may be higher. From a public health perspective, recognizing these routine peaks can inform campus operations and risk communication, and motivate evaluation of a distributed sensor network to improve spatial coverage.

Limitations

Several factors qualify the interpretation of these findings. Foremost is the units distinction: the SE2 PurpleAir system reports mass concentration ($\frac{\mu g}{m^3}$), whereas the handheld instrument reports particle number counts. Under typical ambient conditions, higher PM2.5 mass should coincide with higher counts in the PM2.5 size range, but absolute values are not interchangeable because mass also depends on particle size distribution and density. In this study, the two series were compared using visual scaling rather than a calibration transfer; this supports qualitative alignment of temporal structure but does not place both datasets on a common scale.

Second, the temporal design and coverage impose constraints. Sampling windows were fixed to 8:00–8:30 a.m. and 6:00–6:30 p.m. to improve comparability across days, which limits inference about midday or nighttime conditions. Additionally, the study duration was a single spring term, providing a focused snapshot rather than a full seasonal cycle typical of the San Joaquin Valley (e.g., winter stagnation, wildfire smoke). Finally, the consistency of data collection varied on a small number of days, producing minor gaps in handheld coverage.

These limitations point directly to actionable refinements. Before making quantitative comparisons, both data streams should be expressed in the same unit. Two practical options are:

(1) a short co-location period at SE2 to derive a site-specific conversion factor that maps handheld particle counts to mass; and (2) a bin-based count-to-mass estimate that uses representative particle sizes and density, then is refined by co-location. Either approach keeps the strong agreement in timing while enabling quantitative estimates of concentration differences that can be compared with health guidelines. In parallel, expanding measurements across multiple seasons and deploying a small network of fixed sensors at key high-traffic locations (e.g., parking areas, residence halls, athletic fields, construction zones) would provide the spatial and temporal detail needed for routine decisions and clearer risk communication.

Conclusion

This study examined the representativeness of UC Merced's single fixed PurpleAir sensor by comparing its readings with mobile measurements collected across campus. The results indicate that a single background site near the Science and Engineering 2 (SE2) building is adequate for assessing temporal variation but may not capture the spatial heterogeneity in exposure across the campus. The significant concurrence in peaks and troughs between the SE2 mass concentration record and handheld number counts supports the role of a single node as a campus-level sensor, while weekday patterns and site contrasts demonstrate persistent microenvironmental variability around parking areas, building service zones, construction activity, and open landscaped spaces.

The significance is practical as well as scientific. Decisions about outdoor activity and risk communication benefit from knowing when conditions are shifting and where short-duration increases are most likely. Treating mass and number as complementary indicators allows for those decisions without imposing uncertain conversions; the approach used here delivers actionable insight while avoiding false precision.

Several limitations qualify inference. Sampling was confined to morning and evening windows; a small number of handheld days were missed; the observation period was a single spring term, and the two instruments reported different units without a calibration transfer. These factors constrain statements about magnitude and seasonality but do not alter the central interpretation.

Future work should extend the campaign in duration and coverage, conducting more frequent and wider mobile sampling across campus over multiple seasons, while placing both data streams on a common unit through co-location at SE2, or a bin-based count-to-mass estimate.

While the PurpleAir sensor offers insights into broad air quality trends, this study suggests that a single fixed unit may not be enough to capture the spatial variability of air pollution across the UC Merced campus. These findings emphasize the importance of expanding air monitoring efforts to include a distributed network of sensors, which would provide a more nuanced understanding of local exposure differences and ensure more comprehensive air quality assessments across campus.

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