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Real-time air monitoring of occupational exposures to particulate matter among hairdressers in Maryland: A pilot study

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Abstract

Hairdressers are exposed to particulate matter (PM), a known air pollutant linked to adverse health effects. Still, studies on occupational PM exposures in hair salons are sparse. We characterized indoor air PM concentrations in three salons primarily serving an African/African American (AA) clientele, and three Dominican salons primarily serving a Latino clientele. We also assessed the performance of low-cost sensors (uRAD, Flow, AirVisual) by comparing them to high-end sensors (DustTrak) to conduct air monitoring in each salon over 3 days to quantify work shift concentrations of $PM_{2.5}$, respirable PM (RPM), and PM_{10}. We observed high spatial and temporal variability in 30-min time-weighted average (TWA) RPM concentrations (0.18–5518 μg/m^3). Readings for the uRAD and AirVisual sensors were highly correlated with the DustTrak (R^2 = 0.90–0.99). RPM 8-hour TWAs ranged from 18 to 383 μg/m^3 for AA salons, and 9–2115 μg/m^3 for Dominican salons. Upper 95th percentiles of daily RPM exposures ranged from 439 to 2669 μg/m^3. The overall range of 30-min TWA $PM_{2.5}$ and PM_{10} concentrations was 0.13–5497 and 0.36-,541 μg/m^3, respectively. Findings suggest that hairdressers could be overexposed to RPM during an 8-hour shift. Additional comprehensive monitoring studies are warranted to further characterize temporal and spatial variability of PM exposures in this understudied occupational population.

KEYWORDS
hair salons, indoor air, low-cost sensors, particulate matter, PM10, PM2.5, respirable PM (RPM)

Practical implications

- We characterized indoor particulate matter (PM) concentrations in hair salons primarily serving a Black/Latino clientele and assessed the reliability of low-cost sensors to inform future studies.
- Hairdressers in the salons could be potentially overexposed to respirable particulate matter during an 8-hour shift based on current occupational exposure limits.
- Select low-cost PM sensors are more reliable than others and could potentially be used in future research studies.

- Study findings will allow us to better understand occupational exposures among workers in hair salons predominantly serving clients of Black African descent; and guide us to design future exposure and occupational epidemiologic studies as well as interventions in an effort to reduce workplace exposures and potential-related health risks.

1 | INTRODUCTION

Hair salon workers are occupationally exposed to a variety of indoor air pollutants, including particulate matter (PM) and volatile organic compounds (VOCs) which are generated from services like hair drying and flat ironing or emitted from hair products during hair treatments.[1-3] Many of these indoor pollutants have been previously linked to hormone disruption,[4] adverse coronary and respiratory symptoms (ie, asthma, allergies),[5,6] skin conditions,[7] cancer,[8] and reproductive effects.[9] Still, data on occupational exposures to particulate matter (PM) in hair salon settings remain sparse.[10,11]

Particle size is considered a key parameter to describe transport ability of PM in the atmosphere and/or deposition in the human respiratory system.[12] In the occupational health realm, respirable PM or RPM (ie, particles not otherwise regulated with aerodynamic diameter <4 micrometers [μm]) is the most widely used exposure metric.[13] Both regulatory and non-regulatory occupational exposure limits (OELs) have been established, including Permissible Exposure Limits (PEL) of 5 mg/m^3 (or 5000 $\mu g/m^3$) from the U.S. Occupational Safety and Health Administration (OSHA), and a threshold limit value (TLV) of 3 mg/m^3 (or 3000 $\mu g/m^3$) from the American Conference of Governmental Industrial Hygienists (ACGIH®). The OSHA-PEL also defines an action level of 2500 $\mu g/m^3$, as a reference value to which certain provisions of the proposed standards must be initiated, including periodic employee exposure measurements and training of employees.[14] Other particle sizes of interest which have been associated with adverse health effects include $PM_{2.5}$ (ie, aerodynamic diameters <2.5 μm) and PM_{10} (ie, aerodynamic diameters <10 μm). Currently, there are no occupational exposure guidelines for $PM_{2.5}$ and PM_{10}.

In a recent literature review conducted by our research team,[15] we reviewed studies on occupational chemical exposures in hair and nail salon workers to determine the state of exposure assessment research in recent years among these occupational populations. Our review did not only confirm that PM exposure assessment in hair salons is limited, but also that prior studies in these settings have focused primarily on Caucasian workers and in salons that primarily service a Caucasian clientele. No studies have examined indoor occupational exposures among minority hairdressers who predominantly serve clients of Black African descent (ie, African American, African, Afro Caribbean, Afro Latinas). This gap in the literature stands in contrast to rising concerns that workers in hair salons who predominantly serve women of color may experience elevated exposures to airborne pollutants, due to the chemical composition of hair products specifically marketed to this population.[16]

In the present pilot study, we sought to fill critical data gaps by characterizing the indoor air quality (IAQ) and concentrations of PM in hair salons predominantly serving clients of Black African/Latino descent by monitoring multiple PM metrics in real-time using state of the art and low-cost sensors. While the use of low-cost sensors for indoor or outdoor air pollutant monitoring has been steadily increasing, and tremendous efforts have been made in the past decade to improve the usability of these devices,[17-23] their reliability in research settings remains unclear.[24] Thus, as a secondary aim, we also sought to evaluate the performance of select low-cost sensors in our hair salon scenario to inform future studies.

2 | METHODS

2.1 | Hair salon identification and recruitment

Between December 2018 and July 2019, we recruited six hair salons primarily serving women of color in the Maryland/Washington DC metropolitan area, with assistance from our community partners, Centro de Apoyo Familiar/Center for Assisting Families (CAF) and the Health Advocates In-Reach and Research campaign (HAIR) network of the Maryland Center of Health Equity at the University of Maryland's School of Public Health. Further details on hair salon recruitment can be found in the Supporting information.

Among the six salons recruited, three served a primarily African American/Black clientele (referred to as salons A01, A02, A03). The three remaining salons primarily served a Latino/Dominican clientele (referred to as salons D01 D02 and D03). Salon owners provided written informed consent to participate in the study prior to any data and sample collection; and all study protocols were reviewed and approved by the University of Maryland Institutional Review Board.

2.2 | Study design

A total of four visits were required for each salon. We conducted the first visit prior to any environmental monitoring. During this visit, study staff administered a brief questionnaire to the hair salon owner to capture information on factors that could influence the indoor air quality within the salon, such as types of services provided, cleaning products used, and types of ventilation. Questionnaires were administered by trained bilingual study staff in English or Spanish based on the hair salon owners' preference.

During this first visit, we conducted a brief walk-through inspection and recorded information on factors that could impact indoor air quality, including building characteristics like material composition of the flooring and presence of windows and furniture. We also consulted with the salon owner and salon staff to identify two locations where air monitors could be placed in the subsequent monitoring study visit days (ie, days 2–4). We aimed to place air monitors in locations where we could capture the most representative air samples as well as variability in exposure within the salon while minimally disrupting the salons activities.

We conducted indoor air monitoring in each salon over the course of three days after the initial visit. Selection of monitoring days was based on input from the salon owners and their knowledge as to which days the salon typically experienced the greatest number of clients as 2 of the 3 sampling days were selected to reflect busy days with a large clientele to capture potential high-end exposures. Each salon had two monitoring stations (labeled as locations A and B) in order to capture spatial variability within the salon. These two selected locations were typically at different ends of the salon with each location in close proximity to hairdressers working in that area.

2.3 | Selection of PM sensors

We used one well-validated PM monitor as well as four commercially available low-cost sensors to measure particulate matter in real-time in each salon. The DustTrak (8530, TSI Incorporated) was used in the study as the primary reference or "gold-standard" monitor to measure RPM, $PM_{2.5}$, PM_{10}, and total PM concentrations in hair salons. The four low-cost sensor devices used in our sampling campaign included the following: one uRAD (model A3, Winsen ZH03A PM sensor Magnasci SRL, Romania. https://www.uradmonitor.com/uradmonitor-model-a3/), one AirVisual Pro (AVPM25b PM sensor, USA. https://www.iqair.com/us/air-quality-monitors/airvisual-pro/features), and two FLOW devices (first generation; Plume labs. https://plumelabs.com/en/flow/). All devices are equipped with a light-scattering laser-based PM sensor and have the capacity to measure $PM_{2.5,}$ while the Flow and the AirVisual have the additional capacity of measuring PM_{10}.

2.4 | Calibration of low-cost sensors

We performed a daily calibration of the low-cost sensors against the reference device (DustTrack), by co-locating all devices for 15 minutes before and 15 minutes after each 8-hour sampling period in each salon. For one salon (Salon A03), all instruments were placed side-by-side at one location for the duration of monitoring (ie, 8 hours for 3 days). This arrangement allowed us to increase the number of side-by-side points for validation of the low-cost sensors used.

2.5 | Air sampling protocols

We conducted air sampling in each of the six salons for 8 hours per workday, placing all air monitoring equipment at an approximate height of 1.5 m to capture contaminants that would be present at the breathing zone of the salon workers who typically stand when providing services. During sampling for all salons, one FLOW, AirVisual, and DustTrak were always located together in location A, while the other FLOW and the uRAD were placed in location B.

2.6 | Data cleaning and statistical analysis

We captured and coded all real-time measurement data using Microsoft Excel. We sorted questionnaire and air sampling data by salon ID, sampling date, and time. We evaluated the performance of all four low-cost sensors by comparing their real-time readings against all co-located DustTrak readings and calculating Pearson correlation coefficients and relative bias (Equation 1). A high correlation coefficient value and low absolute value of relative bias indicate good agreement in performance between the low-cost sensor and the DustTrak.

$$\text{relative bias}\,(\%) = \frac{\text{Concentration}_{\text{low - cost sensor}} - \text{Concentration}_{\text{DustTrak}}}{\text{Concentration}_{\text{DustTrak}}} \times 100\,\% \quad (1)$$

We limited comparisons between the DustTrak and low-cost sensors to $PM_{2.5}$ data because it was the only common metric among all the monitoring devices; this performance validation was performed on data obtained from one salon (A03) for 8-hour work shifts over three days. We calculated descriptive statistics for RPM concentrations and compared our findings to occupational guidelines when available. To visualize and compare the variability in PM concentrations between and within salons, we calculated 30-minute time-weighted average (TWA) for all DustTrak data and created heatmaps based on these TWA data. We used SAS 9.4 (SAS Institute Inc.) for all statistical analyses and generated figures using MATLAB R2019b (MathWorks, Inc.). To assess whether workers were overexposed to RPM, for each salon we calculated the upper 95th percentile (X_{95}) for each of the 8-hour TWAs estimated during each of the three sampling days,[25] and compared this statistic to the occupational exposure limits (OELs). The X_{95} value for each salon was calculated using Equation 2:

$$\text{Upper 95th percentile}\,(X_{95}) = e^{(\hat{\mu} + 1.65\hat{\sigma})} \quad (2)$$

where $\hat{\mu}$ is the mean of the natural log of the three 8-hour TWA values of a salon and $\hat{\sigma}$represents the standard deviation of the natural log of the three 8-hour TWA values of a salon.

3 | RESULTS

3.1 | Hair salon characteristics

The indoor environmental characteristics of the six hair salons monitored in this study are presented in Table 1. The size of salons ranged between 592 and 1890 ft^2, and the number of employees ranged from 4 to 13. The number of daily clients reported on busy days varied by salon, ranging from 10 to 25 in any given day. In addition, as shown in Table 1, the indoor environmental characteristics,

TABLE 1 Hair salon characteristics.

Salon ID	A01	A02	A03	D01	D02	D03
Basic Salon Information						
Type	African American salons			Dominican salons		
# of hair salon workers	7	5	4	4	13	4
# of daily clients reported on busy days	20–25	10–15	15–25	15–20	NA[a]	18–20
Salon size (ft^2)	1252	1890	1251	1000	1263	592
Salon layout	Partitioned (Individual rooms were used as workstations)	Open floor plan	Open floor plan	Open floor plan	Open floor plan	Open floor plan
Visit schedules						
Month	December	April	May	January	February	March
Days of the week monitored	Thursday, Friday, Friday	Wednesday, Friday, Saturday	Friday, Saturday, Saturday	Thursday, Friday, Saturday	Wednesday, Friday, Saturday	Wednesday, Friday, Saturday
Indoor air quality measures during the sampling period						
Temperature (°C)						
Mean (Range)	25.4 (23.4, 29.1)	23.1 (21.7, 24.3)	22.9 (20.1, 25.2)	23.5 (16.3, 28.6)	23.1 (20.6, 24.0)	22.5 (19.9, 25.3)
Humidity (RH%)						
Mean (Range)	43.1 (28.0, 56.0)	41.8 (31.0, 56.0)	49.7 (47.0, 53.0)	35.2 (18.0, 54.8)	33.9 (23.0, 46.2)	39.6 (26.2, 51.0)
CO_2 (ppm)						
Mean (Range)	1127 (680, 1541)	754 (536, 1089)	1008 (627, 1239)	687 (470, 1114)	871 (583, 1223)	943 (521, 1474)

[a]Information was not available for this salon.

including carbon dioxide, temperature, and relative humidity, did not vary greatly during sampling days. Mean room temperature was between 22.5 and 25.4°C, and mean relative humidity ranged between 33.9% and 49.7%. Mean carbon dioxide levels were between 687 ppm (Salon D01) to 1127 ppm (Salon A01). The overall range of carbon dioxide levels observed in our study was from 521 ppm (Salon D03 at 13:13 pm) to 1541 ppm (Salon A01 at 18:36 pm), suggesting reasonable ventilation in the salons at even the highest CO_2 levels observed. We generally observed weak correlations between CO_2 and PM concentrations (see Figure S1). In terms of sampling days, African American salons were monitored over 6 weekdays and 3 weekend days, whereas Dominican salons were monitored over 5 weekdays and 4 weekend days.

3.2 | Within-day, between-day, and between-salon variability in PM concentrations

Figure 1 displays the heatmap for the RPM data measured with the DustTrak in all salons. Heat maps for the $PM_{2.5}$ and the PM_{10} showed a very similar pattern (as observed in Figure 2: *Comparison of daily PM range among different exposure metrics*) and are not shown. As displayed in Figure 1, red represents high concentrations (ie, >316 μg/m^3), blue represents low concentrations (ie, <1 μg/m^3), and "X" indicates that no data were available. Overall, our data showed high temporal as well as spatial variability with RPM concentrations ranging between 0.2 and 5518 μg/m^3. Among the salons sampled, salon D01 had high RPM concentrations on all three sampling days, whereas the concentrations in the first two days of Salon A02 were relatively low. The day of the week also played an important role in PM concentrations. Within each salon, weekday concentrations (Wed-Fri) were usually lower than weekend concentrations likely due to higher salon traffic during weekend days (Sat). As an example, Salon A02 concentrations on Wednesday (daily average: 17.4 μg/m^3) and Friday (daily average: 78.1 μg/m^3) were an order of magnitude lower than on Saturday (daily average: 327.8 μg/m^3); and in Salon D02, we observed daily PM average to be 8.6 μg/m^3 on Wednesday, 163.4 μg/m^3 on Friday, and 241.1 μg/m^3 on Saturday. While the temporal pattern within each individual day also varied, in general, PM concentrations during the morning hours were usually lower than those observed at noon or later in the afternoons.

3.3 | DustTrak readings based on different exposure monitoring metrics

We found that the PM profiles were very similar among all three metrics ($PM_{2.5,}$ RPM, and PM_{10}) among African American salons (Figure 2A). PM data from the Dominican salons support this finding as well (Figure 2B).

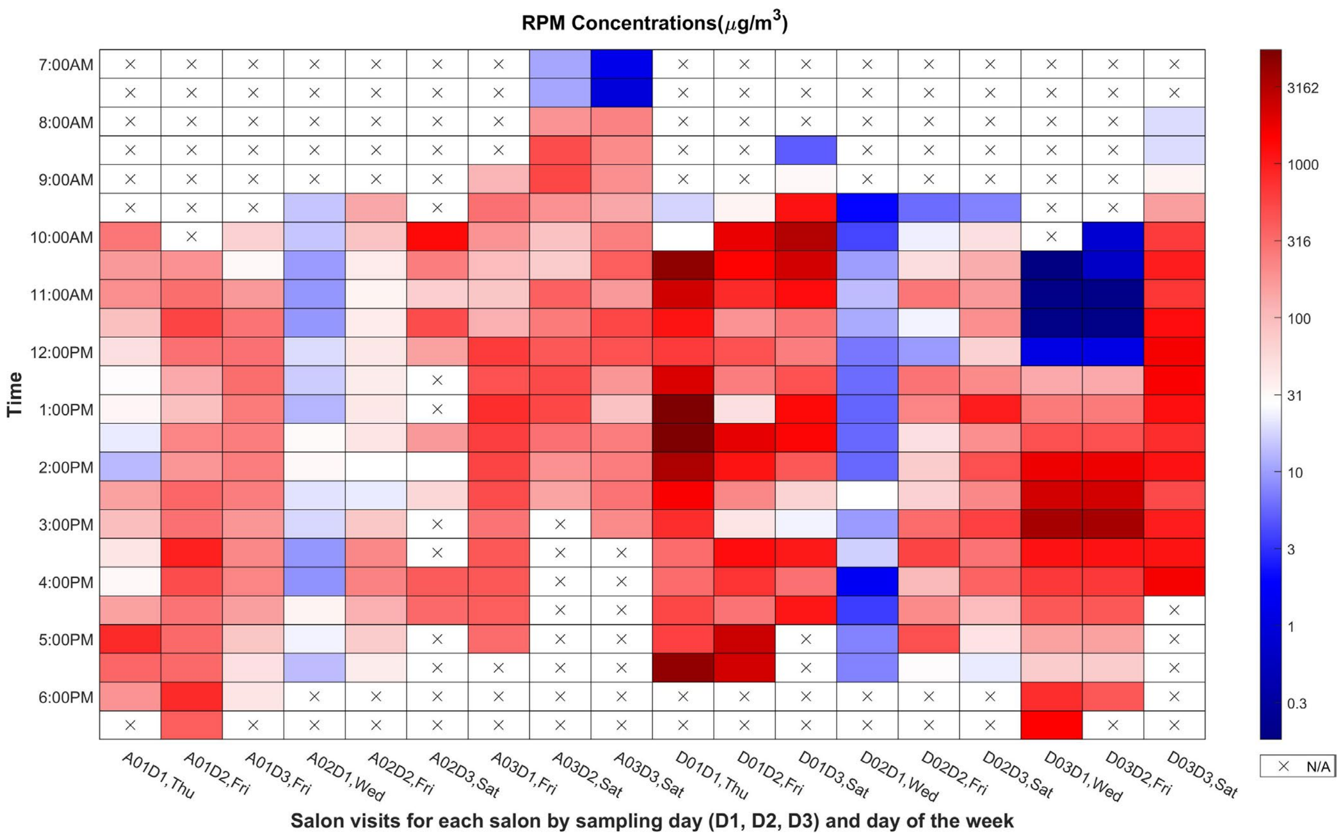


FIGURE 1 Heatmap plot of the 30-minute time-weight averaged (TWA) RPM concentrations across all hair salons and days (DustTrak data).

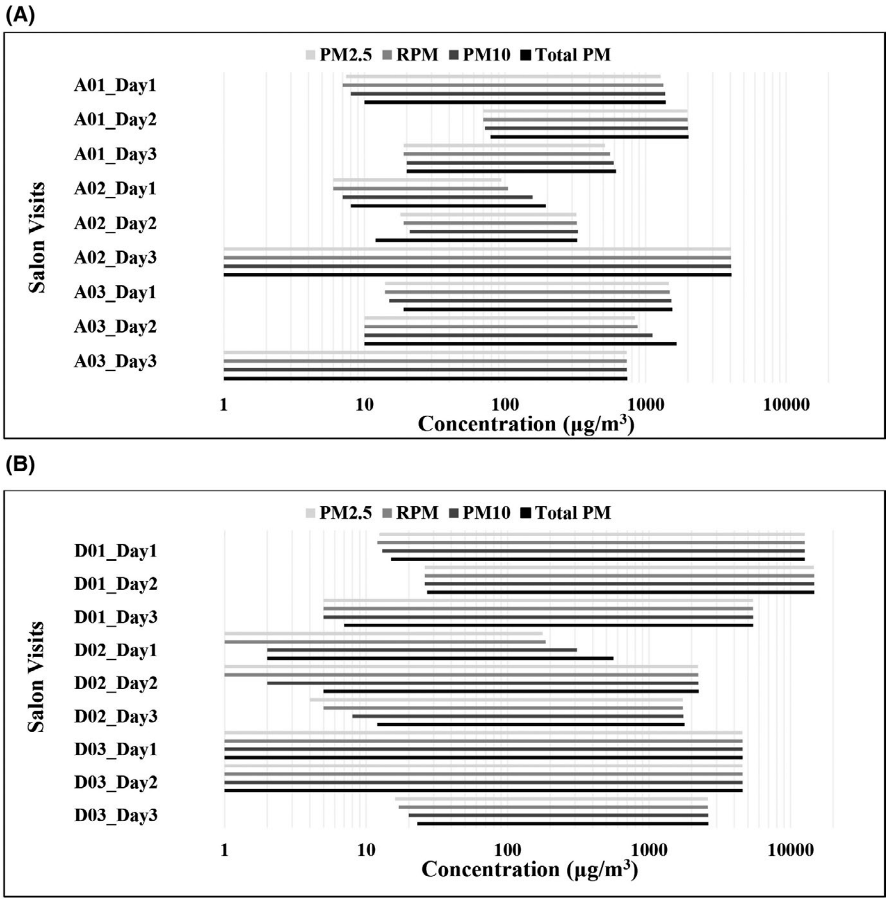
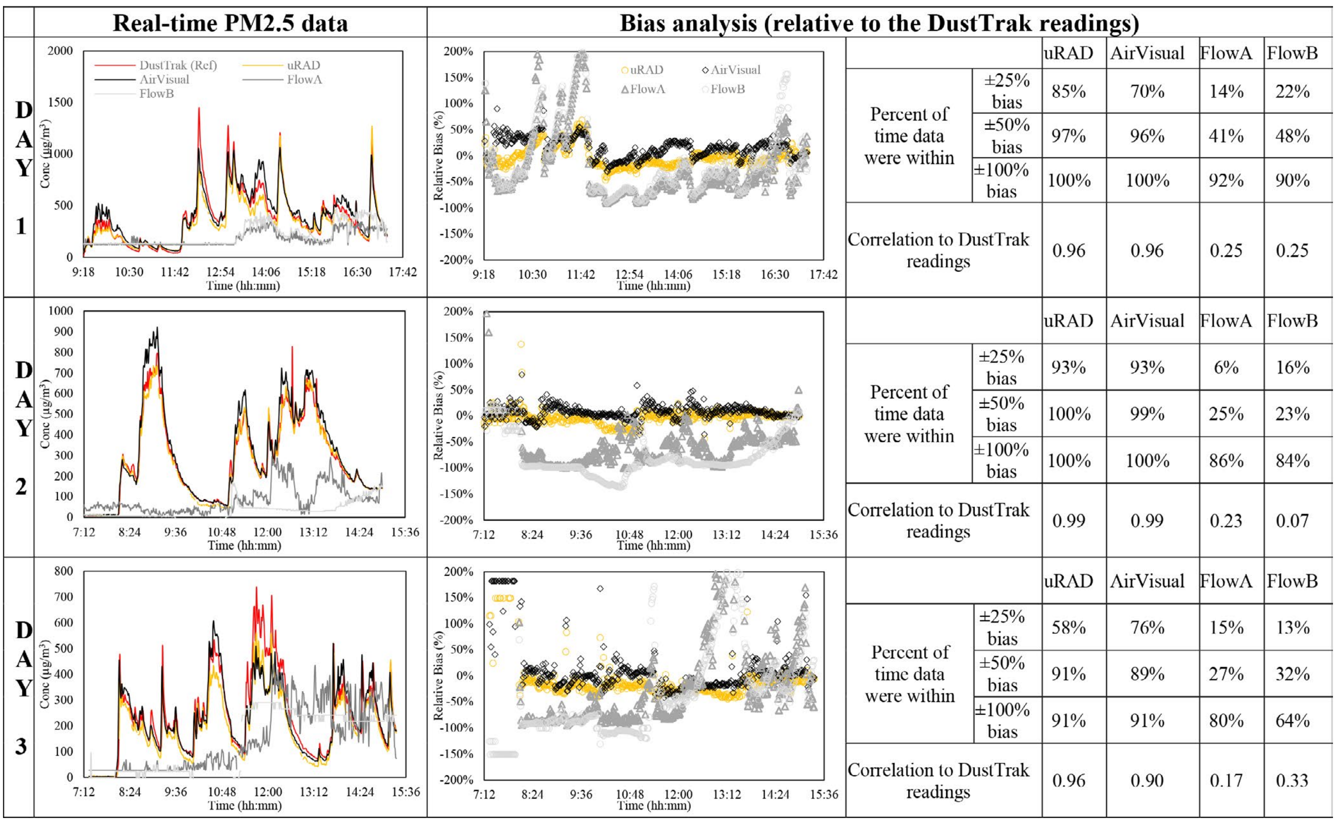


FIGURE 2 Comparison of daily PM range among different exposure metrics (a) African American salons (b) Dominican Salons.



		uRAD	AirVisual	FlowA	FlowB
DAY 1					
Percent of time data were within	±25% bias	85%	70%	14%	22%
	±50% bias	97%	96%	41%	48%
	±100% bias	100%	100%	92%	90%
Correlation to DustTrak readings		0.96	0.96	0.25	0.25
DAY 2					
Percent of time data were within	±25% bias	93%	93%	6%	16%
	±50% bias	100%	99%	25%	23%
	±100% bias	100%	100%	86%	84%
Correlation to DustTrak readings		0.99	0.99	0.23	0.07
DAY 3					
Percent of time data were within	±25% bias	58%	76%	15%	13%
	±50% bias	91%	89%	27%	32%
	±100% bias	91%	91%	80%	64%
Correlation to DustTrak readings		0.96	0.90	0.17	0.33

FIGURE 3 Comparison and bias analysis of the real-time PM2.5 readings from the low-cost sensors versus the DustTrak in Salon A03.

3.4 | DustTrak readings vs. low-cost sensor $PM_{2.5}$ readings

For Salon A03, all instruments were placed side-by-side at one location for the duration of monitoring (8 hours for 3 days). The comparisons between the co-located DustTrak and low-cost sensors data in this salon are displayed in Figure 3. Both time-series plots as well as our bias analyses suggest that the uRAD and AirVisual tracked well with the reference device during the entire 3-day sampling period. The Pearson correlation coefficient values between the uRAD and the reference concentrations in each of the 3 days were 0.96 (day 1), 1.00 (day 2), and 1.00 (day 3), respectively. Similarly, the Pearson correlation coefficient between the DustTrak and the AirVisual readings were 0.96 (day 1), 0.99 (day 2), and 0.90 (day 3), respectively. Both the uRAD and the AirVisual recorded all the peaks recorded by the DustTrak, and both uRAD and AirVisual tracked the DustTrak concentrations between 89% and 100% of the time, with bias values between −50% and 50%. Only 9% of the uRAD and AirVisual data fell outside of the ±100% bias range on day 3, and majority of these high biased values appeared in the morning time when the reference concentration values were very low. Thus, the impact expected from these values is expected to be negligible. Meanwhile, the bias analysis plots show that the bias values clustered around the center line (0%), suggesting that when we integrate these low-cost sensor data over time, the integrated results (time-weighted averages) could serve as unbiased estimates of our reference values.

Conversely, readings collected with both FLOW sensors did not correlate well with the DustTrak measurements (varied by day and device, but between-device correlation R^2 = 0.07–0.25). Our bias analysis results support this finding, in that the percentage of the data that fell within the ±50% bias range was 41% on day 1, 25% on day 2, and 27% on day 3 for "FLOW A" compared to 48% on day 1, 23% on day 2, and 32% on day 3 for "FLOW B," In terms of data reproducibility, FLOW A and FLOW B are the exact same model from the same manufacturer, but we did not see similar results from them for the majority of our monitoring campaign. In addition, the performance of the FLOWS varied throughout the day with similar readings observed during the morning hours and deviations from one another observed about 3.5 hours after the sensors were started.

3.5 | 8-hour Time-Weighted Averages (TWAs) for RPM in hair salons

As shown in Figure 4, all 8-hour TWAs calculated for RPM by day for each salon, (including respective X_{95} statistics) were below both OELs, but data showed high within- and between-salon variability. The range of 8-hour TWA values was between 18 and 383 μg/m^3 in African/African American salons and between 9 and 2115 μg/m^3 in Dominican salons. The X_{95} value of Salon D01 was 2669 μg/m^3, approaching the TLV and exceeding the action level (2500 μg/m^3). Also, all Dominican salons (D01-D03) had higher X_{95} values than any of the African/African American salons (A01-A03). Median 8-hr TWAs for RPM did not significantly differ between African/African American and Dominican salons (236 vs. 792 μg/m^3, p-value =0.18).

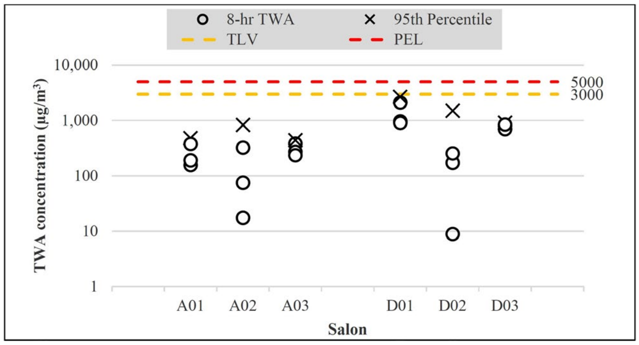


FIGURE 4 Respirable PM 8-hour TWA concentrations and OELs for each salon and sampling day.

3.6 | Comparison of 8-hour TWA $PM_{2.5}$ concentrations between two monitoring locations in each salon

Table 2 compares 8-hour TWA $PM_{2.5}$ concentration readings between monitoring Location A and Location B, for each study salon by visit day. Excluding the two FLOW devices, each salon had three real-time $PM_{2.5}$ measurements from two monitoring locations: DustTrak and AirVisual results for Location A and the uRAD results for Location B. For example, for salon A01 Day 2 (A01D2) at location A, we had two TWA $PM_{2.5}$ values: 366 and 422 μg/m^3, with the AirVisual resulted in TWAs that were 15% higher than those obtained with the DustTrak. At location B, the only $PM_{2.5}$ TWA measurement is 604 μg/m^3, which is about 65% higher than the DustTrak. In contrast, Salon A03 data suggest that a regular relative bias value between our low-cost sensor result and the DustTrak, when they were co-located, should be within ±20% level. Our Location B data, in some days and salons, exceeded the above deviation range. For example, the relative bias observed was 77% in D02D2 and 106% in D03D2, indicative of spatial variability in PM concentrations between hair salon spaces. PM measurements between these two monitoring locations were positively correlated (Pearson r = 0.38–0.94; further details on correlations are provided in the Supporting information).

4 | DISCUSSION

In the present study, we characterized indoor PM concentrations in hair salons primarily serving a Black/Latino clientele and assessed the reliability of low-cost sensors to inform future studies. Selection of these salons was based on rising concerns that workers in hair salons who predominantly serve a racially/ethnically diverse population may experience elevated exposures to indoor pollutants due to the chemical composition of hair products specifically marketed

TABLE 2 8-hour TWA $PM_{2.5}$ concentrations (μg/m^3) by monitoring locations.

Salon, Day	Location A (DustTrak)	Location A (AirVisual) [deviation from the DustTrak result]	Location B (uRAD) [deviation from the DustTrak result]
A01D1	154	194 [26%]	NA[a]
A01D2	366	422 [15%]	604 [65%]
A01D3	185	171 [−8%]	189 [2%]
A02D1	16	10 [−38%]	9 [−44%]
A02D2	73	83 [14%]	55 [−25%]
A02D3	310	NA[a]	NA[a]
A03D1	380	405 [7%]	335 [−12%] (Location A)
A03D2	271	296 [9%]	267 [−1%] (Location A)
A03D3	236	224 [−5%]	194 [−18%] (Location A)
D01D1	2,068	1641 [−21%]	NA[a]
D01D2	943	751 [−20%]	1106 [17%]
D01D3	886	904 [2%]	864 [−2%]
D02D1	8	3 [−63%]	1 [−88%]
D02D2	168	174 [4%]	39 [−77%]
D02D3	248	260 [5%]	181 [−27%]
D03D1	774	748 [−3%]	452 [−42%]
D03D2	684	1112 [63%]	1411 [106%]
D03D3	830	864 [4%]	685 [−17%]

[a]Low-cost sensors failed to record data on those days.

to this population.[16] During this investigation, we also assessed the reliability of low-cost sensors to measure $PM_{2.5}$ in research settings. We found that hairdressers in the salons sampled could be potentially overexposed to RPM during an 8-hour shift based on current occupational exposure limits and that some low-cost sensors were more reliable than others.

To our knowledge, only two other studies to date have assessed indoor PM concentrations in hair salon settings. One study conducted by Saraga et al.[10] evaluated personal exposures to RPM in several workplaces (eg, bars, schools, photocopy stores, taxis, malls, gyms, etc.) throughout Athens, Greece. Authors monitored PM levels in one hair salon and found that it had the highest average RPM concentrations (286 μg/m^3) as well as the lowest ventilation rates compared to the other workplaces sampled. In our study, we observed similar levels of RPM concentrations as those reported by Saraga et al.[10] The median concentration of all the 8-hour TWAs for RPM was 299 μg/m^3 in our study salons. Among all of our 8-hour TWAs for RPM, Salon D01 contributed all top three high values: 2115 μg/m^3 on a Thursday, and 965 and 907 μg/m^3 on the following Friday and Saturday, respectively. This salon was also the only one in our study for which its 95th percentile value (2669 μg/m^3) exceeded OSHA's action level of 2500 μg/m^3. According to the action level rule, certain activities such as exposure monitoring and medical surveillance would be required at workplaces where the action level is exceeded. In general, TWAs were higher in Dominican salons. Dominican salons, from our survey, performed more blow drying and flat ironing services which can produce PM, potentially explaining our findings. We also note that CO_2 levels observed in salons suggested adequate ventilation, providing further evidence that hair services and hair products in combination or alone may have resulted in higher RPM concentrations in some salons. For example, even though salon D01 generally had lower CO_2 concentrations compared to other salons, the highest RPM peak concentrations were observed in this salon indicating that factors other than inadequate ventilation may explain our findings. Another study by Nilsson et al.[11] measured PM_{10} and persulfate concentrations to which hairdressers are exposed to during hair bleaching sessions in a controlled setting. Authors reported that PM_{10} and super-coarse particles (>10 μm) were released during application of hair bleaching in a controlled chamber setting. In contrast, based on our analysis of DustTrak's three exposure metrics (RPM, $PM_{2.5}$, and PM_{10}), we can infer that PM in our study consisted mainly of fine particles ($PM_{2.5}$). In our study, the most frequently reported were the use of hair spray and hair dying, so it is plausible that these activities and services generate smaller particles compared to bleaching (see Table S1 for a list of activities and services performed during the monitoring period).

In the present study, we also tested three brands of PM low-cost sensors. Among these, we found that the uRAD and AirVisual were the sensors that better tracked with the reference device—DustTrak—during most of the sampling time. As shown in Figure 3, both the uRAD and the AirVisual recorded all the peaks also recorded by the DustTrak. The measurement bias of these two sensors relative to the reference measurement varied by day and time, but was within ±50% bias more than 90% of the time. This finding was consistent with the bias reported in a recent study.[26] In addition, the Pearson correlation coefficient values for measurements between the uRAD and the reference concentrations were between 0.96 and 1.00. Similarly, AirVisual readings were also highly correlated with the DustTrak readings (Pearson $R = 0.90–0.99$). The FLOW low-cost sensor, however, did not perform as well as the other sensors in our study (only between 25% and 48% of time within 50% bias). Select factors such as user error or device malfunction could have contributed to the low performance for the two FLOW units used in our study, so more testing is needed for this particular device before reaching a decision on its suitability for use in research studies. There has been a scientific debate over which sampling strategies are better—a small dataset of high-precision monitoring results from few high-end monitors or a large dataset of low-precision monitoring results from a group of low-cost sensors. Our study provides some real-world field monitoring data from both a high-end monitor and low-cost sensors. Additional studies to evaluate low-cost sensor performance in other occupational settings are recommended as the use of low-cost sensors is gaining increased attention and use in research, particularly in citizen science applications. To date, we know that there are several reliable PM low-cost sensors in the market, and that there are newer ones being deployed which still need further validation.[24] Additional studies are needed that include thorough validation tests of each of the sensors that reach the market and real-world validations in both low concentration and high concentrations scenarios.

Our pilot study had several limitations primarily related to restricted available resources. We were unable to place a larger number of monitoring devices to help us better characterize the spatial variability across the entire area of each hair salon. We were also unable to secure an additional reference monitor; thus, we relied on low-cost sensors to assess spatial variability. Furthermore, the number of salons sampled was small ($n = 6$); however, we were still able to conduct extensive monitoring over three days in each salon. Although it was part of our original study design to log salon activities in real time to try to correlate these with peaks in our measurements, we were not able to collect these data because study staff complained about headaches when monitoring in the salons at the beginning of the study. We also did not to ask participants to record this information as we felt it was disruptive to their workday activities. Future studies should consider recording salon activities in a manner that is not disruptive to salon workers or increases health risks to study staff such as by the use of a mobile application to collect data in real time to discern which salon activities contribute to higher PM concentrations in salon settings. Lastly, in the present study, we used CO_2 as a proxy for indoor air quality and ventilation. While many factors can affect CO_2 levels indoors, including occupancy, we were not able to capture these data to examine this further.

Notwithstanding the noted limitations, our study demonstrates that there is large PM spatial and temporal variability, there are differences in PM exposure between Dominican and African/African American salons, and that workers may be exposed to concentrations RPM levels close to the OSHA's Action Level. Additional strengths of our study include that we are the first to investigate occupational PM area exposures among hairdressers who predominantly serve clientele of Black African descent in the United States. The exposure information collected in our study is unique as there are rising concerns that products marketed to this population could contain toxic chemicals, and hairdressers who serve this clientele may experience high occupational PM exposures. We also explored the reliability of three low-cost sensor-based PM monitors in occupational settings, providing valuable data to inform future studies.

In summary, our findings suggest that all study salons had a thermally comfortable indoor environment with sufficient ventilation and that the majority of PM observed included small particles with diameters <2.5 μm. We also found that compared to a reference monitoring device, some low-cost sensors could provide reliable time resolved and time-weighted average PM results with minimal bias, while others may require additional calibrations and validation. Moreover, our study results indicate that hairdressers primarily serving a Black and Latino clientele could be potentially exposed to RPM concentrations above occupational exposure limits. While we generally observed adequate ventilation in the salons monitored, PM levels were sometimes high—approaching PELs and TLVs. While levels were below regulatory limits, they were high enough to indicate potential exposure exceedances for hairdressers in similar salons. Larger studies are needed to further assess spatial and temporal variability of PM and other indoor pollutants.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTION

Yuan Shao involved in formal analysis (lead), methodology (lead), visualization (lead), writing the original draft (lead). **Lucy Kavi** involved in data curation (lead), data cleaning (equal), data collection (equal), writing, reviewing and editing (equal). **Meleah Boyle** involved in data curation (equal), investigation (equal), data cleaning (equal), data collection (equal), generation of study instruments (equal); project administration (equal), writing, reviewing, and editing (equal). **Lydia Louis** involved in project administration (equal), and writing, review and editing (lead). **Walkiria Pool** involved in project administration (equal) and resources (lead). Stephen Thomas involved in resources (equal). **Sacoby Wilson** involved in resources (equal) and generation of study instruments (equal). **Ana María Rule** involved in conceptualization (equal), resources (equal), supervision (equal), writing, reviewing and editing (equal), generation of study instruments (equal), and methodology (equal). **Lesliam Quiros-Alcala** involved in conceptualization (lead), funding acquisition (lead), investigation (equal), methodology (equal), project administration (lead), generation of study instruments (lead), resources (equal), supervision (lead), writing, reviewing, and editing (equal).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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