Personal exposure monitoring of $PM_{2.5}$ by US diplomats in Kathmandu during the COVID-19 lockdown, March-June 2020

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Highlights:

- Ambient $PM_{2.5}$ in Kathmandu was approximately 40% lower during COVID-19 lockdown in 2020 than in the same period of the previous three years
- Reduction in personal $PM_{2.5}$ exposure during the lockdown reflect altered activity patterns and lower $PM_{2.5}$ in selected microenvironments
- Time spent outdoors and cooking at home were large contributors to personal exposure to $PM_{2.5}$ for some diplomats
- Exposure to $PM_{2.5}$ in indoor environments was very low due to apparent effectiveness of room air cleaners and sealing windows and doors
- The home environment represented an important source of exposure for one diplomat despite extensive mitigation measures

ABSTRACT

The 2019 Novel Coronavirus SARS-CoV 2 (COVID-19) pandemic has severely impacted global health, safety, economic development and diplomacy. The government of Nepal issued a lockdown order in the Kathmandu Valley for 80 days from 24 March to 11 June 2020. This paper reports associated changes in ambient $PM_{2.5}$ measured at fixed-site monitors and changes in personal exposure to $PM_{2.5}$ monitored by APT *Minima* by four American diplomats who completed monitoring before and during lockdown (24 hours for each period per person, 192 person-hours in total). Time activities and use of home air pollution mitigation measures (use of room air cleaners (RACs), sealing of homes) were recorded by standardized diary. We compared $PM_{2.5}$ exposure level by micro-environment (home (cooking), home (other activities), at work, commuting, other outdoor environment) in terms of averaged $PM_{2.5}$ concentration and the contribution to cumulative personal exposure (the product of $PM_{2.5}$ concentration and time spent in each microenvironment). Ambient $PM_{2.5}$ measured at fixed-sites in the US Embassy and in Phora Durbar were 38.2% and 46.7% lower than during the corresponding period in 2017-2019. The mean concentration of $PM_{2.5}$ to which US diplomats were exposed was very much lower than the concentrations of ambient levels measured at fixed site monitors in the city both before and during lockdown. Within-person comparisons suggest personal $PM_{2.5}$ exposure was 50.0% to 76.7% lower during lockdown than before it. Time spent outdoors and cooking at home were large contributors to cumulative personal exposure. Low indoor levels of $PM_{2.5}$ were achieved at work and home through RACs and measures to seal homes against the ingress of polluted air from outside. Our observations indicate the potential reduction in exposure to $PM_{2.5}$ with large-scale changes to mainly fossil-fuel related emissions sources and through control of indoor environments and activity patterns.

Keywords

Air Quality, $PM_{2.5}$, Personal monitoring, COVID lockdown, Mitigation, Room air cleaners, Kathmandu

1. INTRODUCTION

The association between fine particulate matter smaller than 2.5 μm ($PM_{2.5}$) and multiple health conditions, including cardio-respiratory disease and premature mortality, is well-established (Cohen et al., 2017; Liu et al., 2019). An individual's personal exposure to $PM_{2.5}$ arises from the time and activity he/she spends in a multitude of different micro-environments throughout the day. COVID-19 restrictions are likely not only to have altered the concentrations of $PM_{2.5}$ and other pollutants in many such environments but also time-activity patterns. There have been many reports about improvements in air quality during COVID-19 restrictions in the US, China, Malaysia, Europe and elsewhere (Berman & Ebisu, 2020; Chen, Wang, Huang, Kinney, & Anastas, 2020; Giani et al., 2020; Kanniah, Kamarul Zaman, Kaskaoutis, & Latif, 2020; Kumari & Toshniwal, 2020). In this paper we report on changes in outdoor $PM_{2.5}$ in Kathmandu, Nepal, as well as personal exposures of four diplomats who remained in the city during a period of COVID-19 restrictions (a 'lockdown') from 24 March to 11 June 2020 imposed by the government of Nepal (United States Embassy in Nepal, 2020).

During the lockdown, schools, all non-essential government and private offices were ordered to close, and many activities were restricted or suspended (as described in Supplement Table A.1). Essential services that remained open included those relating to health care services, food stores, electricity supplies, fuel services, telephone services, transportation and National defense offices. In accordance with local recommendations, the US Embassy in Kathmandu moved to limit personal activities to 'mission critical' only. Staff were advised to work from home where possible. Four of those staff recorded their personal exposure to $PM_{2.5}$ before and during the COVID-19 lockdown. It is the analysis of data from this monitoring as well of two fixed-site outdoor $PM_{2.5}$ monitors that we now report.

2. MATERIALS AND METHODS

2.1 Fixed Site Ambient Air Quality Monitoring

Ambient $PM_{2.5}$ exposure level was measured by two Fixed Site Ambient Air Quality Monitoring stations (beta attenuation monitors, BAMs) supported by the US Embassy and located at: the Embassy grounds at Maharajhung Road in Chakrapath and the Phora Durbar Recreation Center for the Embassy staff in the Thamel neighborhood, approximately 3 miles (4.5 kilometers) from the Embassy (Figure A.1). The Thamel area has heavy road traffic while the US Embassy is located in an area of relatively low population density and vehicular traffic. Data monitoring at both sites began on February 21, 2017 and the $PM_{2.5}$ concentrations are reported as hourly averages of 15-minute sampling (United States Environmental Protection Agency, 2020). The monitoring equipment is maintained and calibrated by US Embassy staff in conjunction with the standard operating procedures of the US Environmental Protection Agency (EPA) for $PM_{2.5}$ monitoring (United States Environmental Protection Agency, 2020). Data used in this study are publicly available at the Air Now website (https://www.airnow.gov/).

2.2 Personal Exposure Monitoring

In September 2019, we recruited US Embassy staff and family members in Kathmandu to a personal monitoring study of exposure to $PM_{2.5}$, with the intention to ask each participant to undertake monitoring for at least 48 hours in each of four three-month periods (‘seasons’) over the following year. However, of the 30 original recruits, many left Kathmandu because of COVID-19. But four of those who remained completed a two-day period of personal monitoring both before and during the lockdown (24 March to 11 June 2020) using an *APT Minima* optical personal exposure monitor (Applied Particle Technology, 2020; Li, 2020) (Figure A.2). The sampling interval for this monitoring was set at 15 seconds and the sampling volume to 0.1 liters air/minute. The *APT Minima* reports $PM_{2.5}$, PM_{10}, PM_1, number concentration in 6 size bins (0.3 to > 10 µm), as well as temperature and humidity for each sampling interval. Periods of monitoring with >30% missing data were excluded from the analysis. Each participant also recorded time-activity patterns for the periods of monitoring using a standardized diary which records time, location, activity and behavior including cooking, commuting, outdoor exercise and the use of RACs. They also completed a questionnaire about efforts to seal the home against the outdoor air and sources of air pollution inside the home.

Two methods were used to check the validity and accuracy of the personal monitoring data:

(1) Periodic co-location of each of the *APT Minima* personal monitors next to the US Embassy's BAM for short periods of side-by-side monitoring. Between September 2019 and June 2020 such co-located monitoring was carried out on four occasions of at least one hour for each monitor. On each occasion, the mean difference between the BAM and Minima monitors was less than the manufacturer's threshold for recalibration. .

(2) Permanent co-location of an APT *Maxima* stationary air quality monitor next to the US Embassy's beta attenuation monitor (BAM-120, MetOne) in Phora Durbar, to track the sensor calibration for local ambient aerosols (Li, 2020). The *Maxima* has the same monitoring technology as the *Minima* used for personal monitoring but is surrounded with a durable, weather resistant exterior case. Comparison of APT *Maxima* with the BAM data showed a regression slope of 0.98, R-value of 0.9429 (Figure A.3).

(3) <GEMMA DATA>

The four study participants (referred as K1, K2, K3 and K4) who carried out personal monitoring lived within one mile (1.5 kilometers) of the US Embassy (Figure A.1). Demographic information and characteristics of the home, including RAC use and other indoor air pollution mitigation activities are included in Table A.2. Participants had six (K4) to eleven (K1) Blueair RACs in their home, with a mixture of Blueair 205 (small) and Blueair 605 (large) models (Table A.2). All participants kept their RACs turned on during the monitoring period. Three participants kept their RACs on the highest available setting ("high") while one participant (K3) kept their RACs on the "medium" setting. Participants K1 and K4 took extra measures to seal their home to limit the inward flow of ambient air pollution, either by adding caulk paste and tape to windows and using door snakes at the base of exterior doors (K1) or by sealing windows and unused exterior doors with plastic sheeting and tape (K4).

2.3 Room air cleaners (RACs)

All US Embassy diplomats and family members benefited from air purification both at the Embassy and at home. US Diplomats are provided with Blueair RACs for their homes, the number and models of which are based on the number of people occupying the home, the size of the home, and the year the employee arrived in Nepal. Families could request additional RACs if they had children in the household, have health conditions exacerbated by air pollution or other concerns about indoor air quality in their home. Blueair RAC model 205 has a certified clean air delivery rate (CADR) of 180 cubic feet per minute with five air changes per hour and the Blue Air RAC model 605 has a CADR of 500 cubic feet per minute with five air changes per hour. American families are advised to change the filter in their RAC once every six months and filters are provided by the US Embassy. Families have the option of sealing their windows and doors with plastic and duct tape or with caulk paste in order to limit inward flow of air pollution.

2.4 Analysis

To assess the influence of the COVID-19 restrictions on ambient $PM_{2.5}$ concentration during the period of COVID-19 restrictions, daily and hourly mean concentrations were compared with that observed in the same period (i.e. 24 March to 11 June) of preceding three years, 2017 to 2019. The differences were tested using the Kruskal-Wallis test.

For personal monitoring, the assignment of micro-environments to $PM_{2.5}$ measurements were determined from the time-activity diary and *APT Minima*-recorded GPS location, when available. We used five microenvironment-activity categories: home (cooking), home (other activities), inside the US Embassy, commuting by car and other outdoor environment (including restaurants, hotels or shops). The occupancy time and averaged $PM_{2.5}$ concentrations were computed by micro-environment using measurement recorded for whole day. The contribution of each microenvironment to cumulative personal exposure ($\mu g/m^3$*hours) was computed by the product of occupancy time and hourly $PM_{2.5}$ concentration.

The study was approved by the US Department of State's Human Subjects Protection Committee and by the London School of Hygiene and Tropical Medicine's Research Ethics Committee.

RESULTS

3.1 Ambient $PM_{2.5}$

Ambient concentrations of $PM_{2.5}$ varied substantially across the year, both at the US Embassy monitoring site and at the Phora Durbar Complex, but levels were appreciably lower in the period of COVID-19 restrictions (24 March to 11 June 2020) compared with the corresponding period in each of the preceding three years (Figure 1). At the Embassy location, the period mean was 32.6 $\mu g/m^3$ (SD 27.7 $\mu g/m^{-3}$) in 2020 compared with 53.1 $\mu g/m^3$ (SD 36.1 $\mu g/m^3$) for 2017-2019 ($p < 0.0001$, Kruskal-Wallis). This represents a reduction of 38.2%. The corresponding figures for Phora Durbar were 33.2 $\mu g/m^3$ (SD 21.6 $\mu g/m^3$) in 2020 *vs* 62.3 $\mu g/m^3$ (SD 18.8 $\mu g/m^3$) in 2017-2019; ($p < 0.0001$, Kruskal-Wallis), a 46.7% reduction. The distributions of ambient $PM_{2.5}$ concentrations monitored at the Embassy and at Phora Durbar are summarized by year in Supplement Table A.3.

The diurnal variation in both locations was also altered in the period of full COVID-19 restrictions compared with the corresponding period of the previous three years. At the Embassy location, there was a relatively pronounced peak (from a lower baseline) between 7 and 10 am in 2020 but a smaller evening rise than seen in the previous years (Figure 2).

At the Phora Durbar Complex, the reduction in levels in 2020 was fairly consistent across the day.

3.2 Personal monitoring

In total, 22,821 $PM_{2.5}$ measurements were recorded in 196 person-hours for the four study participants, including 11,406 measurements in 96 hours recorded before the COVID-19 restrictions and 11,415 measurements recorded in 96 hours during the period of restrictions.

During the lockdown, the mean $PM_{2.5}$ concentration for the period of monitoring for the four study participants ranged from 0.1 $\mu g/m^3$ (K2) to 3.8 $\mu g/m^3$ (K1) – Table 1. The percent change in personal exposure compared to pre-lockdown was -51% for K1, -50% for K2, -76% for K3 and -77% for K4. Corresponding ambient $PM_{2.5}$ monitoring data at the US Embassy monitoring site for the same days during lockdown ranged from 14.6 $\mu g/m^3$ (K3) to 22.0 $\mu g/m^3$ (K1). The changes in outdoor levels compared with pre-lockdown were: -46% for K1 days of monitoring, -63% for K2 days, -79% for K3 days and +11% for K4 days.

The time spent in different environments was different during the period of lockdown compared with before it (Figure 3). During the period of full COVID-19 restrictions, all participants spent a majority of their monitored hours (range: 13 to 23.85 hours) inside their home (Figure 3). Consistent with advice, each participant spent less time at the Embassy (though K1 had no recorded time at the Embassy in either period). Both K3 and K4 worked in the Embassy during the lockdown but spent fewer hours there than they did before the lockdown. The proportion of time spent at home was higher for all four participants during the COVID-19 restrictions, but two participants, K1 and K4, spent slightly longer at non-commuting outdoor locations during the period of COVID-19 restrictions and the two who cooked at home, K1 and K3, cooked for slightly less time than before the lockdown.

It is difficult to compare concentrations of $PM_{2.5}$ in the different micro-environments directly because of the seasonality of outdoor concentrations. Personal monitoring levels at outdoor locations – commuting, commercial business locations and other outdoor locations – were all lower during the period of COVID-19 full restrictions and to an extent greater than the average reduction in the fixed site monitoring data (Figure 4A). This may reflect differences in local sources of emissions in areas where people spend time as opposed to the change in 'urban background' at the fixed site monitors. However, there was an enormous range (0 μg/m^3 indoors at the US Embassy and at home when not cooking to 319 μg/m^3 at home while cooking) in the concentrations of $PM_{2.5}$ in different micro-environments at different times (Table 1).

Participant K2 had the lowest mean $PM_{2.5}$ concentration at home, excluding time spent cooking – 0.1 μg/m^3 both during and before lockdown. K2 sealed their windows and unused exterior doors with plastic sheeting and tape, and had nine RACs in use in the home and the smallest size home among the 4 participants (1,680 ft^2).

K4 had the highest mean $PM_{2.5}$ in the home environment which reduced by from 11.4 μg/m^3 prior to the lockdown to 1.5 μg/m^3 during the lockdown, a decrease of 86%, compared to a decrease of only 11% in the ambient hourly $PM_{2.5}$ measured at the US Embassy. K4 sealed their home with plastic sheeting and tape in January 2020, prior to the COVID-19 lockdown.

The indoor environments of the Embassy and at home for each participant except K4 had generally very low levels of $PM_{2.5}$ except during periods of cooking which generated ambient levels at home appreciably higher on average than in any outdoor environment, including while commuting.

The impact of these changes on day-average cumulative exposure is shown in Figure 4B and Table 4.B. All participants had lower day-average cumulative $PM_{2.5}$ exposure during the COVID-19 restrictions which is attributable to spending less time outdoors and to reduced concentrations of $PM_{2.5}$ in the same environments (Table 2). Participant K2, who spent very little time outdoors and who had very low levels of $PM_{2.5}$ at both the Embassy and home environments, had very low levels of day average $PM_{2.5}$ exposure by comparison with other participants, all of whom had substantial exposure from periods outdoors in commuting and/or non-commuting activities or from relatively high levels in the home (participant K4). The differences in exposure on the basis of these selective days of monitoring was more than an order of magnitude between the least (K2) and most (K4) highly exposed individual both before and during the period of COVID-19 restrictions.

Personal monitoring tracings for participant K4 both before and during the COVID-19 lockdown are shown in Figure 5. Participant K4 worked at the US Embassy and usually walked to work. During personal monitoring on 2 June 2020 (during COVID-19 restrictions), their mean hourly $PM_{2.5}$ concentration was 2.3 $\mu g/m^3$, which was 84.3% lower than the mean hourly ambient $PM_{2.5}$ concentration measured at the US Embassy's fixed site monitor of 14.6 $\mu g/m^3$ (Table 1). The tracing for this day, Figure 5A, shows that cooking at home and walking to and from work contributed 76% and 24%, respectively, to their cumulative exposure for the day. This contrasts with pre-restriction measurements on 14 January 2020, when cooking at home, walking to and from work, and outdoor exercise contributed 32%, 57% and 11%, respectively, to the cumulative day total. In both of these monitoring sessions, participant K4 had six RACs in their home including one Blueair 605 RAC and five Blueair 205 RACs and they placed at least one RAC their living room, bedroom and kitchen. Windows in their home are not sealed shut and they occasionally kept their front door ajar during the daytime.

3. DISCUSSION

In this paper, we provide evidence of the impacts of activity restrictions during the COVID-19 pandemic on personal exposure to $PM_{2.5}$ of four embassy staff based in Kathmandu as well as changes in outdoor $PM_{2.5}$ concentrations. This evidence shows appreciable reductions in both outdoor $PM_{2.5}$ levels and in personal exposure, with the reduction in personal exposure being due to altered activity patterns as well as to the reduced concentrations in various micro-environments. It also provides important evidence about the apparent effectiveness of indoor air filtration combined with anti-infiltration home sealing measures in reducing $PM_{2.5}$ in the home environment.

Ambient concentrations of $PM_{2.5}$ from the fixed-site monitors at the US Embassy and in Phora Durbar were 40% and 47% lower during the period of full COVID-19 restrictions than in the corresponding period of the preceding three years. These changes in ambient levels are somewhat larger than those reported in a study of the change in air quality in 50 capital cities during the first month of lockdown (Rodriguez-Urrego & Rodriguez-Urrego, 2020) which reported a mean decrease of 12% in ambient $PM_{2.5}$ levels (though an increase in ambient $PM_{2.5}$ in Kathmandu). Our observed changes were more similar to those reported in a large-scale study using satellite-level data and more than 10,000 air quality stations which suggested that COVID-19 restrictions were associated with a 31% decrease in $PM_{2.5}$ (95% CI: 17-45%) (Venter, Aunan, Chowdhury, & Lelieveld, 2020), and with a study in New Delhi, India, which found a 39% decrease in $PM_{2.5}$ during the first six weeks of lockdown compared to the same period in 2019 (Mahato, Pal, & Ghosh, 2020).

The reductions we observed for Kathmandu reflect the decrease in economic activity, traffic volumes and the temporary closure of selected industries, although traffic density and source apportionment data would be helpful to better understand the contribution of changes in specific emission sources. An important local source of particle pollution that remained operational during the lockdown was brick manufacturing (Anonymous, 2020; Eli, 2020) and emissions from this source as well as forest fires near Kathmandu may have contributed to the initially high levels of ambient $PM_{2.5}$ in April of that year (Gurung, 2020) before the subsequent decrease in ambient levels as precipitation increased.

Participants had mean concentrations of $PM_{2.5}$ that were 50.0% to 76.7% lower than their own mean hourly concentration prior to lockdown and 82.7% to 99.4% less than the mean hourly ambient $PM_{2.5}$ measured at the US Embassy's fixed site monitor. This low exposure compared with ambient levels reflects the fact that American Embassy staff spent much of their day in indoor environments (at home and at work) where $PM_{2.5}$ concentrations were very low because of the use of high quality RACs and, in some cases, the sealing of homes to the ingress of polluted air from outside by use of plastic sheeting, tape and caulking. Three of four participants reduced their time spent outdoors by 50% during the lockdown while the fourth participant increased their time outdoors by just 15 minutes. This reduction in time outdoors, decreased ambient $PM_{2.5}$ during the lockdown period compared to the monitoring period before COVID-19, and the reduction in indoor $PM_{2.5}$ were responsible for the decrease in personal exposure.

There are several limitations to the study, many of which directly relate to the restrictions of COVID-19: limited monitoring because of the return of many participants to the US and difficulty delivering equipment to participants homes during the lockdown; the absence of data on changes in specific emissions sources, including traffic volumes, that would be helpful in understanding the source contributions to changes in ambient levels; and the fact that we had measurements of only $PM_{2.5}$ concentrations and not of other pollutants or of indoor CO_2 levels. As homes were tightly sealed to reduce the indoor $PM_{2.5}$, there is potential that the concentration of other pollutants derived from indoor sources might increase but data are not available to inform conclusions about ventilation and indoor pollutant levels more generally. This is important because US Embassy staff spend much of their time indoors. While the air inside the US Embassy and many homes is highly filtered, this does not control all pollutants of potential concern to health. Additional studies with a greater number of participants are needed, including of Kathmandu residents who do not have the large number of RACs and other mitigation activities in place in their homes.

4. CONCLUSIONS

COVID-19 restrictions in Kathmandu were associated with substantial reductions in ambient concentrations of $PM_{2.5}$ and with large reductions in the personal exposure to $PM_{2.5}$ of US diplomats, due to both altered activity patterns (with less outdoor activity during lockdown) and lower $PM_{2.5}$ concentrations in many microenvironments. The mean concentration of $PM_{2.5}$ to which US diplomats are exposed is very much lower than the concentrations of ambient levels measured at fixed site monitors in the city, reflecting the high proportion of time they spend in indoor environments with low $PM_{2.5}$ concentrations due to use of room air cleaners and sealing of homes against the ingress of polluted air. However, cooking at home was a leading contributor to personal exposure to $PM_{2.5}$, along with time spent outdoors in commuting or at other locations. Our observations indicate the potential reduction in exposure to $PM_{2.5}$ with large-scale changes to mainly fossil-fuel emissions sources and through control of indoor environments and activity patterns.

CRediT Author Statement

Leslie Edwards: Conceptualization, Data curation, Writing – Original draft preparation**, Ai Milojevic:** Supervision, conceptualization, Writing – review and editing**, Gemma Rutter:** Project administration, Data curation**, Leslie Iverson:** Project Administration, writing **–** review and editing**,** **Laura Wilson:** Data curation**, Tandeep Chadha:** Software, Methodology, Writing – review and editing**,** **Paul Wilkinson:** Formal analysis Supervision, Data curation, conceptualization, Writing – review and editing**.**

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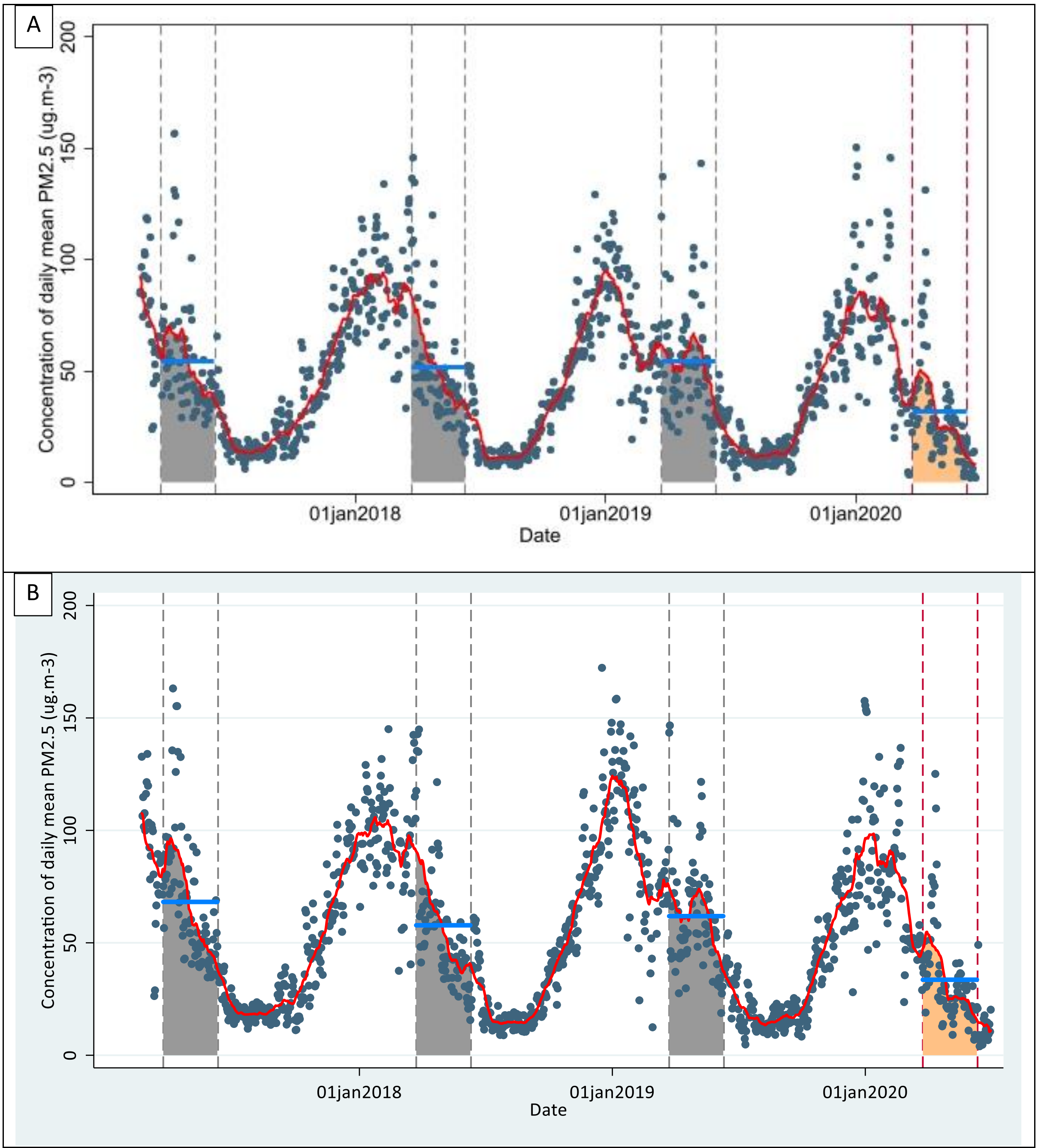

Figure 1. Monitoring data for ambient $PM_{2.5}$ at [A] the US Embassy and [B] the Phora Durbar Recreational Complex, Kathmandu, 2017-2020. Blue dots represent daily means, the red line is the 31-day moving average and the vertical dashed lines and shading indicate 24 March to 11 June corresponding to the period of full COVID-19 restrictions in 2020. The blue bars represent the mean of the $PM_{2.5}$ concentrations in this period.

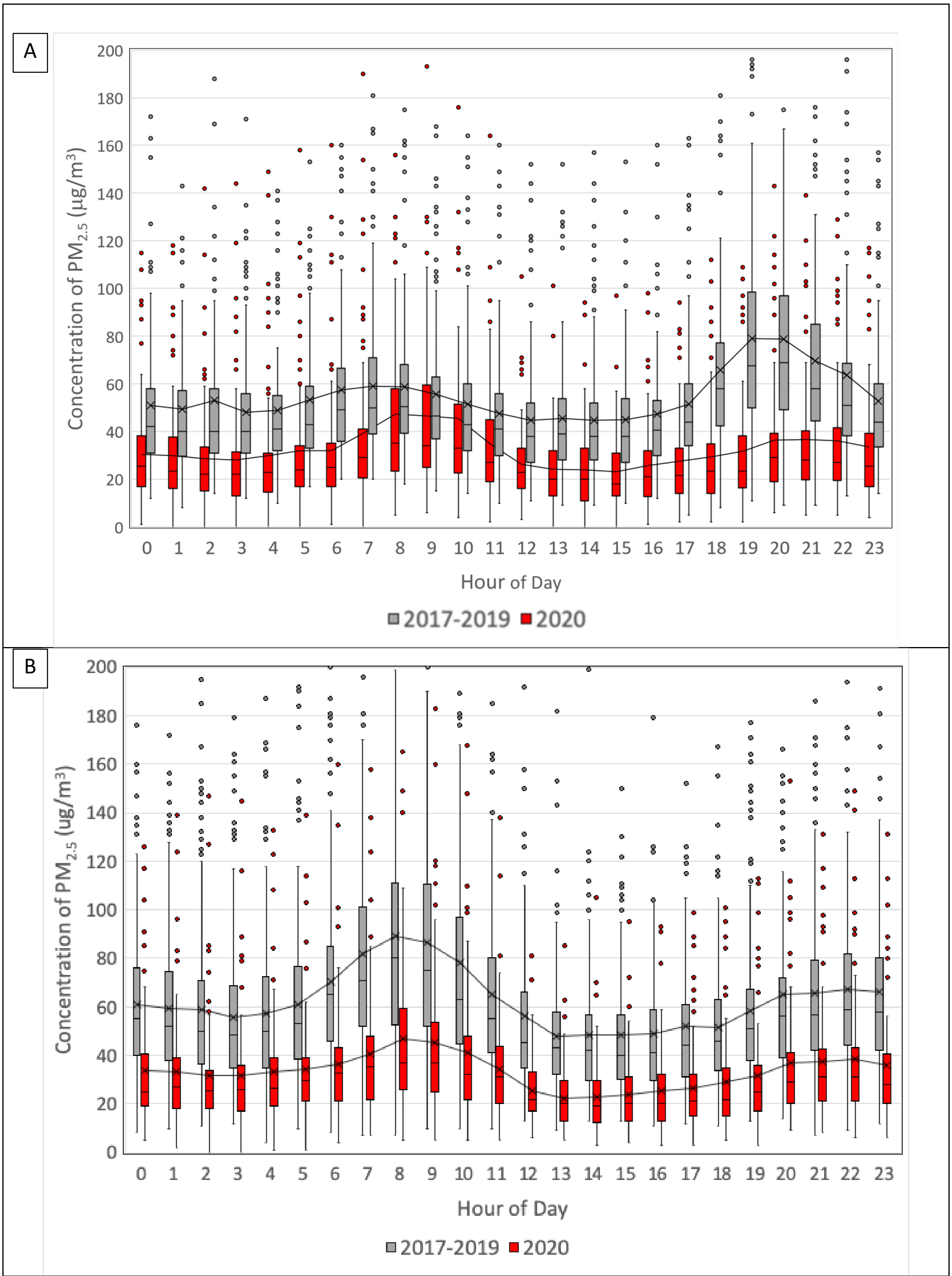

Figure 2. Diurnal pattern of $PM_{2.5}$ concentrations including mean and interquartile ranges (IQR) at [A] the US Embassy and [B] the Phora Durbar Recreational Complex, Kathmandu, during the period of full COVID-19 restrictions in 2020 (24 March to 11 June, red) and corresponding dates in 2017-2019 (grey).

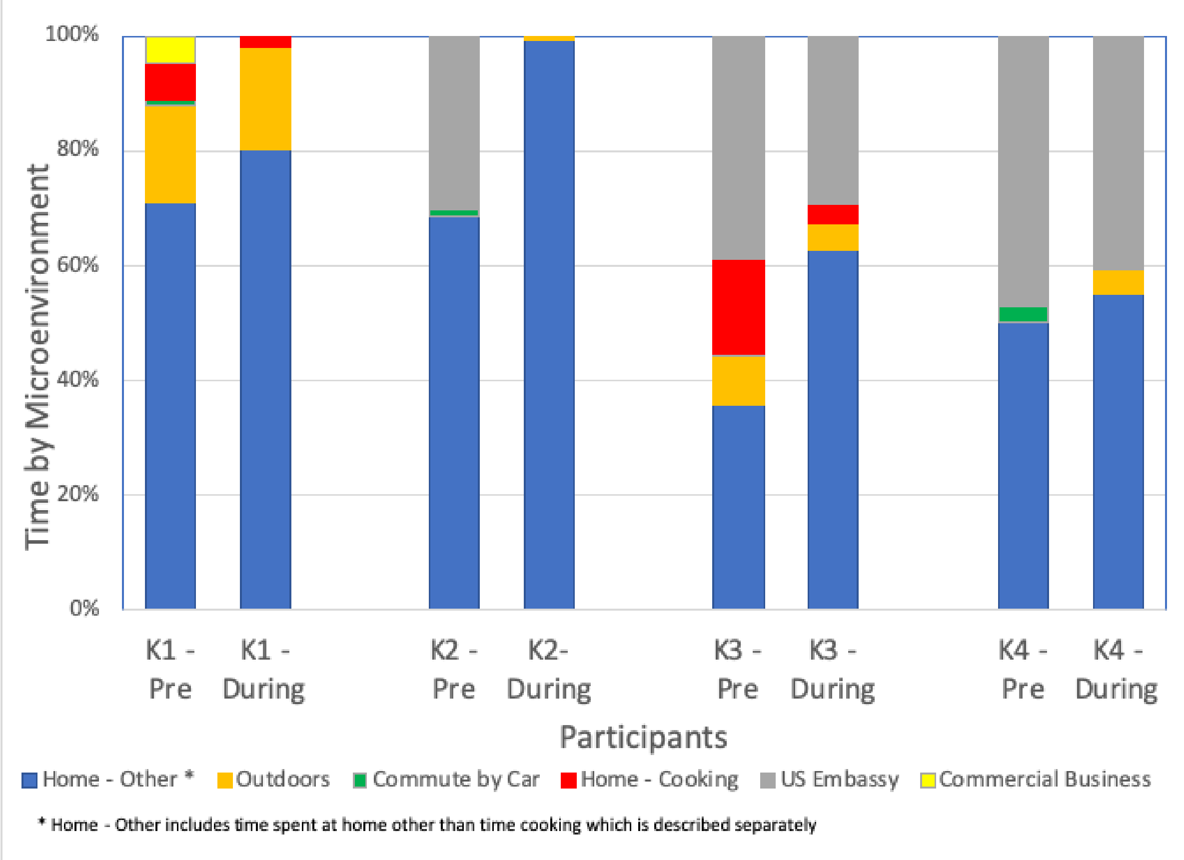

Figure 3. Comparison of time-activity patterns (time in specified microenvironments) before (pre) and during the period of full COVID-19 restrictions (24 March to 11 June 2020).

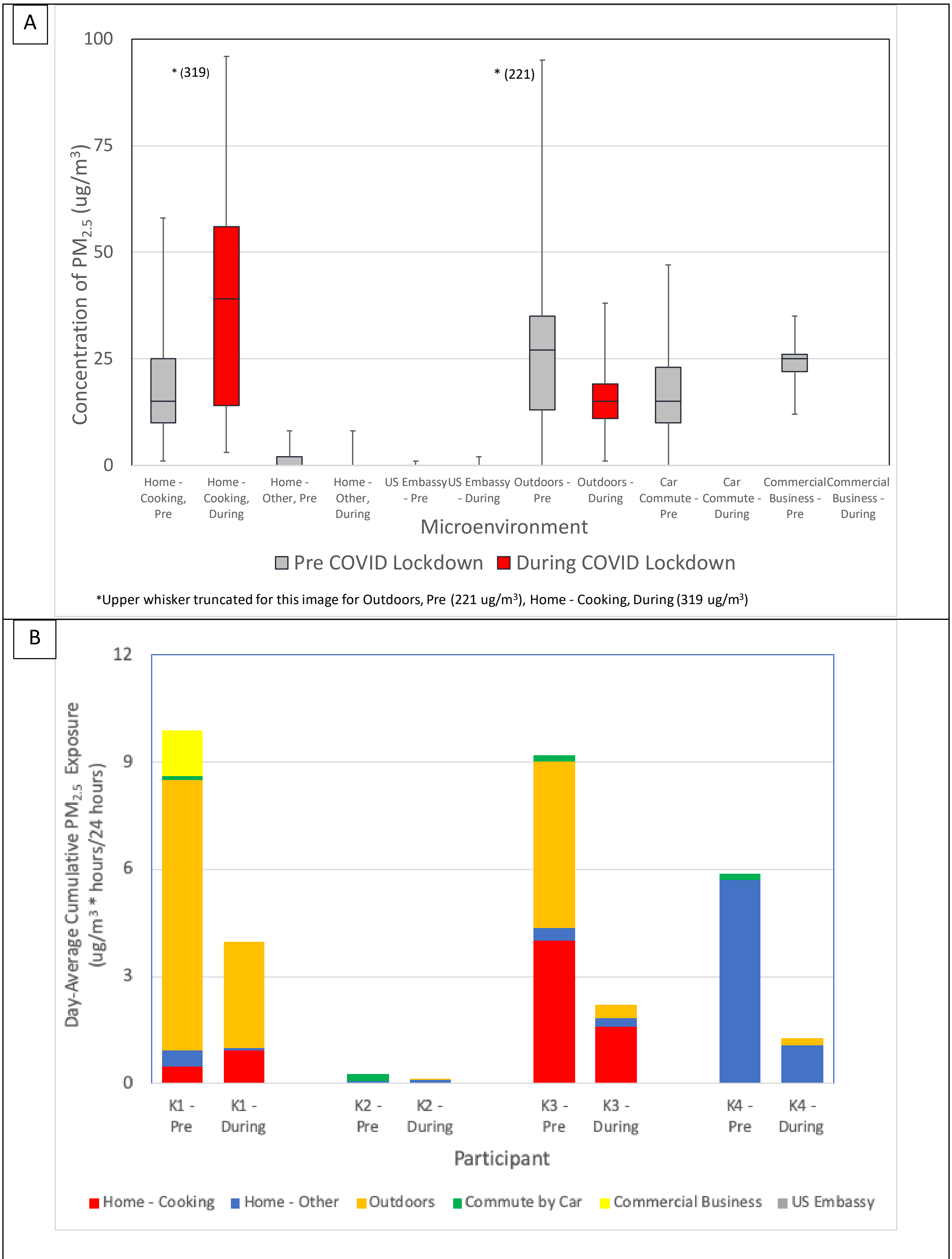

Figure 4. [A] Median, minimum, maximum and interquartile range (IQR) concentrations of $PM_{2.5}$ by microenvironment and [B] contribution of each microenvironment to the day-average cumulative exposure computed as the product of $PM_{2.5}$ concentration and hours of exposure per day ($\mu g/m^{-3}$.hrs). Both graphs prepared using weekday (Monday-Friday) data measured before ("pre") and during the period of COVID-19 restrictions.

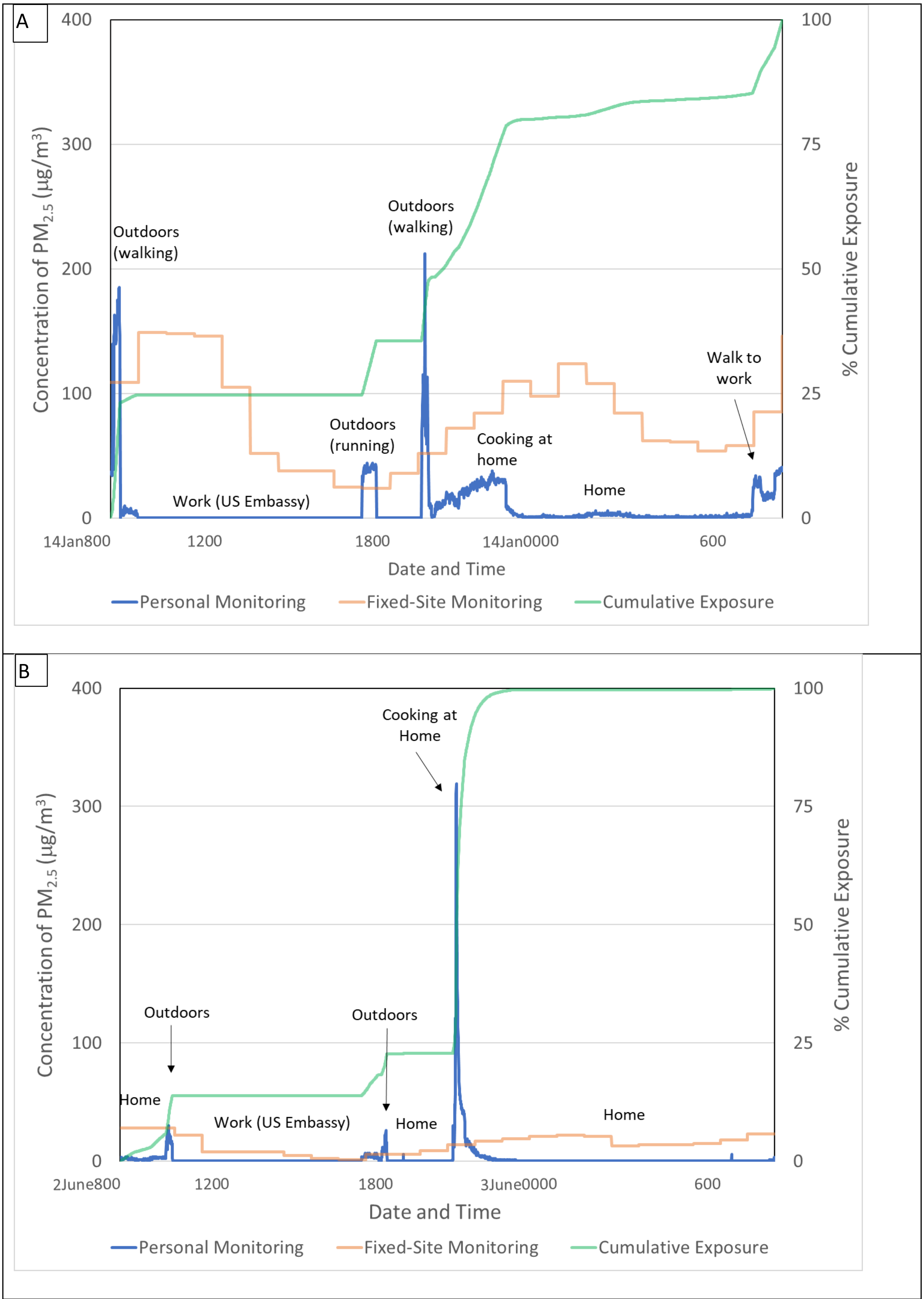

Figure 5. [A] Personal exposure profile for participant and time activity pattern for an example day before and [B] during full COVID-19 restrictions. Data for volunteer K3.

Table 1. Mean concentration of $PM_{2.5}$ by micro-environment for participants K1, K2, K3 and K4 and daily mean $PM_{2.5}$ measured at fixed-site outdoor monitor* for the corresponding days.

		Mean [$PM_{2.5}$] in µg.m^{-3}											
		K1			K2			K3			K4		
		Restriction status		% change	Restriction status		% change	Restriction status		% change	Restriction status		% change
		Pre-	During		Pre-	During		Pre-	During		Pre-	During	
Day mean [$PM_{2.5}$] (IQR) at fixed-site monitor* for days of personal monitoring		40.9 (34, 44)	22.0 (14, 27)	-46%	45.1 (37, 54)	16.8 (14, 21	-63%	70.9 (49, 92)	14.6 (8, 21)	-79%	15.8 (12, 20)	17.6 (14, 23)	11%
Outdoor	Commuting	15.3 (14, 17)	NA	NA	18.8 (6, 26)	NA	NA	24.5 (2, 47)	NA	NA	6.2 (5, 7)	NA	NA
	Business	24.7 (23, 26)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Other	24.1 (13, 33)	16.7 (13, 19)	-31%	NA	6.9 (6,8)	NA	56 (29, 79)	8.4 (3, 12)	-85%	NA	16.4 (12, 18)	NA
Indoor	Embassy	NA	NA	NA	0 (0,0)	NA	NA	0 (0, 1)	0 (0, 0)	0%	0 (0, 0)	0 (0,0)	0%
	Home – cooking	11.2 (8, 15)	44.6 (10, 61)	298%	NA	NA	NA	26 (25, 32)	47.4 (13, 49)	82.3%	NA	NA	NA
	Home – other	0.8 (0, 1)	0.1 (0, 0)	-88%	0.1 (0,0)	0.1 (0,0)	0%	0.9 (0, 1)	0.4 (0, 1)	-56%	9.9 (7, 15)	1.5 (0, 4)	-85%
Total		6.7 (0, 7)	3.8 (0, 0)	-51%	0.2 (0.0)	0.1 (0,0)	-50%	9.5 (0, 8)	2.3 (0, 0)	-76%	4.3 (1, 10)	1.0 (0, 2)	-77%

* Embassy fixed-site monitor
Note: all data related to weekday monitoring

Table 2. Results of weekday personal monitoring: hours of exposure and mean cumulative exposure (product of time in environment x mean $PM_{2.5}$ concentration) by micro-environment for participants K1, K2, K3 and K4

		Cumulative exposure (time x $[PM_{2.5}]$) in $\mu g.m^{-3}$.hrs (hours in microenvironment in brackets)											
		K1			K2			K3			K4		
		Restriction status		change (hours)	Restriction status		change (hours)	Restriction status		change (hours)	Restriction status		change (hours)
		Pre- (hours)	During (hours)		Pre- (hours)	During (hours)		Pre- (hours)	During (hours)		Pre- (hours)	During (hours)	
Outdoor	Commuting	0.10 (0.2 hrs)	NA (0 hrs)	-0.10	0.22 (0.3 hrs)	NA (0 hrs)	-0.22	0.2 (0.2 hrs)	NA (0 hrs)	-0.2	0.18 (0.7 hrs)	NA (0 hrs)	-0.18
	Business	1.29 (1.3 hrs)	NA (0 hrs)	-1.29	NA (0 hrs)	NA (0 hrs)	0	NA (0 hrs)	NA (0 hrs)	0	NA (0 hrs)	NA (0 hrs)	0
	Other	7.56 (7.4 hrs)	2.96 (4.3 hrs)	-4.60	NA (0 hrs)	0.04 (0.15 hrs)	+0.04	4.67 (2 hrs)	0.39 (1.1 hrs)	-4.28	NA (0 hrs)	0.21 (1 hr)	+0.21
Indoor	Embassy	NA (0 hrs)	NA (0 hrs)	0	0 (7.4 hrs)	NA (0 hrs)	0	0 (9.2 hrs)	0 (7 hrs)	0	0 (11.3 hrs)	0 (10 hrs)	0
	Home – cooking	0.47 (1 hrs)	0.93 (0.5 hrs)	+0.46	NA (0 hrs)	NA (0 hrs)	0	4.01 (3.7 hrs)	1.58 (0.8 hrs)	2.43	NA (0 hrs)	NA (0 hrs)	0
	Home – other	0.47 (14.1 hrs)	0.08 (19.2 hrs)	-0.39	0.07 (16.3 hrs)	0.1 (23.85 hrs)	+0.03	0.33 (8.9 hrs)	0.25 (15.1 hrs)	-0.08	5.7 (12 hrs)	1.08 (13 hrs)	-4.62
Total		9.88	3.97	-5.91 (-59.8%)	0.29	0.14	-0.15 (-51.8%)	9.21	2.22	-7.0 (-75.9%)	5.88	1.29	-4.59 (78.1-%)

Supplementary Materials for

Personal Exposure Monitoring of PM2.5 Among US Diplomats in Nepal During the COVID-19 Lockdown, March to June 2020

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Table A.1 Dates that COVID-Related Mitigation Measures Were Implemented and Dates of First and Second COVID Cases Identified in Nepal

Date	Event
January 23	First COVID-19 case identified in Nepal
March 14	All trekking to Mt Everest halted and visa upon entry at Tribhuvan International Airport closed
March 18	Movie theatres, gyms, museums and mass gatherings of more than 25 people halted in Kathmandu
March 20	Non-urgent surgeries postponed in Kathmandu
March 22	International inbound and outbound flights halted in Nepal
March 23	Second COVID-19 case identified in Nepal
March 24	Nationwide lockdown implemented and includes cessation of non-essential government services, prohibition of driving per personal vehicles, and closure of shops that do not sell food, petrol or other essential services
April 4	First case of locally acquired COVID-19 identified in Nepal
June 12	Nationwide easing of lockdown measures including allowing shops to reopen, allowed to drive personal vehicles, but public places including schools, malls, parks, conferences and sporting events remain closed
July 21	Nationwide lockdown in Nepal ended

Table A.2 Demographic characteristics of four study participants

Characteristics	K1	K2	K3	K4
Sex	Male	Female	Female	Female
Age Group (years)	40-49	30-39	50-59	50-59
Workplace	Home and Embassy [1]	Embassy	Embassy	Embassy
Mode of Transportation in Commute to Work?	NA	Personal Car and Walk	Walk	Walk
Total No. Room Air Cleaners in Home	11	9	9	6
No. Blueair 605 (large)	2	2	2	1
No. Blueair 205 (small)	9	7	7	5
Room Air Cleaner in Bedroom	Yes	Yes	Yes	Yes
Room Air Cleaner in Living Room	Yes	Yes	Yes	Yes
Room Air Cleaner in Kitchen	No	Yes	Yes	No
Home has windows and doors that do not close tightly	Yes	Yes	Yes	Yes
Windows Sealed with Tape and Plastic Sheeting	No	Yes	No	Yes
Windows Sealed with Caulk	Yes	No	No	No
Net Square Footage of Personal Residence (ft^2)	2177	1680	1860	2037

[1]Participant worked from home in September 2019 and began to work at the US Embassy in January 2020

Table A.3 Summary statistics for ambient $PM_{2.5}$ hourly measurements at [A] the US Embassy and [B] the Phora Durbar Recreational Complex, Kathmandu, March 24-June 11 each year 2017-2020

[A] US Embassy	**Year**			
	2020	2019	2018	2017
No. Observations	1891	1862	1915	1912
Minimum	0	3	0	8
5%	7	18	18	21
25%	17	33	31	35
50%	26	49	43	48
75%	39	68	61	66
95%	93	110	118	122
Maximum	365	685	252	674

[B] Phora Durbar	**Year**			
	2020	2019	2018	2017
No. Observations	1911	1878	1893	1900
Minimum	0	7	4	10
5%	9	23	20	27
25%	19	39	35	42
50%	28	58	48	58
75%	40	79	69	81
95%	86	124	127	153
Maximum	183	309	290	776

Table A.4 Summary statistics for personal monitoring sessions for Participants K1, K2, K3 and K4 take before (B) COVID-19 lockdown period and during (D) lockdown

	K1 - B	**K1 - D**	**K2 - B**	**K2- D**	**K3 - B**	**K3 - D**	**K4 - B**	**K4 - D**
No. Observations	2838	2859	2810	2856	2880	2845	2878	2855
Minimum	0	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	1	0
25%	0	0	0	0	0	0	1	0
50%	1	1	0	0	1	0	2	0
75%	4	7	0	0	8	0	10	0
95%	26	31	0	0	45	8	18	1
Maximum	56	221	46	7	130	319	26	9

Figure A.1 Beta Attenuation Monitors (BAMs) at the US Embassy in Kathmandu and at the Phora Durbar Recreational Complex in Kathmandu. The two sites are 4.5 km apart. Red circle indicates the area where the four study participants live.

Figure A.2 The APT Minima personal air sampler. The monitor is 3” x 2.75” x 1.25” (L x W x H) and weights 4.9 oz.

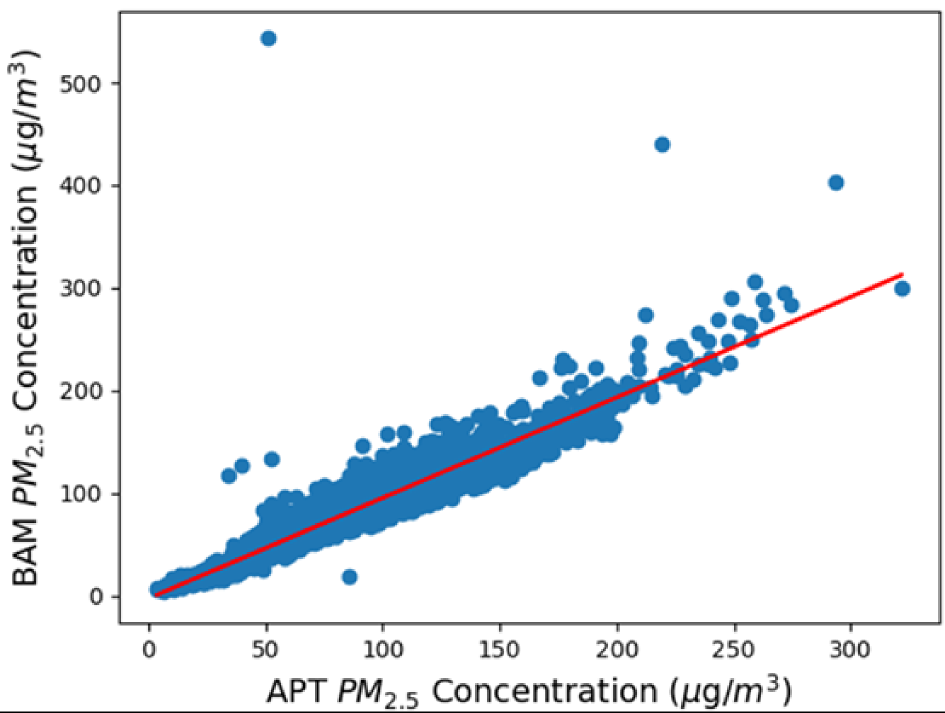

Figure A.3 Pairwise correlation between the APT Maxima (x-axis) and the BAM (y-axis) co-located at the Phora Durbar Recreation Center in Kathmandu. Slope and R^2 values were calculated by least squares method.

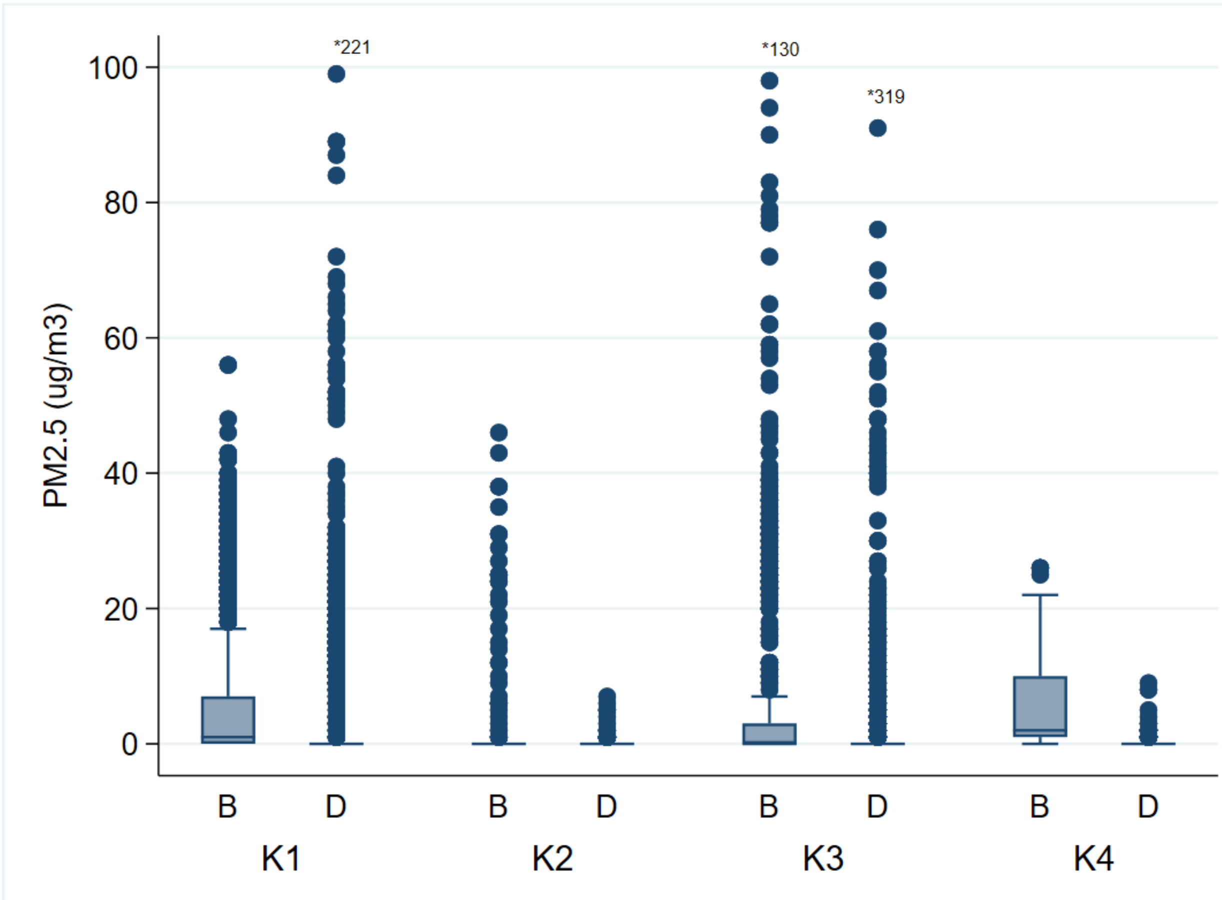

Figure A.4 Distribution of personal $PM_{2.5}$ concentrations (μg/m^3) for study participants K1, K2, K3 and K4 before (B) COVID restrictions were implemented and during (D) COVID restrictions. The y-axis was truncated at 100 to allow for increased viewing of the box plots. Three monitoring sessions had values that exceeded the maximum y-axis value on this graph and those sessions were labelled with the highest recorded value for that session.