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INHALATION OF SMALL PARTICLES (PM2.5) IN URBAN ROAD TUNNELS AND UNDERGROUND MADRID (SPAIN). A CITIZEN SCIENCE PROJECT

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ABSTRACT

Some public infrastructures do not routinely monitor air pollution, particularly in semi-enclosed transport environments such as road tunnels and metro systems. Low-cost sensors (LCS) may complement official monitoring by providing accessible exposure data.

This study aimed to validate LCS performance and to assess PM2.5 concentrations in urban transport microenvironments in a large city with the active participation of various citizens.

LCS measurements were compared with reference station data using Pearson correlation coefficients. The device was mounted outside a vehicle while driving through road tunnels, and additional measurements were conducted on metro platforms and inside subway carriages. All measurements were carried out by different citizens who had been previously trained.

The correlation between LCS and the reference station was high (r = 0.9301; 95% CI: 0.926–0.934), supporting device reliability. In road tunnels, mean PM2.5 increased from 12.62 μg/m³ (SD 11.3) in the first half of the journey to 16.6 μg/m³ (SD 15.2) in the second half ($p < 0.001$). On metro platforms, concentrations exceeded 10 μg/m³ (mean 20 μg/m³; range 10–32), while inside carriages levels remained above 5 μg/m³ (mean 10 μg/m³; range 5.8–17.8).

These results have been reviewed, assessed, and discussed by all participating citizens from the signatory associations. As no safe threshold for PM2.5 exposure has been established, systematic monitoring and the integration of low-cost technologies into public health surveillance are needed to inform regulation and urban transport policies.

233 words

INTRODUCTION

Small-sized particles present in inhaled air are responsible for numerous respiratory and systemic diseases, even at low concentrations and within short exposure times—ranging from hours to days **(Wenhua et al., 2024; Orellano et al., 2020; Sun et al., 2024)**. Among respiratory illnesses, their association with asthma, chronic obstructive pulmonary disease (COPD), and lung cancer is particularly noteworthy **(Kampa and Castanas, 2008)**. Moreover, due to their small size, these particles can penetrate the alveolar–capillary membrane, enter the bloodstream, and reach distant organs such as the heart, brain, and kidneys **(Vanbrabant et al., 2024)**. Exposure to fine particles (e.g., PM2.5) is a recognized risk factor for premature death, pulmonary or cardiac disease, pregnancy complications, cancer, diabetes, and neurological disorders **(Manisalidis et al., 2020; World Health Organization, 2025)**.

Although efforts are made to control their concentrations in large cities through fixed or mobile air quality monitoring stations, there remains variability in the available data regarding their concentrations inside urban tunnels **(Advisory Committee on Tunnel Air Quality, 2018; Svartengren et al., 2000; Jiang et al., 2024; Zhao et al., 2021; Wang et al., 2021; Skerker, 2017; Zamorategui-Molina et al., 2021; Zhou et al., 2014; Miller and Newby, 2020)** and subway systems **(Luglio et al., 2023; Zhao et al., 2017; Cartenì et al., 2015; Figueroa-Lara et al., 2019; Querol et al., 2012; Van Ryswyk et al., 2017; Luglio et al., 2021; Martins et al., 2016; Nieuwenhuijsen et al., 2007; Moreno et al., 2015)**.

In Madrid (Spain), several tunnels are used for transportation. These include the so-called M30 ring road, with 10 km of underground highway, and the extensive metro network comprising 13 lines, 303 stations, and a total length of 295 km. In 2023, approximately 374 million vehicles and 487.5 million users circulated through the M30, while 662 million passengers used the metro network during the same year. In 2025, 736,974,012 trips were made on the metro.

The M30 system includes 1,000 ventilation fans and 90 pumping wells with a flow capacity of 8,000 m³/day **(EMESA M-30, n.d.)**. According to information provided by M30 management (April 22, 2024; personal communication), there are 19 PM2.5 particle filtration stations within the tunnels. However, few data exist regarding PM2.5 concentrations (cPM2.5) inside the M30 tunnels—either within or outside vehicles. Only two publications related to the M30 were identified, one concerning the ventilation systems **(del Rey Llorente et al., 2005)** and another on the advantages of reducing the speed limit to 70 km/h **(Pérez-Prada and Monzón, 2014)**.

In 2024, a Spanish research group examined gas and particle concentrations in a segment of the M30 **(López-de Abajo et al., 2024)**. Their objective was to assess the potential deterioration of concrete caused by gas exposure. Regarding PM2.5, they could only measure concentrations in the ventilation gallery, as no sensors were installed inside the traffic tunnels themselves.

Similarly, in the Madrid metro system, there is insufficient information about cPM2.5 levels on platforms and inside train carriages. Only a few press reports exist **(elDiario.es, n.d.; Donostiarrak, n.d.; ConBici, n.d.)**. Recently, the initiation of a pilot study to measure PM2.5 levels in the Madrid metro was announced **(Envira, n.d.)**.

The concept of Citizen Science seeks to generate knowledge through the participation of civil society **(Froeling et al., 2024; Vohland et al., n.d.)**. Several professionals from different disciplines, together with neighborhood organizations from Madrid's Latina District, decided to conduct a civic environmental monitoring initiative focused on air quality in various urban environments.

The objective of this study was to measure cPM2.5 levels in the M30 tunnels and the metro using a portable PM2.5 monitoring device.

MATERIALS AND METHODS

This is an observational study examining environmental risk factors. All spot determinations of cPM2.5 in this study were performed using a portable monitoring device (AirBeam3 HabitatMap, USA) (AB3), which had been validated by comparing its measurements with those of a fixed municipal monitoring station (see supplementary material: *Performance evaluation and utility of a low-cost particulate matter sensor for use in a citizen science context*).

To analyze the relationship between AB3 values and government hourly data, an initial analysis was conducted by obtaining the correlation coefficient between the hourly averages obtained from both instruments. All linear model fitting calculations were performed using RStudio.

Using a different approach, agreement between both datasets was assessed with the Bland and Altman method, which involves plotting the difference between AB3 and TEOM hourly measurements against their mean and calculating the mean differences and their confidence intervals. To assess the validity of AB3, its ROC curve was constructed for the TEOM 10 µg/m³ threshold (political limit of the European Union), and predictive values for AB3 at that cutoff point were calculated using Stata v16.1 statistical software (see supplementary material).

The data collected by the AirBeam device are transmitted via Wi-Fi or 4G cellular communication technologies. The measurements recorded by the AB3 can be viewed, mapped, and graphically displayed in real time through devices running Android or iOS operating systems, as well as via the AirCasting web platform, which is openly accessible.

The longest section of the M30 tunnel, including its access ramps, spans 16.4 km. The measurement of cPM2.5 levels was carried out by driving inside the M30 tunnels with the AB3 device mounted on the exterior of a vehicle. Multiple measurements were conducted at different times during 2024 and early 2025, all on working days. All measurements were taken during periods of low utilization Only data collected between tunnel entry and exit were included.

This study was carried out by several citizens from Madrid’s Latina District who voluntarily contributed to this initiative. The date, exact entry and exit times, and exposure duration were recorded for each measurement.

All recordings exhibited a similar pattern: an initial phase showing a mild-to-moderate increase in cPM2.5, followed by a later phase with a marked rise and a sharp decrease upon exiting the tunnel. Based on this behavior, the cPM2.5 data were divided into two phases (A and B), corresponding respectively to the first and second halves of each tunnel transit. Both sets of values were compared using ANOVA testing. Extreme invalid data (outliers) with abnormally high figures were excluded.

https://doi.org/10.5194/ar-2026-22
Preprint. Discussion started: 12 June 2026

During 2024 and early 2025, additional cPM2.5 measurements were performed on metro platforms and inside train carriages of the Madrid underground network. The same AB3 device was used, handled by different volunteer citizens from the Latina District. For each measurement, the date, time, and exposure duration were documented. All measurements were taken during periods of low utilization

According to the World Health Organization (WHO) 2021 report, the recommended annual mean limit for PM2.5 in ambient air should not exceed 5 µg/m³ **(World Health Organization, 2021)**. The European Union, in 2024, set the limit at 10 µg/m³ **(Council of the European Union, 2024)**. The WHO guidelines explicitly state that their limits apply both outdoors and indoors worldwide, covering all environments where people spend time. Nevertheless, clinical effects have been observed even at concentrations below 5 µg/m³ **(Wei et al., 2024; Wei and Schwartz, 2024; Marks, 2022; Bloss, 2021; Wei et al., 2022)**.

RESULTS

Performance evaluation of a low-cost particulate matter sensor

Since the AB3 records data every minute and only ten-minute data were available from the governmental station, ten-minute averages were obtained from AB3 data using the same notation and method as for official data. A total of 6,321 valid and coincident observations were obtained. The correlation coefficient for ten-minute data was 0.92, with a 95% confidence interval (CI) of 0.921–0.928 (see supplementary material: *Performance evaluation and utility of a low-cost particulate matter sensor for use in a citizen science context*).

M30

A total of 14 routes were conducted inside the M30 tunnels. The cumulative measurement time for cPM2.5 within the tunnel amounted to 3.8 hours. The mean cPM2.5 concentration was 14.62 µg/m³ (SD 13.5), with a median of 11 µg/m³ and values ranging from 0 to 123 µg/m³.

Figure 1 illustrates one of the cPM2.5 measurements obtained inside the M30 (January 2025). The average value recorded was 31.3 µg/m³. At the same time, the nearest outdoor fixed station (M. Álvaro) reported a cPM2.5 level of 10 µg/m³. This graphical pattern was consistent across all M30 measurements, with a clear distinction between two phases of concentration increase, which justified separate analysis of both periods.

As shown in Figure 1, throughout the entire tunnel traversal, PM2.5 concentrations exceeded 10 µg/m³, reaching peaks above 50 µg/m³, followed by a rapid drop upon exiting the tunnel.

The PM2.5 concentrations in both phases—initial and final—were mean PM2.5 values of 12.60 (SD 11.3) and 16.64 (SD 15.2) µg/m³, respectively. These differences were statistically significant ($p = .000$). During 3.3 hours of the total 3.8 hours (87%), cPM2.5 levels inside the M30 tunnels surpassed the limit of 5 µg/m³. For approximately 12 minutes of a 14-minute journey, cPM2.5 remained

https://doi.org/10.5194/ar-2026-22
Preprint. Discussion started: 12 June 2026

above the WHO guideline for ambient air quality. Using the threshold of 10 µg/m³, concentrations exceeded this limit for 2 hours (45%) of total tunnel time—equivalent to roughly 6 minutes of exposure per trip.

On September 26, 2024 (11:00–12:00 AM), the AB3 monitor was placed inside a vehicle traveling through the M30 at a moderate speed, using standard cabin ventilation with windows closed, and without heating or air conditioning. The total journey lasted 21 minutes. For 6.5 minutes (31%), cPM2.5 exceeded 10 µg/m³, and for 9.8 minutes (47%), it exceeded 5 µg/m³. At the same time, the nearest external government station reported outdoor cPM2.5 concentrations between 1 and 4 µg/m³.

On November 3, 2024, a section of the M30 was closed to vehicular traffic and opened to pedestrians. Two of the study authors walked through this section carrying the AB3 device. The measurement started at 9:00 AM and lasted 88 minutes. For 47 minutes (53%), cPM2.5 levels were above 10 µg/m³, and for 71 minutes (81%), at or above 5 µg/m³. Unlike the pattern observed with vehicular traffic, there was no final-phase peak followed by a sharp drop at the exit. At the same time, nearby outdoor stations reported cPM2.5 levels between 1 and 2 µg/m³. Vehicular traffic had been halted at midnight on November 3, suggesting that residual pollution persisted in the tunnels for at least 9–10 hours afterward.

Madrid Metro

Across all analyzed metro platforms in different Madrid stations, mean cPM2.5 concentrations were equal to or above 10 µg/m³ (overall mean 20 µg/m³; SD 9), with marked variability. Recorded values ranged from 10 µg/m³ at A. América to 32 µg/m³ at Oporto station (Table 1).

At P del Ángel station, monitoring began on the platform and continued until the AB3 reached surface level (Figure 2). cPM2.5 values decreased from 25 µg/m³ on the platform to 9 µg/m³ upon reaching the surface.

Inside metro carriages, variability was also observed, even within the same day, between different train types. In a train with open inter-car connections, cPM2.5 averaged 13 µg/m³ (range 9–19 µg/m³). In another train with separated cars and excellent ventilation, the mean was 10 µg/m³ (range 8–12 µg/m³). As a reference, the nearest outdoor fixed monitoring station recorded 8 µg/m³ at that time.

A total of 13 spot measurements of varying durations were performed inside metro carriages across several lines. These results are summarized in Table 2. In all cases, concentrations exceeded the limit of 5 µg/m³ (mean 10 µg/m³; SD 5.6), with mean values ranging from 5.8 µg/m³ to 17.8 µg/m³.

DISCUSSION

This citizen science study presents multiple measurements of cPM2.5 across different dates and urban environments in Madrid, Spain, addressing the lack of publicly accessible data. Measurements were conducted in the M30 vehicle tunnels and the metro system.

https://doi.org/10.5194/ar-2026-22
Preprint. Discussion started: 12 June 2026

According to the Open Data Portal of the Madrid City Council, cPM2.5 data from the M30 are currently not available for public release (personal communication, 17 October 2025). Similarly, the Madrid Metro Transparency Portal reports that no cPM2.5 data are available for its facilities (personal communications, 5 September 2024 and 1 September 2025).

A consistent finding was the variability of results across days and locations, both in the M30 and on metro platforms and inside train carriages.

M30 Tunnel

The average values across multiple measurements indicated a global mean PM2.5 concentration of 14.6 μg/m³ (SD 13.5). All M30 measurements exhibited the same pattern: an initial mild-to-moderate increase in cPM2.5, followed by a pronounced rise and a sharp decrease at tunnel exit (Figure 1). This "piston effect" suggests that polluted air is pushed along the tunnel in the direction of vehicular traffic, potentially exacerbated by uphill driving and acceleration at tunnel exits.

Previous studies focusing on other objectives allowed direct measurements inside the M30 ventilation gallery **(López-de Abajo et al., 2024)**. Gas concentrations were recorded, but cPM2.5 inside the tunnel could not be measured due to the absence of sensors. Data from the ventilation gallery, collected over 15 days in late 2019, showed cPM2.5 levels averaging 26.74 μg/m³ (max 65, min 1.80). A citizen request in December 2018 for M30 air pollution data via the City Council Open Data Portal received no response, and similar requests in 2025 have also gone unanswered **(Ayuntamiento de Madrid, n.d.)**.

Madrid Metro

For the metro, only limited press reports were found regarding a citizen measurement campaign in 2018 **(elDiario.es, n.d.; Donostiarrak, n.d.; ConBici, n.d.)**.

Our measurements inside Madrid metro stations and carriages showed high variability, influenced by factors such as platform ventilation and train type. In general, platform concentrations were higher (100% > 10 μg/m³) than inside carriages (100% > 5 μg/m³).

Except for maintenance workers inside tunnels or metro staff, most users experience short and limited exposures each time they enter the platforms, although exposure inside metro cars is usually longer.

Public health implications

Short-term exposure to airborne particles and gases has been less studied than long-term exposure, but recent evidence suggests significant health effects. A recent literature review **(Orellano et al., 2020)** reported that brief exposures to cPM2.5 (hours or a few days) were associated with all-cause mortality (RR 1.0065; 95% CI 1.0044–1.0086) and with respiratory, cardiovascular, and cerebrovascular mortality, with the highest certainty of evidence.

Globally, approximately one million premature deaths per year (2000–2019) have been attributed to short-term PM2.5 exposure, representing 2.08% (1.41–2.75) of all deaths per 100,000 inhabitants. Mortality estimates were similar across different exposure thresholds (5.9, 10, or 15 µg/m³) **(Wenhua et al., 2024)**.

A daily increase of 10 µg/m³ in PM2.5 concentrations is associated with a rise in daily all-cause mortality **(Ma et al., 2024)**. These findings support the conclusion that even short-term exposure to cPM2.5 can have measurable health impacts.

There is evidence indicating that there is no safe threshold for PM2.5 concentrations and that some health effects occur immediately after exposure and can persist for at least three years **(Wei et al., 2024; Wei and Schwartz, 2024; Marks, 2022; Bloss, 2021; Wei et al., 2022)**.

Air inside vehicle tunnels typically exhibits higher pollutant concentrations than outdoor air. The clinical significance of short-term exposure remains poorly understood. Some studies have reported respiratory effects in asthmatics and inflammatory or cardiovascular responses after brief exposure to traffic-related tunnel air **(Liu et al., 2024)**.

International studies have documented extremely high cPM2.5 levels in traffic tunnels: 77.2 ± 17.4 µg/m³ in China **(Wenhua et al., 2024)**, up to 468 µg/m³ in another Chinese study **(Zhou et al., 2014)**, and 75–160 µg/m³ in Mexico **(Zamorategui-Molina et al., 2021)**. These observations align with our findings, showing progressive increases from tunnel entry to exit **(Wang et al., 2021)**.

In hypertensive patients at high cardiovascular risk, maintaining systolic blood pressure at 120–130 mmHg (compared with 140–150 mmHg) reduces major vascular events **(Hudda et al., 2021; Guo et al., 2025)**. A recent 2-hour exposure experiment to traffic-related air pollution demonstrated dose-dependent increases in systolic and diastolic blood pressure, with early responses observable within 20 minutes **(Young et al., 2023),** an effect that was reduced with high-efficiency particulate air (HEPA) filtration **(Larsson et al., 2007)**.

Exposure of healthy individuals to traffic-related air pollution in tunnels also induced mild lower airway inflammation and early activation of bronchial epithelial signaling pathways **(Qiu et al., 2019)**. Multiple regression analyses suggest that in-vehicle pollutant concentrations are mainly influenced by roadside levels, temperature, and ventilation settings **(London Underground., 2024)**.

Air pollutant levels inside subway tunnels have been more extensively studied both within and outside Spain. Critical reviews indicate that subway tunnel air

https://doi.org/10.5194/ar-2026-22
Preprint. Discussion started: 12 June 2026

pollution can be more harmful to health than outdoor air **(Zhao et al., 2017)**. Concentrations inside tunnels were reported as 2–14 times higher than outdoors, and inside train carriages, PM2.5 ranged from 18 to 36 µg/m³.

PM2.5 concentrations are higher in underground environments due to poor ventilation and frequent train traffic **(Cartenì et al., 2015)**, with deeper stations showing higher particle levels **(Figueroa-Lara et al., 2019)**. In Canada, studies of subway PM2.5 composition identified iron (Fe) as the dominant component **(Van Ryswyk et al., 2017)**. In the USA, cPM2.5 levels in underground systems of various cities were extremely high: 779 ± 249, 548 ± 207, 341 ± 147, 327 ± 136, and 112 ± 46.7 µg/m³, compared with outdoor levels of 20.8 ± 9.3, 24.1 ± 9.3, 12.0 ± 7.8, 10.0 ± 2.7, and 12.6 ± 12.6 µg/m³, respectively **(Luglio et al., 2021)**. Coal and iron accounted for approximately 80% of subway PM2.5.

In the London Underground, annual cPM2.5 measurements are publicly available for both platforms and driver cabins **(Smith et al., 2020)**. Mean subway concentrations were 88 µg/m³, compared with 22 µg/m³ outdoors **(Smith et al., 2020)**, with iron oxide representing 47% of the particulate composition.

Subway dust is considered more toxic than outdoor PM, inducing higher genotoxicity in cultured human lung cells **(Loxham and Nieuwenhuijsen, 2019)**, likely due to its high iron content. Although in vivo evidence is limited, in vitro studies confirm significant toxicity. Its toxicity has been compared to welding fumes **(Loxham and Nieuwenhuijsen, 2019; Health and Safety Executive, n.d.)**.

Occupational exposure in the metro shows mixed results. London Underground staff exposed to high PM levels did not exhibit clear associations with absenteeism **(Mak et al., 2024)**. However, highly exposed employees in the Stockholm underground showed elevated cardiovascular risk markers compared with low-exposure staff **(Bigert et al., 2008)**.

In Barcelona, subway cPM2.5 levels inside trains ranged from 11 to 32 µg/m³, while platforms were higher, averaging 46 µg/m³ (Line 9) and 125 µg/m³ (Line 3) **(Querol et al., 2012)**.

For an annual average outdoor PM2.5 level of 19 µg/m³ (Madrid, 2003–2005), the relative risk (RR) of daily overall respiratory mortality was 1.028 (1.004–1.052); occurring at lag 1 for respiratory failure, RR was 1.082 (1.012–1.151) **(Guaita et al., 2011)**.

Variability in cPM2.5 may be attributed to differences in ventilation, air conditioning, wheel and braking materials, seasonal changes, and passenger density **(Moreno et al.,2014)**, with an estimated increase of 0.4 µg/m³ per passenger during peak hours **(Xu et al., 2016)**. Concentrations tend to be lower in summer due to increased ventilation to reduce platform temperature.

Limitations

https://doi.org/10.5194/ar-2026-22
Preprint. Discussion started: 12 June 2026

Several limitations apply to this study. The most significant is the lack of continuous data across multiple days, stations, weather conditions, traffic intensity, and vehicle speeds in the M30 and metro. Instead, numerous spot measurements were collected at different times and months.

In metro environments, PM2.5 is often dominated by iron-rich dust. The AB3 sensor shows a −83% bias when measuring welding smoke **(Sousan et al., 2017)**, which is chemically analogous to the hematite present in tunnels. To date, no published studies have evaluated the reliability of optical sensors such as the AB3 for assessing iron-rich PM2.5, highlighting the need for future measurements to employ validated non-optical methods to ensure accuracy. If such an extreme bias truly reflects real-world conditions, the degree of underestimation in our data would be even more concerning.

The health risks of short-term exposure to cPM2.5 for 15–20 minutes remain uncertain due to the lack of targeted studies. Accumulation and repeated high exposures over days, weeks, or months are assumed to have a greater health impact. Epidemiologically, even short exposures can have significant public health consequences if large populations are affected. In 2023, 374 million vehicles circulated on the M30, and 662 million passengers used the Madrid Metro, including sensitive individuals such as the elderly, children, pregnant women, or individuals with chronic cardiopulmonary diseases **(Hernandez et al., 2025)**.

CONCLUSIONS

Substantial international evidence indicates excessive PM2.5 pollution inside urban tunnels with high vehicle traffic and within metro systems. Official data for cPM2.5 in Madrid's M30 and metro were unavailable to the authors. However, the spot measurements presented here demonstrate that cPM2.5 may have health implications, particularly for susceptible populations.

Deployment of PM2.5 monitors in urban tunnels with heavy traffic, as well as on metro platforms and inside train carriages, is recommended. Measuring pollutant concentrations in these environments is justified by high vehicle and passenger flows and by estimates of preventable mortality in Madrid (**López-Encuentra et al**., 2025). The resulting data should be publicly available to inform users and protected when necessary. If PM exceeds thresholds, corrective measures must be implemented accordingly

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Station	Mean PM2.5 (µg/m³)	Standard Deviation PM2.5 (µg/m³)	Median PM2.5 (µg/m³)	Min–Max PM2.5 (µg/m³)	Mean HR (%) HR Min–Max (%)
P. ANGEL	19.6	4.98	22	10 – 30	47.5 46 – 49
P. ANGEL	18.6	2.1	18	12 – 24	66 60 – 72
C CAMINOS	14.8	2.9	15	9 – 22	51 50 – 53
ARGUELLES	13.1	1.7	13	10 – 16	69 67 – 71
OPORTO	32.4	5.2	30	23 – 46	50 48 – 58
M VADILLO	15.2	1.9	15	8 – 20	54 48 – 58
AV AMERICA	10	1.7	10	7 – 14	48 47 – 51
LEGAZPI	11	2.3	10	6 – 16	53 50 – 56

TABLE 1. Spot measurements of cPM2.5 on platforms of the Madrid Metro. PM2.5 concentrations are expressed in micrograms per cubic meter (µg/m³). HR indicates relative humidity. Observation durations are in minutes.

Metro Line (*)	Start Time	Observation Duration (min)	Mean PM2.5 (µg/m^3)	Standard Deviation PM2.5 (µg/m^3)	Median PM2.5 (µg/m^3)	Min–Max PM2.5 (µg/m^3)	Mean RH (%)	RH Min–Max (%)
L2 c	7:14	840	5.8	2.6	6	1–25	37	28–47
L6 c	10:17	59	17.8	6.2	18.6	7.5–37.6	47	41–62
L6 c	11:18	58	11.7	3.9	10.3	6–22	56	49–68
L6 p	11:47	15	16	1.9	15	13–19	53	51–54
L6 p	12:37	14	9	1.7	9	7–12	49	48–50
L5 p	10:44	35	9.2	1.6	8.6	7–12	48	43–57
L5 p	11:22	15	8.3	1.8	8.1	5.6–11	44	43–46
L5 p	11:44	21	8.8	1.1	8.9	6.7–12	43.5	43–44
L5 p	11:47	15	16	1.9	15	13–19	53	51–54
L5 p	11:21	31	11	2.5	11	7–19	46	44–49
L5 p	11:57	40	9.5	2.1	9.3	6–15	44	42–49
L5 p	12:43	60	6.2	1.9	6.3	2–11	45	40–57

TABLE 2. Spot Measurements of cPM2.5 Inside Madrid Metro train carriages. (*) Partial data collection on the line: p; complete data collection: c. RH: Relative humidity (%). Observation durations are in minutes. PM2.5 concentrations are in µg/m^3.

cPM2.5 CONCENTRATION TRENDS IN M30

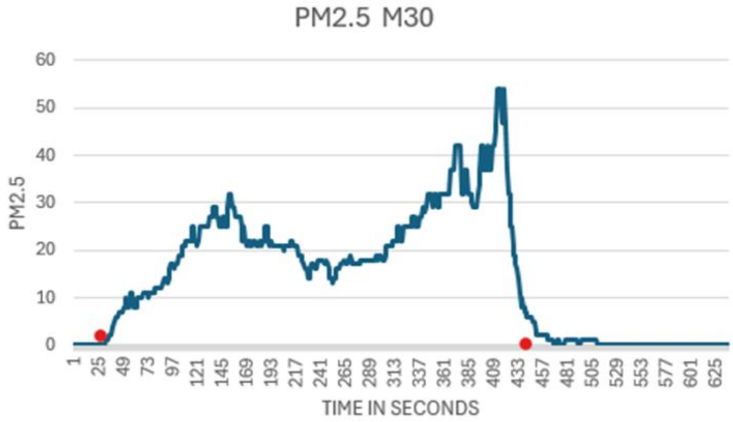

FIGURE 1. PM2.5 in µg/m³. The ideal anual PM2.5 concentration level from a health care perspective is 5 µg/m³ (WHO, 2021). The start and end of the vehicle’s journey in the M30 tunnel are marked with two red dots.

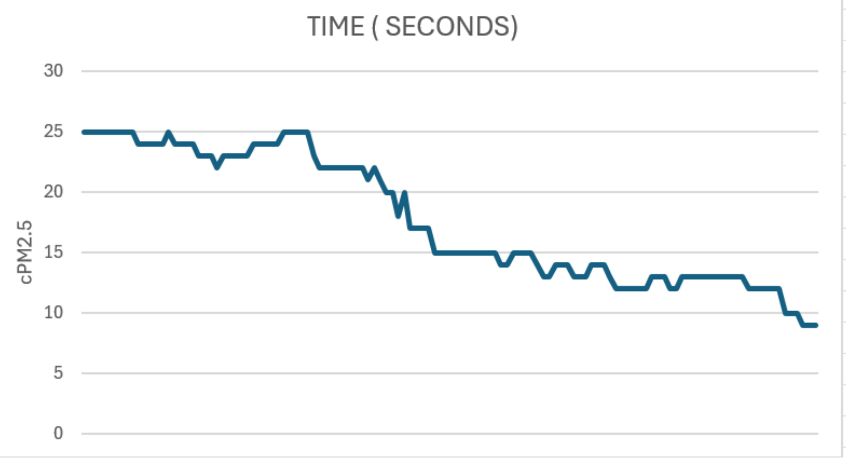

FIGURE 2. cPM2.5 Measurements from the Platform to the Outdoor Exit.
Initial cPM2.5 data on the platform: 25 µg/m³; final outdoor cPM2.5 data: 9 µg/m³