

High-Temporal-Resolution Characterization of PM_{2.5} and PM₁₀ in Contrasting Urban Environments of Korhogo, Northern Côte d'Ivoire

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How to cite this paper: Adon, A.J., Keita, S., Bahino, J., Soro, G., Gnamien, S., Madina, D., Dajuma, A., Adon, M., Silué, S. and Yoboué, V. (2026) High-Temporal-Resolution Characterization of PM_{2.5} and PM₁₀ in Contrasting Urban Environments of Korhogo, Northern Côte d'Ivoire. *Open Journal of Air Pollution*, 15, 203-221. <https://doi.org/10.4236/ojap.2026.154011>

Received: June 1, 2026

Accepted: October 27, 2026

Published: October 30, 2026

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Abstract

Particulate matter pollution remains poorly characterized in secondary cities of West Africa, particularly in northern Côte d'Ivoire. This study investigated PM_{2.5} and PM₁₀ concentrations and their diurnal variability during sequential dry-season monitoring at three contrasting urban sites in Korhogo: UPGC, Kassirimé, and Petit-Paris. Measurements were performed using a SENSIT RAMP monitor at 15-s resolution and processed following quality-control procedures. Measurements from the two particulate matter sensing channels were averaged and aggregated to hourly concentrations. A field calibration model incorporating relative humidity was then applied to PM_{2.5}, whereas PM₁₀ was retained as an uncorrected sensor-derived concentration estimate because no independent reference-based PM₁₀ calibration was available. Daily means were retained when at least 75% hourly coverage was available. Mean daily corrected PM_{2.5} concentrations were 31.0 µg·m⁻³ at UPGC, 25.2 µg·m⁻³ at Kassirimé, and 24.7 µg·m⁻³ at Petit-Paris, while corresponding uncorrected PM₁₀ concentrations were 28.1, 20.0, and 20.4 µg·m⁻³, respectively. The UPGC deployment exhibited both the highest concentrations and the greatest day-to-day variability, although differences in daily means between deployments were not statistically significant (Kruskal-Wallis, $p = 0.056$). During all three deployments, PM_{2.5} and PM₁₀ displayed pronounced bimodal diurnal pat-

terns, with morning and evening peaks separated by lower midday concentrations. Weekday-weekend contrasts differed among the three site-period deployments: Kassirimé showed markedly higher peak concentrations on weekdays, whereas Petit-Paris generally exhibited higher peaks during weekends; however, weekday-weekend differences in daily mean concentrations were not statistically significant, and the weekend profiles rested on a few days. The $PM_{2.5}/PM_{10}$ ratio, calculated from paired uncorrected sensor-derived estimates, was highest at Petit-Paris (0.85), intermediate at UPGC (0.81), and lowest at Kassirimé (0.79); it is interpreted only as a relative sensor-derived metric and not as a direct particle-size measurement. Overall, the results highlight substantial dry-season particulate pollution in Korhogo and demonstrate the value of high-temporal-resolution monitoring for characterizing short-term pollution dynamics in contrasting urban environments.

Keywords

$PM_{2.5}$, PM_{10} , Diurnal Variability, Low-Cost Sensors, Urban Air Pollution, Korhogo, Côte d'Ivoire

1. Introduction

Particulate matter (PM) is one of the major air pollutants of concern for human health, with both short- and long-term exposure associated with respiratory and cardiovascular diseases and premature mortality [1] [2]. Fine particles ($PM_{2.5}$) are of particular concern because they can penetrate deeply into the respiratory system, while PM_{10} represents a broader inhalable particle fraction that also includes particles generated by mechanical processes such as soil and road-dust resuspension. Beyond their mean concentrations, PM levels can vary markedly over the course of a day in response to changes in emission intensity, human activities, atmospheric mixing and regional transport. Characterizing this temporal variability is therefore essential for identifying periods of elevated pollution and improving population exposure assessment. Yet ground-based observations remain sparse in many African cities, particularly outside major capitals, limiting knowledge of these short-term pollution dynamics [2] [3].

Urban particulate pollution in West Africa reflects a combination of local anthropogenic emissions and regional natural influences. Road traffic, household biomass combustion, waste burning, unpaved roads and construction activities coexist with seasonal transport of mineral dust from the Sahara. Measurements conducted in Abidjan and Cotonou have demonstrated strong spatial and seasonal contrasts in PM concentrations and composition, with major contributions from domestic combustion in residential environments and from mineral and re-suspended dust at traffic-influenced sites [3]-[6]. These studies also showed that the long dry season, influenced by Harmattan conditions and regional dust transport, can substantially modify surface particulate concentrations. Such

source diversity makes high-temporal-resolution observations particularly valuable for distinguishing persistent pollution levels from short-lived episodes associated with daily urban activities.

Air-quality monitoring in West Africa has long been constrained by the limited availability of continuous reference-grade instruments. This has encouraged the development of complementary monitoring strategies. Long-term networks based on passive samplers have provided valuable information on gaseous pollutants such as NO_2 , SO_2 , NH_3 , HNO_3 and O_3 across African ecosystems and, later, at multiple sites in Abidjan [7] [8]. Particulate matter has meanwhile been investigated through filter-based sampling and intensive field measurements [4] [5]. Although these approaches have considerably improved knowledge of pollution levels and sources, they provide limited information on rapid intra-day variations. More recently, field-calibrated low-cost sensors have emerged as a useful complement to reference monitoring when appropriate calibration and quality-control procedures are applied [3] [9]–[11]. In Abidjan and Accra, calibrated Real-time Affordable Multi-Pollutant (RAMP) monitors revealed pronounced $\text{PM}_{2.5}$ morning peaks at traffic-influenced locations, evening enhancements in residential areas and higher concentrations during the Harmattan season, demonstrating the value of continuous measurements for resolving urban pollution dynamics [3].

Much less is known about these temporal patterns in secondary West African cities. Korhogo, located in northern Côte d'Ivoire within the forest-savanna transition zone, is exposed to a combination of urban traffic, household biomass combustion, soil and road dust, and seasonal Saharan dust transport during the dry season. Previous investigations have already established the relevance of particulate pollution in the city. Gnamien *et al.* 2021 [12] documented high $\text{PM}_{2.5}$ and PM_{10} concentrations during the dry season in Korhogo and Abidjan, while subsequent chemical characterization of $\text{PM}_{2.5}$ collected in Korhogo between 2018 and 2020 highlighted contributions from both combustion-related sources and mineral dust [13]. These studies provided valuable information on pollution levels, seasonal behaviour and aerosol composition, but the high-resolution diurnal variability of both $\text{PM}_{2.5}$ and PM_{10} across contrasting urban environments in Korhogo remains poorly documented, particularly with respect to weekday-weekend differences.

This study therefore investigates the concentrations and diurnal variability of $\text{PM}_{2.5}$ and PM_{10} through sequential dry-season monitoring at three contrasting urban sites in Korhogo, northern Côte d'Ivoire. Particular attention is given to the timing and magnitude of morning and evening pollution episodes and to differences between weekdays and weekends. The $\text{PM}_{2.5}/\text{PM}_{10}$ ratio of paired uncorrected sensor-derived estimates is also examined as a complementary, relative indicator of differences between the two sensor-derived fractions. Because measurements were conducted sequentially using the same monitoring instrument rather than simultaneously at all three sites, each dataset corresponds to a site-period deployment, and observed differences are interpreted as differences between deployments rather than as purely spatial site effects.

2. Materials and Methods

2.1. Study Area

The study was conducted in Korhogo, a major urban centre in northern Côte d'Ivoire, located at approximately 9.45 N and 5.63 W. The city lies within the forest-savanna transition zone and experiences a marked seasonal cycle. The dry season, extending approximately from November to March, is influenced by north-easterly Harmattan winds and may be associated with the transport of mineral dust from the Sahara and Sahelian regions.

Korhogo has undergone substantial urban development, accompanied by increasing road traffic and widespread motorcycle use. Local particulate emissions may arise from vehicle exhaust, road-dust resuspension, domestic combustion using wood and charcoal, waste burning, construction activities and the resuspension of dry soil. These urban sources coexist with regional atmospheric influences, particularly during the dry season.

Monitoring was conducted between November 2024 and March 2025 at three contrasting urban locations: a traffic-influenced site at Kassirimé, a residential site influenced by domestic combustion at Petit-Paris, and a site located at Peleforo Gon Coulibaly University (UPGC). The UPGC site had initially been selected to represent urban-background conditions; however, major road-construction activities occurred near the site during the monitoring period. It is therefore considered here as an urban environment additionally influenced by construction-related dust. Detailed site characteristics and monitoring periods are provided in Section 2.2.

2.2. Monitoring Sites and Study Design

Three monitoring locations were selected in Korhogo to represent contrasting urban environments: Peleforo Gon Coulibaly University (UPGC), Kassirimé and Petit-Paris. Their geographical locations within the city are shown in **Figure 1**.

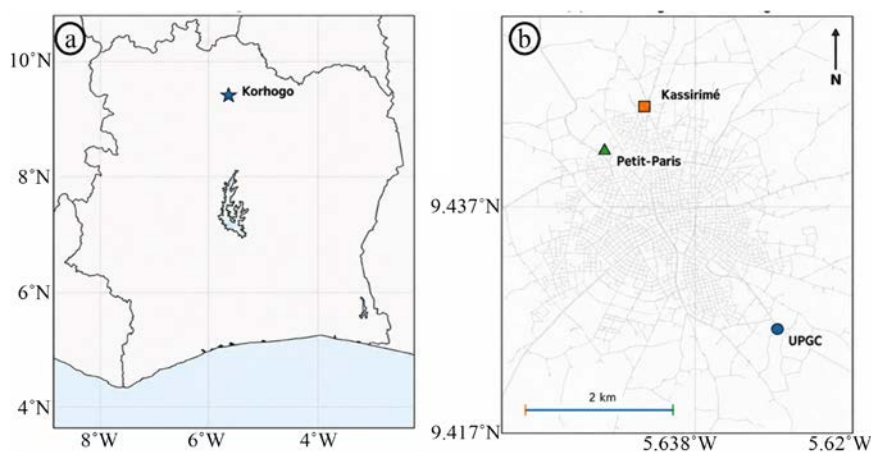


Figure 1. Location of Korhogo in Côte d'Ivoire (a) and location of the three particulate matter monitoring sites within the Korhogo urban area (b): UPGC, Kassirimé, and Petit-Paris.

UPGC was initially selected as an urban-background location because of its relative distance from major commercial and industrial activities. However, road-construction activities were ongoing near the site during the monitoring period and were recorded as part of the local site context. Kassirimé was selected as a traffic-influenced location along a major urban road characterized by frequent vehicle and motorcycle circulation, while Petit-Paris was selected as a residential location where biomass fuels, mainly wood and charcoal, are commonly used for cooking.

Measurements were conducted sequentially using the same SENSIT RAMP instrument. Monitoring was carried out at UPGC from 19 November 2024 to 8 January 2025, at Kassirimé from 9 to 26 January 2025, and at Petit-Paris from 17 February to 4 March 2025. The corresponding field deployment durations were 51, 17 and 16 calendar days, respectively. The site characteristics, geographical coordinates and monitoring periods are summarized in **Table 1**.

Table 1. Characteristics, deployment periods, of the three monitoring deployments in Korhogo.

Monitoring site	Site context	Coordinates	Monitoring period	Field deployment
UPGC	Initially selected as urban background; road construction ongoing nearby during measurements	9.4266°N 5.6298°W	19 Nov 2024-8 Jan 2025	51 days
Kassirimé	Traffic-influenced urban site	9.4470°N 5.6435°W	9 - 26 Jan 2025	17 days
Petit-Paris	Residential site influenced by domestic biomass combustion	9.4432°N 5.6458°W	17 Feb-4 Mar 2025	16 days

2.3. Instrumentation and Calibration

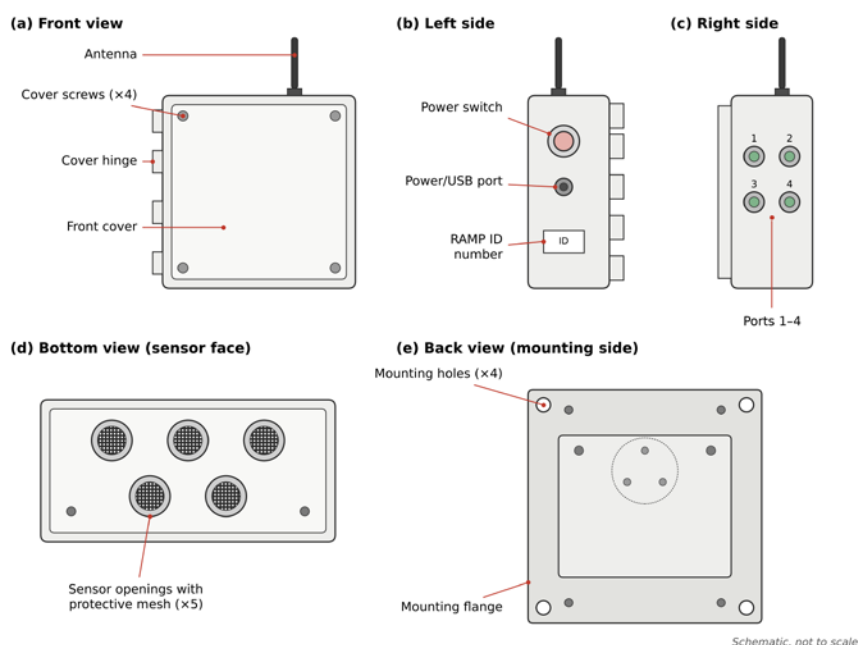


Figure 2. Schematic representation of the external components of the RAMP monitoring unit used during the Korhogo field measurements: (a) front view; (b) left side; (c) right side; (d) bottom view (sensor face); and (e) back view (mounting side). Redrawn with reference to manufacturer documentation; not to scale.

Particulate matter concentrations were measured using a SENSIT RAMP (Real-time Affordable Multi-Pollutant) monitor (Sensit Technologies, USA). The RAMP uses a nephelometric particle sensor (Plantower PMS5003) to provide continuous particulate matter measurements at a native temporal resolution of 15s [14]. The general configuration and main external components of the SENSIT RAMP used for the field measurements are shown in **Figure 2**.

Reference-based calibration was available for PM_{2.5} through a prior RAMP-BAM-1022 co-location experiment in Abidjan, whereas no independent reference-based PM₁₀ calibration was available for the instrument used in the present study. Accordingly, the reference-based correction described below was applied exclusively to PM_{2.5}. PM₁₀ values were retained as uncorrected sensor-derived concentration estimates and were not corrected using the PM_{2.5} calibration equation, which has not been validated for the coarse fraction. For PM_{2.5}, the field calibration model previously developed for RAMP monitors in Abidjan, Côte d'Ivoire, by Bahino *et al.* 2024 [3] was used. The calibration was based on hourly averaged data from a co-location experiment with a BAM-1022 (Beta Attenuation Monitor) reference instrument. A multiple linear regression model incorporating the raw PM_{2.5} response from the RAMP and relative humidity was applied:

$$PM_{2.5,corrected} = 18.1746 + 0.88536 PM_{2.5,RAMP} - 0.22924 RH \quad (1)$$

where PM_{2.5,RAMP} is the PM_{2.5} concentration reported by the RAMP (µg·m⁻³), RH is the relative humidity (%) measured by the instrument, and PM_{2.5,corrected} is the calibrated PM_{2.5} concentration.

During the PM_{2.5} co-location experiment, the raw hourly RAMP measurements showed a Pearson correlation coefficient of $R = 0.83$, a mean normalized bias of $MNB = 0.01$, and a bias-corrected coefficient of variation of the mean absolute error of $CVMAE = 0.29$ relative to the BAM-1022. After application of the calibration model, the corresponding performance metrics were $R = 0.87$, $MNB = -0.05$ and $CVMAE = 0.22$, indicating improved agreement and reduced absolute error relative to the reference monitor [3].

Although this calibration model was developed from a RAMP-BAM-1022 co-location experiment conducted in Abidjan, it was applied to the Korhogo measurements because no local reference co-location was available. Differences in aerosol composition, particle-size distribution, and ambient humidity between Abidjan and Korhogo may nevertheless affect sensor response and introduce residual uncertainty in the corrected PM_{2.5} concentrations.

2.4. Data Processing and Quality Control

Before further analysis, quality-control procedures were applied to the raw particulate matter data recorded at 15-s intervals. The dataset was screened for negative concentrations, duplicate records, and timestamp inconsistencies. Negative concentrations were considered invalid and removed, duplicate timestamps, when present, were excluded, and the chronological consistency of the time series was verified.

For each particle fraction, a 15-s time step was retained when both particulate matter sensing channels reported valid values, and the two channels were averaged to obtain a single $PM_{2.5}$ and PM_{10} concentration. A single 15-s time step at Kassirimé in which $PM_{2.5}$ exceeded PM_{10} was removed. The two channels were very strongly correlated ($R \geq 0.99$), although channel 1 consistently reported higher mean concentrations than channel 2. The agreement between the two particulate matter sensing channels was evaluated for each deployment using hourly uncorrected values (**Table S1**). No observations were excluded solely on the basis of inter-channel differences. The retained observations were then aggregated into hourly mean concentrations.

The calibration function described in Section 2.3 was applied exclusively to the hourly mean $PM_{2.5}$ concentrations obtained by averaging the two particulate matter sensing channels, with relative humidity included as a predictor. PM_{10} measurements underwent the same quality-control, channel-averaging, and hourly aggregation procedures, but no reference-based calibration was applied because an independent PM_{10} calibration was not available.

Daily mean concentrations were calculated from the validated hourly dataset. A daily mean was considered valid when at least 18 hourly observations, corresponding to 75% temporal coverage, were available for both $PM_{2.5}$ and PM_{10} .

2.5. Statistical Analysis

Descriptive statistics were calculated separately for $PM_{2.5}$ and PM_{10} at each monitoring site, including the mean, median, interquartile range (IQR), minimum, maximum, and coefficient of variation (CV) (**Table S2**). Valid daily mean concentrations, as defined in Section 2.4, were used as the statistical unit for comparisons among the three sequential site-period deployments. Because each site was monitored during a single, non-overlapping period, location is completely confounded with period; the site-period deployment is therefore the unit of comparison for both concentrations and $PM_{2.5}/PM_{10}$ ratios, and differences between deployments are not interpreted as spatial site effects.

Diurnal variability was assessed from mean hourly concentrations grouped by local hour of day (00:00 - 23:00). Profiles were calculated separately for $PM_{2.5}$ and PM_{10} and further stratified into weekdays (Monday-Friday) and weekends (Saturday-Sunday).

Differences in daily mean concentrations among the UPGC, Kassirimé, and Petit-Paris deployments were assessed using the Kruskal-Wallis test. When the overall test was significant, pairwise comparisons were performed using Dunn's post hoc test with Holm adjustment for multiple comparisons. Within each deployment, weekday and weekend daily means were compared using the Mann-Whitney U test. Statistical significance was set at $p < 0.05$. All analyses and graphical representations were performed using Python.

The $PM_{2.5}/PM_{10}$ ratio was calculated from paired uncorrected sensor-derived $PM_{2.5}$ and PM_{10} estimates to avoid modification of the ratio by the additive terms

of the calibration model. Daily ratios were calculated as the ratio of daily mean $PM_{2.5}$ to daily mean PM_{10} for days meeting the 75% completeness criterion, whereas hourly ratios were averaged by local hour of day. Differences in daily $PM_{2.5}/PM_{10}$ ratios among deployments were assessed using the Kruskal-Wallis test followed, when significant, by Dunn's post hoc test with Holm adjustment. The ratio is a ratio of sensor-derived concentration estimates rather than a direct particle-size measurement.

3. Results

After quality control and application of the final deployment time windows, 1223, 341, and 362 hourly observations were retained at UPGC, Kassirimé, and Petit-Paris, respectively. No duplicate timestamps or negative PM concentrations were identified in the retained datasets. Application of the 75% daily completeness criterion resulted in 50 valid days at UPGC, 13 at Kassirimé, and 14 at Petit-Paris for the analysis of daily concentrations (36, 8 and 10 weekdays and 14, 5 and 4 weekend days, respectively).

3.1. Particulate Matter Levels during the Three Site-Period Deployments

Daily mean $PM_{2.5}$ and PM_{10} concentrations varied among the three site-period deployments (**Figure 3**). The highest concentrations were observed during the UPGC deployment, with mean values of $31.0 \mu\text{g}\cdot\text{m}^{-3}$ for corrected $PM_{2.5}$ and $28.1 \mu\text{g}\cdot\text{m}^{-3}$ for uncorrected PM_{10} . Median concentrations were 33.5 and $30.3 \mu\text{g}\cdot\text{m}^{-3}$, respectively. Daily $PM_{2.5}$ concentrations ranged from 15.3 to $49.2 \mu\text{g}\cdot\text{m}^{-3}$, while PM_{10} ranged from 6.1 to $53.8 \mu\text{g}\cdot\text{m}^{-3}$. The UPGC deployment also exhibited the greatest day-to-day variability, with IQRs of $22.3 \mu\text{g}\cdot\text{m}^{-3}$ for $PM_{2.5}$ and $29.1 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , and corresponding CVs of 34.4% and 50.4%.

Lower concentrations were measured at Kassirimé. Mean daily concentrations were $25.2 \mu\text{g}\cdot\text{m}^{-3}$ for $PM_{2.5}$ and $20.0 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , with medians of 23.4 and $19.6 \mu\text{g}\cdot\text{m}^{-3}$, respectively. $PM_{2.5}$ concentrations ranged from 17.5 to $35.2 \mu\text{g}\cdot\text{m}^{-3}$ and PM_{10} from 8.7 to $32.8 \mu\text{g}\cdot\text{m}^{-3}$. Variability was lower than at UPGC, with IQRs of 7.5 and $11.9 \mu\text{g}\cdot\text{m}^{-3}$ and CVs of 21.5% and 38.7% for $PM_{2.5}$ and PM_{10} , respectively.

Petit-Paris showed the lowest mean $PM_{2.5}$ concentration, whereas mean uncorrected PM_{10} was similar to that measured at Kassirimé. Mean daily concentrations were $24.7 \mu\text{g}\cdot\text{m}^{-3}$ for $PM_{2.5}$ and $20.4 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , with median values of 25.3 and $21.2 \mu\text{g}\cdot\text{m}^{-3}$, respectively. Daily concentrations ranged from 17.1 to $29.2 \mu\text{g}\cdot\text{m}^{-3}$ for $PM_{2.5}$ and from 12.6 to $26.0 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} . Petit-Paris exhibited the lowest temporal variability, with IQRs of 3.8 and $5.0 \mu\text{g}\cdot\text{m}^{-3}$ and CVs of 13.5% and 18.1% for $PM_{2.5}$ and PM_{10} , respectively.

Overall, the UPGC deployment was characterized by both the highest particulate matter concentrations and the greatest day-to-day variability, whereas the Kassirimé and Petit-Paris deployments showed lower and comparatively less variable concentrations.

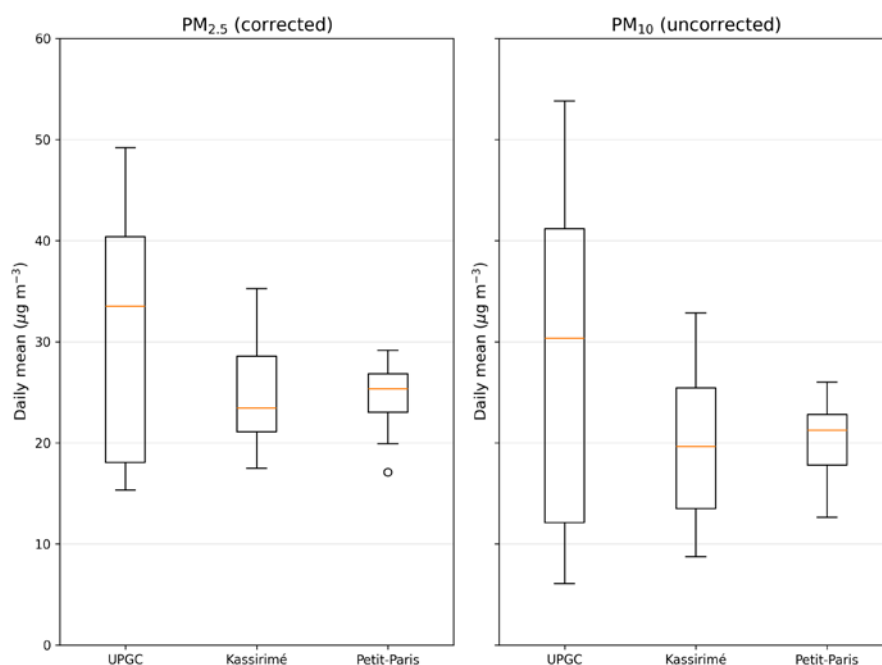


Figure 3. Distribution of valid daily mean $PM_{2.5}$ and PM_{10} concentrations during the three site-period deployments in Korhogo.

3.2. Diurnal Variations of $PM_{2.5}$ and PM_{10}

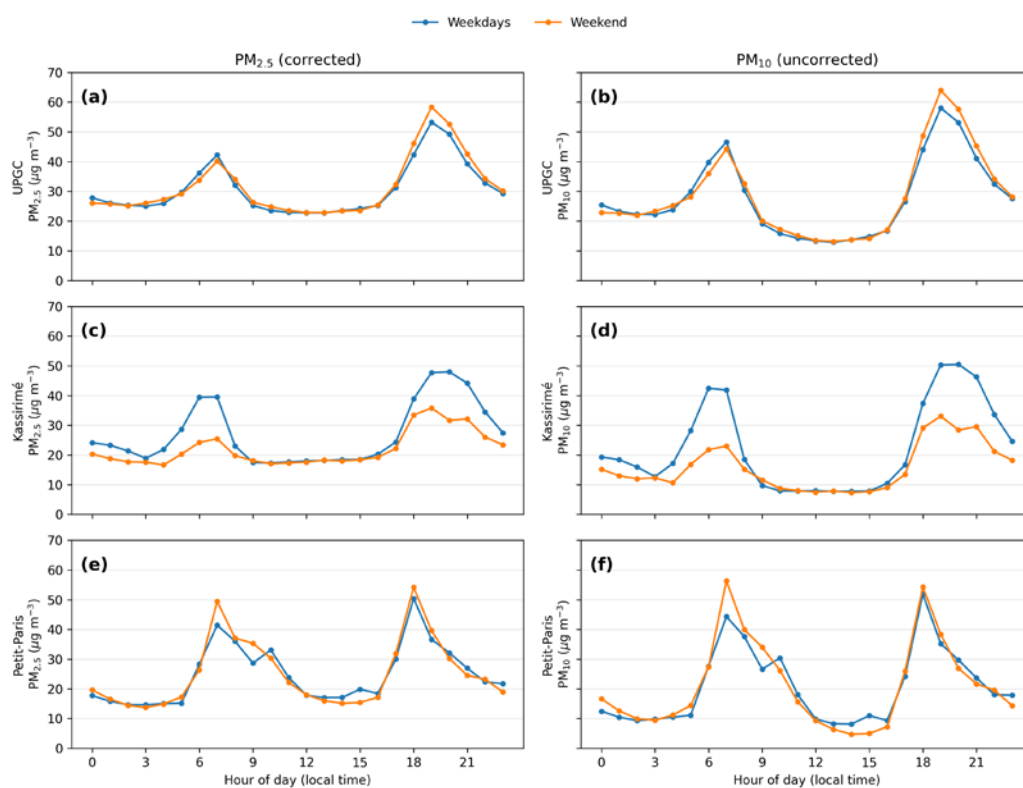


Figure 4. Weekday and weekend diurnal profiles of $PM_{2.5}$ and sensor-derived PM_{10} concentrations at UPGC (51 days: 37 weekdays/14 weekend days), Kassirimé (17 days: 11/6), and Petit-Paris (16 days: 12/4).

Diurnal variations in PM_{2.5} and PM₁₀ concentrations were examined separately for weekdays and weekends during the three site-period deployments. The hourly profiles are based on 51 days (37 weekdays/14 weekend days) at UPGC, 17 days (11/6) at Kassirimé and 16 days (12/4) at Petit-Paris; at Kassirimé, no hour on 23 January 2025 had both channels valid. The corresponding hourly profiles are presented in **Figure 4**, with UPGC shown in panels (a-b), Kassirimé in panels (c-d), and Petit-Paris in panels (e-f).

3.2.1. Diurnal Variations at UPGC

The diurnal profiles of PM_{2.5} and PM₁₀ at UPGC exhibited a clear bimodal pattern on both weekdays and weekends (**Figure 4(a)** and **Figure 4(b)**). Concentrations increased from approximately 05:00 and reached a first maximum at 07:00. At this time, weekday mean concentrations were 42.2 $\mu\text{g}\cdot\text{m}^{-3}$ for PM_{2.5} and 46.6 $\mu\text{g}\cdot\text{m}^{-3}$ for PM₁₀, compared with 40.2 and 44.3 $\mu\text{g}\cdot\text{m}^{-3}$, respectively, on weekends.

Following the morning peak, concentrations decreased and remained comparatively low from late morning to mid-afternoon. The lowest mean concentrations occurred around 13:00, reaching 22.7 $\mu\text{g}\cdot\text{m}^{-3}$ for PM_{2.5} and 12.9 $\mu\text{g}\cdot\text{m}^{-3}$ for PM₁₀ on weekdays, and 22.9 and 13.1 $\mu\text{g}\cdot\text{m}^{-3}$, respectively, on weekends.

A second increase began in the late afternoon, with the highest hourly mean concentrations observed at 19:00. Weekday concentrations reached 53.3 $\mu\text{g}\cdot\text{m}^{-3}$ for PM_{2.5} and 58.0 $\mu\text{g}\cdot\text{m}^{-3}$ for PM₁₀, while weekend concentrations were higher, reaching 58.3 and 63.9 $\mu\text{g}\cdot\text{m}^{-3}$, respectively. Concentrations then decreased, more steeply after 20:00.

Overall, PM_{2.5} and PM₁₀ followed closely similar diurnal patterns at UPGC (absolute levels of the corrected and uncorrected fractions are not compared; Section 2.4). Weekday and weekend profiles were relatively similar during the morning and midday periods, whereas a clearer difference was observed during the evening peak.

3.2.2. Diurnal Variations at Kassirimé

At Kassirimé, PM_{2.5} and PM₁₀ exhibited a pronounced bimodal diurnal pattern, with higher peak concentrations on weekdays than on weekends (**Figure 4(c)** and **Figure 4(d)**). On weekdays, concentrations increased rapidly from approximately 05:00 and reached the morning maximum around 06:00 - 07:00. PM_{2.5} reached 39.4 $\mu\text{g}\cdot\text{m}^{-3}$ at 06:00 and 39.5 $\mu\text{g}\cdot\text{m}^{-3}$ at 07:00, while PM₁₀ reached 42.4 and 41.8 $\mu\text{g}\cdot\text{m}^{-3}$, respectively.

Following the morning peak, concentrations declined sharply and remained comparatively low from approximately 09:00 to 16:00. The lowest weekday mean PM_{2.5} concentration occurred at 10:00 (17.3 $\mu\text{g}\cdot\text{m}^{-3}$), and uncorrected PM₁₀ remained at about 7.8 - 8.0 $\mu\text{g}\cdot\text{m}^{-3}$ from 10:00 to 15:00, before concentrations increased progressively again in the late afternoon.

The evening episode was more pronounced than the morning peak. At 19:00, PM_{2.5} reached 47.7 $\mu\text{g}\cdot\text{m}^{-3}$ and increased slightly to its maximum of 48.0 $\mu\text{g}\cdot\text{m}^{-3}$ at 20:00. PM₁₀ reached 50.3 $\mu\text{g}\cdot\text{m}^{-3}$ at 19:00 and its maximum of 50.5 $\mu\text{g}\cdot\text{m}^{-3}$ at 20:00.

Weekend profiles followed the same general temporal pattern but showed lower morning and evening maxima. At 07:00, concentrations reached $25.4 \mu\text{g}\cdot\text{m}^{-3}$ for $\text{PM}_{2.5}$ and $23.0 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , while the evening maximum occurred at 19:00, reaching 35.8 and $33.0 \mu\text{g}\cdot\text{m}^{-3}$, respectively. Overall, the most distinctive feature of the Kassirimé deployment was the marked weekday-weekend contrast during the morning and evening peak periods.

3.2.3. Diurnal Variations at Petit-Paris

At Petit-Paris, $\text{PM}_{2.5}$ and PM_{10} exhibited a clear bimodal diurnal pattern on both weekdays and weekends (**Figure 4(e)** and **Figure 4(f)**). Concentrations increased after 05:00 and reached a first maximum at 07:00. Weekday mean concentrations were $41.5 \mu\text{g}\cdot\text{m}^{-3}$ for $\text{PM}_{2.5}$ and $44.4 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , compared with higher weekend values of 49.5 and $56.4 \mu\text{g}\cdot\text{m}^{-3}$, respectively.

After the morning peak, concentrations declined toward midday and remained comparatively low during the afternoon. For corrected $\text{PM}_{2.5}$, the lowest hourly means occurred during the early-morning period, around 02:00 - 03:00, with concentrations of approximately $13.8 - 14.7 \mu\text{g}\cdot\text{m}^{-3}$, whereas uncorrected PM_{10} reached its lowest values in the early afternoon (about $8.2 - 8.3 \mu\text{g}\cdot\text{m}^{-3}$ on weekdays and $4.8 - 6.4 \mu\text{g}\cdot\text{m}^{-3}$ on weekends at 13:00 - 14:00). On an uncorrected basis, $\text{PM}_{2.5}$ also reached its lowest values at 13:00 - 14:00; the earlier night-time minimum of corrected $\text{PM}_{2.5}$ reflects the relative-humidity term of Equation (1), as relative humidity was higher at night.

A second increase occurred from late afternoon, with both particle fractions reaching their evening maximum at 18:00. Weekday concentrations reached $50.4 \mu\text{g}\cdot\text{m}^{-3}$ for $\text{PM}_{2.5}$ and $51.8 \mu\text{g}\cdot\text{m}^{-3}$ for PM_{10} , while weekend values were higher, at 54.2 and $54.3 \mu\text{g}\cdot\text{m}^{-3}$, respectively. The evening maximum exceeded the morning maximum except for weekend PM_{10} , for which the 07:00 peak was slightly higher. Concentrations subsequently decreased during the evening.

Overall, $\text{PM}_{2.5}$ and PM_{10} showed closely synchronized diurnal variations at Petit-Paris, with higher morning and evening peaks during weekends than on weekdays. This pattern contrasts with Kassirimé, where the strongest peaks occurred on weekdays. These weekday-weekend contrasts should be interpreted descriptively given the limited number of weekend days.

3.3. Statistical Comparison of Daily Particulate Matter Concentrations between Site-Period Deployments

Because each site was monitored during a single, non-overlapping period, these tests compare site-period deployments and cannot distinguish location effects from temporal or seasonal effects. Daily mean corrected $\text{PM}_{2.5}$ concentrations did not differ significantly among the three deployments (Kruskal-Wallis, $H = 5.76$, $p = 0.056$). Similarly, daily mean uncorrected PM_{10} concentrations did not differ significantly ($H = 5.78$, $p = 0.056$); no post hoc test was therefore performed.

No significant weekday-weekend differences in daily mean concentrations were observed during any deployment. At UPGC, Mann-Whitney U tests yielded $p =$

0.787 for $PM_{2.5}$ and $p = 0.957$ for PM_{10} . At Kassirimé, daily concentrations tended to be higher on weekdays, but the differences were not statistically significant for either $PM_{2.5}$ or PM_{10} ($p = 0.093$ for both). Similarly, no significant weekday-weekend differences were found at Petit-Paris ($p = 0.733$ for $PM_{2.5}$ and $p = 0.539$ for PM_{10}). These comparisons should be interpreted in light of the number of valid weekday and weekend days available for each deployment.

Thus, although marked weekday-weekend contrasts were apparent at specific hours of the diurnal cycle, particularly at Kassirimé, these differences were not significant when concentrations were averaged at the daily scale.

3.4. $PM_{2.5}/PM_{10}$ Ratio and Its Diurnal Variability

The $PM_{2.5}/PM_{10}$ ratio showed distinct patterns among the three deployments (**Figure 5**). Based on valid daily observations, the mean ratio was highest at Petit-Paris (0.848), followed by UPGC (0.808) and Kassirimé (0.786). Median values showed the same ordering, reaching 0.853, 0.813, and 0.789, respectively. Daily ratios were relatively stable within each deployment, with interquartile ranges of 0.029 at Petit-Paris, 0.042 at UPGC, and 0.023 at Kassirimé (**Figure 5(a)**). Daily ratios differed significantly among deployments (Kruskal-Wallis, $H = 25.91$, $p < 0.001$). Dunn's post hoc tests with Holm adjustment indicated significant differences between UPGC and Kassirimé ($p = 0.022$), UPGC and Petit-Paris ($p < 0.001$), and Kassirimé and Petit-Paris ($p < 0.001$).

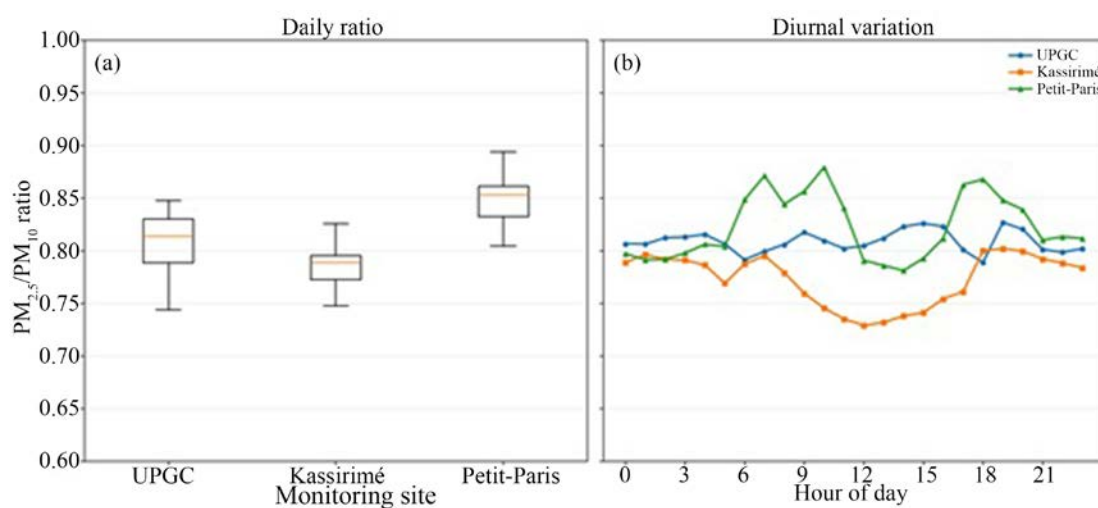


Figure 5. Daily distribution (a) and mean diurnal variation (b) of the $PM_{2.5}/PM_{10}$ ratio at UPGC, Kassirimé, and Petit-Paris. Ratios were calculated from paired sensor-derived $PM_{2.5}$ and PM_{10} estimates.

The diurnal profiles further revealed differences in the temporal behaviour of the ratio (**Figure 5(b)**). At UPGC, $PM_{2.5}/PM_{10}$ remained comparatively stable throughout the day, generally between approximately 0.79 and 0.83. Kassirimé exhibited a more pronounced diurnal cycle: the ratio decreased progressively during the morning, reached its lowest values of approximately 0.73 - 0.74 around 12:00 - 14:00, and subsequently increased to about 0.80 during the early evening.

Petit-Paris displayed greater short-term variability, with higher ratios during the morning and late afternoon-evening periods. Values reached approximately 0.87 - 0.88 around 07:00 - 10:00 and again about 0.86 - 0.87 around 17:00 - 18:00, while lower ratios of approximately 0.78 - 0.79 occurred during the early afternoon.

Overall, the sensor-derived ratio varied both between deployments and over the course of the day. It was highest during the Petit-Paris deployment, whereas Kassirimé showed the lowest values and a daytime decrease. Because the ratio is a relative sensor-derived metric (Section 2.5), these differences are not interpreted as direct changes in particle-size distribution; their possible implications are discussed in Section 4.

4. Discussion

4.1. Particulate Matter Levels and Comparison with Previous Studies

Measurements during the three site-period deployments revealed substantial particulate matter pollution during the dry season in Korhogo, with the highest concentrations observed during the UPGC deployment. Mean daily concentrations reached $31.0 \mu\text{g}\cdot\text{m}^{-3}$ for corrected $\text{PM}_{2.5}$ and $28.1 \mu\text{g}\cdot\text{m}^{-3}$ for uncorrected PM_{10} at UPGC, compared with 25.2 and $20.0 \mu\text{g}\cdot\text{m}^{-3}$ at Kassirimé and 24.7 and $20.4 \mu\text{g}\cdot\text{m}^{-3}$ at Petit-Paris, respectively. UPGC also showed the greatest day-to-day variability. Road-construction activities occurred near UPGC during monitoring and may have contributed to particulate concentrations. Because monitoring was sequential, differences among deployments should be interpreted as site-period patterns rather than purely spatial contrasts.

All valid daily corrected $\text{PM}_{2.5}$ concentrations remained above the 2021 WHO 24-h air-quality guideline value of $15.0 \mu\text{g}\cdot\text{m}^{-3}$ [2], highlighting elevated fine-particle concentrations during the study period. This comparison is used to characterize the magnitude of particulate pollution rather than regulatory compliance.

The elevated concentrations observed in the present study are consistent with previous measurements in Korhogo. Gnamien *et al.* [12] reported high dry-season $\text{PM}_{2.5}$ and PM_{10} concentrations across several locations in Korhogo, with daily $\text{PM}_{2.5}$ concentrations exceeding WHO guideline values and particulate pollution generally more pronounced in Korhogo than in Abidjan. Longer-term observations by Gnamien *et al.* [13] further showed that $\text{PM}_{2.5}$ concentrations in Korhogo during the dry season were more than twice those measured during the wet season. Source-apportionment analysis identified biomass burning and domestic combustion as the dominant contribution to $\text{PM}_{2.5}$ in Korhogo (70.7%), followed by road traffic (16%), with smaller contributions from road and natural dust and agricultural activities.

The monitoring periods, from November to March, also coincided largely with the Harmattan season, during which regional transport can enhance urban particulate pollution. High-temporal-resolution RAMP measurements in Abidjan and Accra showed that $\text{PM}_{2.5}$ concentrations were generally highest during the

long dry season, commonly reaching approximately $20.0 - 40.0 \mu\text{g}\cdot\text{m}^{-3}$, and demonstrated that Saharan dust transport can substantially increase urban $\text{PM}_{2.5}$ concentrations during regional pollution episodes [3]. The concentration levels measured in Korhogo are therefore consistent with a particulate environment influenced by both local urban emissions and broader dry-season atmospheric conditions.

4.2. Interpretation of Diurnal Patterns and Weekday-Weekend Contrasts

All three deployments exhibited a broadly similar bimodal diurnal pattern, with concentration increases during the morning and evening and lower levels from late morning to mid-afternoon. Such temporal behaviour is consistent with the combined influence of daily emission cycles and atmospheric dispersion. Morning accumulation may occur when urban activities intensify while atmospheric mixing remains limited, whereas increasing daytime convection promotes dilution. In the evening, reduced vertical mixing combined with continuing human activities may favour a renewed accumulation of particles near the surface. Comparable morning and evening PM enhancements have been reported in West African urban environments [3]-[5].

At UPGC, $\text{PM}_{2.5}$ and PM_{10} displayed similar weekday and weekend profiles during the morning and midday periods, while weekend concentrations were somewhat higher during the evening maximum. The absence of a pronounced weekday-weekend contrast suggests that the observed pattern cannot be explained by a simple weekly traffic cycle. Moreover, the road-construction activities occurring near the monitoring site may have contributed episodically to particulate emissions through soil disturbance, vehicle movement and resuspension of deposited dust. This interpretation is consistent with the comparatively high concentrations and greater day-to-day variability observed at UPGC, although the contribution of construction activities cannot be quantified from concentration measurements alone.

Kassirimé showed the clearest weekday-weekend contrast. Morning and evening peaks were markedly higher on weekdays, whereas weekend concentrations were substantially reduced during the same periods. Given the location of the site along a major urban road with frequent motorcycle and vehicle circulation, this pattern is consistent with variations in traffic and mobility-related activities. Similar traffic-associated morning and evening enhancements have been documented in other West African cities, where exhaust emissions and road-dust resuspension contribute jointly to particulate matter concentrations [3]-[5]. However, in the absence of simultaneous traffic counts, the observed temporal pattern should be interpreted as indicative rather than as direct evidence of traffic-source contributions.

A different weekly pattern was observed at Petit-Paris, where morning and evening peaks were generally higher during weekends. Petit-Paris is predomi-

nantly residential and is characterized by the frequent use of wood and charcoal for cooking. The timing of the observed peaks is therefore compatible with household and neighbourhood activities, including domestic combustion, which has previously been identified as an important source of particulate pollution in Côte d'Ivoire [13]. Nevertheless, the weekend profiles rest on only four days, so this contrast should be considered primarily as a descriptive feature of the observed monitoring period.

The $PM_{2.5}/PM_{10}$ ratio of uncorrected sensor-derived estimates provides complementary, relative information on the two fractions during the three deployments. Petit-Paris exhibited the highest mean daily ratio (0.848), followed by UPGC (0.808) and Kassirimé (0.786). The higher ratio at Petit-Paris is compatible with a greater influence of combustion-related emissions, whereas the lower ratio and daytime decrease at Kassirimé are compatible with a relatively greater contribution from particles in the PM_{10} - $PM_{2.5}$ size range. At UPGC, the comparatively stable ratio may reflect a more persistent mixture of the two sensor-derived fractions. These interpretations remain indicative, as the sensor-derived $PM_{2.5}/PM_{10}$ ratio alone does not allow quantitative source attribution.

Despite visible weekday-weekend differences in the hourly profiles, no statistically significant differences were detected in daily mean $PM_{2.5}$ or PM_{10} concentrations during any of the three deployments. This apparent discrepancy reflects the different temporal scales considered: short morning and evening episodes can produce marked hourly contrasts while having a more limited influence on 24-h averages. The results therefore emphasize the added value of high-temporal-resolution measurements for identifying periods of elevated exposure that may not be apparent from daily mean concentrations alone.

4.3. Study Limitations and Implications

The main limitation of this study is the sequential monitoring design. Because a single RAMP instrument was deployed successively at UPGC, Kassirimé, and Petit-Paris, differences among site-period deployments may reflect both spatial contrasts and temporal variations between monitoring periods. The unequal deployment durations and the limited number of weekend days should also be considered when interpreting weekday-weekend differences. A further limitation concerns the transfer of the $PM_{2.5}$ calibration model from Abidjan to Korhogo. Differences in aerosol composition, particle-size distribution, and atmospheric humidity between the two environments may introduce residual measurement uncertainty.

No simultaneous traffic counts, detailed household-activity records, construction-intensity data, or particle chemical-composition measurements were available for quantitative source attribution. Nevertheless, the high-temporal-resolution measurements clearly identified recurrent morning and evening pollution episodes and contrasting weekday-weekend patterns across the three urban environments. These results provide useful information for targeting future monitoring

efforts in Korhogo.

5. Conclusions

This study characterized PM_{2.5} and PM₁₀ concentrations and their diurnal variability through sequential dry-season monitoring at three contrasting urban sites in Korhogo, northern Côte d'Ivoire; each dataset corresponds to a site-period deployment. The highest daily mean concentrations were observed during the UPGC deployment, with 31.0 µg·m⁻³ for corrected PM_{2.5} and 28.1 µg·m⁻³ for uncorrected PM₁₀, while lower and relatively similar levels were recorded at Kassirimé and Petit-Paris. UPGC also exhibited the greatest day-to-day variability.

Across the three deployments, PM_{2.5} and PM₁₀ displayed a consistent bimodal diurnal pattern, with morning and evening concentration peaks separated by lower levels during the middle of the day. The weekday-weekend contrast differed among deployments: Kassirimé showed higher peak concentrations on weekdays, whereas Petit-Paris generally exhibited higher morning and evening peaks during weekends. At UPGC, weekday and weekend profiles were more similar, apart from somewhat higher evening concentrations on weekends. However, these hourly contrasts did not translate into statistically significant weekday-weekend differences in daily mean concentrations.

The PM_{2.5}/PM₁₀ ratio of uncorrected sensor-derived estimates provided complementary, relative information on the two fractions among the deployments. Petit-Paris exhibited the highest ratio, whereas Kassirimé showed the lowest ratio and a pronounced daytime decrease, compatible with a comparatively greater contribution of particles in the PM₁₀-PM_{2.5} size range. These patterns are compatible with differences in dominant local activities, although the ratio alone does not allow quantitative source attribution.

Overall, the results demonstrate the value of high-temporal-resolution monitoring for identifying short-duration pollution episodes and characterizing urban particulate matter dynamics in Korhogo. Extending such measurements across seasons and combining them with source-related activity data would further improve understanding of particulate pollution and support the development of locally adapted air-quality management strategies in northern Côte d'Ivoire.

Acknowledgements

The authors would like to thank Peleforo Gon Coulibaly University and its staff for providing the institutional framework, facilities, and material support necessary for carrying out this scientific work. The authors also gratefully acknowledge the Aerosols and Pollution Research Team of Félix Houphouët-Boigny University for providing the air-quality monitoring instruments and for their scientific and technical expertise in the analysis and interpretation of the results.

Author Contributions

Conceptualization, A.J.A., J.B. and S.K.; methodology, A.J.A., J.B. and S.K.; inves-

tigation, G.S.; formal analysis, G.S.; data curation, G.S.; resources, S.G. and J.B.; logistical support, S.S., M.D. and A.D.; interpretation of results, S.G. and J.B.; writing and original draft preparation, G.S., A.J.A., J.B. and S.K.; supervision, M.A., S.S. and V.Y. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Supplementary Tables

Table S1. Agreement between the two particulate matter sensing channels for each deployment (hourly means, uncorrected values; hours with both channels valid). Median relative difference = (channel 1 – channel 2)/mean of the two channels.

Deployment	PM	n (h)	R	Channel 1 mean ($\mu\text{g}\cdot\text{m}^{-3}$)	Channel 2 mean ($\mu\text{g}\cdot\text{m}^{-3}$)	Median relative difference (%)
UPGC	PM _{2.5}	1223	0.998	25.1	20.2	22.7
UPGC	PM ₁₀	1223	0.998	30.9	25.1	21.3
Kassirimé	PM _{2.5}	341	0.998	17.7	13.8	25.5
Kassirimé	PM ₁₀	341	0.998	22.1	17.8	22.8
Petit-Paris	PM _{2.5}	362	0.994	20.4	15.1	33.3
Petit-Paris	PM ₁₀	362	0.993	23.9	17.9	31.5

Table S2. Descriptive statistics of valid daily mean corrected PM_{2.5} and uncorrected sensor-derived PM₁₀ concentrations during the three site-period deployments in Korhogo. Concentration statistics are expressed in $\mu\text{g}\cdot\text{m}^{-3}$.

Site	PM	n	Mean	Median	IQR	Min	Max	CV (%)
UPGC	PM _{2.5}	50	31.0	33.5	22.3	15.3	49.2	34.4
UPGC	PM ₁₀	50	28.1	30.3	29.1	6.1	53.8	50.4
Kassirimé	PM _{2.5}	13	25.2	23.4	7.5	17.5	35.2	21.5
Kassirimé	PM ₁₀	13	20.0	19.6	11.9	8.7	32.8	38.7
Petit-Paris	PM _{2.5}	14	24.7	25.3	3.8	17.1	29.2	13.5
Petit-Paris	PM ₁₀	14	20.4	21.2	5.0	12.6	26.0	18.1