

Analysis of Variations in the OC/EC Ratio in PM_{2.5} and PM₁₀ Aerosols during the Dry and Wet Seasons in Two West African Cities (Abidjan and Korhogo) in Côte d'Ivoire

Sylvain Gnamien^{1*}, Siélé Silué², Eric-Michel Assamoi¹, Mohamed Kassamba-Diaby³, Sekou Keita², Julien Bahino¹, N'Datchoh E. Touré¹, Cathy Liousse⁴, Véronique Yoboué¹

¹Laboratoire des Sciences de la Matière, de l'Environnement et de l'Energie Solaire (LASMES), Université Félix Houphouët-Boigny (UFHB), Abidjan, Côte d'Ivoire

²Département de Mathématiques Physique Chimie, Université Peleforo GON COULIBALY (UPGC), Korhogo, Côte d'Ivoire

³Institut de Recherche sur les Énergies Nouvelles (IREN), Université Nangui Abrogoua, Abidjan, Côte d'Ivoire

⁴Laboratoire d'Aérodologie, Centre National de la Recherche Scientifique (CNRS), Toulouse, France

Email: *gnkonans@gmail.com, gnamien.sylvain@ufhb.edu.ci

How to cite this paper: Gnamien, S., Silué, S., Assamoi, E.-M., Kassamba-Diaby, M., Keita, S., Bahino, J., Touré, N.E., Liousse, C. and Yoboué, V. (2026) Analysis of Variations in the OC/EC Ratio in PM_{2.5} and PM₁₀ Aerosols during the Dry and Wet Seasons in Two West African Cities (Abidjan and Korhogo) in Côte d'Ivoire. *Atmospheric and Climate Sciences*, 16, 27-40. <https://doi.org/10.4236/acs.2026.161003>

Received: September 22, 2025

Accepted: December 2, 2025

Published: December 5, 2025

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Air quality in West Africa is strongly influenced by interactions between anthropogenic and natural emissions of particulate matter (PM). In this study, we examine variations in carbon aerosol concentrations (organic carbon (OC) and elemental carbon (EC)) during the dry and wet seasons, focusing on OC/EC ratios. This study is based on sampling from 2018 to 2020 at five urban sites in Côte d'Ivoire, including three in Abidjan (A1, A2, and A3) and two in Korhogo (K1 and K2). The results show that in Abidjan, OC/EC ratios in PM_{2.5} almost double between the wet season (WS) and the dry season (DS), reflecting a stronger organic contribution during the DS, while in PM₁₀, the ratios remain stable or decrease slightly, suggesting a higher proportion of elemental carbon in coarse particles. In Korhogo, seasonal contrasts are more pronounced: at the K1 and K2 sites, OC/EC ratios increase from around 2 - 3 during the wet season to values above 5 during the dry season, with extremes at K2 where ratios in PM_{2.5} and PM₁₀ double vs. WS. This variability highlights the strong influence of biomass and domestic waste combustion during the dry season, as well as marked differences between northern and southern sites in the contribution of carbonaceous species to PM_{2.5} and PM₁₀ aerosols. Overall, the results highlight the value of OC/EC ratios as indicators of combustion sources and the need for seasonal monitoring in West Africa.

Keywords

OC/EC Ratio, PM_{2.5}/PM₁₀ Ratio, Dry Season (DS), Wet Season (WS), West Africa

1. Introduction

Cities in West Africa, which are experiencing rapid urban and population growth, are facing increasing challenges in understanding air quality. These challenges are amplified by multiple sources of pollution, including biomass burning, domestic fires, waste burning, industrial emissions, and road traffic, which contribute to high concentrations of particulate matter [1]-[3]. The study of certain ratios, such as PM_{2.5}/PM₁₀ and OC/EC in PM_{2.5} and PM₁₀, is of great importance to characterize the nature of particles and understand their origins [4]. Organic and elemental aerosols have opposite optical properties; OC is light scattering while EC is absorbing.

The OC/EC ratio, which is a powerful indicator of anthropogenic and natural combustion sources, is highly dependent on the size of PM₁₀ or PM_{2.5} particles, from which carbonaceous species (OC and EC) originate. PM_{2.5} is mainly emitted by anthropogenic activities [5]-[8]; its OC and EC content will be more anthropogenic in origin. These carbonaceous species can originate from savanna fires (regional fires), which are more noticeable in the north during the dry season, so their impact can vary depending on the season [8] [9].

It has also been suggested that the importance of the biological/inflammatory impact of aerosols could be related to the relative OC content in combustion aerosols (e.g., the OC/EC ratio) due to the higher water solubility properties of OC than EC [10]. However, despite their importance already demonstrated by numerous articles [11] [12], studies on the carbonaceous species in particulate matter, particularly carbonaceous aerosols, remain limited in West Africa. This study analyzes the seasonality of PM_{2.5}/PM₁₀ and OC/EC ratios in PM₁₀ and PM_{2.5} in two geographical areas with different geographical, economic, and meteorological characteristics. It is based on original data from two years of in-situ observations at five measurement sites.

2. Methodologies

2.1. Study Areas

In this study, five urban sites spread over 2 cities were sampled. These are the cities of Abidjan, with sites A1, A2, and A3, and Korhogo, with sites K1 and K2. These 2 cities are being studied simultaneously as part of the PASMU project, as their characteristics are very different. Indeed, the two cities differ in terms of economic activities, modes of transport, types of roads, cooking fuels, demographic practices, and local weather. In addition, the population densities of these two cities

are also very different, with the population of Abidjan being 10 times greater than that of Korhogo, as shown in [2] [4] [5].

2.2. Sampling and Measurement Sites

Measurements were carried out using aerosol-type samplers such as those of the INDAAF project [13], but also in the framework of the DACCIWA program [14]. This sampling method was described in [2]. Samples are collected weekly on quartz fiber filters to obtain mass concentrations and carbon content (OC and EC) in PM_{2.5} and PM₁₀ aerosols after analysis.

Sampling begins in March 2018 for A1 and K1 and in December 2018 for A2, A3, and K2, and ends in March 2020 for all sites. The monitoring network includes five sites representing diverse urban environments (Table 1). In Abidjan, the A1 site in the Cocody area is an urban background located in a middle- and high-income residential area, influenced by the source of road traffic. The A2 site, located in the Plateau, captures the direct impact of heavy traffic in the city's main business district. The A3 site in Treichville is in a low-income, high-density neighborhood exposed to significant sources of urban pollution. In Korhogo, the K1 site, at the entrance to the city, represents an urban background indirectly affected by various anthropogenic sources, while the K2 site, in the city center, is surrounded by transport stations and the main market, concentrating emissions from transport and commercial activity.

Table 1. Location of the Abidjan and Korhogo measurement sites.

Cities	Sites	Type	Location
Abidjan	A1: Felix Houphouët-Boigny University (UFHB)	Urban Background	Lat (5°20'47.58"N) Long (3°59'23.96"W)
	A2: Hotel of the Plateau District	Urban Road	Lat (5°19'15.74"N) Long (4°01'11.50"W)
	A3: Modern High School of Treichville	Urban	Lat (5°18'32.36"N) Long (4°00'13.53"W)
Korhogo	K1: Peleforo Gon Coulibaly University (UPGC)	Urban Background	Lat (9°25'37.09"N) Long (5°37'47.17"W)
	K2: Northern Pharmacy	Urban Road	Lat (9°27'27.00"N) Long (5°37'46.05"W)

2.3. Determination of the Mass and Concentration of Carbonaceous Aerosols

Gravimetric analysis and particulate carbon analysis of weekly samples collected from the 5 sites over the medium term were performed according to the protocols described in [12]. For each quartz filter, weighing was carried out before and after sampling using a high-precision balance (Sartorius MC21S). The difference in mass is used to obtain the mass of aerosols collected.

The analysis of the carbonaceous aerosols was carried out by the multi-phase thermal method, using a BRUKER G4 ICARUS analyzer and developed by Cach-

ier *et al.* [15] and applied in many works [3] [6] [12]. An analytical scheme is provided by Gnamien *et al.* [12] in practice. Multipoint calibrations of the analyzer are performed using sucrose solution assays (1 $\mu\text{C}/\mu\text{L}$ concentration), and regression lines have been drawn for low total carbon and high total carbon conditions, comparing the values of the resulting integrals with known sucrose concentrations. A sample tray is used to pass the filters for analysis and is initially cleaned in an analysis furnace at 1000°C. Blanks (tray) and (tray + white filters) are carried out before each major series of analysis. Double analyses of the same sample and blanks give differences representing 1% to 6% of the carbon mass detected. A passage of a fraction of the filter is exposed to pre-combustion in a furnace heated to $\sim 340^\circ\text{C}$ under an oxygen stream for 2 h to remove organic carbon (OC), thus determining the elemental carbon mass (EC), while another fraction of the same filter is passed directly to the analysis, allowing the total carbon mass (TC) to be obtained. Finally, the difference in mass between TC and EC gave the OC mass.

The periods sampled include 2 dry seasons (DS) and 2 wet seasons (WS). For these 2 cities [12], it was shown that the 1st dry season (DS1) is defined from December 2018 to February 2019, and the 2nd (DS2), from December 2019 to February 2020. The first wet season (WS1) runs from March to November 2018, and the second (WS2) runs from March to November 2019. In the following, we will group DS1 and DS2 into DS and WS1 and WS2 into WS.

2.4. Meteorological Data and Environmental Pollution

Gnamien *et al.* [2] show daily variations in specific humidity and rainfall in Abidjan and Korhogo from 2018 to 2020. They highlight significant differences between the two localities, related to their distinct geographical and climatic contexts, while revealing similar seasonal dynamics due to the tropical climate. This study shows that in Abidjan, rainfall is scarce during the dry season (DS) period, but the specific humidity remains relatively high (15 to 20 g/kg) due to the maritime influence, as the city is located on the Atlantic coast. In Korhogo, the dry season (DS), from December to February, is characterized by low specific moisture levels (2 to 6 g/kg) and almost no rainfall. These conditions reflect the dominant influence of the harmattan winds, which carry dry air from the Sahara and create a particularly arid atmosphere. During the rainy season, from March to November, both localities record a marked increase in specific humidity and rainfall. In Abidjan, rainfall is more regular and sometimes more intense (up to 160 mm/day), particularly in June and November, and specific humidity reaches even higher levels (20 to 25 g/kg). In Korhogo, during the wet season (WS), the specific humidity reaches maximum values of 15 to 20 g/kg, accompanied by rainfall concentrated mainly between June and September, with episodes of intense rainfall. Abidjan has high ambient humidity throughout the year, even during the dry season (DS), and more regular rainfall during the wet season (WS). These differences underline the impact of geographical location (inland for Korhogo, coastal for

Abidjan) on seasonal climatic dynamics, which in turn impacts atmospheric chemistry processes.

2.5. Statistical Analysis: Mann-Whitney U Test

An analysis of the seasonal variability of aerosol composition ratios was performed using the Mann-Whitney U [16]-[18] test to compare the distributions between the wet season (WS) and the dry season (DS) at all sites in Abidjan (A1, A2, A3) and Korhogo (K1, K2). This non-parametric test was chosen because it does not assume normality in the data and allows the difference in median between two independent groups to be assessed.

The results are expressed in terms of seasonal medians, DS/WS factor (median ratio), and p-values. The p-values were corrected using Benjamini-Hochberg's false discovery rate (p_FDR) method to control for the risk of errors associated with multiple testing. A difference is considered statistically significant when $p_FDR < 0.05$. The conclusions of this statistical analysis will be presented in the results.

3. Results and Discussion

3.1. Analysis of PM_{2.5} and PM₁₀ Concentrations and Their Carbon Content (OC and EC) in the Dry Season (DS) between the Wet Season (WS)

Figure 1 presents the median, mid-max, and average WS and DS concentrations of PM_{2.5} and the elemental carbon (EC) and organic carbon (OC) content, obtained from sampling carried out in cities between 2018 and 2020, respectively, in Abidjan and Korhogo sites.

PM_{2.5} shows particularly marked variability at A1, with values ranging from 7.55 to 127.59 $\mu\text{g}/\text{m}^3$, more than six times the median (20.36 $\mu\text{g}/\text{m}^3$), while A2 and A3 show narrower ranges of values. For EC, the maximum values were observed at the A2 site (3.20 - 19.30 $\mu\text{g}/\text{m}^3$), while OC showed greater variability at A1 (0.24 - 23.85 $\mu\text{g}/\text{m}^3$), followed by the A2 and A3 sites. This wide dispersion between minimum and maximum values may reflect isolated episodes of high pollution, characterized by sudden increases in organic and carbonaceous carbon inputs due to local anthropogenic sources.

In Korhogo, PM_{2.5} shows wide variability in K1 (from 6.90 to 165.35 $\mu\text{g}/\text{m}^3$) and K2 (from 10.18 to 168.60 $\mu\text{g}/\text{m}^3$), with maximum values more than four times the median value, including intense and pollution peaks. For EC, variations remain significant but more contained, ranging from 0.52 to 10.04 $\mu\text{g}/\text{m}^3$ at K1 and from 0.70 to 10.20 $\mu\text{g}/\text{m}^3$ at K2. OC shows the greatest relative amplitude, particularly at K2 (0.10 - 54.40 $\mu\text{g}/\text{m}^3$) and K1 (0.13 - 25.59 $\mu\text{g}/\text{m}^3$), reflecting highly variable organic inputs, probably linked to biomass combustion and local activities [4].

The analysis of **Figure 1** shows that the dry season (DS) is associated with a widespread and marked increase in PM₁₀, EC, and OC concentrations at all sites.

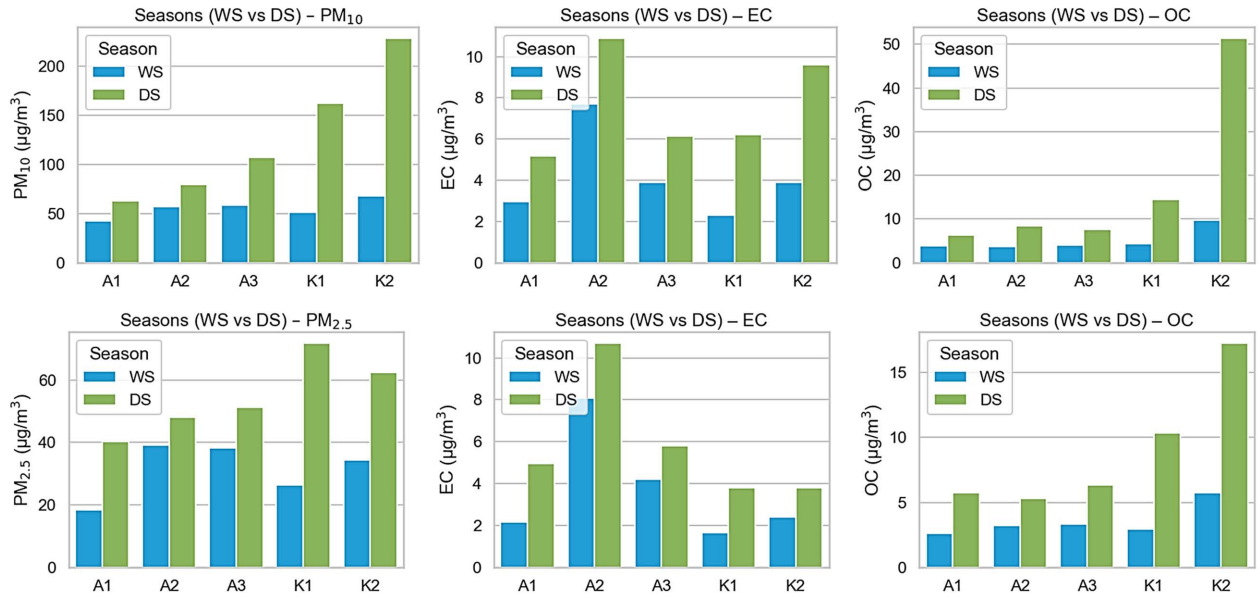


Figure 1. PM_{2.5} and PM₁₀ concentrations between 2018 and 2020 at Abidjan (A1, A2, and A3) and Korhogo (K1 and K2) measurement sites.

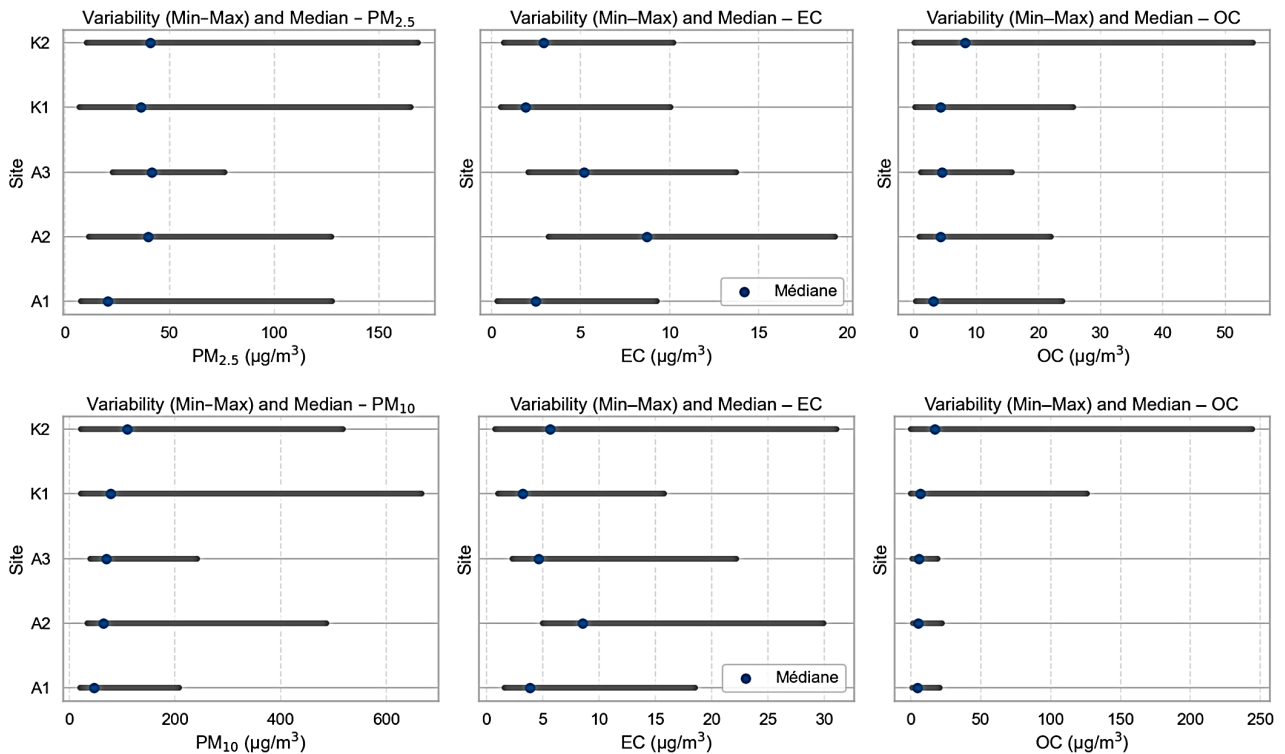


Figure 2. Median, minimum, and maximum in WS and in DS of PM_{2.5} and PM₁₀ concentrations between 2018 and 2020 at Abidjan (A1, A2, and A3) and Korhogo (K1 and K2) measurement sites.

Figure 2 shows median, minimum, and maximum values of PM_{2.5} and PM₁₀, and their OC and EC content. The median of PM₁₀ concentration is lowest at A1 (45.90 $\mu\text{g}/\text{m}^3$) and highest at A3 (69.28 $\mu\text{g}/\text{m}^3$), but variability is greatest at A2,

with a range from 34.20 to 485.91 $\mu\text{g}/\text{m}^3$. EC follows this trend with greater variability at A2 (5.00 - 29.90 $\mu\text{g}/\text{m}^3$), while OC varies greatly at all sites, reaching maximums of 20.49 $\mu\text{g}/\text{m}^3$ at A1, 22.00 $\mu\text{g}/\text{m}^3$ at A2, and 19.00 $\mu\text{g}/\text{m}^3$ at A3. These significant amplitudes reflect marked episodes of pollution, as with $\text{PM}_{2.5}$. In Korhogo, PM_{10} shows very high variability at both sites, with maximum concentrations reaching 666.20 $\mu\text{g}/\text{m}^3$ at K1 and 517.83 $\mu\text{g}/\text{m}^3$ at K2, more than 6 times their respective medians.

EC varies from 1.00 to 15.75 $\mu\text{g}/\text{m}^3$ at K1 and from 0.80 to 31.09 $\mu\text{g}/\text{m}^3$ at K2, reflecting episodes of pollution, as with $\text{PM}_{2.5}$. EC varies from 1.00 to 15.75 $\mu\text{g}/\text{m}^3$ at K1 and from 0.80 to 31.09 $\mu\text{g}/\text{m}^3$ at K2, reflecting marked fluctuations but less extreme than for PM_{10} . OC has the highest relative amplitude, particularly at K2 (0.10 - 244.40 $\mu\text{g}/\text{m}^3$) and K1 (0.10 - 125.70 $\mu\text{g}/\text{m}^3$), reflecting a highly variable organic contribution, probably linked to the intensity of biomass fires. This high variability in PM_{10} concentrations, which is unrelated to that of EC, may therefore be due to very high dust levels during the Harmattan and to biomass fires, which are a significant contributor to OC.

3.2. Mann-Whitney U Test Results

Table 2. Main parameters derived from the Mann-Whitney U statistical analysis test.

Site	Parameter	N (WS)	N (DS)	Median WS	Median DS	Factor DS/WS	U	p_value	p_value FDR	Significant (FDR < 0.05)
A1	$\text{OC}_{\text{PM}_{2.5}}/\text{EC}_{\text{PM}_{2.5}}$	65	26	1.08	1.24	1.15	606	0.04	0.07	False
	$\text{OC}_{\text{PM}_{10}}/\text{EC}_{\text{PM}_{10}}$	38	24	1.13	1.15	1.02	461	0.95	0.95	False
	$\text{PM}_{2.5}/\text{PM}_{10}$	35	24	0.53	0.62	1.16	195	0	0	True
A2	$\text{OC}_{\text{PM}_{2.5}}/\text{EC}_{\text{PM}_{2.5}}$	42	25	0.46	0.58	1.25	369	0.04	0.07	False
	$\text{OC}_{\text{PM}_{10}}/\text{EC}_{\text{PM}_{10}}$	42	23	0.55	0.74	1.35	196	0	0	True
	$\text{PM}_{2.5}/\text{PM}_{10}$	38	23	0.32	0.48	1.49	251	0.01	0.01	True
A3	$\text{OC}_{\text{PM}_{2.5}}/\text{EC}_{\text{PM}_{2.5}}$	32	18	0.83	1.18	1.42	190	0.05	0.07	False
	$\text{OC}_{\text{PM}_{10}}/\text{EC}_{\text{PM}_{10}}$	40	18	1	1.13	1.13	294	0.27	0.29	False
	$\text{PM}_{2.5}/\text{PM}_{10}$	40	18	0.57	0.48	0.85	433	0.21	0.25	False
K1	$\text{OC}_{\text{PM}_{2.5}}/\text{EC}_{\text{PM}_{2.5}}$	68	26	1.74	2.89	1.66	526	0	0.01	True
	$\text{OC}_{\text{PM}_{10}}/\text{EC}_{\text{PM}_{10}}$	43	21	1.88	2.28	1.21	309	0.04	0.07	False
	$\text{PM}_{2.5}/\text{PM}_{10}$	43	24	0.53	0.29	0.54	690	0.02	0.05	True
K2	$\text{OC}_{\text{PM}_{2.5}}/\text{EC}_{\text{PM}_{2.5}}$	68	26	1.74	2.89	1.66	526	0	0.01	True
	$\text{OC}_{\text{PM}_{10}}/\text{EC}_{\text{PM}_{10}}$	38	17	3.24	3.96	1.22	228	0.09	0.11	False
	$\text{PM}_{2.5}/\text{PM}_{10}$	36	18	0.47	0.28	0.59	558	0	0	True

n_WS and **n_DS**: number of observations used for the wet season and dry season, respectively. **Median_WS** and **Median_DS**: median values of the parameter considered for the WS and DS seasons. **Factor_DS/WS**: ratio of DS/WS medians, indicating the relative variation between seasons (values > 1 indicate an increase in the dry season). **U**: Mann-Whitney U test statistic, calculated from the ranks of observations for both seasons. **p_value**: raw probability associated with the test, indicating significance before correction. **p_value_FDR**: p-value adjusted according to Benjamini-Hochberg's False Discovery Rate (FDR) method, allowing for the correction of the effect of multiple comparisons. **Significant (FDR < 0.05)**: indicates whether the seasonal difference is statistically significant after correction (True = significant, False = not significant).

Table 2 presents the results of the Mann-Whitney U test, applied to compare the ratios between the wet season (WS) and the dry season (DS). It shows noticeable seasonal variability across all sites. In general, $OC_{PM_{2.5}}/EC_{PM_{2.5}}$ ratios show an upward trend in DS, which is more pronounced at northern sites (K1 and K2), where the differences are statistically significant after correction ($p_{FDR} < 0.05$). The $OC_{PM_{10}}/EC_{PM_{10}}$ ratios vary little according to the season, with the exception of site A2, which shows a significant difference. Finally, the $PM_{2.5}/PM_{10}$ ratios show the most marked contrasts, with the test revealing increases during DS in the south (A1 and A2) and decreases in the north (K1 and K2).

These results may suggest that seasonality influences the composition and particle size distribution differently depending on geographical location.

3.3. $PM_{2.5}/PM_{10}$ Ratio during the Wet and Dry Seasons

Figure 3 shows box plots of the $PM_{2.5}/PM_{10}$ ratio compared between the wet season (WS) and the dry season (DS) for the five measurement sites in this study. The $PM_{2.5}/PM_{10}$ ratio is an important indicator of the proportion of fine particulate matter ($PM_{2.5}$) to total or coarse particulate matter (PM_{10}). A high ratio indicates a dominance of fine particles, often associated with anthropogenic sources such as combustion, while a low ratio is usually related to coarser particles, such as dust or sand [19]-[21].

At site A1, the $PM_{2.5}/PM_{10}$ ratio is slightly higher during the dry season. In Abidjan (A1 and A2), the ratios increase significantly in DS, from 0.53 to 0.62 ($p_{FDR} = 0.00$) and from 0.32 to 0.48 ($p_{FDR} = 0.01$), respectively, with DS/WS factors of 1.16 and 1.49. This indicates a relative accumulation of fine particles during the dry season, linked to increased urban combustion emissions and road traffic [2] [14] [22], weather conditions that promote the stagnation of pollutants.

Site A3 shows significant variability during the wet season, with several outliers, which could indicate specific events or variable sources affecting fine particulate matter. On this site, there is no significant variation ($p_{FDR} = 0.25$), confirming a moderate seasonal influence in this urban area. In addition, this lack of significance reveals the permanent nature of the sources on this site, mainly anthropogenic, such as biomass fires, waste burning, and road traffic.

In the north (K1 and K2), the ratios $PM_{2.5}/PM_{10}$ decrease significantly in DS, from 0.53 to 0.29 ($p_{FDR} = 0.05$) and from 0.47 to 0.28 ($p_{FDR} = 0.00$), respectively. These decreases reveal an increase in the coarse fraction (PM_{10}), characteristic of Sahelian dust, resuspended dust, and agricultural activities [2] [23] [24].

The results show significant variations between seasons and sites, as shown by Léon *et al.* [25]. At the Abidjan site (A1 and A2), the $PM_{2.5}/PM_{10}$ ratio is higher during the dry season, suggesting a relative dominance of fine particles. This may be due to low humidity and the absence of precipitation, which promotes atmospheric stability. Indeed, according to Slinn [26], Petroff & Zhang [27], and Seinfeld & Pandis [28], dry deposition of atmospheric particles is favored by dry and windy weather conditions, characterized by low relative humidity, absence of pre-

precipitation, and increased turbulence near the ground, which increase the sedimentation rate of particles, particularly those that are large and dense.

In contrast, during DS at the Korhogo sites (K1 and K2), the ratio generally decreases, reflecting an increase in coarse particles due to the particular weather conditions during this period. The Harmattan winds carry Saharan dust, promoting a significant contribution of coarse particles [29]-[31].

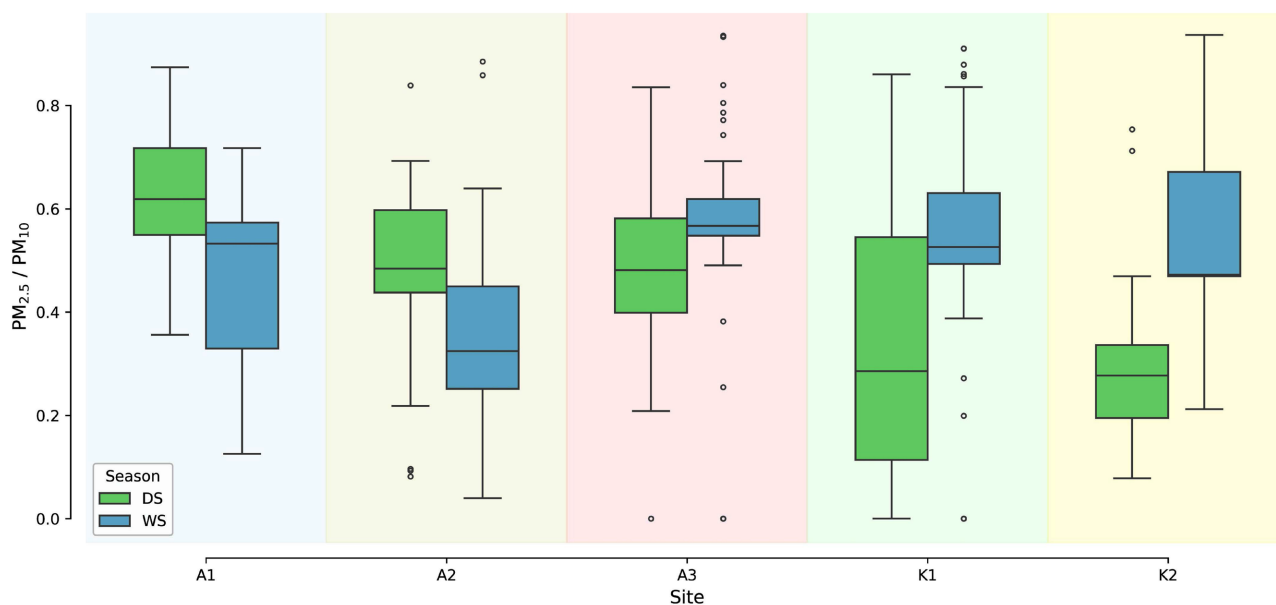


Figure 3. $PM_{2.5}/PM_{10}$ concentration ratios observed for the dry season (DS) and wet season (WS) at A1, A2, A3, K1, and K2 sites.

3.4. OC/EC in $PM_{2.5}$ and PM_{10}

Figure 4 shows the OC/EC ratios in $PM_{2.5}/PM_{10}$ at WS and DS at the Abidjan and Korhogo sites. The data are available in Table S3 in the supplementary materials. In the wet season (WS), the OC/EC ratio at site A1 is 1.32 for $PM_{2.5}$ and 1.51 for PM_{10} , while in the dry season (DS) it reaches 2.36 for $PM_{2.5}$ ($\times 1.79$ WS value) and drops to 1.19 for PM_{10} ($\times 0.79$ WS value). At site A2, it is 0.50 ($PM_{2.5}$) and 0.54 (PM_{10}) in WS, compared to 0.66 ($PM_{2.5}$, $\times 1.32$) and 0.84 (PM_{10} , $\times 1.56$ WS value) in DS. At site A3, the ratio OC/EC values increase from 0.89 ($PM_{2.5}$) and 1.18 (PM_{10}) in WS to 2.36 ($PM_{2.5}$) and 1.27 (PM_{10}) in DS, *i.e.*, $\times 2.65$ and $\times 1.08$ WS values for respectively $PM_{2.5}$ and PM_{10} .

The OC/EC ratio increases significantly in the fine fraction ($PM_{2.5}$) in A1 and A3, due to an increase in OC that may be linked to biomass combustion, waste burning [32], and contributions from secondary organic aerosols [9] [33]-[36].

In the wet season, the OC/EC ratio at the K1 site is 2.03 for $PM_{2.5}$ and 1.82 for PM_{10} , while in the dry season it reaches 3.02 for $PM_{2.5}$, according to Djossou *et al.* [36], and 2.42 for PM_{10} , which is 30 to 50% higher than the WS values. At the K2 site, the values are 2.60 ($PM_{2.5}$) and 3.80 (PM_{10}) in WS, compared to 5.20 ($PM_{2.5}$) and 7.09 (PM_{10}) in DS, almost 2 times the WS values.

The $OC_{PM_{2.5}}/EC_{PM_{2.5}}$ and $OC_{PM_{10}}/EC_{PM_{10}}$ ratios show an overall upward trend

during the dry season (DS) at all sites, reflecting a higher proportion of organic carbon (OC) relative to elemental carbon (EC). However, this trend is more pronounced for the fine fraction ($PM_{2.5}$) than for the coarse fraction (PM_{10}).

The differences observed are statistically significant only at sites K1 and K2 for the $OC_{PM_{2.5}}/EC_{PM_{2.5}}$ ratio, with correlation coefficients R^2 with OC of 0.69 and 0.54 (p-value < 0.05), respectively, and at A2 for the $OC_{PM_{10}}/EC_{PM_{10}}$ ratio with a correlation $R^2 = 0.76$ (p-value < 0.05), thus an increase in OC in DS. This increase in the OC/EC ratio observed in Abidjan during the dry season can be attributed to more incomplete fuel combustion linked to heavy road traffic and the age of the vehicle fleet, conditions typical of large African cities, but also to biomass fires [33] [37].

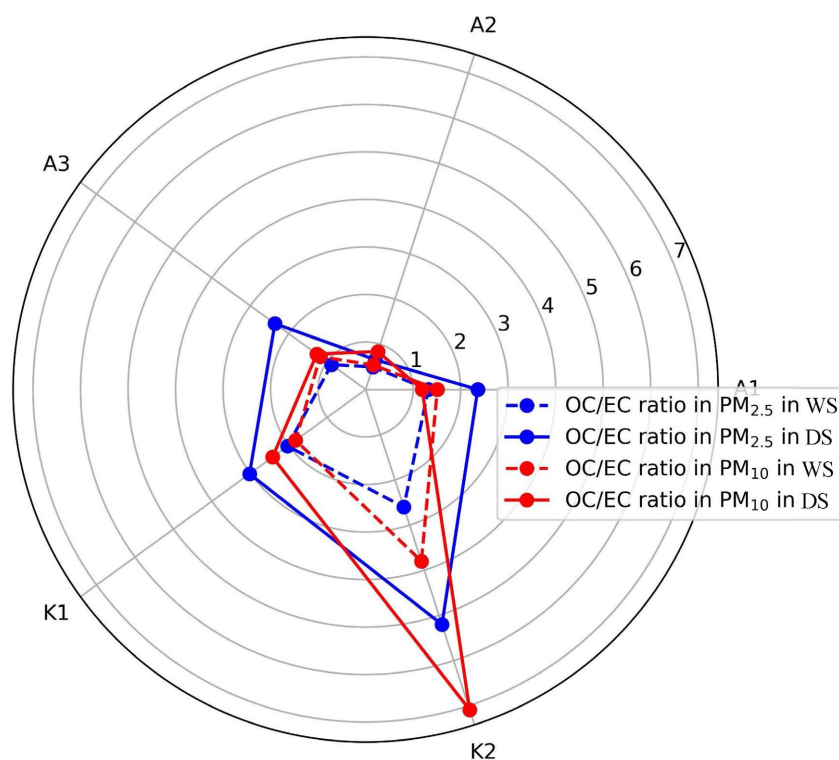


Figure 4. Radar plot of OC/EC ratios in PM_{10} and $PM_{2.5}$ at sites A1, A2, A3, K1, and K2.

4. Conclusions

The results highlight a clear but spatially variable seasonal pattern in particulate matter ($PM_{2.5}$ and PM_{10}) and carbonaceous aerosols (OC and EC). Overall, concentrations tend to increase during the dry season (DS), particularly in Korhogo sites, where biomass burning, local combustion activities, and meteorological conditions favor pollutant accumulation. The Mann-Whitney U test confirms that several ratios, especially OC/EC in $PM_{2.5}$, exhibit statistically significant differences between DS and WS, with more pronounced contrasts in Korhogo than in Abidjan. These findings suggest that OC sources, mainly from biomass combustion, dominate during the dry season, while urban emissions remain more stable throughout

the year in coastal areas.

Such seasonal and regional variations are crucial for improving the parameterization of atmospheric models in West Africa. Accounting for these dynamics enhances the representation of emission sources, aerosol transformation processes, and seasonal effects on particle composition. Conversely, neglecting these variations could lead to biases in air quality simulations, radiative forcing estimations, and health exposure assessments in this climatically sensitive region.

Funding

This study was supported by the Ministry of Education and Research of Côte d'Ivoire as part of the Debt Reduction and Development Contracts (C2D), as well as AMRUGE-CI (Support for the Modernization and Reform of Universities and Grandes Écoles in Côte d'Ivoire) for its grant, managed by the French Research Institute for Sustainable Development (IRD). The research received financial support from the IRD's Young Associated Team "Air Pollution and Impacts" (JEA1 PATI).

Acknowledgements

The authors would like to thank all the members of the Aerosols and Pollution teams in Abidjan (LASMES, UFHB) and Korhogo (UPGC), as well as the scientific and technical staff of the Aerology Laboratory (LAERO, France).

Conflicts of Interest

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

References

- [1] Bahino, J., Giordano, M., Yoboué, V., *et al.* (2021) MOPGA/Improving Air Quality in West Africa: Low-Cost Sensors as a Solution to Improve the Understanding of Spatial and Temporal Variability in Urban Air Pollution. *EGU General Assembly 2021*, 19-30 Apr 2021, EGU21-8210. <https://doi.org/10.5194/egusphere-egu21-8210>
- [2] Gnamien, S., Lioussé, C., Keita, S., Silué, S., Bahino, J., Gardrat, E., *et al.* (2023) Chemical Characterization of Urban Aerosols in Abidjan and Korhogo (Côte d'Ivoire) from 2018 to 2020 and the Identification of Their Potential Emission Sources. *Environmental Science: Atmospheres*, **3**, 1741-1757. <https://doi.org/10.1039/d3ea00131h>
- [3] Adon, A.J., Lioussé, C., Doumbia, E.T., *et al.* (2020) Physico-Chemical Characterization of Urban Aerosols from Specific Combustion Sources in West Africa at Abidjan in Côte d'Ivoire and Cotonou in Benin in the Frame of DACCIWA Program. *Atmospheric Chemistry and Physics*, **20**, 5327-5354. <https://doi.org/10.5194/acp-2019-406>
- [4] Gnamien, S., Yoboué, V., Lioussé, C., Ossouhou, M., Keita, S., Bahino, J., *et al.* (2021) Particulate Pollution in Korhogo and Abidjan (Cote d'Ivoire) during the Dry Season. *Aerosol and Air Quality Research*, **21**, Article ID: 200201. <https://doi.org/10.4209/aaqr.2020.05.0201>
- [5] Kassamba-Diaby, M.L., Galy-Lacaux, C., Yoboué, V., Hickman, J.E., Mouchel-Valon, C., Jaars, K., *et al.* (2023) The Chemical Characteristics of Rainwater and Wet Atmospheric Deposition Fluxes at Two Urban Sites and One Rural Site in Côte d'Ivoire.

- Atmosphere*, **14**, Article 809. <https://doi.org/10.3390/atmos14050809>
- [6] Keita, S., Lioussé, C., Yoboué, V., Dominutti, P., Guinot, B., Assamoi, E., *et al.* (2018) Particle and VOC Emission Factor Measurements for Anthropogenic Sources in West Africa. *Atmospheric Chemistry and Physics*, **18**, 7691-7708. <https://doi.org/10.5194/acp-18-7691-2018>
- [7] Doumbia, E.H.T., Lioussé, C., Galy-Lacaux, C., Ndiaye, S.A., Diop, B., Ouafu, M., *et al.* (2012) Real Time Black Carbon Measurements in West and Central Africa Urban Sites. *Atmospheric Environment*, **54**, 529-537. <https://doi.org/10.1016/j.atmosenv.2012.02.005>
- [8] Vodička, P., Schwarz, J., Cusack, M. and Ždímal, V. (2015) Detailed Comparison of OC/EC Aerosol at an Urban and a Rural Czech Background Site during Summer and Winter. *Science of The Total Environment*, **518**, 424-433. <https://doi.org/10.1016/j.scitotenv.2015.03.029>
- [9] Pio, C., Cerqueira, M., Harrison, R.M., Nunes, T., Mirante, F., Alves, C., *et al.* (2011) OC/EC Ratio Observations in Europe: Re-Thinking the Approach for Apportionment between Primary and Secondary Organic Carbon. *Atmospheric Environment*, **45**, 6121-6132. <https://doi.org/10.1016/j.atmosenv.2011.08.045>
- [10] Val, S., Lioussé, C., Doumbia, E.H.T., Galy-Lacaux, C., Cachier, H., Marchand, N., *et al.* (2013) Physico-Chemical Characterization of African Urban Aerosols (Bamako in Mali and Dakar in Senegal) and Their Toxic Effects in Human Bronchial Epithelial Cells: Description of a Worrying Situation. *Particle and Fibre Toxicology*, **10**, Article No. 10. <https://doi.org/10.1186/1743-8977-10-10>
- [11] Doumbia, T., Lioussé, C., Ouafu-Leumbe, M., Ndiaye, S.A., Gardrat, E., Galy-Lacaux, C., *et al.* (2023) Source Apportionment of Ambient Particulate Matter (PM) in Two Western African Urban Sites (Dakar in Senegal and Bamako in Mali). *Atmosphere*, **14**, Article 684. <https://doi.org/10.3390/atmos14040684>
- [12] Benchrif, A., Tahri, M., Guinot, B., Chakir, E.M., Zahry, F., Baghdad, B., Bounakhla, M., Cachier, H. and Costabile, F. (2022) Aerosols in Northern Morocco-2: Chemical Characterisation and PMF Source Assignment of Ambient PM_{2.5}. *Atmosphere*, **13**, Article 1701. <https://doi.org/10.3390/atmos13101701>
- [13] Osohou, M. (2020) Etude des tendances des concentrations atmosphériques de gaz azotés en Afrique—Bilan de dépôts atmosphériques secs et humides d'azote de l'écosystème de savane humide de Lamto (Côte d'Ivoire). These de doctorat, Université Félix Houphouët-Boigny.
- [14] Djossou, J., Léon, J., Akpo, A.B., Lioussé, C., Yoboué, V., Bedou, M., *et al.* (2018) Mass Concentration, Optical Depth and Carbon Composition of Particulate Matter in the Major Southern West African Cities of Cotonou (Benin) and Abidjan (Côte d'Ivoire). *Atmospheric Chemistry and Physics*, **18**, 6275-6291. <https://doi.org/10.5194/acp-18-6275-2018>
- [15] Cachier, H., Bremond, M. and Buat-Ménard, P. (1989) Determination of Atmospheric Soot Carbon with a Simple Thermal Method. *Tellus B. Chemical and Physical Meteorology*, **41**, 379-390. <https://doi.org/10.3402/tellusb.v41i3.15095>
- [16] Mann, H.B. and Whitney, D.R. (1947) On a Test of Whether One of Two Random Variables Is Stochastically Larger than the Other. *The Annals of Mathematical Statistics*, **18**, 50-60. <https://doi.org/10.1214/aoms/1177730491>
- [17] McKnight, P.E. and Najab, J. (2010) Mann-Whitney U Test. In: Weiner, I.B. and Craighead, W.E., Eds., *The Corsini Encyclopedia of Psychology*, Wiley, 1.
- [18] Wilcoxon, F. (1945) Individual Comparisons by Ranking Methods. *Biometrics Bulletin*, **1**, 80-83. <https://doi.org/10.2307/3001968>

- [19] Bamola, S., Goswami, G., Dewan, S., Goyal, I., Agarwal, M., Dhir, A., *et al.* (2024) Characterising Temporal Variability of PM_{2.5}/PM₁₀ Ratio and Its Correlation with Meteorological Variables at a Sub-Urban Site in the Taj City. *Urban Climate*, **53**, Article ID: 101763. <https://doi.org/10.1016/j.uclim.2023.101763>
- [20] Espinoza-Guillen, J.A., Alderete-Malpartida, M.B., Navarro-Abarca, U.F. and Gómez-Muñoz, H.K. (2024) Temporal Variation of the PM_{2.5}/PM₁₀ Ratio and Its Association with Meteorological Factors in a South American Megacity: Metropolitan Area of Lima-Callao, Peru. *Environmental Monitoring and Assessment*, **196**, Article No. 452. <https://doi.org/10.1007/s10661-024-12611-4>
- [21] Xu, G., Jiao, L., Zhang, B., Zhao, S., Yuan, M., Gu, Y., *et al.* (2017) Spatial and Temporal Variability of the PM_{2.5}/PM₁₀ Ratio in Wuhan, Central China. *Aerosol and Air Quality Research*, **17**, 741-751. <https://doi.org/10.4209/aaqr.2016.09.0406>
- [22] Adon, A.J. (2019) Évaluation de l'impact sur la santé de l'aérosol de combustion pour différentes sources urbaines en Afrique de l'Ouest en saison sèche et humide: Caractérisation physico-chimique et toxicologique. Master's Thesis, Université Toulouse III—Paul Sabatier.
- [23] Parra, Y.J., Pereira, G.M., Custódio, D., de Figueiredo, S.B., Alves, C. and de Castro Vasconcellos, P. (2023) Aerosol Characterization in a Central-West Site of Brazil: Influence of Farming Activities and Toxicity. *Air Quality, Atmosphere & Health*, **17**, 599-620. <https://doi.org/10.1007/s11869-023-01467-1>
- [24] Sharma, S.K., Mukherjee, S., Choudhary, N., Rai, A., Ghosh, A., Chatterjee, A., *et al.* (2021) Seasonal Variation and Sources of Carbonaceous Species and Elements in PM_{2.5} and PM₁₀ over the Eastern Himalaya. *Environmental Science and Pollution Research*, **28**, 51642-51656. <https://doi.org/10.1007/s11356-021-14361-z>
- [25] Léon, J., Akpo, A.B., Bedou, M., Djossou, J., Bodjrenou, M., Yoboué, V., *et al.* (2021) PM_{2.5} Surface Concentrations in Southern West African Urban Areas Based on Sun Photometer and Satellite Observations. *Atmospheric Chemistry and Physics*, **21**, 1815-1834. <https://doi.org/10.5194/acp-21-1815-2021>
- [26] Slinn, W.G.N. (1982) Predictions for Particle Deposition to Vegetative Canopies. *Atmospheric Environment* (1967), **16**, 1785-1794. [https://doi.org/10.1016/0004-6981\(82\)90271-2](https://doi.org/10.1016/0004-6981(82)90271-2)
- [27] Petroff, A. and Zhang, L. (2010) Development and Validation of a Size-Resolved Particle Dry Deposition Scheme for Application in Aerosol Transport Models. *Geoscientific Model Development*, **3**, 753-769. <https://doi.org/10.5194/gmd-3-753-2010>
- [28] Seinfeld, J.H. and Pandis, S.N. (2016) *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. John Wiley & Sons. [https://books.google.com/books?hl=fr&lr=&id=n_RmCgAAQBAJ&oi=fnd&pg=PR5&dq=Seinfeld,+J.H.,+%26+Pandis,+S.N.,+\(2016\),+Atmospheric+Chemistry+and+Physics:+From+Air+Pollution+to+Climate+Change+\(3rd+ed.\),+Wiley&ots=gTL7CLpeaP&sig=GoLkHtHjXNlwaVQaIVFh6dpNfpE](https://books.google.com/books?hl=fr&lr=&id=n_RmCgAAQBAJ&oi=fnd&pg=PR5&dq=Seinfeld,+J.H.,+%26+Pandis,+S.N.,+(2016),+Atmospheric+Chemistry+and+Physics:+From+Air+Pollution+to+Climate+Change+(3rd+ed.),+Wiley&ots=gTL7CLpeaP&sig=GoLkHtHjXNlwaVQaIVFh6dpNfpE)
- [29] Kok, J.F., Ridley, D.A., Zhou, Q., Miller, R.L., Zhao, C., Heald, C.L., *et al.* (2017) Smaller Desert Dust Cooling Effect Estimated from Analysis of Dust Size and Abundance. *Nature Geoscience*, **10**, 274-278. <https://doi.org/10.1038/ngeo2912>
- [30] Formenti, P., Caquineau, S., Desboeufs, K., Klaver, A., Chevaillier, S., Journet, E., *et al.* (2014) Mapping the Physico-Chemical Properties of Mineral Dust in Western Africa: Mineralogical Composition. *Atmospheric Chemistry and Physics*, **14**, 10663-10686. <https://doi.org/10.5194/acp-14-10663-2014>
- [31] Knippertz, P. and Todd, M.C. (2012) Mineral Dust Aerosols over the Sahara: Mete-

- orological Controls on Emission and Transport and Implications for Modeling. *Reviews of Geophysics*, **50**, RG1007. <https://doi.org/10.1029/2011rg000362>
- [32] Djossou, J. (2018) Analyse de la pollution atmosphérique en zones urbaines en Côte d'Ivoire et au Bénin dans le cadre du programme DACCIWA: Pollution particulaire. These de doctorat, Université d'Abomey-Calavi.
- [33] Putaud, J.P., Cavalli, F., Yttri, K.E., *et al.* (2025) A Worldwide Aerosol Phenomenology: Elemental and Organic Carbon in PM_{2.5} and PM₁₀. *Atmospheric Environment*, **358**, Article ID: 121338.
- [34] Rai, A., Mukherjee, S., Chatterjee, A., Choudhary, N., Kotnala, G., Mandal, T.K., *et al.* (2020) Seasonal Variation of OC, EC, and WSOC of PM₁₀ and Their CWT Analysis over the Eastern Himalaya. *Aerosol Science and Engineering*, **4**, 26-40. <https://doi.org/10.1007/s41810-020-00053-7>
- [35] Wu, C. and Yu, J.Z. (2016) Determination of Primary Combustion Source Organic Carbon-to-Elemental Carbon (OC/EC) Ratio Using Ambient OC and EC Measurements: Secondary OC-EC Correlation Minimization Method. *Atmospheric Chemistry and Physics*, **16**, 5453-5465. <https://doi.org/10.5194/acp-16-5453-2016>
- [36] Djossou, J., Mathos, K.P., Lamah, S.P., Yombouno, F.M., Camara, N., Diallo, A.M., *et al.* (2025) Characterization of Atmospheric Organic Carbon and Element Carbon of PM_{2.5} during the Long Dry Period in Cotonou, Benin. *Open Journal of Air Pollution*, **14**, 14-28. <https://doi.org/10.4236/ojap.2025.141002>
- [37] Bhattu, D., Tripathi, S.N., Bhowmik, H.S., Moschos, V., Lee, C.P., Rauber, M., *et al.* (2024) Local Incomplete Combustion Emissions Define the PM_{2.5} Oxidative Potential in Northern India. *Nature Communications*, **15**, Article No. 3517. <https://doi.org/10.1038/s41467-024-47785-5>