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Research Article

Characterization Of Air Pollution By Pm2.5 And Black Carbon In An Urban Industrial Zone: Case Of Yopougon Industrial Zone, Côte D'ivoire.

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Abstract

Air pollution from fine particulate matter (PM2.5) and black carbon (BC) represents a major public health challenge, particularly in urban industrial areas. This study was conducted in the Yopougon industrial zone of Abidjan, Côte d'Ivoire, to characterize the levels of these pollutants over a three-month period. PM2.5 concentration was assessed using the gravimetric method, while BC concentration was determined using the EEL Smoke Stain reflectometer (Model 43M, Diffusion Systems Ltd) from sampled filters. The results indicate that the average PM2.5 and BC concentrations were 46.48 μg/m³ (27.11–70.68 μg/m³) and 55.26 μg/m³ (43.85–66.07 μg/m³), respectively. These values exceed national standards and World Health Organization recommendations, highlighting the urgency of implementing mitigation measures to protect the population exposed to the harmful effects of air pollution.

Keywords: PM2.5, black carbon, gravimetric method, EEL reflectometer, air pollution.

INTRODUCTION

Air pollution is a major environmental and health issue worldwide. According to the World Health Organization (WHO), air pollution is responsible for more than 7 million premature deaths each year, largely due to exposure to fine particulate matter (PM2.5) (WHO, 2021). Among these particles, black carbon (BC) stands out for its particularly harmful effects on human health and the climate (Bond et al., 2013).

Black carbon is a byproduct of the incomplete combustion of fossil fuels, biomass, or waste. It is one of the major constituents of PM2.5 in urban environments, particularly in areas with high industrial and transportation activity [3]. This pollutant is associated with respiratory and cardiovascular diseases and may even play a role in certain neurodegenerative diseases (Janssen et al., 2011). In terms of climate, BC contributes to global warming by absorbing solar radiation and altering cloud properties (Ramanathan, Carmichael, 2008).

In developing countries, particularly in West Africa, air quality monitoring remains inadequate, despite rapid urbanization and increasing industrialization. In Côte d'Ivoire, the township of Yopougon, home to one of the country's largest industrial zones, is subject to constant environmental pressure. However, few studies have focused on precisely quantifying black carbon pollution levels.

This study aims to characterize black carbon air pollution in the industrial zone of Yopougon by measuring and analyzing PM2.5 and black carbon concentrations over a two-month period. It contributes to decision-making support for urban environmental management.

MATERIALS AND METHODS

Study area

The study was conducted in the township of Yopougon, within its industrial zone. The selected sampling site was the Abidjan Detention and Correctional Center (MACA), located in the immediate vicinity of major sources of air pollution, including heavy road traffic and surrounding industrial activities.

MACA, the largest prison in Côte d'Ivoire, is located in the northwestern part of the Abidjan district, at the geographic coordinates 5°20′56″ N and 4°00′56″ W. The townwship of Yopougon, with an area of 152 km² (Madina et al., 2018), is both the largest and most populated in the country, with an

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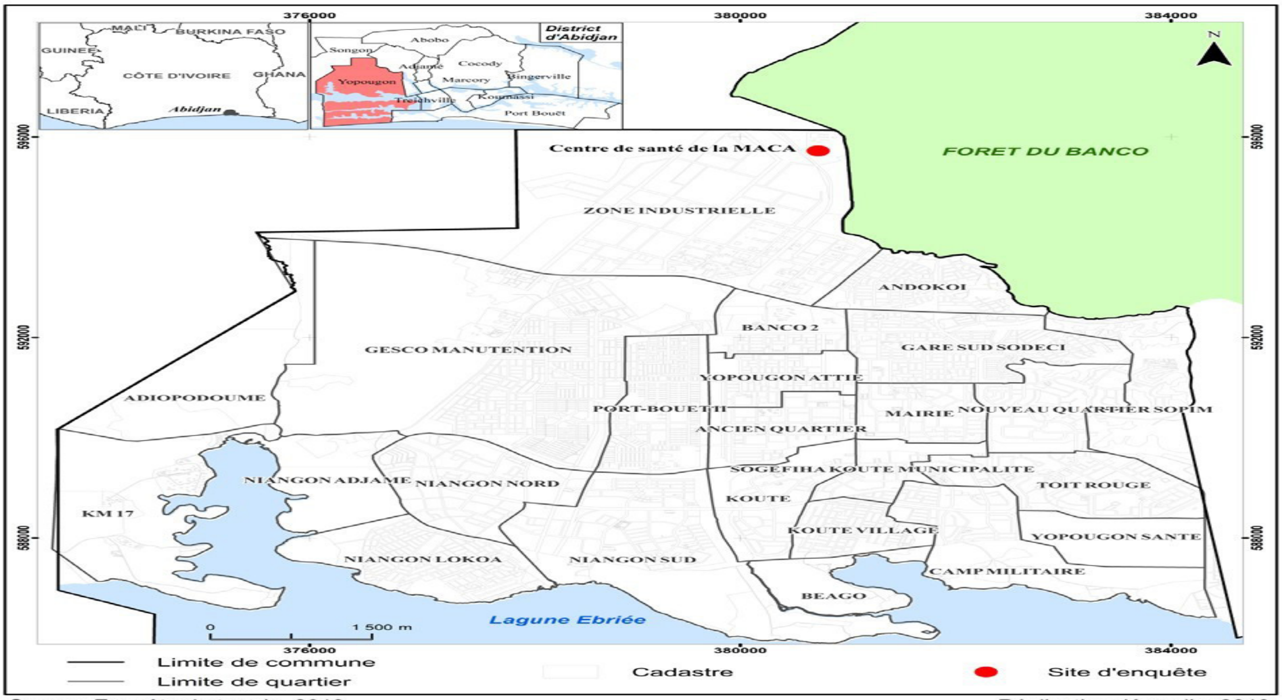
estimated population of 1,571,065 inhabitants (INS, 2022).

The industrial zone of Yopougon comprises over 400 companies operating in sectors such as cement manufacturing, metallurgical products, food processing, cosmetics, and chemicals. The sampling site is located on a busy road, exposed to heavy vehicular traffic and high pedestrian traffic, making it a strategic location for studying PM2.5 and black carbon concentrations.

Figure 1. Location of the sampling site in the township of Yopougon.



Source: Enquête de terrain, 2019 Réalisation: Kouadio, 2019

(Fig.1) shows the study area and the air sampling point marked in red on the map. It is taken from (Popouen et al., 2021).

Air sampling method and storage

Air samples were collected using the LVS/LVS6-RV low-volume sampler, manufactured by Sven Leckel. The filters used for particle retention were high-retention borosilicate glass microfiber filters (Grade GF/A 1820-47), with a diameter of 47 mm and a porosity of 1.6 µm. They have a smooth, spherical surface capable of withstanding temperatures exceeding 50°C.

Figure 2 shows the installation of the sample at the sampling area. On the site, approximately 200 meters from a busy road, the LVS/LVS6-RV sampler was installed 2.5 meters above the ground on a rooftop to avoid disturbances at ground level caused by accidental local sources or various turbulences.

Figure 2. Positioning of the LVS/LVS6-RV sampler on the site (MACA).

Before aerosol sampling, the equipment was pre-configured. During the PM2.5 particulate matter sampling campaign, conducted from May 1 to July 28, 2018, during the rainy season, samples were taken from filters placed in thoroughly cleaned Petri dishes. To prevent contamination, the filters in the Petri dishes were stored in a desiccator to protect them from moisture. A total of 19 PM2.5 samples were collected and placed in the desiccator. During the sampling campaign, meteorological conditions were recorded, including wind speed, rainfall, and relative humidity.

Calculation of mass concentrations of particulate patter Aerosol Mass

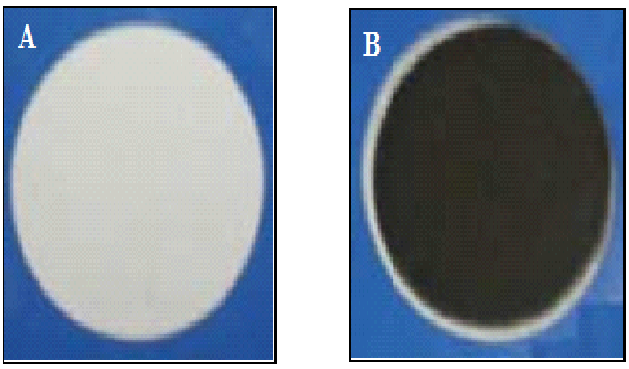
The collected samples are shown in (**Fig. 3A & 3B**) below. To determine the mass of the collected fine particles, the unused filters (**Fig. 3A**) and the sampled filters (Fig. 3B) were weighed using a Sartorius microbalance (Quintix 65-1S). This microbalance, with a sensitivity of 1 µg, is located in a temperature- and humidity-controlled environment in the Physics Lab at the University.

(**Fig. 3A**) shows a filter before sampling while (Fig. 3B) indicates a filter after sampling which contains aerosol particulates.
The mass of the aerosols is therefore the difference between the two masses obtained with the microbalance and is given by the following equation:

$$m = m_B - m_A \tag{1}$$

With: m_B, the mass of the sampled filter and m_A, the mass of the blank filter.

Figure 3. Unfiltered (A) and sampled Filter (B).



Climatic conditions and calculation of aerosol Concentrations

The concentration of particulate matter is the ratio of the mass of aerosols to the volume of air sampled. The volume of air sampled is calculated based on the flow rate (2.3 m³/h) or (38.33 L/min) and the sampling duration (24 h). The volume of air was calculated using the equation below.

$$V = \frac{60.F.\Delta t}{1000} \tag{2}$$

Where V: sampled air volume, F: pumping flow rate (L/min), and Δt: sampling time (h)
Thus, the mass concentration of particulate matter is determined in micrograms per cubic meter (µg/m³) using the following equation :

$$C_m = \frac{m}{V} = \frac{m_f - m_i}{V} \tag{3}$$

With: C_m: Mass concentration of deposited particles (µg/m³), m: Net mass of particles collected on the sampled filters (µg), m_f: Mass of the filter after sampling (µg), m_i: Mass of the empty filter (µg), and V: Sampled air volume (m³).

Determination of black carbon concentrations

The sampled filters were examined for black smoke to measure reflectance using an EEL Smoke Stain reflectometer (Model 43M diffusion system Ltd 43). The reflectometer, connected to the main unit, was placed on the white standard for at least 20 minutes. Then, to measure the reflectance of the black carbon deposited on the filters, each filter was examined using the five-point method, which considers the points most likely to be reached by the reflectometer's light beam (**Fig. 4**).

The concentration of black carbon in the air sample is determined by relation (4) below:

$$C = \frac{100}{Fxe}.a \tag{4}$$

C: black carbon concentration expressed in µg/m³
ε: mass absorption coefficient for a given wavelength, equal to 5.27 m³/g
F: correction factor, equal to 1 according to (UE, 2002)
α: absorption coefficient of the collected aerosols given by the equation :

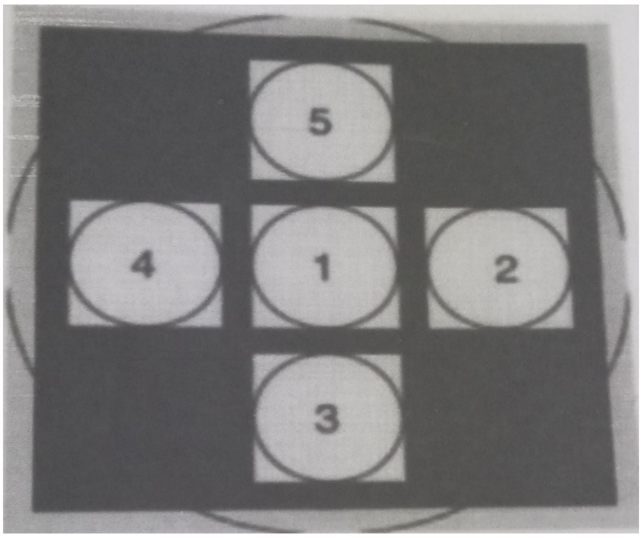
$$\alpha = \left(\frac{A}{2V}\right).\ell n\left(\frac{RO}{RS}\right) \tag{5}$$

Where: RS: the average reflectance of the five points on the filter
RO: the reflectance of the white filter (by definition equal to 100)
V: the volume of air aspirated during sampling in m³
A: the active surface area of the filter loaded with particulate matter, given by:

$$A = \pi.\left(\frac{d}{2}\right)^2 \tag{6}$$

d: the diameter of the loaded filter equals 41mm, i.e. A = 0.132 cm² = 13.2×10^{-6}m².

Figure 4. Five-point method for measuring filter reflectance



RESULTS AND DISCUSSION

PM2.5 and carbon black concentrations

The PM2.5 and carbon black concentrations measured in the industrial area from May 1st to July 28th are shown in T**able 1** below. The mass concentrations of PM2.5 and carbon black ranged from 27.11 to 70.68 μg/m³ and from 43.85 to 66.07 μg/m³, respectively, with average values of 46.48 ± 12.18 μg/m³ and 55.26 ± 6.65 μg/m³, respectively. The study shows that the average carbon black concentration is higher than that of PM2.5 at the site. The PM2.5 concentration levels obtained at the site were all above the reference value established by the WHO (15 μg/m3), thus indicating an accumulated health risk for the population residing in the area (WHO, 2021). As for black carbon (BC), its concentrations were high in PM2.5 because it preferentially binds to this particle size category. This suggests that BC pollution is associated with incomplete combustion sources (Marcazzan et la., 2001), which is consistent with the significant industrial activity and road traffic that characterize the study area.

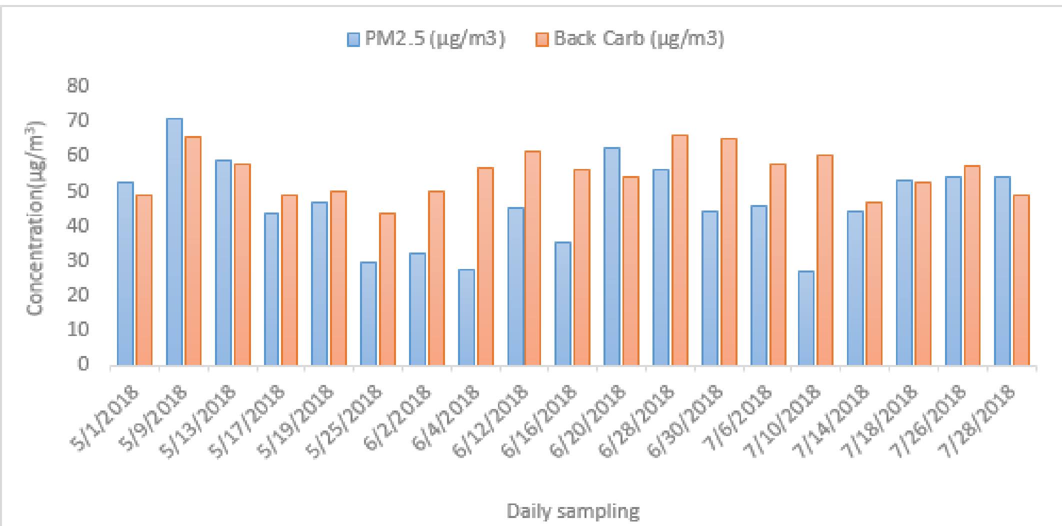
(**Table 2**) presents the daily mass concentrations of PM2.5 and black carbon in the PM2.5 fraction in μg/m³. The averages of these parameters are also provided.

Table 1. PM2.5 and black carbon concentrations.

Sample codes	Sampling date	Concentrations (μg/m3)	
		PM2.5	**Back Carb on**
F001	01/05/2018	52.67 ± 2.36	48.89 ± 2.44
F002	09/05/2018	70.68 ± 0.78	65.58 ± 3.27
F003	13/05/2018	59.06 ± 6.06	57.90 ± 2.89
F004	17/05/2018	43.80 ± 5.54	49.03 ± 2.45
F004	19/05/2018	46.80 ± 5.88	50.18 ± 2.50
F005	25/05/2018	29.61 ± 8.09	43.85 ± 2.19
F006	02/06/2018	32.08 ± 1.22	49.81 ± 2.34
F007	04/06/2018	27.36 ± 2.02	56.73 ± 2.83
F008	12/06/2018	45.12 ± 1.23	61.76 ± 3.08
F009	16/06/2018	35.25 ± 1.18	56.47 ± 2.82
F010	20/06/2018	62.63 ± 3.98	54.35 ± 2.71
F011	28/06/2018	56.03 ± 1.46	66.07 ± 3.30
F012	30/06/2018	44.28 ± 0.45	65.18 ± 3.25
F013	06/07/2018	45.63 ± 2.06	57.95 ± 2.89
F014	10/07/2018	27.11 ± 1.06	60.49 ± 3.02
F015	14/07/2018	43.99 ± 1.41	46.76 ± 2.35
F016	18/07/2018	52.88 ± 1.59	52.87 ± 2.64
F017	26/07/2018	54.11 ± 0.58	57.15 ± 2.85
F018	28/07/2018	54.04 ± 0.42	48.93 ± 2.44
Average		**46.48 ± 12.18**	**55.26 ± 6.65**

The variation in Black Carbon (BC) concentrations in PM2.5 measured daily is shown in (Fig. 5). It also shows that during the PM2.5 particulate fraction sampling period, BC concentrations were higher than PM2.5 concentrations in several samples. (**Fig. 5**) indicates peak concentrations of PM2.5 and BC observed on 9 May, 2018, and 28 June, 2018.

Figure 5. Concentrations of black carbon in PM2.5.



Comparison of PM2.5 and BC concentrations obtained with other studies.

The PM2.5 and BC values obtained in this study were compared with those obtained at the national and international levels (**Table 2**).

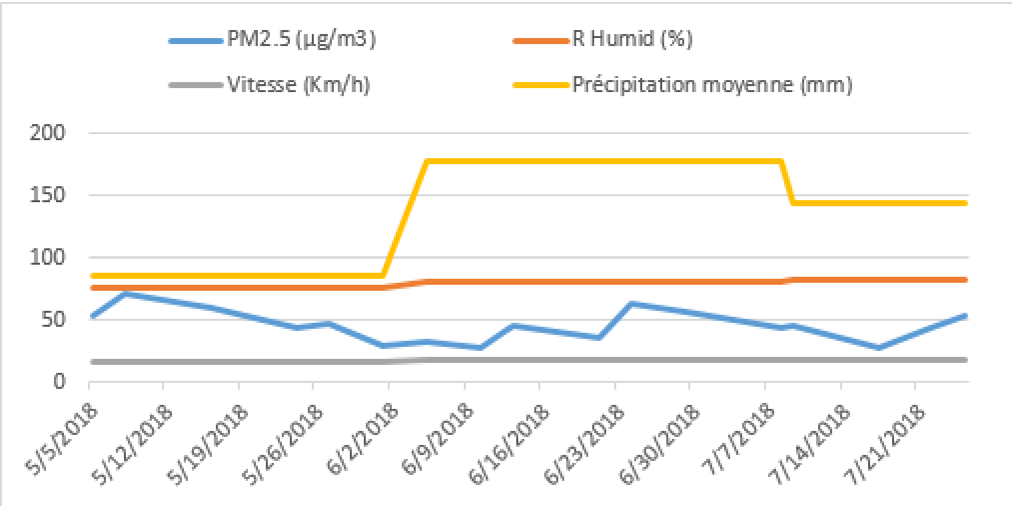
Table 2. PM2.5 and BC concentration levels in Côte d'Ivoire, some African capitals and others.

Study area	Concentration (µg/m3)		BC (PM2.5)	References
	PM2.5	BC		
Abidjan, industrial area, C.I	27.11 -70.68	43.85- 66.07	55.26%	Present study
Abidjan, industrial area, CI	17.25 - 161	40.01 - 59.23	52.31%	(Popouen et al., 2021)
Accra, industrial area, Ghana	27 - 67	1 - 14	19%	(Alli et al., 2021)
Korhogo, Cote d'Ivoire	54.3 - 218	-	-	(Gnamien et al., 2021)
Dakar, sites urbains, Sénégal	-	0.1 - 6.84	-	([Traore et al., 2023)
Pékin (Chine)	60.5	8.3	13.7%	(WHO, 2024)

It can be noted that the PM2.5 values in our study are lower than those observed in various African countries, but they remain above international standards (WHO, 2021). However, black carbon concentrations are significant at the study sites.

Furthermore, meteorological parameters are likely to influence pollutant concentrations at a study site; these include wind speed, relative humidity, and any rainfall. A time series of PM2.5 concentrations is shown in (**Fig. 6**).

Figure 6. Variation of PM2.5 concentrations according to meteorological parameters.



(**Fig. 6**) shows that the highest PM2.5 concentrations are recorded on sunny days with an average rainfall of 86 mm, and a maximum value of 70.68 ± 0.78 µg/m³. Conversely, on rainy, cloudy days (high humidity) with wind, PM2.5 concentrations in the atmosphere of the Yopougon industrial zone are relatively low. This decrease in concentration during rainy days is explained by the wet deposition of particulate matter caused by rainfall, and by the role played by wind in dispersing the particles away from the sampling site. A negative correlation between PM2.5 and rainfall was observed during June 2018; this is well supported by the data.

CONCLUSION

PM2.5 and black carbon concentrations were studied over three months in the Yopougon industrial zone of Abidjan. Significant variability was observed in mass concentrations. The results showed that during the study period:

- PM2.5 concentrations generally exceeded WHO recommended levels.
- Black carbon was found to be a significant component of the PM2.5 fraction.

Based on the results of this study, the ambient air in the Yopougon industrial zone is heavily polluted by respirable PM2.5 particles from industrial activities on the site. Further in-depth studies are therefore necessary to fully understand the risks associated with particulate pollution, identify the sources, and quantify the contribution of each.

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