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Link between the combustion of household waste from Akouédo landfill, air quality and vitamin A status among residents

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Abstract

The Akouédo landfill was the only official landfill of Abidjan (Côte d'Ivoire) since more than 40 years. Huge amount of waste it received each year increasingly polluted the environment of the landfill but also that of the surrounding neighbourhoods and villages. The aim of this study was to assess particulate pollution in the neighbourhoods surrounding Akouédo landfill and its impact on the nutritional status of residents. To achieve this objective, mass concentration of fine particles $PM_{2.5}$ was determined at Akouédo landfill site and four surrounding neighbourhood using passive sampling. Also, after blood sampling from local residents, vitamin A was determined by HPLC. Results showed that Akouédo Attié is most affected by particulate pollution with $PM_{2.5}$ concentration of 119.9 $\mu g.m^{-3}$. Then follow Génie 2000 (82.3 $\mu g.m^{-3}$), Lauriers 9 (74.9 $\mu g.m^{-3}$) and Akouédo village (62.7 $\mu g.m^{-3}$). The neighbourhoods with the highest $PM_{2.5}$ concentrations are in the wind direction of the landfill. In addition, there is a link between $PM_{2.5}$ concentrations and vitamin A levels. The oxidative stress caused by the Akouédo landfill would lead to a reduction in vitamin A levels among residents: 55.3% in Akouédo Attié, 35.1% in Lauriers 9, 23.4% in Akouédo village and 14.9% in Génie 2000.

1. Introduction

Air pollution is "the release by humans into the atmosphere of compounds that can be harmful in the short or long term" [1]. These compounds are called pollutants and fall into two main groups: primary pollutants and secondary pollutants. Primary pollutants are directly derived from pollution sources. These are carbon oxides (COx), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs) and particulates matters (PM). In contrast, secondary pollutants are formed by photochemistry or chemical reaction and also from primary pollutants. This is the case for halocarbons, secondary organic carbon (SOC), ozone etc.

The measurement of these different pollutants provides information on air quality. In recent decades, scientists of various nationalities have taken an interest in air pollution [2-5]. In Côte d'Ivoire, the dumping of toxic waste by the Probo Koala in 2006 led to a major environmental disaster that led to several research projects. Several areas of the Abidjan district were victims of these spills. Among them, the village of Akouédo, which for more than forty years housed the only landfill in the Abidjan district. For several years, considerable damage and disasters have been attributed to this landfill. Previous studies have shown that the environment of this landfill (soil, air and water) is totally polluted [6, 7]. As a result, it represents a risk not only to public health, but also to the ecosystem in Abidjan. Given the diversity of pollutants involved, the work carried out in this study was limited to the problem of particulate pollution. Indeed, fine particles are made up of a mixture of gaseous and solid particles with varied physico-chemical properties. The composition of these particles depends on the different sources in the vicinity and their contribution to the final concentration. They are classified by their size: $PM_{2.5}$ and PM_{10} for particles with aerodynamic diameters less than 2.5 and 10 µm respectively. Our choice in terms of pollutants was particularly focused on $PM_{2.5}$. Due to their small size, they can enter the lungs and reach the bloodstream through the alveoli [8, 9]. These particulates matters are a good means of transporting toxic substances such as trace metals (ETM), hydrocarbons (PAH), reactive gases and sulphuric acid (H_2SO_4), which accumulate in the body and affect the nervous system, liver and respiratory functions [10]. In addition, they can cause oxidative stress, creating certain metabolic dysfunctions and chronic diseases with nutritional implications such as cancer, diabetes, obesity, cardiovascular disease and metabolic syndrome [11, 12]. To protect itself from this oxidative stress, the body has developed defence systems. These systems are composed of antioxidants (vitamins A, C and E), trace elements (selenium, zinc) and proteins. Also, there is daily production of black smoke from solid waste burning at the landfill site that moves towards the surrounding neighbourhoods and villages depending on wind direction. This black smoke could contain several pollutants including these particulates matters. It is therefore important for us to assess the impact of the particulate pollution caused by this landfill on the air quality of the surrounding neighbourhoods and villages and on the vitamin A status of population.

2. Material and Methods

2.1. Site locations

The Akouédo landfill is located in the northeast of Abidjan district (Côte d'Ivoire), in the municipality of Cocody (5°21’07”N, 3°56’30”W) [13] (Figure 1). To the north, it is bounded by the high standing residential cities ATCI, Génie 2000 and Lauriers 8, 9 and 10; to the west by the village of Akouédo and the residential cities SYNACACI; to the east by the village of Akouédo Attié and to the south by Riviera 4, the village of M'Badon and the lagoon Ebrié (Figure 2). Created in 1965, this landfill was the only landfill in the Abidjan district until December 2018. Its surface area is 153 ha. Today unused because of its largely outdated capacity, the Akouédo landfill has long been considered as an uncontrolled open landfill. On average, this landfill received more than one million tons of waste per year. The area of this landfill was chosen because at the time it was very far from the city of Abidjan and residential areas. The rapid urbanization of the city of Abidjan has brought this landfill closer to the city [7]. Today, the populations live close the landfill.

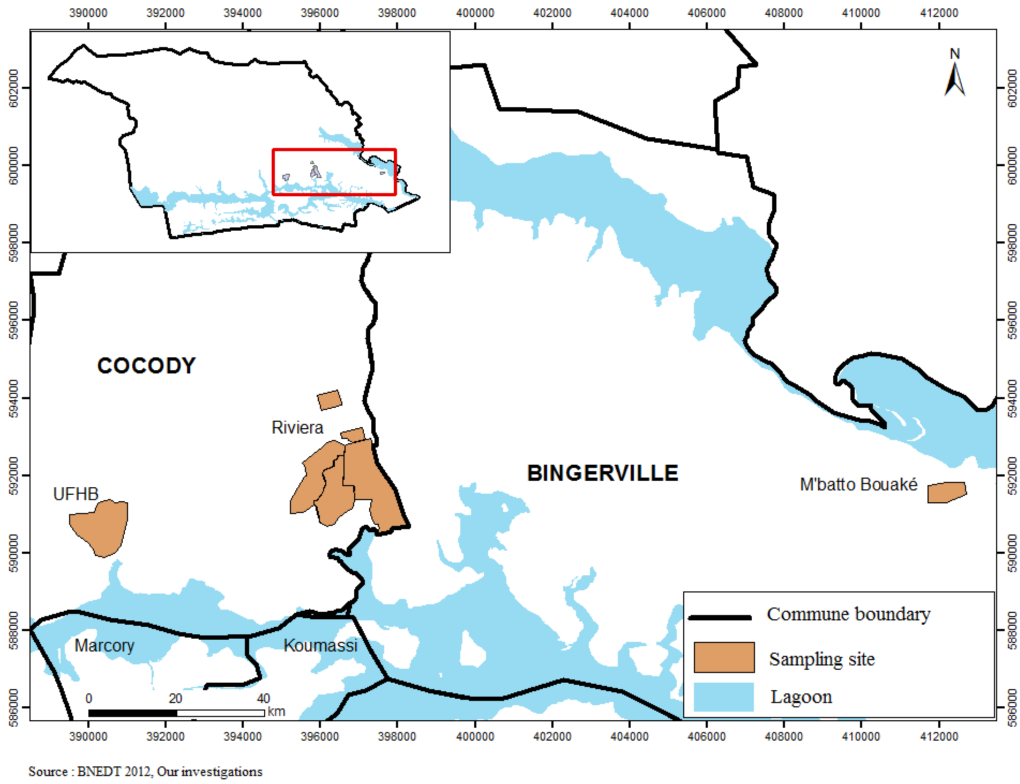


Figure 1: Geographical location of the sampling site.

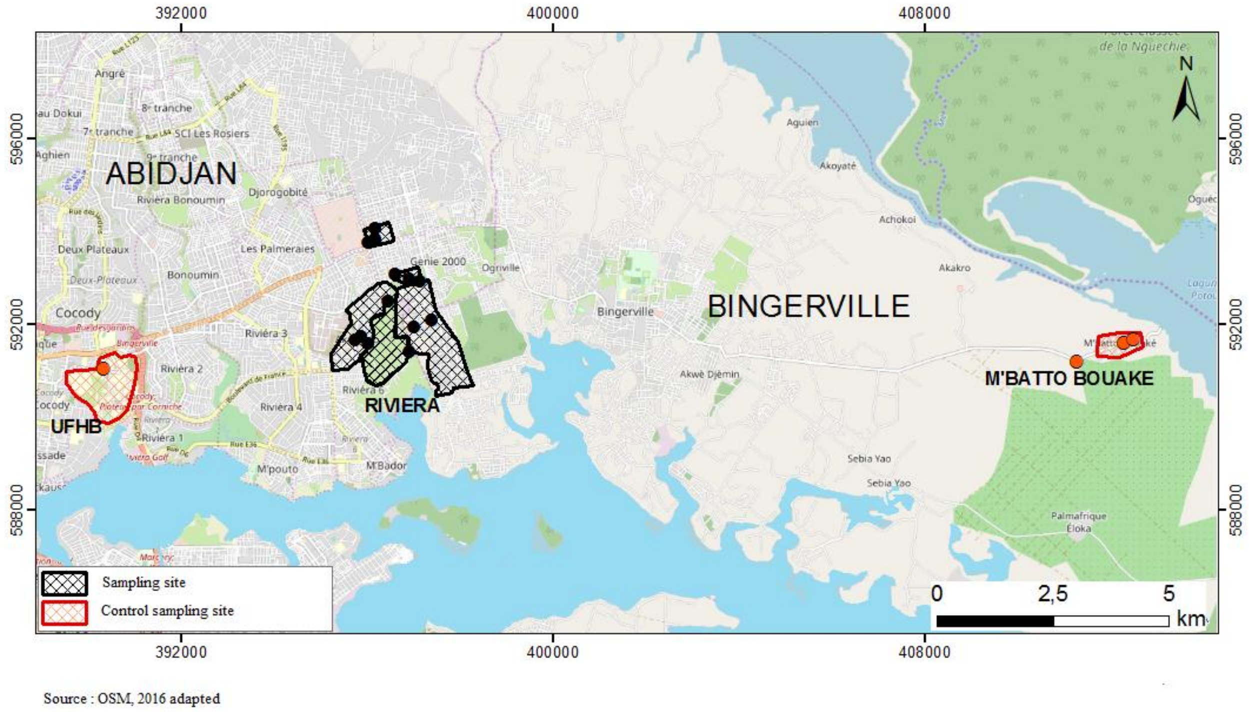


Figure 2: Sampling site and distribution of the stations.

2.2. Material

2.2.1. Particulate sampling equipment

The equipment used to determine the mass concentration of particulates matters $PM_{2.5}$ is a sampling box developed by the Laboratoire d'Aérologie of Toulouse (France) [14]. The device consists of a sampling line equipped with a cut-off head, filter holder, flow meter, gas meter and pump (Figure 3). The particles were collected on quartz filters with a diameter of 47 mm. These filters were subjected to gravimetric analysis in Toulouse (France) at Laboratoire d'Aérologie. The mass of pollutants was determined by double weighing the filters (before and after sampling) using a submicron balance of the SARTORIUS MC21S type with a sensitivity of 1.95 µg.

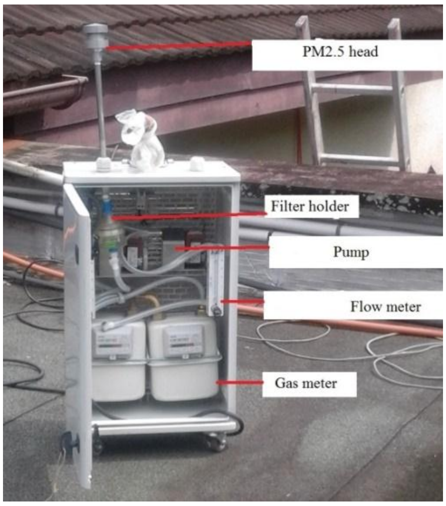


Figure 3: Sampling box showing the elements of the sampling lines.

2.2.2. Subjects

150 volunteers (72 women and 78 men in the age 21 and 74 years with an average age of 40.7 ± 12 years were included in this study. They gave written informed consent to participate in this study, which was approved by the Comité National d'éthique et de la Recherche (CNER) ORG00075.

2.2.3. Biological material

The biological material consists of vein blood samples taken from volunteers living near the Akouédo landfill site (Akouédo village, Akouédo Attié, Lauriers 9, Génie 2000) and in M'Batto-Bouaké. Blood samples were taken at healthcare centers (Centre de santé urbain d'Akouédo Attié, Centre de santé urbain d'Akouédo village, M'Batto-Bouaké Dispensary, Centre de santé Espoir de Génie 2000) and a Primary School (EPP Les Lauriers 9 et 10).

2.3. Methods

2.3.1. Selection criteria

2.3.1.1. Choice and spatial distribution of the stations

The choice and spatial distribution of the stations were made according to proximity to the landfill, population density, consent of the head of the family, accessibility of the tracks, safety and electrification of the housing. The measurement stations have been installed in the following districts and villages: Génie 2000, Lauriers 9, Akouédo Attié, Akouédo village, Félix Houphouët Boigny University and M'Batto-Bouaké. The villages chiefdom and districts chairmans were approached to obtain their consent before the start of the study. They were involved in the successful completion of the study.

2.3.1.2. Inclusion and exclusion criteria of participant

Each participant in this study had to meet certain criteria: be in good physical health and live in Akouédo village, Akouédo Attié, Lauriers 9, Génie 2000 and M'Batto-Bouaké for a period of ten years or more. They had to give their consent and be at least 21 years old. Pregnant and lactating women and people with metabolic or cardiovascular diseases were excluded.

2.3.2. Sampling sites

Three stations were installed in each of the districts (Génie 2000, Lauriers 9, Akouédo Attié, Akouédo village and M'Batto-Bouaké), one station at Université Félix Houphouët Boigny and another one at the Akouédo landfill, for a total of seventeen (17) stations (Figures 2 et 4). Main sites characteristics (period of measurement, coordinates, main sources of pollution) are presented in the table I. The stations have been classified into three main categories:

- "Entry" Stations (SE): Measurements were performed at the main entrance of each neighbourhood located near major roads or main streets.
- "Centre" Stations (SC): Measurements were carried out in households located in the centre of each district. These sites are many influenced by local sources such as domestic fires and waste burning.
- "Bottom" Stations (SF): These are sites far from the "entry" station and main traffic routes.

In addition to these stations, reference stations were searched.

- Reference Stations (SR): Reference stations are located in an environment not directly impacted by pollutants of Akouédo landfill. These stations are also out off the trajectory of prevailing winds. One station is located in an urban area (Université Félix Houphouët Boigny) and the other in a rural area (M'Batto-Bouaké).

2.3.3. Sampling

2.3.3.1. Particulate sampling

Sampling was daily, i.e. at a time step of 24 hours per sample. For each site, aerosol was collected continuously by suction at a flow rate of 5 L/min. Figure 4 shows the spatial distribution of the stations. Sampling box was installed on the roofs of low-rise houses at heights ranging from two to three meters. For each station, samples were taken continuously for 24 hours. Table I presents the different measuring stations and their characteristics. The measurements were repeated over three days.

2.3.3.2. Blood samples collection

For each participant, vein blood samples were collected on an empty stomach during the recruitment period between 6:30 and 10:30 in a single sampling from April to December 2018 on a serum tube without clot activator or gel. After sampling, the tubes were stored at + 4°C in a cooler containing ice-packs. Samples are transferred two hours later to the Laboratoire de Biochimie Clinique et Fondamental of Institut Pasteur (Côte d'Ivoire) according to safety rules for pre-treatment. Tubes were covered with an aluminum foil to minimize exposure of blood samples to daylight. Plasma was separated from blood cells by centrifugation (3000 rpm, 5 min, 4°C) and immediately stored at -20°C in 1 mL polypropylene tubes.

2.3.3.3. Blood samples preparation

Quantitative analysis of vitamins A was performed after prior extraction of the lipid fraction from serum using the method used by Boyvin [14]. For the analysis of blood serum, 300 μL of the internal standard of retinyl acetate solution (1 mg/L) in 300 μL pure ethanol (96°C) were pipetted into amber test tube. 300 μL of serum were added and the content mixed vigorously on a vortex mixer for 5 min. 1200 μL of extraction solvent n-Hexane for HPLC were then added. The solution was vortexed for 5 min, and centrifuged (3 500 rpm, 15 min, 4°C). 900 μL of upper hexane layer was transferred into amber glass tubes. Combined hexane extracts were evaporated to dryness, under nitrogen, at 4∘C. The dried residue was resuspended in 300 μL of elution solvent of methanol and vortexed for 30 s. The sample was then filtered through a nylon filter (pore size 0.20 μm, 4 mm diameter, Millex-HN Syringe Filter), transferred into 0.2 mL cramped amber vial. The extract is used for quantitative vitamin A analysis. All procedures were performed in a darkened room.

2.3.4. Instrumentation

The analysis of vitamin A was performed using an HPLC chain of the Waters® type, USA, in isocratic mode. A C18 Waters SPHERISORB® ODS 2 reverse phase column, 4.0 mm in diameter and 25 mm long with a particle size of 5 µm was used as the stationary phase. It is preceded by a precolumn adapted to columns C18. The mobile phase consists of a Methanol/Water mixture (97/3; v/v) at a flow rate of 1 mL/min. Spectrophotometric analyses were carried out on at UV-Visible at 290 nm wavelength. High performance liquid chromatography (HPLC) is a quantitative method based on the fact that the area of the chromatographic peaks is proportional to the concentration of the vitamins present in the medium. Detection is carried out using a UV-Visible detector that detects the peak corresponding to vitamin A at a very specific wavelength.

2.3.5. Concentration determination method

2.3.5.1. Method for determination of $PM_{2.5}$ concentration

Sampling boxes operate continuously for 24 hours. The volume of air pumped (Vpp) is then raised and the filter is removed. After weighing, the aerosol mass (ma) is determined by the difference between the filter mass after and before exposure. The daily concentration of $PM_{2.5}$ is determined by the following formula:

$$[\mathrm{PM2.5}] = \frac{\mathrm{ma}}{Vpp}$$

Sampling was carried out from March 11, 2018 to August 20, 2018 (Table I).

2.3.5.1. Method for determination of retinol concentration

The quantitative analysis is performed by automatic injection of 20 µL of the lipid extract into the chromatographic system. The peaks corresponding to vitamin A are presented on the chromatogram displayed by the recording integrator. The concentrations of vitamins are determined from the peak surfaces by the following formula:

$$C = K.\frac{SV\ Ech}{SRA\ Ech}\ with\ K = \frac{CV\ GE\ .\ SRA\ GE}{SV\ GE}$$

SV Ech : Vitamin peak area in the serum sample, CV GE : Concentration determined from the standard range, SRA GE : Retinyl acetate peak area corresponding to 1 mg/L obtained from the standard range, SV GE : Peak area corresponding to the vitamin concentration from the standard range, SRA Ech : Retinyl acetate peak area in the serum sample corresponding to 1 mg/L concentration.

The percentage of vitamin reduction is calculated by the formula below:

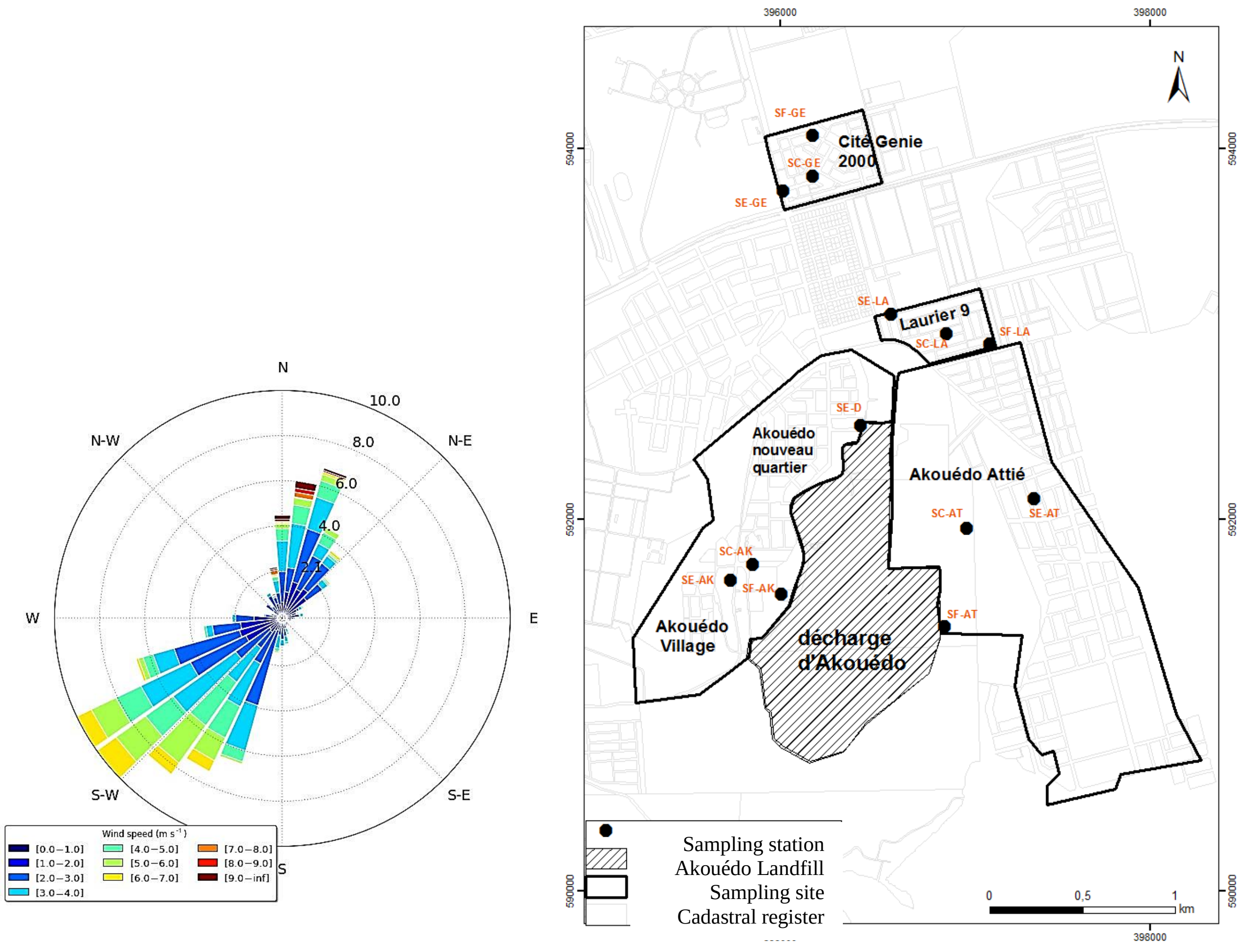
$$Reduction = 100 * \frac{Mean\ Not\ Exposed - Medium\ Exposed}{Mean\ Not\ Exposed}$$

The reference serum values for vitamin A are 0.35 - 1.75 µmol/L.

2.3.5. Spatial and statistical analysis

2.3.5.1. Spatial analysis

In this study, we interpolated of $PM_{2.5}$ concentrations measured. of thirteen (13) sites to obtain the spatial distribution of $PM_{2.5}$ concentrations from the Akouédo landfill and surrounding areas using a geographic information system (GIS). The mapping tool used is the version of QGIS software 3.4.5. The characteristics were projected with the world geodetic system (WGS 1984) UTM Zone 30N (Universal Transverse Mercator). The interpolation method used to study the spatial distribution of PM2.5 is inverse distance weighting (IDW). The general formula used for the interpolation is: $Z(S_0) = \Sigma \lambda i\, Z(Si)$, where $Z(S_0)$ is the predicted concentration at location S_0 and is calculated as a weighted linear sum of N observations surrounding the predicted location. Z (Si) is the measured concentration at the location of Si, i is an unknown weight for concentration measured at the location of Si, S_0 is the location prediction and N is the number of concentration measured. In IDW, the weight i only depends on the distance between the measurement points and the prediction location. IDW calculates the predicted concentrations at the site as a weighted average of neighbouring measured concentrations [15, 16]. This method provides a spatial distribution of pollutants much closer to reality.



[17]

Source : BNEDT 2012, Our investigations

Figure 4: Sampling stations with hourly wind rose diagram of Abidjan.

2.3.5.2. Statistical analysis

The data were entered and analyzed using Microsoft Excel 2010 software to calculate averages concentrations and standard deviations. Data vitamin A were collected digitally using chromatography sofware Breeze 2. The data are presented as mean ± S.D. Differences between studied groups were analyzed using the Student's *t*-test. The STATA software was used for the paired correlation tests between $PM_{2.5}$ pollutant concentrations and vitamin A concentrations. A $P < 0.05$ value was considered statistically significant.

Table I : Characteristics of the sampling stations

N	Areas	Sampling stations	Measurement period	Characteristics	Coordinates	
					Latitude (N)	**Longitude (E)**
1	**Akouédo Attié**	"Entry" station	3 to 6 july 2018	Akouédo Attié Urban Health Centre - Working site at 50m - Unpaved street	5°21'22.2"N	3°55'34.6"W
2		"Centre" station	17 to 20 july 2018	Village football field - Unpaved street	5°21'17.0"N	3°55'46.4"W
3		"Bottom" station	8 july to 17 august 2018	Second to last house near the landfill - Unpaved street Ravine and lagoon Ebrié to the south - Landfill to the west	5°20'59.2"N	3°55'53.7"W
4	**Akouédo Village**	"Entry" station	11 march to 20 april 2018	Asphalt street - Bistro at the entrance of the courtyard	5°21'07.8"N	3°56'28.0"W
5		"Centre" station	11 march to 16 august 2018	Uncemented family yard with mango tree - Presence of small businesses Asphalted street	5°21'10.6"N	3°56'24.0"W
6		"Bottom" station	12 march to 20 august 2018	Highly fenced house - Artisanal recycling units nearby - Akouédo Village border boundary - Landfill	5°21'05.4"N	3°56'19.1"W
7	**Lauriers 9**	"Entry" station	11 to 13 june 2018	12th house with school entrance - Construction site at 10m	5°21'54.5"N	3°55'59.8"W
8		"Centre" station	7 april to 14 august 2018	Main streets of the city paved	5°21'51.2"N	3°55'50.0"W
9		"Bottom" station	8 to 10 august 2018	3rd house Abatta entrance - Main street on the unpaved Abatta side	5°21'49.4"N	3°55'42.4"W
10	**Génie 2000**	"Entry" station	5 april to 3 juin 2018	1st house after main entrance - Bakery at 5m House with medium flowered garden with sandbox backyard -	5°22'16.1"N	3°56'18.8"W
11		"Centre" station	9 april au 11 august 2018	Medium flowered garden with large sandbox - 10m from the green area	5°22'18.7"N	3°56'13.6"W
12		"Bottom" station	11 april au 5 juin 2018	Artificial garden located 100m from the large lawn and the primary school	5°22'26.0"N	3°56'13.7"W
13	**Discharge**	"Entry" station	5 april au 2 juin 2018	Weighbridge dump - ANAGED/BNEDT/PFO Agents Office 3km from the main spill site - 300 trips/day by garbage collection vehicles	5°21'35.0"N	3°56'05.0"W
14	**Félix Houphouët Boigny University**	Reference station	21 au 23 may 2018	IRD - Beautiful and large lawn - Near the Secondary Entrance - Heavy traffic during rush hour - Electric bus station 50m away	5°20'47.4"N	3°59'23.8"W
15	**M'Batto-Bouaké**	"Entry" station	25 june au 24 july 2018	Residence with private forest	5°20'53.2"N	3°48'03.2"W
16		"Centre" station	25 au 27 july 2018	Preparation of the Attiéké on a wood fire	5°21'06.2"N	3°47'30.0"W
17		"Bottom" station	30 july au 3 august 2018	Village primary school - 200m from the lagoon and 100m from the cemetery	5°21'08.6"N	3°47'23.8"W

3. Results and discussion

3.1 Daily concentrations of $PM_{2.5}$

The daily average concentrations determined for each site are presented in Table II.

3.1.1. Daily concentrations of $PM_{2.5}$ in Akouédo Attié

Mean concentrations at the entry, centre and bottom stations were 157.3 ± 68.9 µg/m^3, 117.7 ± 16.7 µg/m^3 and 84.8 ± 51.2 µg/m^3 respectively. Concentrations measured at the three stations in Akouédo Attié are all very high and exceed the WHO daily standard (25 µg/m^3 per 24 hours average) [18] for fine particles ($PM_{2.5}$). They are three to four times higher than the daily standard. These concentrations are higher at the entrance to the village and decrease as we get closer to the landfill. These observed values are explained by the intensification of southwest winds with an average of 2.75 ± 0.6 m.s^{-1} according to Bahino *et al*. [17]. Which show that Akouédo Attié is more impacted by the pollutants emitted at the Akouédo landfill. These results show that the populations most exposed of Akouédo Attié are the people living at the entrance of the village.

3.1.2. Daily $PM_{2.5}$ concentrations in Akouédo village

$PM_{2.5}$ concentrations in Akouédo village were 72.1 ± 22.4 (entry station); 42.6 ± 39.7 (centre station) and 73.5 ± 30.3 µg.m^{-3} (bottom station). As Akouédo Attié village, all concentrations measured at Akouédo village are higher than WHO standards [18] and are higher at the entrance and bottom of the village. These high pollutants concentrations are explained by the intensification of northeast winds from the landfill according to Bahino *et al*. [17]. In addition, the lowest concentrations in the centre station are the result of relatively light winds in this direction and the presence of trees. These results could be explained by the fact that air pollution is not evenly distributed over time and space [19] and that vegetation contributes to the capture of some pollutants [20].

3.1.3. Daily concentrations of $PM_{2.5}$ at Lauriers 9

Lauriers 9 daily concentrations at the entry, centre and bottom stations were 135.7 ± 19.6 µg.m^{-3}, 68.7 ± 73.5 µg.m^{-3} and 20.4 ± 1.0 µg.m^{-3} respectively. Concentrations at the entry and centre station are well above WHO daily standard [18]. However, the bottom station concentrations are below the WHO standard [18]. Concentrations at the entry station are higher than those at the centre station. Thus, housing located next to the bottom station is not very affected by air pollution. At the entrance to Lauriers 9, the houses are subject to the influence of pollutants from road traffic in addition to the air pollution caused by the landfill. Indeed, according to the Île-de-France air observatory, "in the vicinity of road traffic, the daily and annual limit values for fine particles are still largely exceeded" [21].

3.1.4. Daily concentrations of $PM_{2.5}$ at Génie 2000

At Génie 2000, daily $PM_{2.5}$ concentrations at the entry (86.4 ± 36.5 µg.m^{-3}), centre (63.4 ± 41.9 µg.m^{-3}) and bottom (97.1 ±19.8 µg.m^{-3}) stations are high and exceed WHO standards [18]. The centre station has slightly lower $PM_{2.5}$ concentrations than the other stations. Concentrations at the bottom station are higher than those at the entry station. Indeed, since the entrance station is close to the main road (Abidjan-Bingerville axis) and the neighbourhood bakery, concentrations are higher in the habitats near the entrance to the neighbourhood. Pollutants are strongly emitted near roads with very high traffic volumes [21]. In addition, the lower PM2.5 concentrations at the central station may be due to the presence of several green spaces at the Génie 2000 centre. Also, the bottom dwellings are downwind of the Akouédo landfill.

3.1.5. Daily concentrations of $PM_{2.5}$ in M'Batto-Bouaké

PM2.5 concentrations were 15.5 ± 3.4 µg.m^{-3}, 22.5 ± 1.7 µg.m^{-3}, 13.2 ± 2.7 µg.m^{-3} were recorded at M'Batto-Bouaké for the entry stations, the centre and the bottom respectively. All $PM_{2.5}$ concentrations in the various M'Batto-Bouaké stations are very low and comply with WHO standards [18]. The village of M'Batto-Bouaké is not affected by particulate pollution. The concentrations at the entrance and exit of the village are approximately equal. However, those of the centre station are slightly high. This is explained by the presence of Attiéké's processing units where women use firewood to cook Attiéké. Indeed, particulate pollution is more significant along trade routes where combustion sources are more numerous [21].

3.1.6. Daily concentrations of $PM_{2.5}$ at the Akouédo landfill

Average daily concentration $PM_{2.5}$ at the Akouédo landfill site were 89.7 ± 5.1 µg.m^{-3}. This concentration is three times higher than the WHO daily standard (25 µg.m^{-3}) [18]. This is due to the fact that the waste buried at the Akouédo landfill is constantly burning and producing black smoke. This waste burns spontaneously due to the presence of biogas [6]. In addition, traffic caused by the presence of waste transport vehicles has a strong influence on $PM_{2.5}$ concentrations in the landfill. Indeed, the National Waste Management Agency (ANAGED) recorded more than 200 daily trips at that time. According to Djossou *et al.* [22], the seasonal average concentrations of $PM_{2.5}$ at the Akouédo landfill range from 18 ± 6 to 48 ± 1 µg.m^{-3}. These weekly measurements are three times higher than the WHO weekly recommendations (10 µg.m^{-3}) [18].

3.1.7. Daily $PM_{2.5}$ concentrations at Félix Houphouët Boigny University (UFHB)

The station chosen at Félix Houphouët Boigny University is the Research Institute (IRD). The average PM2.5 concentration obtained at this station was 86.7 ± 3.5 µg.m-3. These concentrations are high and well above WHO standards [18]. This result is consistent with previous studies in sub-Saharan West Africa conducted in urban areas [9, 23-25]. Indeed, within the UFHB, car traffic is low. In addition, the buses that run within it are electric. However, there is very dense traffic around the UFHB, especially during peak hours. Wind being a factor of atmospheric dispersion, the pollutants will therefore transport the pollutants to the UFHB [26].

Table II : Daily concentrations of $PM_{2.5}$ per station

N	Areas	Stations	$PM_{2.5}$ (µg.m^{-3})
1	Akouédo Attié	"Entry" station	157.3
2		"Centre" station	117.7
3		"Bottom" station	84.8
			119.9 ± 36.3
4	Akouédo Village	"Entry" station	72.1
5		"Centre" station	42.6
6		"Bottom" station	73.5
			62.7 ± 17.4
7	Lauriers 9	"Entry" station	135.7
8		"Centre" station	68.7
9		"Bottom" station	20.4
			74.9 ± 57.9
10	Génie 2000	"Entry" station	86.4
11		"Centre" station	63.4
12		"Bottom" station	97.1
			82.3 ± 6.5
13	Akouédo landfill	"Entry" station	**89.7 ± 5.1**
14	Université Félix Houphouët Boigny	Reference station	**86.7 ± 3.5**
15	M'Batto-Bouaké	"Entry" station	15.5
16		"Centre" station	22.6
17		"Bottom" station	13.2
			17.1 ± 4.9

3.1.8. Comparisons of data from different sites

Among the neighbourhoods and villages in the study area, Akouédo Attié village has the highest $PM_{2.5}$ concentrations (119.9 ± 36.3 µg.m^{-3}). Then follow the Akouédo landfill (89.7 ± 5.1 µg.m^{-3}), Félix Houphouët Boigny University (86.7 ± 3.5 µg.m^{-3}), Génie 2000 (82.3 ± 6.5 µg.m^{-3}), Lauriers 9 (74.9 ± 57.9 µg.m^{-3}), Akouédo village (62.7 ± 17.4 µg.m^{-3}) and M'Batto-Bouaké (15.5 ± 4.9 µg.m^{-3}). Except for the village of M'Batto-Bouaké, whose concentrations meet WHO standards, all the concentrations in the study areas are well above the standards (Figure 6). In fact, average concentrations of particulate matter in cities are systematically higher than in urban outskirts or rural areas [21]. The average daily concentration of $PM_{2.5}$ in the landfill is lower than that of Akouédo Attié. These values would be the fact that the village of Akouédo Attié is located exactly downwind of the landfill while the station chosen for the landfill is located at the entrance of the landfill and located a few kilometres from the point of discharge. According to Bahino *et al.* [17], a predominance of southwest (SW) and northeast (NNE) winds with respective speeds between 1 and 9 m.s^{-1} strongly influences particle transport (Figure 5). The average daily $PM_{2.5}$ concentration at the Félix Houphouët Boigny University station located not far from the city centre of Abidjan, is very close to that of Ouagadougou (86 ± 42 µg.m^{-3}) [27]. In West Africa (Burkina Faso, Ghana and Senegal), daily concentrations range from 24 µg.m^{-3} (Dakar) to 86 µg.m-3 (Ouagadougou). These results show that the level of air pollution in West African capitals is very high. The measures taken in Akouédo Attié and at the landfill are relatively higher than the other measures in West Africa.

(a) (b) (c)

(d)

Figure 5: Pictures showing the immediate environment of some stations: (a) Black smoke from the landfill at Akouédo Attié (SE-AT station), (b) Black smoke from the landfill at Akouédo village (SC-AK station), (c) Black smoke from the landfill at Genie 2000 (SF-GE station), (d) Auto-burning of waste at the landfill.

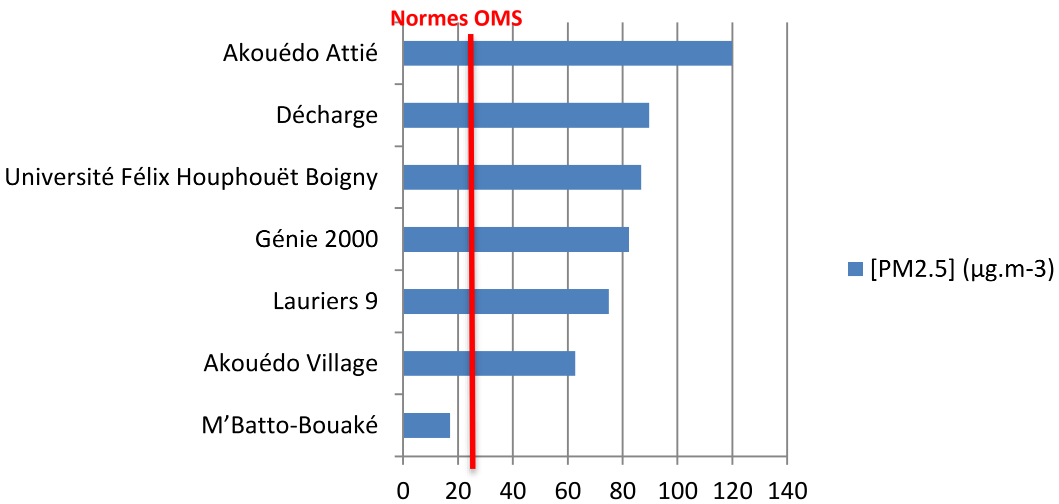
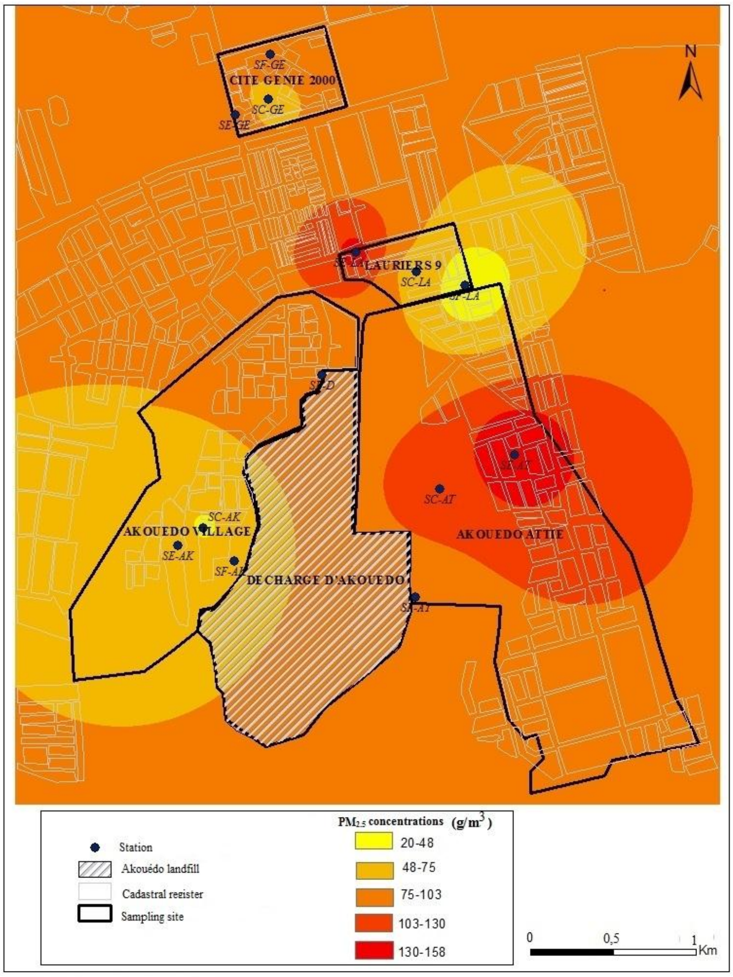


Figure 6 : Comparison of average $PM_{2.5}$ concentrations at different measurement sites.

3.1.9. Spatial distribution of pollutants

The spatial distribution of $PM_{2.5}$ at the Akouédo landfill and surrounding area is shown in Figure 7. The pollutant is represented using a scale from yellow (low concentration of $\mu g.m^{-3}$) to red (high concentration of $\mu g.m^{-3}$). The sampling stations are represented by black dots and referenced with an identification code with the suffix SE, SC and SF. The hatched area indicates the Akouédo landfill. The black lines indicate the cadastral register while the dark black lines delimit the sampling sites.



Source : BNEDT 2012, Our investigations

Figure 7 : Spatial distribution of $PM_{2.5}$ in the study area (April 11 to August 20, 2018)

3.2 Vitamin A status and link with particulate pollution

Table III presents the level of vitamin A concentration and reduction according to districts and villages. All populations exposed to landfill have vitamin A deficiency with a reduction rate of 55.3%, 35.1%, 23.4% and 14.9% and an average concentration equal to 0.0042 µmol/L, 0.0061 µmol/L, 0.0072 µmol/L and 0.0080 µmol/L respectively for participants from Akouédo Attié, Lauriers 9, Akouédo village and Génie 2000. Mean concentrations among participants living along the Akouédo landfill are reduced compared to those living in M'Batto-Bouaké. In the unexposed population (M'Batto-Bouaké), vitamin A deficiency was observed in 100% of cases. Generally, the reduction in serum vitamin A can be explained by either insufficient intake of vitamin-rich foods [28], poor absorption [29], increasing its use or inability to build up reserves due to liver disease, loss urinary of vitamin A during infection [30] and a defect in the transport of this vitamin in plasma by Retinol Binding Protein (RBP) [31]. All volunteers in this study are in good physical health. This observation therefore excludes the hypothesis of inability to build up reserves and loss urinary of vitamin A among the volunteers. In addition, According to our investigations, the participants in this study all live in the south of Côte d'Ivoire and have the same eating habits. The hypothesis of a decrease in dietary vitamin A intake is excluded. Indeed, dishes from southern Côte d'Ivoire are generally served with sauces made with vegetables. Fruits and vegetables are the main sources of β-carotene, also called provitamin A, which, after hepatic hydrolysis, gives rise to two molecules of retinol (vitamin A). Vitamin A is an antioxidant necessary for the good functioning of the immune system [32]. For health workers and the general public, the terms "free radicals, oxidative stress, activated oxygen species, antioxidants" are increasingly being used. Oxidative stress would be defined as "the incapacity of the body to defend itself against the aggression of reactive oxygen species, due to the existence of an imbalance between the production of these substances and the ability to defend antioxidants" [33]. In recent decades, several scientific publications have revealed that an increase in oxidative stress can lead to the appearance of various diseases such as diabetes, obesity, high blood pressure, etc.[34, 35] To protect against these diseases, it is important to have adequate antioxidant defences because the lower an individual's antioxidant status, the higher the risk of developing these diseases. As a result, vitamin A deficiency in landfill residents makes them more vulnerable to disease as retinol increases disease resistance [36]. Air pollution being one of the causes of oxidative stress, the body will gather all its anti-free radical agents to neutralize both electronically and chemically active species. This leads to an increase in the use of vitamin A by the body, which leads to a deficiency. Vitamin A deficiency, in turn, further weakens the immune system by leaving people even more susceptible to opportunistic diseases. Absorbed $PM_{2.5}$ can have harmful effects on the body by causing oxidative stress [37]. The study of vitamin A levels as a function of $PM_{2.5}$ concentration showed a negative correlation ($r = 0.27$; $p = 0.005$).

Table III: Comparison of levels of vitamin A between the populations exposed and a population unexposed.

(N = 150)	Akouédo Attié (%)	Akouédo Village (%)	Génie 2000 (%)	Lauriers 9 (%)	M'Batto-Bouaké (%)	Reference	P
Male (M) (n = 78)	40	63,3	46,7	53,3	56,7		
Female (F) (n = 72)	60	36,7	53,3	46,7	43,3		
Sexe ratio (M/F)	0,67	1,72	0,88	1,14	1,31		
Mean vitamin A (µmol/L)	0,0042 ± 0,0034	0,0072 ± 0,0057	0,0080 ± 0,0064	0,0061 ± 0,0062	0,0094 ± 0,0059	0,35 - 1,75	< 0,05
Reduction (%)	55.3	23.4	14.9	35.1	0		

n = 30 in each district and village.

Conclusion

Our study revealed that, with the exception of the village of M'Batto-Bouaké, all average daily pollutant concentrations recorded at all the different stations are above WHO standards. Also, among the districts and villages neighbouring the Akouédo landfill, Akouédo Attié is the village most affected by air pollution. Then follows Génie 2000, Lauriers 9 and Akouédo village. The neighbourhoods with the highest $PM_{2.5}$ concentrations are in the wind direction of the landfill. In addition, there is a link between $PM_{2.5}$ concentrations and vitamin A levels. The results showed a significant deficiency of vitamin A in populations living near the Akouédo landfill compared to populations far from the landfill. Corrective measures must be taken with the resident populations in the proximity of the landfill. Indeed, it is imperative for these populations to plant trees around the landfill and around their homes and to provide their bodies with vitamin supplements. These measures can help them improve immune system functions, disease tolerance and life expectancy.

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