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Exposure to indoor and outdoor air pollution among children under five years old in urban area

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ABSTRACT

Indoor air pollution associated with cooking and heating biomass fuel burning is estimated to be responsible for 7 million deaths in 2016 and most of these deaths occur in low and middle income countries. In Côte d'Ivoire, 73% of the population is reported using biomass (charcoal or wood) for cooking. The active device 3M EVM-7 was used to measure $PM_{2.5}$ daily average concentrations inside and outside households in areas close (Andokoi) and far (Lubafrique) to an industrial zone in two popular neighborhoods of Yopougon, the largest and most populated municipality of the city of Abidjan (Côte d'Ivoire). $PM_{2.5}$ daily average concentrations indoors and outdoors are respectively 121±12 µg/m^3 and 117±8 µg/m^3 in Andokoi and 32±3 µg/m^3 and 41±4 µg/m^3 in Lubafrique well above the World Health Organization guideline value (25 µg/m^3) for air quality. Using multivariable models, the results were the number of windows in bedrooms and kitchens located outdoor were negatively correlated with the concentration of indoor $PM_{2.5}$. The outdoor concentrations of $PM_{2.5}$, were higher according to the cooking fuel type.

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INTRODUCTION

Exposure to indoor air pollutants from biomass fuels combustion has become a public health concern in low-middle incomes countries (LMICs). Many women and children are exposed every day to toxic gases and particles emissions while using wood and charcoal for cooking purpose in inadequately ventilated traditional stoves. In sub-Saharan Africa, 700 million of people depend on biomass for cooking (Lambe *et al.,* 2015). For example, in Ghana, between 46 % and 71 % of households use wood and charcoal (Dionisio *et al.*, 2010). Thereby, the exposure levels of pollutants are important in sub-Saharan Africa where biofuels remain the main source of energy for cooking. Biomass combustion is well known to emit pollutants including fine particles ($PM_{2.5}$), which can penetrate deeply into the lung and have health adverse effects

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(Kim *et al.,* 2011). Children under 5 years are more sensitive to air pollution than adults, hence present a greater risk for respiratory infections since children respiratory systems are not fully developed on one hand (Porebski *et al*., 2018; WHO, 2018) and they spend more time in the indoor environment on the other hand (Devakumar *et al*., 2014). Air pollution resulting from biomass combustion, increase the risk of acute respiratory infections (Gurley *et al*., 2014; Nandasena *et al*., 2013) such as chronic respiratory diseases, including acute lower respiratory tract infections (ARIs) in children and chronic obstructive pulmonary disease in adults (Ni *et al*., 2015). There is growing evidence that air pollution is associated with asthma exacerbation and its prevalence in Africa was estimated at 13.9 % among children under 15 years in 2010 (Adeloye *et al.,* 2013). Besides particulate matter (PM), many other harmful gases such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NOx), benzene (C_6H_6), formaldehyde (CH_2O), black carbon (C), ozone (O_3) and other carcinogens can threaten both children's health and the climate (Kumar *et al*., 2015). According to WHO, (2018), 100 % of children under five in Africa are exposed to high level of fine particulate matter ($PM_{2.5}$) in outdoor air pollution (higher than the WHO air quality guideline levels). Exposure to outdoor air pollution increased the number of deaths each year which range from 4.2 million deaths in 2015 (Cohen *et al*., 2017) to 7 million in 2016 (WHO, 2018). In high-income countries, while the development of policies contribute in reducing air pollution health effects, in middle-income and low-income countries, outdoor and indoor air pollution from burning solids fuels still increase the numbers of deaths and disability-adjusted life-years (DALYs) (Cohen *et al*., 2017). Moreover, exposure to outdoor and indoor air pollution has become one of the cause of children's death in the world with a risen mortality and disease rate among children under five years old. For example, between 2015 and 2016, the number of total deaths among children under five in the World increased from 237 000 to 543 000 due to outdoor air pollution with highest deaths in Africa (127900) and Asia (106800) (Lelieveld *et al*., 2018). Up to now only few studies investigated pollution and health in Africa particularly West Africa. The Dynamic Aerosol–Cloud–Chemistry Interaction in West Africa (DACCIWA) was one of the first research program which characterized air pollution and assess it induced health impact on population in Abidjan (Cote d'Ivoire) and Cotonou (Benin). Their results revealed high concentrations of $PM_{2.5}$ at various sources such as road traffic (32 µg/m^3 for both traffic sites in Benin and Côte d'Ivoire), waste burning (28 µg/m^3 Abidjan), domestic fires (145 µg/m^3 Abidjan) (Djossou *et al*., 2018). The further study will do to confirm this finding. These high $PM_{2.5}$ concentrations may contribute to increase poor air quality in surrounding households and therefore increase population especially children risk of exposure to the air the air pollution. Côte d'Ivoire located in sub-Saharan Africa is also a LMICs where the population is young with a growth rate of 16 % and life expectancy is 58.7 years (Institute National de la Statistique and IFC, 2012). The demand of cooking fuel has been increasing with population growth. Charcoal production has been increasing in the last ten years from 400850 tons in 2003 to 488128 tons in 2012 (UNDP, 2016). Wood as cooking fuel has also been increasing over the last ten years from 8699979 m^3 to 9,034,617 m^3 although the government subsidies the butane gas (UNDP, 2016). National statistical Institute in Côte d'Ivoire estimated that 8864490 inhabitants in 2015 rely to biomass (charcoal and wood) for cooking (INS, 2015). This survey aims to evaluate the exposure of children from 0 – 5 years old to fine particles ($PM_{2.5}$) in indoor air in neighborhoods of Yopougon. A cross-sectional survey was conducted to quantify indoor and outdoor air pollution in households using butane gas and biomass fuel and identify factors contributing to the high air pollution levels both indoor and outdoor in Yopougon municipality (Abidjan, Cote d'Ivoire). This study was carried out in Yopougon Municipality, Abidjan, Cote d'Ivoire in 2016 to 2017.

MATERIALS AND METHODS

This study was about an assessment of children under 5 years old exposure to indoor and outdoor $PM_{2.5}$ in Yopougon Municipality (Abidjan, Côte d'Ivoire). The choice of this type of populations was motivated on one hand by children vulnerability to air pollution and other hand the country has young population (44 % of total population under 15 years and only 6 % are 60 years of age or older) combined to the life expectation of 58.7 years. The Methodology is based on field survey (socioeconomic questionnaire, Time-Activity Diary) and $PM_{2.5}$ daily measurements in each housing.

The study area

Two sites have been chosen in Yopougon (Abidjan, Cote d'Ivoire), considered as a city within a wide town (Doumbia *et al.,* 2018), focused on domestic fires. Nonetheless, each site has the specifics sources which are the traffic a crossroads at site L and industry area at site A (Fig. 1). Municipality of Yopougon has a population of over 1071543 inhabitants or 219 651 households (INS, 2015) that live in 15300 hectares (8984 inhabitants/km^2). Almost 10.3 % subjects live in low income housing and the rest in middle income housing (Table 1). The transportation system in Yopougon is dominated by personal cars, local public taxis, inter-communal taxis and small buses on 1501 roads segments classified in highways, boulevards, main roads, secondary roads and backstreets (Doumbia *et al.*, 2018). The work was conducted in two neighborhoods of Yopougon, Andokoi and Niangon (Nord Lubafrique). The first neighborhood Yopougon Andokoi called site A, is a popular area close to an industrial zone (central thermal power plant, cement plant, chemical industry, food industries, etc.) and a highway. With 35852 inhabitants including 6432 children under 5 years living over 1.85 km^2 (19379.5 inhabitants/km^2), site A has an average of 10 inhabitants per household, with in general men working in the nearby industrial zone and women small traders in the surrounding areas (INS, 2015). The site is also one of the former village in Abidjan city, and housing quality is characterized by low housing quality with traditional sanitation system. The traffic flow on the highway is estimated at 78,360 vehicles/day (Doumbia *et al.*, 2018) and the traffic flow of local public taxis, inter-communal taxis inside the neighborhood on the degraded roads is less important. The site Lubafrique (site L) is one of residential areas of Yopougon, and characterized by middle income housing. The site L has 39831 inhabitants including 5894 children living in 2.58 km^2 (15438.4 inhabitants/km^2), with an average of 7 inhabitants per household, with generally men and women mainly employed in public or private (INS, 2015). The traffic flow of local public taxis, inter-communal taxis inside the neighborhood on the main road is estimated to 91,329 vehicles/day

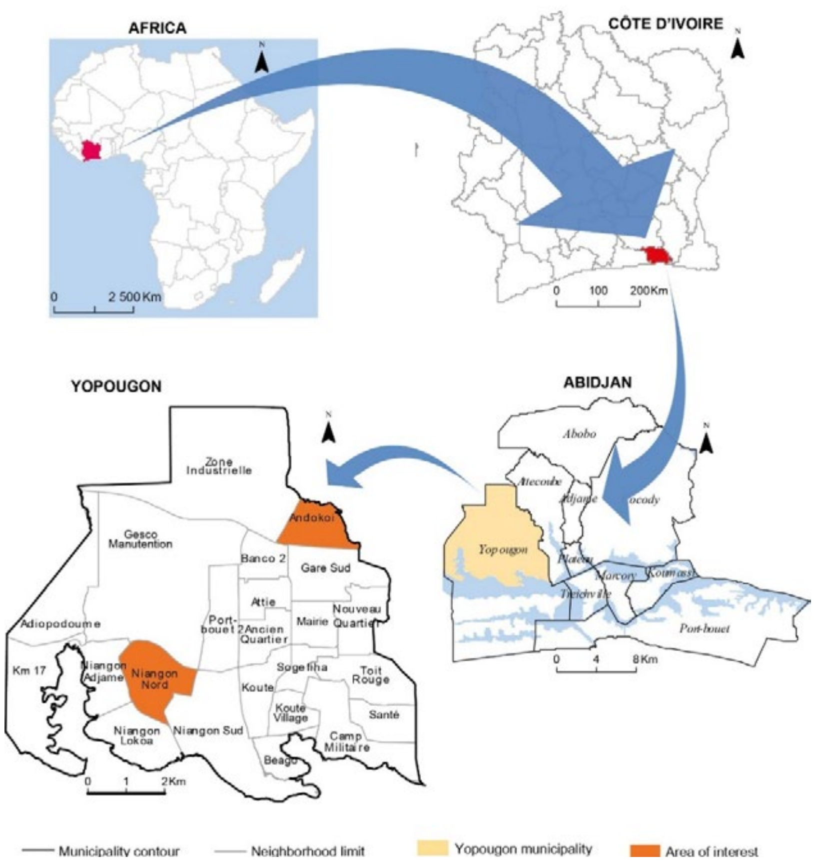

Fig. 1. Geographic location of the study area in Yopougon Municipality at the north-west of the city of Abidjan in Cote d'Ivoire (West Africa)

Table 1. Housing types and characteristics depend on the criteria of quality

Housing type	Primary building material	Private open space	Toilet facilities
Middle income housing (Medium quality)	Brick or cement	Private Yard	Individual household toilet
Low quality housing (Low income)	Brick or cement	Shared Common Area	Public toilet
Very low quality housing (Slum)	Wood or sheet metal	Shared Common Area	Public toilet or none

on the secondary road and 700 vehicles/day on the backstreet (Doumbia *et al.*, 2018).

Surveyed population

The survey underlying target population was children under 5 years old living at Site A and Site L, sub-districts of Yopougon municipality, Abidjan, Cote d'Ivoire. This survey was conducted as the part of the Eco-Health Chair "Urban Air Pollution and Non-Communicable Diseases (ChairePol)", which is the regional initiative in West Africa for education, research and the application of knowledge in environmental health. Project's team has conducted knowledge, attitudes, and practices survey on the relationship between air pollution and non-communicable diseases in Yopougon on March 4 – 9, 2016. For the ChairPol study, 220 randomly selected households (110 households in each community) were surveyed. For sampling method, the investigators went to the center of the selected neighborhood to randomly select a direction by spinning a pen on the ground. The choice of households and women surveyed was arbitrary. From January 1st to December 31th in 1551761 patients visited Yopougon health care aged to 15 years old. the number of total respiratory infections was 4150 patients including 380 children with asthma (9.15 %) (Gnaze *et al*., 2017). This cross sectional study was done to estimate in one hand the indoor and outdoor air pollution in households and other hand the prevalence of asthma symptoms among children under five in two neighborhoods in Yopougon. Sample size formula was calculated with fisher's formula sample size determination as Eq. 1.

$$\frac{Z^2 * p(1-p)}{d^2} \quad (1)$$

Z= Is standard normal variate (at 5% Type I error)
P=Expected proportion in population based on previous studies (10 %)
d= Absolute error (0.06).

The sample size calculated was 96 households with a standard error of 10%. For this survey, households in which, children under 5 years old were living were selected. After the screening, 60 households in Andokoi (Site A) and 44 households in Lubafrique (Site L) were selected. Finally, the children's mothers (or other primary caregivers) were interviewed with an updated version of the ChairPol questionnaire to fit the purpose of the present survey.

Data collection

This study included 104 households participating in field survey at the main location of children in housing during 24 hours (Time-Activity Diary), had daily concentration level of $PM_{2.5}$ in main location over 48 hours (h). The study focus essentially on particulate pollution, however some ongoing studies especially in the "PASMU" project include both particles and gas.

Time-activity diary (TAD) of children under 5 years

The children's mothers were interviewed with a modified version of the survey used in the Matz *et al.* (2015) survey to collect households data about daily time-activity diary of all children under five in each house. In this survey the memory bias during the questionnaire administration (space-time budget) was observed but the high rate of illiterate people limits to use other accurate methods (self-report) to minimize the memory bias. The children spend their time during the day, inside and outside the dwelling and at different places. The survey results indicated that most of them in the two areas (Andokoi and Lubafrique) spend more time in the bedroom (44 % of the days' time) followed by the living room (26%), yard (18 %), outside housing (11 %) and the kitchen (1%). The children between 0 and 5 years old in the survey spend about 71% of their daily time in the indoor environments of the house. Thereby, the result helped to find the best locations for two devices that monitored indoor and outdoor air pollutants in the survey.

Socio-demographic information and $PM_{2.5}$ measurement

The second survey was used to collect socio-demographic information (type of housing, location of kitchen, cooking fuels, number of windows in bedroom, etc.). This survey was used in indoor and outdoor $PM_{2.5}$ concentration measurements to better understand and interpret $PM_{2.5}$ concentration levels and their variation from house to house. The factors such as combustion of biomass fuel for cooking, non-separate kitchen room in house, absence of windows, low quality building materials have contributed to higher exposure level to indoor pollutants (Sharma and Jain, 2019; Balakrishnan *et al.*, 2015). Slum was not considered in this survey in order to prevent equipment damages or prevent theft. Fine particulate matter ($PM_{2.5}$), temperature and humidity were measured with a laser photometer 3M EVM-7, simultaneously in indoor and outdoor of the housing over 48 hours in each dwelling, based on number of equipment available and size of surveyed population. The 3M EVM-7 instruments are referenced in previous air monitoring surveys (Al-Dabbous *et al.*, 2018; Kolluru *et al.*, 2018; Ekren *et al.*, 2017). In this survey, the device located in children's bedroom and convenient protected outside location (balcony, courtyard, etc.) of the housing was assumed to measure indoor and outdoor air quality respectively.

Statistical analyses

Statistical analysis was performed with STATA software version 15.0. Descriptive statistics was performed with household variables and measures of concentrations of indoor and outdoor $PM_{2.5}$ and meteorological parameters (temperature and humidity). Six categories were created for housings characteristics: 1) housing type (middle, low and very low quality housing), 2) number of windows in bedroom, 3) kitchen location (indoor vs outdoor), 4) kitchen type (closed with window, closed without window, open-air kitchen), 5) chamber volume (m^3), and 6) fuel type. Open-air kitchen is type of kitchen with less than four walls. Indoor and outdoor concentration of $PM_{2.5}$ follow normal distribution. Differences observed between the types of fuel used, the characteristics of housing and the location of the site were surveyed using Pearson Chi-squared test. The linear regression models were used to predict the variation of $PM_{2.5}$ (continuous variable), based to literature review, significance correlation between variables as Eq. 2 (Balakrishnan *et al.*, 2015; Jafta *et al.*, 2017; Vanker *et al.*, 2015).

$$\begin{aligned} &Indoor\ PM\ 2.5 = \beta 0 + \beta 1(fuel\_type)\sim + \beta 2(outdoor\_PM\ 2.5) \\ &+ \beta 3(\#window\_bedroom)\sim\sim + \beta 4(housing\_type)\sim\sim\sim \\ &+ \beta 5(kitchen\_location) + \beta 6(Temperature\_indoor) + \beta \end{aligned} \quad (2)$$

~= Wood, charcoal, butane gas

~~= number of windows in bedroom

~~~=1= medium quality, 2= low quality

The point estimate was noted to be the most likely value, based on the observed data, and the 95% confidence interval quantifies the random error associated with the estimate.

RESULTS AND DISCUSSIONS

Characteristics and household practices of the two sites

Most of the characteristics of housings and practices at Site A and Site L are similar in urban areas in LMICs. Different characteristics of housing are identifying in each area and summarized in Table 2. The survey shows that 80% of the housings of site A are low-income housing whereas those of site L are 100% of middle income housing. More than 50% of housings in site A have no ceiling and proportion of kitchen outside are 77% and 59% respectively in site A and site L. In addition, many kitchens outside the housing (40 %) are open-air kitchen at Site A. Finally, zero window in 14% of the households on site A and 4% on site L was noted. The characteristics differ from one site to another and suggest that site A has lower socio-economic position than site L. In LMICs, even in cities, a substantial fraction of the population may live in informal or poor house. Highly variable are used to characterize housing types and relationship with exposure to pollutants in LMICs. Primary building material, water supply, toilet facilities, kitchen type, ventilation in the kitchen area to characterize housing type and exposure sources and risks, found that 77.6 % of homes have poor structure (Vanker *et al.*, 2015). The presence and size of windows is also used as criteria to characterize LMIC homes. The survey in Durban, South Africa, used the absence of windows (independent of indoor air pollution sources) to found the concentration of pollutants, PM_{10} (92.27 µg/m^3), NO_2 (21.43 µg/m^3) and SO_2 (0.95 µg/m^3) in living rooms without windows higher than living rooms with window and the difference was statistically significant ($p < 0.001$) (Jafta *et al.*, 2017). The general
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Table 2. Descriptive statistics of participating (n=104) housing characteristics where sampling was performed for indoor and outdoor air pollutants

	Site A (%)	Site L (%)
Housing type		
Medium quality	20	100
Low quality	80	0
Type of kitchen		
Indoor		
Closed with window	20	41
Closed without window	3	0
Outdoor		
Closed with window	12	36
Closed without window	25	2
Open-air kitchen	40	21
Number of windows in the bedroom		
0	14	4
1 and more	86	96
Bedroom with ceiling		
Yes	42	100
No	58	0
Non-intentional emissions (aerosol spread, burning incense)		
Yes	85	75
No	15	25

characteristics of houses are already used to find associations with indoor air pollutants. The factors such as burning of biomass fuel for cooking, non-separate kitchen room in house, absence of windows, low quality building materials have contributed to higher exposure level to indoor pollutants (Apte and Salvi, 2016; Balakrishnan *et al*., 2015; Jafta *et al.*, 2017; Noubiap *at al.*, 2015).

Table 3. Type of cooking energy used at the two surveys sites

Fuel type	Site A (%)	Site L (%)
Butane gas	23.3	79.6
Wood	3.3	0
Charcoal	11.7	0
Gas/ charcoal	50	20.4
Gas/ wood	11.7	-

Energy sources

The main fuel used for the cooking on site L is gas (79.6 %), compared to 23.3 % on site A where the biomass fuel (charcoal and wood) remains the most important (Table 3). The combination of gas and charcoal for domestic energy represents 50 % of the households on site A. It is worth remembering that wood and charcoal are mainly used in low-income neighborhoods. National statistical Institute in Côte d'Ivoire estimated that 85 % of poor population (Household which consumption per person was under 410.18 Euro/year) rely to biomass for cooking (INS, 2015). And three low socio-economic areas located at Yopougon municipality (Kramakoupe, Yaossei and Mossikro), energy consumption were wood fuel (33 %), charcoal and wood fuel (31 %), charcoal (22 %), and 14 % gas (Zidago and Wang, 2016). In this survey, biomass fuels (charcoal and wood) remain an important source of cooking energy and it's sometimes associated with butane gas in more than 76 % of households surveyed in poverty households on Site A. Butane gas and biomass using at the same time could be explained by socio-economic position and local behaviors. People used wood or charcoal instead of butane gas subsidy by the government for making traditional dishes (palm seed sauce, Attiéké, etc.), smoke fish and/or meat and boil water which highly consumed energy. Thereby, socio-economic position causes to rely on biomass sources for their basic needs and exposes children to air pollution (WHO, 2018). The result is consistent with the proportion of biomass using in sub-Saharan Africa, where biomass fuels remain the main energy source for 60 % of urban population in LMICs (IEA, 2010). Socio-economic status for households influence the choice of fuel for cooking, as biomass fuels (charcoal, wood, dung and crop residues), tend to be easily accessible, affordable for poor population (Shen, 2015). In most culture, women have responsibility for cooking activities at home and could be exposed to high level of pollutant during daily cooking (Du *et al.,* 2018). Also, children were exposed to high level of pollutant while they are carried on the back or placed close to their mother during the cooking period (Gordon *etal.*, 2014).

Indoor and outdoor concentrations of $PM_{2.5}$

Daily average concentrations of $PM_{2.5}$ measured indoor and outdoor the housings on the two sites of the survey and the meteorological parameters (temperature, humidity) are summarized in the Table 4. The daily average concentration of $PM_{2.5}$ in indoors and outdoors are well above World Health Organization (WHO) recommended value (25 µg/m^3) for air quality. Average concentration of indoor (73 ± 9 µg/m^3) and outdoor $PM_{2,5}$ (85 ± 8 µg/m^3) for butane gas energy are 3 times higher than WHO guideline value at Site A. $PM_{2.5}$ concentrations measured in and out of households using gas as fuel showed lower levels than those using wood or charcoal at both sites with concentrations much lower on the site L (30 ± 5 µg/m^3 indoor and 35 ± 3 µg/m^3 outdoor). Researchers identified liquid petroleum gas (LPG) or electricity as clean stove which are least polluting form of domestic energy (Gordon *et al.*, 2014). Average outdoor $PM_{2.5}$ concentrations for butane gas energy at sit A and L are 85 ± 8 µg/m^3 and 35 ± 8 µg/m^3 respectively. The results are higher by a factor of 2–3 than the WHO guidelines. Researchers identified liquid petroleum gas (LPG) or electricity as clean stove which are least polluting form of domestic energy (Gordon *et al.,* 2014). In addition, outdoor $PM_{2.5}$ concentrations in Abidjan was estimated at 32 µg/m3 (Djossou *et al.*, 2018) at the traffic site having very similar characteristics to site L of this study, suggesting that site L is more influenced by outdoor activities such as traffic than domestic fires. Therefore, site L indoor pollution may be characteristic pollution of residential areas, using clean energy source such as gas and greatly influenced by traffic. At the site A, though industrial air pollution was not directly measured, a comparative study between household using clean energy located in sites A and L allow deducting the potential influence of the industrial pollution. Knowing that both site A and L are influenced by traffic, the $PM_{2.5}$ concentration difference of 50 µg/m^3 between gas household located in each site may be attributed to industrial air pollution. The result agree with the finding of air monitoring in the communities living close to industrial areas which highlighted the problem of environmental pollution caused by industries (Oyinloye, 2015). According to Junaid *et al*.,(2018), the outdoor emission from industrial sources increased the significantly indoor air quality. The closer location of the households to industrial area increased outdoor concentrations beyond WHO guideline compared to residential Site L. In the purpose of assessing the impact of domestic fires (charcoal and wood) on indoor and outdoor pollutions, comparisons were done on site A, household only clean energy (gas) to those using both gas and charcoal. Result revealed that average $PM_{2.5}$ concentrations 73 ± 9 µg/m^3 and 85 ± 8 µg/m^3 for indoor and outdoor at gas using households and 160 ± 8 µg/m^3 and 127 ± 21 µg/m^3 for indoor and outdoor at charcoal using households (Table 4). Also, average $PM_{2.5}$ concentrations 136 ± 41 µg/m^3 and 144 ± 52 µg/

Table 4. Daily average concentrations of $PM_{2.5}$ (µg/m^3), temperature (T, °C) and relative humidity (RH, %) in indoor and outdoor air for hundred and four housing

Fuel	Site	$PM_{2,5\,I}$ (mean, SD)	$PM_{2,5O}$ (mean, SD)	T_I (mean, SD)	T_O (mean, SD)	RH_I (mean, SD)	RH_O (mean, SD)
Butane Gas	Site A	73 ± 9	85 ± 8	30.8 ± 0.3	30.3 ± 0.4	72.4 ± 1.0	73.7 ± 1.0
	Site L	30 ± 5	35 ± 3	30.4 ± 0.3	28.8 ± 1.9	72.1 ± 0.7	76.3 ± 1.5
Butane Gas + charcoal	Site A	122 ± 14	112 ± 12	31.9 ± 0.3	30.5 ± 0.2	70.7 ± 0.7	73.5 ± 0.6
	Site L	41 ± 7	68 ± 10	30.5 ± 0.6	29.3 ± 2.1	74.2 ± 1.7	78.5 ± 1.7
Butane Gas + wood	Site A	174 ± 38	187 ± 22	31.4 ± 0.3	30.7 ± 0.4	70.2 ± 1.2	72.5 ± 1.2
	Site L	-	-	-	-	-	-
Charcoal	Site A	160 ± 68	127 ± 21	31.8 ± 0.7	31.3 ± 0.6	69.2 ± 1.8	70.8 ± 1.5
	Site L	-	-	-	-	-	-
Wood	Site A	136 ± 41	144 ± 52	31.3 ± 0.2	31 ± 0	71.7 ± 0.1	72.7 ± 0.3
	Site L	-	-	-	-	-	-

I: Indoor, O: Outdoor, SD: Standard deviation m^3 for indoor and outdoor at gas using households. Therefore, on the site A, charcoal or wood burning increased indoor $PM_{2.5}$ concentrations (range of 63 µg/m^3 to 87 µg/m^3) and outdoor $PM_{2.5}$ concentrations (range of 42 µg/m^3 to 59 µg/m^3). The same observation was done with gas/charcoal burning at site L. Average $PM_{2.5}$ concentrations 30±5 µg/m^3 and 35 ± 3 µg/m^3 for indoor and outdoor at gas using households and 41 ± 7 µg/m^3 and 68±10 µg/m^3 for indoor and outdoor at charcoal using households. At site L, gas/charcoal burning increased indoor $PM_{2.5}$ concentrations to 11 µg/m^3 and outdoor $PM_{2.5}$ concentrations to 33 µg/m^3 at site L. The daily average concentration of $PM_{2.5}$ in households using wood (144 ± 52 µg/m^3) was six times higher than WHO guideline and similar to the result (145 µg/m^3) at the urban domestic fires site in Abidjan (Djossou *et al.*, 2018). Previous surveys suggested that cooking, heating, lighting with solids fuels were the major source of indoor air pollution in the world (Du *et al.*, 2018; Li *et al.*, 2017; Rokoff *et al.*, 2017; Shen, 2015). Biomass fuel combustion is well known to produce chemicals compounds including carbon monoxide (CO), sulfur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM), black carbon (BC), polycyclic aromatic hydrocarbons (PAH) and at high temperature nitrogen oxides (NOx) (Li *et al.*, 2017; Shen, 2015). The high level of exposure to pollutants resulted by biomass combustion could induce local inflammation into lung tissue, conduct a lot respiratory disorders including chronic obstructive pulmonary disease (COPD), asthma, bronchitis, and cardiovascular disease (Wu *et al*., 2018). Domestic fires (charcoal and wood) and background pollution in each area could explain the level of indoor and outdoor air pollution in two areas which were above the WHO guideline value (25 µg/m^3) for air quality.

Since most of indoor and outdoor pollution measurement in several places were done over 24h (Kim *et al.,* 2011; Gurley *et al.,* 2014; Oliveira *et al,* 2018), the 48 h measurements made here, present the advantage of better characterization of the studied households. For example, the 48 h measurement allows eliminating “extra-event” as parties that may imply extra cooking hours in a particular household, thus directly impact the indoor and outdoor air pollution. Also, these 48 h measurement combined with characteristics of dwellings were used to find the predictors of $PM_{2.5}$ in home settings. Between 20 to 71 % of population in Yopougon municipality use mix cooking fuel including biomass in order to cook traditional dishes. This practice is common in the low and middle income population and may contributed to increased average indoor pollutants increment compare to clean fuel (gas). Using PM_{10} concentrations over Durban (South Africa), Jafta *et al*., (2017) found that mixing cooking fuel (electricity and biomass) households were more polluted than clean fuel (electricity or gas) households. Also, the mix cooking fuel was promoted by Zidago and Wang, (2016) for indoor and outdoor pollution reduction in households using exclusively wood/charcoal fuel in Cote d’Ivoire. Although their recommendation allows tackling the indoor and outdoor air pollution, our study revealed that the good environment for children under 5 remain the clean energy used. Therefore, governments, decision-makers and/or NGOs in the LMICs should continue encouraging the use of clean energy in household.

In this study, the environmental factors were also identified, which may influence level of indoor and outdoor concentrations of $PM_{2.5}$ in the housings and is becoming the risk factors of children’s health. Association was found between continuous variable (Indoor $PM_{2.5}$, Outdoor $PM_{2.5}$) and household variables through Pearson correlation. On the Site A, there is a relationship between Indoor $PM_{2.5}$ and respectively Outdoor $PM_{2.5}$ ($r=0.74$, $p <0.001$) and Fuel ($r=0.29$, $p = 0.020$). Also, correlation existed between Outdoor $PM_{2.5}$ and Fuel ($r=0.32$, $p = 0.024$). The second statistical analysis (linear regression models) performed with the data of $PM_{2.5}$ (Indoor or Outdoor) are given the following findings (Fig. 1). Adjusted with the co-variables, the number of windows in bedroom decreasing concentration to 61.48 µg/m^3 [95% IC (-114.99 – -7.96)] indoor concentration of $PM_{2.5}$. The same analysis was done with concentration of outdoor $PM_{2.5}$ adjusted with the co-variables on the Site A. The predictor of concentrations of outdoor $PM_{2.5}$ on the Site A is fuel type for cooking (biomass) which predicted increasing concentration to 93.99 µg/m^3 [95% IC (41.39 – 146.58)] of outdoor $PM_{2.5}$. On the Site L, there is a relationship between Indoor $PM_{2.5}$ and Outdoor $PM_{2.5}$ ($r=0.53$, $p =0.005$), between Indoor $PM_{2.5}$ and Kitchen type ($r=-0.45$, $p <0.001$), between Indoor $PM_{2.5}$ and Humidity in chamber ($r=0.39$, $p =0.009$). Also, a relationship was observed between Outdoor $PM_{2.5}$ and Fuel type ($r=0.45$, $p <0.001$). Adjusted with the co-variables on the Site L, concentrations of outdoor $PM_{2.5}$ increasing

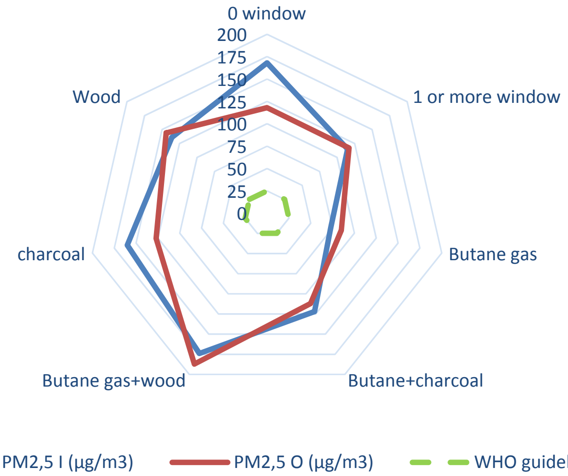

Fig. 2. Average concentration of indoor $PM_{2.5}$ and outdoor $PM_{2.5}$ are ranked on each of the 6 parameters and the line helps to visually influence of each aspect over $PM_{2.5}$ concentrations in site A compare to WHO guideline value (25 µg/m³)

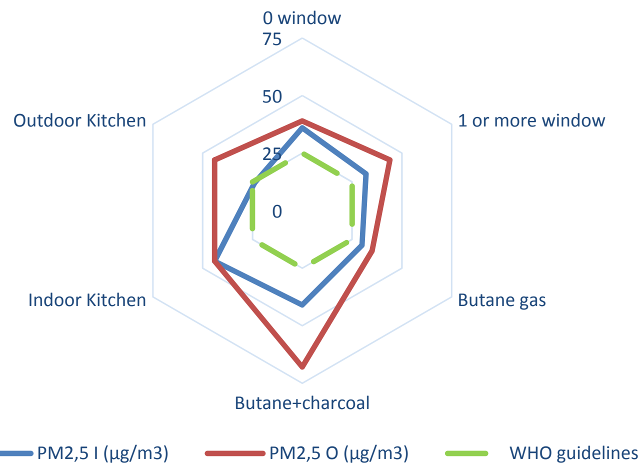

Fig. 3. Average concentration of indoor $PM_{2.5}$ and outdoor $PM_{2.5}$ are ranked on each of the 6 parameters and the line helps to visually influence of each aspect over $PM_{2.5}$ concentrations in site L compare to WHO guideline value (25 µg/m³)

concentrations of indoor $PM_{2.5}$ to 0.37 µg/m³ [95% IC (0.15 - 0.58)] and Kitchen type (outdoor) decreasing to 16.38 µg/m³ [95% IC (-27.6 – -5.10)] concentration of indoor $PM_{2.5}$ (Fig. 2). Concerning Outdoor $PM_{2.5}$ on the Site L, adjusted with the co-variables, biomass fuel increasing concentrations of indoor $PM_{2.5}$ to 37.30 µg/m³ [95% IC (17.52 – 57.08)]. This survey is consistent with surveys in LMICs, where the factors such as a non-separate kitchen, poor ventilation (indoor outdoor air exchange), low quality building materials contributed to raise the level of indoor air pollutants (Apte and Salvi, 2016; Noubiap *et al.,*2015).

CONCLUSION

The present study performed the measurement of indoor and outdoor concentration of $PM_{2.5}$ samplings continuously over 48 hours on two different sites. One is a residential area far from industries and middle income housings and the other one is a popular area dominated by low income housings both located in Yopougon municipality. The questionnaires and measurement data used to evaluate risk of exposure of children under 5 in each housing. In the survey, children under 5 years spend about 71% of the day in indoor environments such as the bedroom and living room. In addition, most of children live in dirty environment characterized by $PM_{2.5}$ background level higher than 25 µg/m^3, biomass burning and poor ventilation in bedroom and kitchen. The average concentrations of $PM_{2.5}$ recorded in indoors and outdoors were above the WHO guideline value (25 µg/m^3) for air quality especially on the popular sites where $PM_{2.5}$ were 4 or 5 times higher. The main source of household pollution is a local practice of biomass burning for cooking in more than 76 % of households which increased indoors and outdoors $PM_{2.5}$ background level and exposed children to air pollution. However, better ventilation in bedroom and kitchen location to outdoor contribute to decreased indoor concentration of $PM_{2.5}$. From this study, it can be suggested that cleaning cooking energy remains the idealized conditions for reducing indoor and outdoor air pollution. However, the mix-cooking fuel may be a transition solution under the condition of well-ventilated households. Also, the important difference of 50 µg/m^3, between households using gas in industrial and residential areas, it is recommended LMICs of making effort of the implementation of industrial zone outside residential areas. Regarding asthma, there is growing evidence that air pollution is associated with its exacerbation or increased prevalence, therefore future work will investigate the relationship between exposure to source of household air pollution and asthma in children population in Cote d'Ivoire.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

β	Beta
ε	Epsilon
3M EVM 7	Environnemental monitor equipment
BC	Black carbon
C_6H_6	Benzene
CH_2O	Formaldehyde
ChairPol	Eco-Health Chair "Urban Air Pollution and Non-Communicable Diseases"
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
Euro/year	Euro per year
Eq.	Equation
h	Hour
I	Indoor
IC	Confidence interval
IEA	International Energy Agency
inhabitant/km^2	Inhabitant per square kilometer
INS	Institut national de la statistique (Cote d'Ivoire)
LMICs	Low-middle incomes countries
LPG	Liquid petroleum gas
O	Outdoor
O_3	Ozone
NGOs	Non-governmental organizations
NOx	Nitrogen oxides
p	p-value
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a size less than 2.5 micrometers (µm)
PM_{10}	Particulate matter with a size less than 10 micrometers (µm)
SO_2	Sulfur dioxide
T	Temperature
TAD	Time-activity diary
Vehicles/day	Vehicle per day
VOCs	Volatile organic compound
WHO	World Health Organization
PAH	Polycyclic aromatic hydrocarbons
PASMU	Pollution de l'air et santé dans les milieux urbains de Côte d'Ivoire

r	Correlation coefficient
RH	Relative humidity
SD	Standard deviation
Site A	Yopougon Andokoi
Site L	Yopougon Niangon
%	Percentage
°C	Degree centigrade
μg/m³	micrograms per cubic meter

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