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DACCIWA

"Dynamics-aerosol-chemistry-cloud interactions in West Africa"

Deliverable

D2.3 Epidemiological Effects of Air Pollution

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1 Introduction and objectives

Rapid urban expansion has severely increased ambient levels of air pollution, including both particulate matter consisting of a diverse set of suspended solid and liquid particles of varying size and chemical composition, as well as gases, including nitrogen oxides (NO_X) and sulphur dioxide (SO_2) (Liousse et al., 2014; Newell et al., 2017). For many African cities, there is no governmental system for monitoring and tracking air pollution concentrations, nor have there been enough epidemiological studies coupled with air pollution in order to assess the resulting health impacts. Worldwide, air quality and the impact of air pollution are capturing more governmental and public attention. Indeed, air pollution has detrimental consequences for the short and long-term impact on the health of populations. Epidemiological studies have contributed much to the understanding of both the short and long term effects by documenting adverse effects of air pollution on various organ systems, such as the respiratory, cardiovascular, metabolic and central nervous systems (Thurston et al., 2017). In addition, air pollution has been related to cancer development as well as to premature birth, decreased birthweight and peri-mortality. In Côte d'Ivoire, despite the lack of a national system to measure the quality of air, efforts are being made within the metropolitan area of Abidjan to understand the association between air pollution and health outcomes in a tropical, urban setting, including an epidemiological study done in five hospitals in Abidjan with regard to air pollution concentration levels, which will provide new results.

This research falls under Task 3 of DACCIWA work package 2, and seeks to answer the following research questions:

- What is the current state of cardiorespiratory and dermatological diseases including asthma, heart and skin pathologies in Côte d'Ivoire?

- What are the levels of air pollutants that are listed by WHO as causes of cardiac, respiratory and skin diseases in Abidjan, as a city representative of other African metropoles?
- Finally, what is the relationship between exposure to air pollution and the health events mentioned above?

The objective of this study was therefore to assess the impact of air pollution on health in Abidjan, with special attention to cardiorespiratory and skin diseases, by measuring both exposure to air pollution and health objectively. This report describes efforts to relate pollutant levels and these health outcomes by assessing Particulate Matter, NO_2 and O_3 concentrations and compiling health statistics at the secondary health care level for Abidjan, Cote d'Ivoire within the context of the DACCIWA project (Knippertz et al., 2015).

The main objective of the work was to implement a Health Impact Assessment (HIA) in Abidjan in order to quantify the impacts of air pollution levels have on major health outcomes.

2 Study design

The study was conducted over the period of July 2015 to February 2017, with two separate campaigns carried out in order to measure air pollutant levels across Abidjan, as well as to gather and compile health statistics at the secondary health care level describing the number of hospital visits for respiratory, cardiovascular and dermatological outcomes (symptoms and diseases). The locations for the pollutant measurement sites were chosen based on the proximity to major sources of emissions of air pollution and focused on three of Abidjan's top contributors: waste burning emissions at a local landfill site, motor vehicle emissions due to heavy traffic and biomass burning emissions from domestic cooking fires. Hospital visit statistics were compiled for outpatient health centers in three districts of Abidjan, Cocody, Adjamé and Yopougon respectively (summarized in Table 1), where each of these emission sources is considered a primary contributor to emissions in that district. Emergency Room visits from the University Center Hospital of Cocody (CHU) are also included. Data were assessed daily or weekly according to the possibilities in order to allow for the computation of the risk of a health outcome related to exposure to an air pollutant, and a subsequent health impact analysis. Seasonal effects were considered from the outset of the study and data was taken to reflect both the rainy and dry seasons.

3 Exposure Assessment

3.1 Measurement Campaign

Three pollutants were considered for the deliverable 2.3: $PM_{2.5}$, NO_2 and O_3. For $PM_{2.5}$, which describes the total count of particulate matter with a diameter of 2.5µ or less, measurements were taken at weekly intervals, while the gasses were sampled every two weeks using a passive sampler. Specific details on the measurements are given in (Djossou et al., 2017).

Air pollutant concentrations were measured over the course of July 2015 to March 2017 in three different locations within the metropolitan region of Abidjan to account for three very different sources of ambient air pollution. The measuring station in Cocody, on the eastern side of the city, was chosen for its proximity to a landfill where waste burning regularly occurs, both intentionally and spontaneously. The site in Adjamé, in the central part of the city, was chosen for its high level of motor vehicle traffic. Measurements were taken next to a bus station, with a large number of 4-wheel diesel vehicles. Finally, the westernmost site was located in Yopougon, in a market with several wood burning fireplaces used for food preparation. These and other details are further explained in (Djossou et al., 2017).

The different nature of these three sources of pollution suggest three separate analyses and are the basis for the separation of health data in order to reflect primary exposure, as explained further in section 3. It should also be emphasized that while the authors understand that every area of the city may be affected by a large combination of emission sources, in this report we focus on waste burning, traffic and domestic fires separately, as they each represent a distinct difference between each district.

Table 1: Municipalities and outpatient health centres

Municipality	Health centre
Cocody	Riviera Palmeraie Community Health Centre Urban Health Centre of Akouedo Centre Hospitalier Universitaire de Cocody
Yopougon	Port-Bouet 2 Community Health Centre Soeurs Catherine Health Centre
Adjamé	Adjamé General Hospital

4 Health data

4.1 Locations

This study considers both clinical outpatient visits to one of five outpatient health centers (OHC) within Abidjan (FSU Communautaire de Port Bouet 2, Dispensaire de Soeur Catherine in Yopougon, Hopital Général d'Adjamé in Adjamé and FSU Communautaire de la Riviera Palmeraie and Centre de Santé Urbaine d'Akouédo in Cocody) and Emergency Room (ER) visits collected from a sixth hospital, Centre Hospitalier Universitaire (CHU) de Cocody (CHU) for 2016. The hospitals were selected for their proximity to the pollutant data collection sites, located in three municipalities of the district of Abidjan (Figure 1, Table 1).

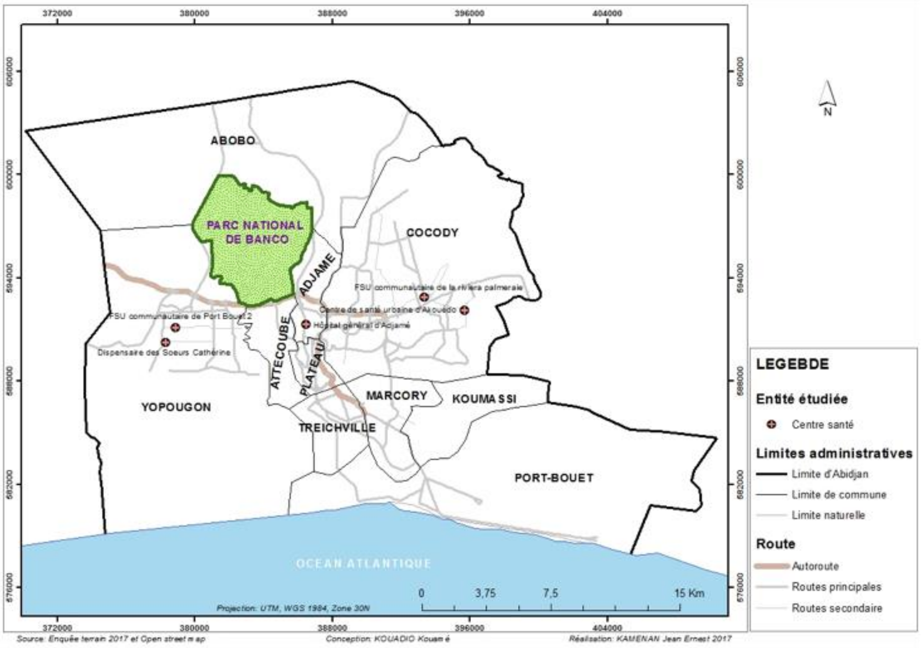


Figure 1: Map of Abidjan, Cote d'Ivoire, showing the location of the five outpatient health centres used for health data collection. CHU, where emergency room visits

4.2 Health outcomes

Three primary health outcomes were studied in relation to air pollutant concentrations in both the OHC and ER. These are respiratory outcomes, both infectious and non-infectious, cardiac problems and dermatological conditions, such as rashes or outbreaks. Health outcomes of interest in the survey were those diagnosed by the doctor and included: respiratory, cardiac or dermatological illness, including chest pain, cough, bronchitis, bronchiolitis, bronchospasm, rhinorrhoea, dyspnoea, pruritus, skin rash with no apparent causes identified, eczema, and skin desquamation. In the case of ER visits, mortality was also considered, including both cases where the patient was dead on arrival or passed during the course of their hospital stay.

4.3 Outpatient Health Centers

4.3.1 Population

All outpatients coming in for a medical consultation to any of the five health centres were considered as includable in the analysis. However, due to privacy issues, not all outpatients' visits were considered in the analysis. Outpatients were selected based on diagnosis of clinical symptoms or diseases in relation to the lungs, skin, or heart.

4.3.2 Data Collection

For the OHC, data were collected by surveying doctors and included information on the patients age, sex, region of origin, profession and their primary, secondary and tertiary symptoms and diseases collected through a standardized form/questionnaire. The final diagnosis, and number of previous consultations for the same symptoms were also recorded, as well the type of treatment they received as a result of their visit (such as a bronchodilator or other medication in the case of respiratory diseases).

All questionnaires were completed by the recruiting physician following informed consent of the patient. The following data were collected:

- ID number,sex, age, profession, school level, place of residence
- Date of consultation
- Wait time
- Clinical symptoms

- Previous consultations
- Final diagnosis
- Medication prescribed
- Whether further hospitalization was required

Data was collected continuously during weekdays for 3 months during the rainy season and 3 months during the dry season for almost two consecutive years from July 2015 to April 2017. It was analysed at the Institut Pasteur of Côte d'Ivoire and Sorbonne University in Paris. All ethical and legal obligations were respected in order to protect patients' private information and data. Data was organized by both the district in which the hospital was located, as well as by the district in which the patient lived.

4.4 University Center Hospital of Cocody

4.4.1 Data Collection

ER data was compiled for the year of 2016. Recorded information included

- Sex, age, place of residence
- Date of consultation
- Final diagnosis
- Length of stay
- Whether further hospitalization was required.

Cases for which the cause of the visit was related to intoxication from medication, alcohol or other substances were omitted, as were cases for which the diagnosis was not listed or did not result in the death of the patient. All deaths, recorded with or without causes, were counted in the mortality totals.

5 Methods

5.1 Variable definitions

Air pollutants concentrations were expressed in µg/m^3. Each outpatient's visit is used as an indicator of a negative health outcome. Only final diagnoses by the doctor are included.

While CHU is located within the commune of Cocody, emergency room data was organized by the patients neighbourhood of residence, as their local neighbourhood is a better indicator of exposure levels than that the of hospital. For patients outside of the three areas of interest, the closest neighbourhood was chosen for those living in adjacent communities or else was not included. Health outcomes for the OHC and the ER are kept separate throughout this analysis as, while they apply to the same urban population, they are not directly comparable. Outpatient health centers saw an overwhelming majority of young children, primarily with respiratory issues. Emergency rooms, however, saw more urgent health concerns for mostly adult patients. While respiratory and cardiac issues were present at both types of hospital, dermatological issues, were significant only at the OHC. And mortality, as expected, was only as issue for the emergency rooms. Furthermore, the data collection periods for each do not overlap entirely, as the ER data was collected only during 2016.

The number of visits are recorded daily, but grouped together in weekly totals to be compared with the weekly pollutant averages for $PM_{2.5}$.

5.2 Statistical methods and Poisson Regression

Poisson regression techniques were used in order to determine the concentration response function describing the interaction between a specific exposure and a specific health outcome.

Relative Risks (RR) of the relationship between the observed outcomes and air pollution exposure were estimated using a Poisson Regression model. The relative risk is a ratio of the probability of an occurrence of a specific event within an exposed group to the probability of an occurrence within a non-exposed group. RR values can be calculated for specific causes and effects. For this study, relative risks were determined for each health outcome (respiratory illness, cardiovascular illness, skin problems, mortality) with each pollutant ($PM_{2.5}$, NO_2, O_3). Analyses were further separated by district (Cocody, Adjamé, Yopougon) as well as by season (annual, rainy, dry).

Calculations were primarily done using the R software package, but repeated for comparison using the Stata software package in order to verify the results. The focus from here on considers associations with $PM_{2.5}$ only, as the specific sample size for both NO_2 and O_3 were limited and results were inconclusive.

5.3 Missing Values

In the case of $PM_{2.5}$, pollutant measurement values were missing in all three neighbourhoods. In Cocody, there were 1/74 missing value (average $PM_{2.5}$ for one week), 3/74 missing values in Adjamé and 4/74 missing values in Yopougon. In order to conduct an analysis relating these values to health outcomes, missing values were estimated by taking a random uniform value between the values for the two periods just before and just after.

For NO_2 and O_3, there were no missing values for the areas of Adjamé and Yopougon, but 2 missing values, representing periods of 13 days (February 2016) and 16 days (March 21016) for Cocody.

Data were missing values for a final diagnoses were not included.

6 Health Impact Assessment

The goal of Health Impact Assessment is to provide an estimate of the number of health events that could be prevented for a given exposure.It has been used in the context of air pollution related morbidity and mortality (Medina et al., 2013) and has been employed to give context to policy makers and others outside of epidemiology when discussing adverse health outcomes from air pollution.

HIA uses previous epidemiological research on understanding health risks associated with exposure in order to extrapolate to the larger population. The exposure-response function is the key contribution of epidemiology to HIA. While HIA is able to use correlations to predict an effect, it does not explain the underlying mechanisms for why a given exposure is associated with a specific health outcome.

In the case of DACCIWA, novel data were evaluated in an epidemiological context in order to determine a relative risk, which was then applied in order to determine the number of premature deaths due to various forms of air pollution. In particular, as said before, an RR was obtained through the Poisson regression model.

HIA employs standardized functions to generate estimates based on changes in pollutant concentration levels. Changes in a specific health outcome are defined by the impact function

$$\Delta y = y_0(1 - e^{-ß\Delta x}).$$

Here, y_0 is the baseline health data, Δx is the difference in pollutant concentration, and β is the concentration response function (CRF), derived from epidemiological studies. The concentration response functions are log-linear functions which describe the correlation between a specific pollutant, and are based on the relative risk (RR) between a specific morbidity or the risk of mortality

$$ß = \frac{\ln(RR)}{10}.$$

The quantity Δy, then, describes the number of adverse health outcomes avoided for a decrease in pollutant level by an amount Δx.

In the context of this study, the y_0 values are obtained from the number of visits to both the OHC and the ER, according to diagnosis. The pollutant values are changes in the measured annual averages compared to a hypothetical reduction scenario.

7 Results

7.1 Air pollution concentrations

Here we focus on the distribution and long-term averages of the pollutant concentration values as a way to understand the nature of each of the three primary emission sources.

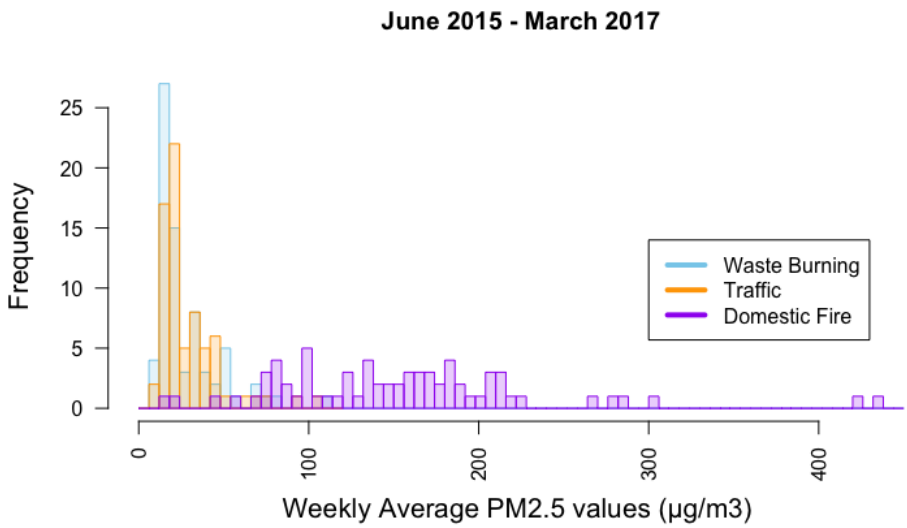


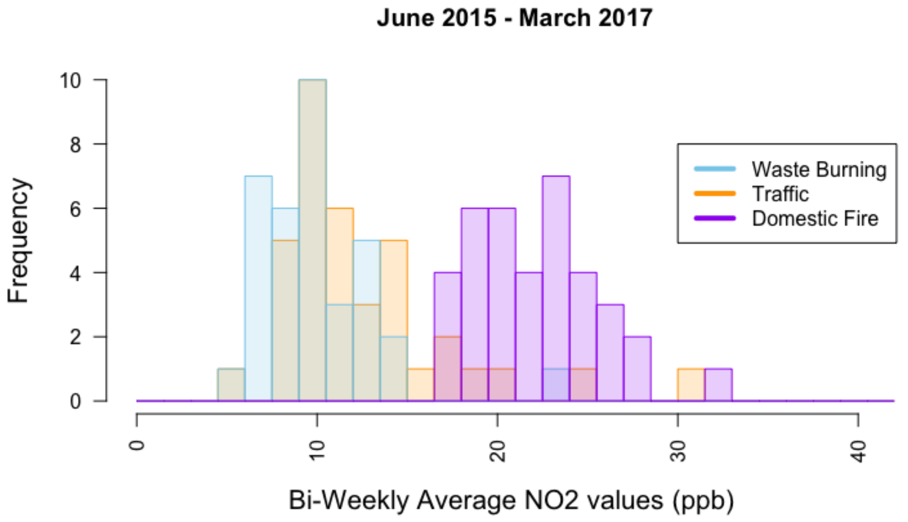
Figure 2: Histogram of PM2.5 values for three different measurement sites in Abidjan. Waste Burning takes place in Cocody, Traffic refers to the heavy traffic in Adjamé, and Domestic Fires are common in Yopougon. Concentrations for Waste Burning and Traffic are roughly equal, while those due to domestic fires extend beyond 400 µg/m3.

Figure 2. Shows the distribution for $PM_{2.5}$ for each site over the course of the study period. The distributions for both the waste burning site in Cocody and the traffic site in Adjamé are roughly similar, and have similar long-term averages just under 30 µg/m^3, where long-term refers to the entire study period rather than an annual value for a specific year (Table 2). The distribution for the domestic fire site in Yopougon, however, is drastically different, and extends past 400 µg/m^3, with an average long-term value of 155 µg/m^3.

Table 2: Seasonal and average PM2.5 measurements for each neighbourhood for the period of July 2015 – March 2017.

Average PM2.5 values (µg/m^3)			
Location	Rainy	Dry	Overall
Cocody(waste burning)	19.39	38.4	28.51
Adjamé (heavy traffic)	21.35	38.76	29.69
Yopougon (domestic fires)	187.8	118.4	155.1

Distributions for the gasses are shown in Figure 3. NO_2 values show a similar separation between both the waste burning and traffic sites, and the domestic fire site, without the drastic difference in mean values (not shown). For O_3, the concentrations are more clustered together, and the domestic fire site shows lower values overall than the other two sites.



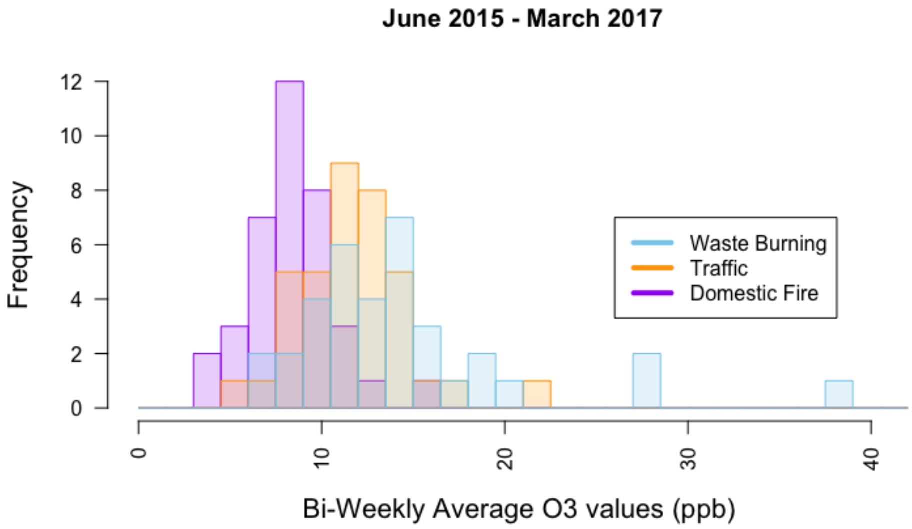


Figure 3: Histograms of NO2 (left) and O3 (right) concentrations averaged over 2 week periods for each of the three measurement sites in Abidjan. NO2 concentrations are higher for Domestic Fires, while O3 is slightly lower.

7.2 Health data

A total of 57,805 health outcome visits were recorded during the survey period. 10,593 of those visits were conducted at an OHC within Abidjan and focused on one or more of respiratory, cardiac or dermatological issues. Most patients (10,444) were discharged after their visit, 62 patients were transferred to another hospital or clinic, 60 patients were hospitalized, 26 were hospitalized in a specialty unit and 1 patient died. Additionally, 4843 ER visits conducted during a subset of this period (2016) were included in this investigation as well, but was analysed separately from outpatient visits.

The age distributions for the OHC and the ER are much different, as seen in Figure 4. Overall, ages ranged from 0 to 99 years, however the OHC were primarily visited by small children. Over 54% (5776) of OHC visits were by children under 18 years old, and 46% (4878) by children under the age of 10 years. In contrast, the ER saw a fairly flat distribution of ages, but very few children under the age of 16.

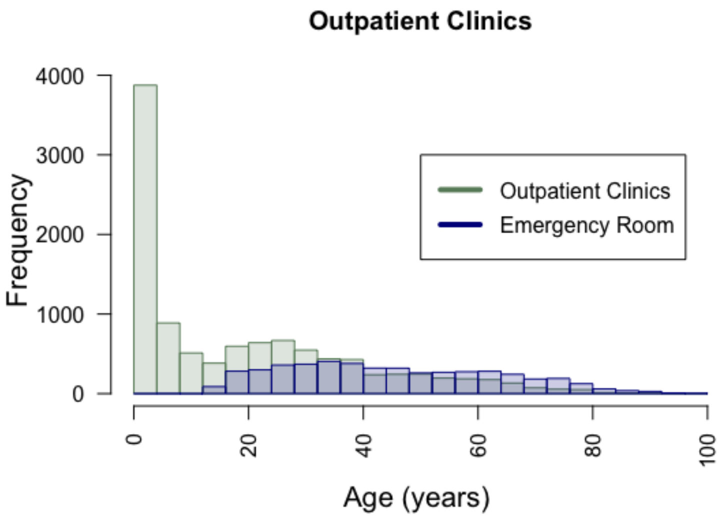


Figure 4: Age distribution for the outpatient health centers (green) and the emergency room (blue). Outpatient health centers primarily saw large numbers of small children, while the emergency room hosted a much wider distribution of ages, but very few small children

ER data were compiled for the year of 2016 and included 5,634 individual cases. Excluding intoxication from medication, alcohol or other substances reduced the final available dataset to a length of 4841 emergency room visits.

Both the OHC (54%) and the ER (52%) saw more female visitors than male (Figure 5).

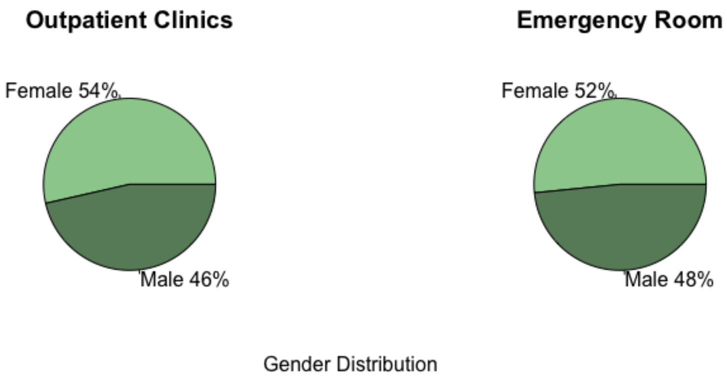


Figure 5: Gender Distribution for both the outpatient health centers and the emergency room. Female visits were slightly more common in both settings.

In Cocody, the number of visits for both the OHC and the ER were roughly the same during the rainy season (50.37%, 50.2% respectively) as during the dry season (49.63%, 49.8% respectively), however a slight seasonal effect was observed for both Adjamé (Rainy: 53.35% OC, 57.7% ER) and Yopougon (Rainy: 56.29% OC, 50.51% ER). Percentages are illustrated in Figure 6.

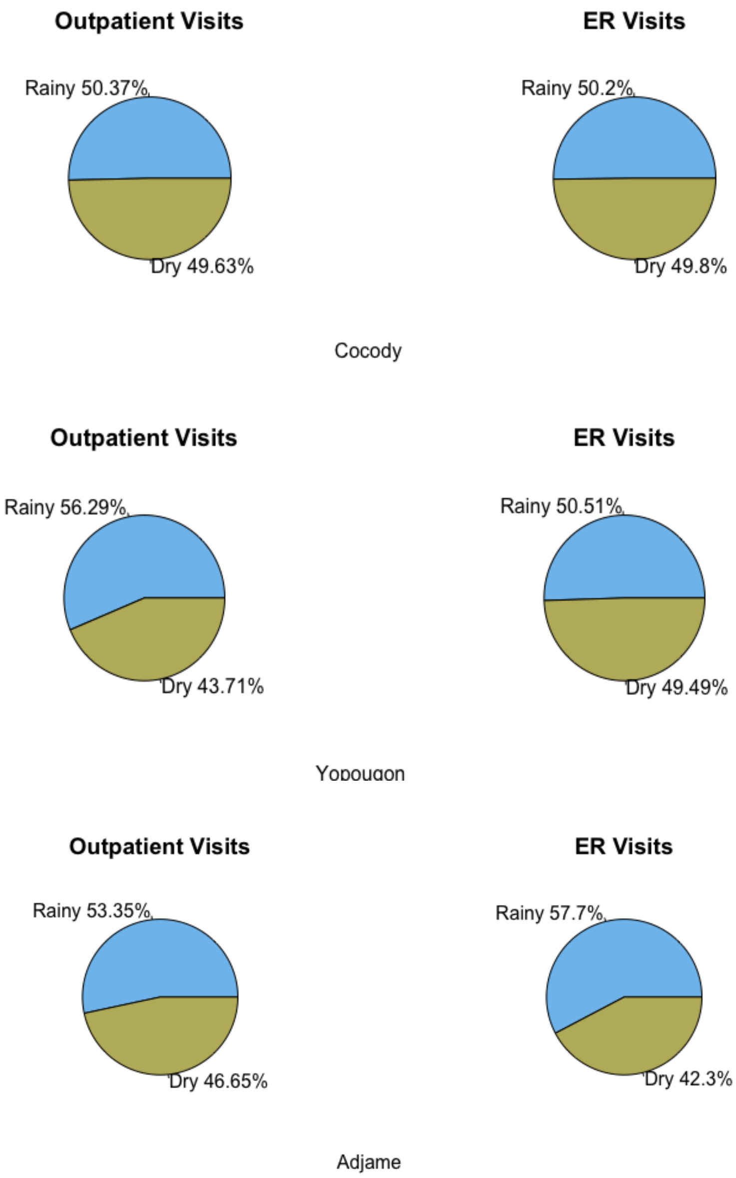


Figure 6: Percentage of hospital visits by season for the neighbourhoods of Cocody, Adjamé and Yopougon. Slightly more visits were conducted during the rainy season.

The total number of observable OHC visits was reduced from 10593 to 10179 after excluding non-related diagnoses and compiling the total number of visits per period, where each period corresponds to a measurement period for $PM_{2.5}$. Visit numbers for the OHC are broken down into respiratory, cardiac, dermatological visits (Table 3). For the ER (Table 4), 4030 visits out of an observed total of 4843 fell within the $PM_{2.5}$ measurement time windows and are broken down into respiratory, cardiac, other morbidity, and mortality, where the mortality figures include patients determined dead on arrival as well as those who passed during their hospital stay.

Respiratory issues were far more common than cardiac or other specific problems for both the OHC and the ER. Dermatological problems were primarily addressed at OHC, most likely because these issues aren’t typically considered urgent or life threatening.

Table 3: Number of outpatient health center visits for all five hospitals during the study period of July 2015 – February 2017. Not shown are figures for patients suffering from multiple ailments, and only the primary diagnosis is considered. Table 2 (right) shows the number of emergency room visits for CHU during 2016

Outpatient Health Centers				
Final Diagnosis	**Cocody**	**Adjamé**	**Yopougon**	**Total # of Visits**
Respiratory	2773	1063	2689	6525
Cardiac	261	621	351	1233
Dermatology	1160	381	880	2421
Total	4194	2065	3920	10179

Table 4: Number of emergency room visits for CHU during 2016

Emergency Room				
Final Diagnosis	**Cocody**	**Adjamé**	**Yopougon**	**# of People**
Respiratory	400	113	226	739
Cardiac	354	89	117	560
Other	1292	263	312	1867
Mortality	502	126	236	864
Total	2548	591	891	4030

7.3 Relative Risk

The relative risks (RR) were calculated using standard Poisson regression methods separately for the districts of Yopougon, Adjamé and Cocody, as well as by season. Risks were also calculated separately for the OHC visits and the ER visits. For the gasses, the lack of specific data was an issue in obtaining a significant association for any of the health outcomes.

Only cases with a significant relative risk above 1.0, which indicates the existence of a risk, are reported here. In theory, a value of 1.0 would indicate no effect, and a value below 1.0 would indicate a protective, rather than an adverse, effect. Combinations of health outcome, district and season are left out of Tables 5-7 below because they did not produce valid results.

The Tables 5, 6 and 7 then, show, according to district, the relative risk of requiring a visit to either an OHC or ER for respiratory, cardiac, or dermatological symptoms or mortality, depending on the season, as a result of exposure to $PM_{2.5}$.

In most cases, risks were only observed during the rainy season. The exception is that the risk of non-urgent respiratory symptoms is present throughout the year in Yopougon, which had the highest levels of $PM_{2.5}$. These RR are valid for long term (several months) exposure to $PM_{2.5}$. No significant results were observed for the dry season only.

Table 5: Relative Risk (RR) values and 95% Confidence Interval (CI) for the neighbourhood of Cocody according to season.

Relative Risk Values – Cocody (Waste Burning)						
Health Outcome	**Ages**	**Season**	**Pollutant**	**Term**	**RR (and CI)/10µg/m^3**	**RR/10µg/m^3 95% C.I.**
Respiratory ER Visit	all	Rainy	$PM_{2.5}$	LT	**1.033**	**[0.99 - 1.082]**
Cardiac ER Visit	all	Rainy	$PM_{2.5}$	LT	**1.032**	**[0.989 - 1.076]**
Mortality ER Visit	all	Rainy	$PM_{2.5}$	LT	**1.042**	**[1.00-1.086]**
Respiratory Outpatient Visit	all	Rainy	$PM_{2.5}$	LT	**1.008**	**[0.966 - 1.053]**

Table 6: Relative Risk (RR) values and 95% Confidence Interval (CI) for the neighbourhood of Adjamé according to season.

Relative Risk Values – Adjamé (Traffic)						
Health Outcome	**Ages**	**Season**	**Pollutant**	**Term**	**RR (and CI)/10µg/m^3**	**RR/10µg/m^3 95% C.I.**
Respiratory ER Visit	all	Rainy	$PM_{2.5}$	LT	**1.029**	**[0.994 - 1.065]**
Cardiac ER Visit	all	Rainy	$PM_{2.5}$	LT	**1.030**	**[1.001 - 1.059]**

Table 7: Relative Risk (RR) values and 95% Confidence Interval (CI) for the neighbourhood of Yopougon according to season.

Relative Risk Values – Yopougon (Domestic Fire)						
Health Outcome	**Ages**	**Season**	**Pollutant**	**Term**	**RR (and CI)/10µg/m^3**	**RR/10µg/m^3 95% C.I.**
Respiratory Outpatient Visit	all	ALL	$PM_{2.5}$	LT	**1.001**	**[0.997 - 1.004]**
Respiratory Outpatient Visit	all	Rainy	$PM_{2.5}$	LT	**1.003**	**[1.000 - 1.006]**
Cardiac Outpatient Visit	all	Rainy	$PM_{2.5}$	LT	**1.004**	**[1.002 - 1.007]**
Dermatology Outpatient Visit	all	Rainy	$PM_{2.5}$	LT	**1.002**	**[0.999 - 1.005]**

7.4 Health Impact Assessment (HIA)

Health Impact Assessment was performed for each of the cases above in section 7.3 where a significant relative risk was observed between either the number of OHC visits or ER visits and excess exposure to $PM_{2.5}$. Excess exposure to $PM_{2.5}$ is defined, for the purposes of this study, as the difference in concentration levels determined in section 2 for each of the three districts of Abidjan and the WHO recommendation value of 10 µg/m^3 (World Health Organization, 2006).

In each case, the number of observed visits applicable is listed in Tables 8, 9 and 10, according to neighbourhood. For both the OHC and ER visits, the district of habitation is used rather than the

hospital location. For persons living in Cocody, up to 22 ER visits could have been avoided during our study period, for the rainy seasons alone, including 10 deaths, had the $PM_{2.5}$ levels been in accordance with the WHO. Further, 11 OHC visits could have also been avoided during the rainy seasons between 2015 and 2017.

Table 8: HIA results for Cocody. The observed outcomes give the number of hospital visits by people living in Cocody during the listed season, and the outcomes avoided give the number of visits that could be avoided if the PM2.5 levels were reduced by the amount listed. In the case of Mortality, this means 10 deaths by people living in Cocody could have been avoided during the rainy season of 2016. 95% Confidence Interval (CI)

Health Impact Assessment - Cocody (Waste Burning)							
Health Outcome	Ages	Season	$\Delta PM_{2.5}$ ($\mu g/m^3$)	Term	Observed Outcomes	Outcomes Avoided	95% C.I.
Respiratory ER Visit	all	Rainy	9.39	LT	**194**	**5.8**	**[-2.7 - 13.9]**
Cardiac ER Visit	all	Rainy	9.39	LT	**209**	**6.0**	**[-2.2 - 13.9]**
Mortality ER Visit	all	Rainy	9.39	LT	**264**	**10.1**	**[0.02 - 19.7]**
Respiratory Outpatient Visit	all	Rainy	9.39	LT	**1415**	**10.9**	**[-46.9 - 66.6]**

For Adjamé, where heavy traffic is a problem, 4 emergency room visits for both respiratory and cardiovascular symptoms could been avoided during the rainy seasons between 2015 and 2017.

Table 9: HIA results for Adjamé. The observed outcomes give the number of hospital visits by people living in Cocody during the listed season, and the outcomes avoided give the number of visits that could be avoided if the PM2.5 levels were reduced by the amount listed. 95% Confidence Interval (CI)

Health Impact Assessment - Adjamé (Traffic)							
Health Outcome	Ages	Season	$\Delta PM_{2.5}$ ($\mu g/m^3$)	Term	Observed Outcomes	Outcomes Avoided	95% C.I.
Respiratory ER Visit	all	Rainy	11.35	LT	**61**	**2.0**	**[-0.39 - 4.2]**
Cardiac ER Visit	all	Rainy	11.35	LT	**54**	**1.8**	**[0.1 - 3.4]**

In Yopougon, respiratory visits to the outpatient health centres could be reduced more significantly. In considering results for the entire year (26.5 avoided outcomes) and the rainy season (76.7 avoided outcomes), we obtain different results as the HIA for the rainy season was calculated using a different timeframe at a higher risk level. A further 30 outpatient visits for heart and skin problems could also be avoided during the rainy season, given an adherence to WHO recommended levels.

Table 10: HIA results for Yopougon. The observed outcomes give the number of hospital visits by people living in Cocody during the listed season, and the outcomes avoided give the number of visits that could be avoided if the PM2.5 levels were reduced by the amount listed. 95% Confidence Interval (CI)

Health Impact Assessment - Yopougon (Domestic Fire)							
Health Outcome	Ages	Season	$\Delta PM_{2.5}$ ($\mu g/m^3$)	Term	Observed Outcomes	Outcomes Avoided	95% C.I.
Respiratory Outpatient Visit	all	ALL	145	LT	**2689**	**26.5**	**[-103.5 - 150.1]**
Respiratory Outpatient Visit	all	Rainy	177.8	LT	**1518**	**76.7**	**[-6.4 - 155.3]**
Cardiac Outpatient Visit	all	Rainy	177.8	LT	**200**	**14.1**	**[5.7 - 22.2]**
Dermatology Outpatient Visit	all	Rainy	177.8	LT	**465**	**15.7**	**[-12.3 - 42.1]**

8 Conclusions

Using the number of visits to either an outpatient health center or an emergency room as a proxy for adverse health effects, we see a slight association between $PM_{2.5}$ concentration levels and respiratory, cardiological, dermatological symptoms as well as mortality in the metropolitan area of Abidjan.

$PM_{2.5}$ concentration levels were measured on a weekly basis in three separate districts within Abidjan in order to assess any variations in contributions from waste burning, heavy motor vehicle traffic and biomass burning. $PM_{2.5}$ Concentrations from the waste burning (Cocody) and traffic (Adjamé) sites were comparable with annual averages of 28.51 µg/m^3 and 29.69 µg/m^3 respectively. In Yopougon, where domestic fires are common, the annual average is drastically higher at 155.1 µg/m^3.

NO_2 and O_3 concentration measurements were also made, however the variability of the measurement periods, and limited dataset did not allow for comparisons with daily or weekly health visit totals.

Outpatient visits were conducted at five different health centres in all three districts over the entire duration of the study, while the emergency room data was collected for only at one hospital, CHU, located in Cocody, for the year of 2016.

Weekly $PM_{2.5}$ concentration values were then compared to the number of hospital visits during the same period. Using Poisson regression techniques, relative risk values describing the increased risk of requiring a visit to the health centre or the emergency room, and hence the risk of respiratory, cardiac or dermatological symptoms as a result of local $PM_{2.5}$ concentrations.

Ten of the health outcome/district combinations showed a significant association with the number of hospital visits and $PM_{2.5}$ concentrations, primarily during the rainy season, leading to relative risk values applicable to a health impact assessment. In Cocody, near the landfill site, significant associations between emergency room visits for respiratory and cardiac problems and $PM_{2.5}$ were seen, as well as emergency room mortality and respiratory visits to outpatient health centers.

In Adjamé, where traffic is a significant cause of PM concentrations, significant associations were seen between emergency room visits for respiratory and cardiac symptoms.

The highest $PM_{2.5}$ concentrations were due to biomass burning, seen in Yopougon. Here, outpatient visits for all three types of symptoms- respiratory, cardiac and dermatological showed a significant association with $PM_{2.5}$ concentrations during the rainy season and respiratory outpatient visits were significant throughout the entire year.

Overall, we estimate that 143 hospital visits could have been avoided during the rainy seasons of our study period, including 10 mortalities, had the average $PM_{2.5}$ concentration levels across Abidjan been at the WHO recommended value of 10 µg/m^3.

9 Discussion

While HIA is a straightforward analysis, the considered factors may be complex and require detailed data in order to assess properly. This analysis combined the results of an air pollutant measurement campaign with a compilation of health statistics collected during the same period in order to determine any associations between adverse health effects and air quality. For the cases in which as association was seen, a health impact analysis was performed in order to estimate the number of avoided outcomes given a hypothetical scenario, in this case – an overall adherence to the 10 µg/m^3 limit set by the WHO. A concentration was placed on major global health concerns, including respiratory health.

Health impacts due to pollution are being studied worldwide in response to high levels of pollution and a growing understanding of the damages air pollutants have on respiratory, cardiovascular, and neurological systems, as well as on reproduction and development and certain metabolic outcomes (Thurston et al., 2017). It has been estimated that over 3 million premature deaths annually occur as a result of ambient air pollution, over 85% of which concern low and middle income countries (Lelieveld et al., 2015). These values are expected to double within the next few decades if emission profiles do not drastically improve, and do not include the global impact of the host of morbidities associated with air pollution.

Despite the disparity with higher income countries, there are few air quality measurements done outside Europe and North America, with the exception of the growing number of studies now being done in China and South East Asia. Studies estimating health impacts rely not only on epidemiological studies done in higher income countries, which may or may not be applicable, but also on estimated average concentration values for pollutants usually based on large scale chemical transport models and/or satellite data without enough information to consider local variations in concentrations. While such studies have been crucial in advancing our global understanding of the problem, they are unable to capture the detail required to make specific statements for any given population. Additionally, associated risks may be different at higher ambient levels (Burnett et al., 2014), further decreasing the confidence in using non-local risk values to estimate health impacts. Considering the burgeoning growth African urban centres are experiencing, local measurements are imperative.

In Yopougon, for example, where average $PM_{2.5}$ concentrations are between 100 – 200 µg/m^3, health risks are likely to be drastically different than for those where concentrations are much lower. This study shows a significant increase in risk for requiring a trip to the doctor – for all three health concerns – in Yopougon, as these risks were undetectable for the other districts , with the exception of OHC visits for respiratory symptoms in Cocody. That we do not see an effect for ER visits in Yopougon may be due to the fact that fewer emergency patients attended CHU, located in Cocody, and the more severe cases for those in Yopougon were sent to a closer hospital.

That we see an effect primarily during the rainy season suggests that humidity may play a larger role than previously thought in the presentation of particulate matter to the lungs. Indeed, there are recent analyses covering the issue of particulate matter and humidity (Lepeule et al., 2018; Lou et al., 2017). To date, there are very few studies done in tropical regions on the health impacts of air pollution, which opens up many possibilities for further inquiry.

9.1 Strengths

The strength of this study lies in its approach to understanding local variations even within a single specific metropolitan area, with an awareness for the relative contribution of different emissions sources and the differing levels of toxicity each source.

In some sense, this study can be seen as a pilot study to look more in depth at the association between health and pollution in tropical urban areas. It is clear from this study that domestic fires are a huge health risk, while the risks from heavy traffic or waste burning were less extreme. As this study focused on the inhabitants of these neighbourhoods, rather than a specific population of bus drivers, or people working in food preparation or at the landfill site, we may be obscuring the serious risk associated with long periods of time near a significant emission source.

This study also presents the first results of an epidemiological study on cardiorespiratory impacts of air pollution in Cote d'Ivoire.

9.2 Weaknesses

These results only consider some of the outpatient health centres and hospitals in the city of Abidjan, and focused on the inhabitants from only three districts. Including information from every hospital and health center would provide a more complete and accurate picture. Further, measurements for both $PM_{2.5}$ and OHC and ER counts were not taken for the entire period of June 2015 – Feb 2017. Including socio-economic information may also provide a lever to understand both the data better, as not all inhabitants are equally likely to visit a doctor.

We suspect that a larger, more significant effect would be observed with more detailed data, covering a larger fraction of the city. A further long-term, continuous study looking at daily fluctuations in air pollutant levels, and a more detailed health data set could provide a deeper understanding of health impacts in an urban tropical metropolitan area.

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