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Research Article

Outdoor Air Pollution in Dakar City (Senegal) and Health Risk Assessment: A Pilot Study

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ABSTRACT

Outdoor air pollution is the underlying cause of 4.2 million premature deaths per year, of which some 18% were due to Chronic Obstructive Pulmonary Disease (COPD) and 23% due to acute lower Respiratory Tract Infections (IRI). In West African countries, anthropogenic sources of air pollution are concentrated near residential areas, thus exposing populations to high risks of adverse effects. In order to stimulate the implementation of policies to reduce population exposure, this study aimed to describe outdoor air pollution in Dakar (Senegal) and to estimate its health impact. The description was made by comparing the annual averages of various pollutants (NO_2, SO_2, PM_{10} and $PM_{2.5}$) to guideline values and on the other hand by converting the monthly averages into time-series which trends and seasonality are described using the R software. The impact was estimated with Air Q+ software by calculating the number of specific health outcomes (hospital admissions for respiratory diseases and all-cause mortality) from short-term exposure to outdoor air pollutants' levels above the threshold of 10 ug/m^3. Monthly levels follow a linear trend (except that of NO_2), with a seasonal component. Pollution peaks are always observed in the December-January-February quarter, while the lowest levels are observed in the July-August-September quarter. Moreover, the annual levels are all above the guideline values, except for SO_2. Between 2016 and 2018, and for all ages combined, 1379 (13.38%) cases of hospital admission for respiratory diseases can be attributed to short-term exposure to PM_{10}. The latter is also the underlying cause of 315 (7.48%) non-accident deaths noted in 2017. Air pollution is a real problem in Dakar in view of the level of indicators. With regard to their health impact, more exhaustive and more robust estimation would be very useful for better exposure reduction policies. To this end, air quality monitoring and health data management could be improved.

Keywords: Outdoor air pollution; Health risk assessment; Hospital admission; Respiratory diseases; Mortality; Dakar; Senegal

INTRODUCTION

Atmospheric pollution is the alteration of the normal composition of air (78% nitrogen, 21% oxygen and 1% (argon, neon, helium, etc.)) mainly by chemical agents [1]. Polluted air thus corresponds to a heterogeneous mixture of chemical compounds in gaseous or particulate form. The main gaseous pollutants are Nitrogen Oxides (NO_x), Carbon Monoxide and Dioxide (CO and CO_2), Ozone (O_3), Sulfur Dioxide (SO_2) and certain Volatile Organic Compounds (VOCs). As for airborne particulate pollutants, they are classified according to their aerodynamic diameter and are adsorbed with organic and inorganic substances such as Polycyclic Aromatic Hydrocarbons (PAHs) and Metallic Trace Elements (MTEs...). Air pollution is the greatest environmental threat to public health. Environmental pollutants are a major cause of Non-

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Communicable Diseases (NCDs). Indeed, outdoor air pollution is the underlying cause of 4.2 million premature deaths per year, of which some 18% were due to Chronic Obstructive Pulmonary Disease (COPD) and 23% due to acute lower respiratory tract infections (IRI) [2,3]. In West African countries, air pollution has increased in recent years. This pollution mainly results from anthropogenic activities which are concentrated near residential areas, exposing residents of large African cities to a higher risk of adverse effects. In Dakar (Senegal), monitoring of air pollution indicators often reveals levels well above the guideline values, especially for airborne particulate matter. To our knowledge, no study has to date estimated the health impact of air pollution in Dakar. The few studies have either focused on pollution levels and their variation, or documented the link between air pollution and health, specifically respiratory health. A recent study looked at hospital admissions for respiratory diseases in relation to air pollution, however, it is a correlation that was sought, whereas more robust epidemiological studies have already largely documented this link. Regarding this link, the gap in Africa is to find exposure-risk relationships more adapted to local contexts [4]. Failing that, the exposure-risk relationship derived from European or American studies should be used even if only on a pilot basis to estimate the health impact of air pollution. This study falls within this framework and aimed to describe ambient air pollution in Dakar and estimate its health impact.

MATERIALS AND METHODS

Setting and study design

This is an analytical cross-sectional study combining a description of outdoor air pollution in Dakar and a health risks assessment. Dakar is a peninsula of 550 km² (0.3% of the national territory) located in the far west of Senegal (République du Sénégal and JICA 2016). It concentrates 23% of the country's population, representing a density of 5,374 inhabs/ km^2. The total population between 2016 and 2018 is estimated at 3,529,665 inhabitants, of which 2,103,618 inhabitants are between 15 and 64 years old and 125,932 inhabitants are 65 and over. Moreover, in 2017, the adult population (30 years and over) is estimated at 1,337,217 inhabitants. The growing urbanization in Dakar causes a degradation of the living environment and thus a greater vulnerability of populations to environmental factors. In addition, Dakar holds 55% of the national GDP and is home to 80% of businesses [5]. Thus, the close relationship between pollutants emission and production activities predicts higher pollution in this locality compared to the rest of the country. Moreover, Dakar concentrates more than half of the national car fleet, the latter being mainly composed of outdated vehicles rejecting thousands of cubic meters of toxic substances into the environment [6-8]. In addition, in most households in Dakar, biofuels are burnt in open fires or in stoves where combustion is very incomplete, resulting in significant emissions of pollutants.

Description of outdoor air pollution

Dakar has an air quality monitoring network equipped with a reference laboratory and five fixed measurement stations. A group of four pollutants monitored by these stations (SO_2, NO_2, $PM_{2.5}$ and PM_{10}) and a five-year period from 01/01/2014 to 01/01/2018 were selected to describe outdoor air pollution. For each pollutant, the monthly values collected by stations were obtained from the air quality management center. An arithmetic mean of these values was then calculated to estimate an average monthly level of each pollutant in the region. The missing SO_2 and PM_{10} values for October 2016 and September 2017 respectively were imputed to the average over the five-year period of the values available for each of the corresponding months [9-11]. For $PM_{2.5}$, missing values were estimated from monthly PM10 averages, using a $PM_{2.5}/PM_{10}$ ratio equal to 0.5, as recommended by the WHO. The annual averages of air pollutants were calculated and compared to the guideline values (WHO: 10 µg/m^3 (NO_2), 15 µg/m^3 (PM_{10}) and 5 µg/m^3 ($PM_{2.5}$), French legislation: 50 µg/m^3 (SO_2)) and on the other hand by converting the monthly averages into time-series which trends and seasonality are described using the R software.

Outdoor Air Pollution Health Risk Assessment (AP-HRA)

The approach is based on WHO guidelines, and involves using exposure-risk relationships (Relative Risk (RR)) derived from epidemiological studies and the frequency of specific health outcomes (hospital admissions for respiratory diseases and all-cause mortality) to calculate the number of cases attributable to outdoor air pollutants' exposure levels above the threshold of 10 ug/m^3. The RRs used in the study are shown in Table 1, and are those used by the different air pollution risk assessments in Europe, particularly in France. These relationships, established for short-term exposure to a 10 µg/m^3 increase in the level of pollutant, come from European studies such as Improving Knowledge and Communication for Decision-Making on Air Pollution and Health in Europe (APHEKOM), Air Pollution and Health: A European Approach (APHEA) and "Programme de surveillance air et santé-9 villes". For health outcomes, the frequencies reported in Senegal's health and social statistics yearbook were used. Over a five-year period, hospital admissions were only available for the last three years 2016–2018 and the causes are not mentioned in the yearbook. The results of Sylla have thus made it possible to estimate admissions for respiratory diseases. Indeed, this study, which looked at the period 2013-2015, found 6.10% of hospital admissions for respiratory diseases in Dakar. This rate was applied to the total number of admissions recorded in the yearbook in order to estimate those due to respiratory diseases. Furthermore, for SO_2 exposure, the RRs of hospital admissions for respiratory diseases are those applicable to the 15 to 64 and over 65 age groups. Due to the lack of information on the age structure of patients, the proportions of 9% (patients aged 63 and over) and 78% (patients aged between 15 and 63) of hospital admissions for respiratory diseases reported by Sylla were also applied to the total respiratory admissions calculated above, in order to estimate those for over 65 and 15 to 64 age groups respectively.

Furthermore, mortality is only reported for 2017 period and for all causes. In order to estimate that relating to adults (aged over 30), pediatric hospitals were just subtracted from the calculation of the totals also due to lack of information on age structure. As for pollutants, exposure is estimated by the average values over the considered period [12]. The attributable cases of hospital admission for respiratory diseases and all-cause mortality from short-term exposure to levels above the threshold of 10 ug/m^3 were calculated with the following formula: NA=((RR-1) N)/RR (with NA: number of attributable cases; N: total number of specific health outcome; RR: Relative Risk). This calculation is made easy by using AirQ+ software developed by the European Centre for Environment and Health (ECEH).

RESULTS

Time-series description of outdoor air pollution

Figure 1 shows monthly variations in air pollutants between 2014-2018. Similar variations are observed for particles (PM_{10} and $PM_{2.5}$) and Sulfur Dioxide (SO_2). It is indeed a saw tooth variation reflecting the presence of a seasonal component, with a linear trend. As for Nitrogen Dioxide (NO_2), we also observe the presence of seasonality, however, the trend is non-linear. The conversion of monthly values into time-series made it possible to extract more information on the seasonal components. Indeed, pollution peaks are always observed in the December-January-February quarter, while the lowest levels are observed in the July-August-September quarter.

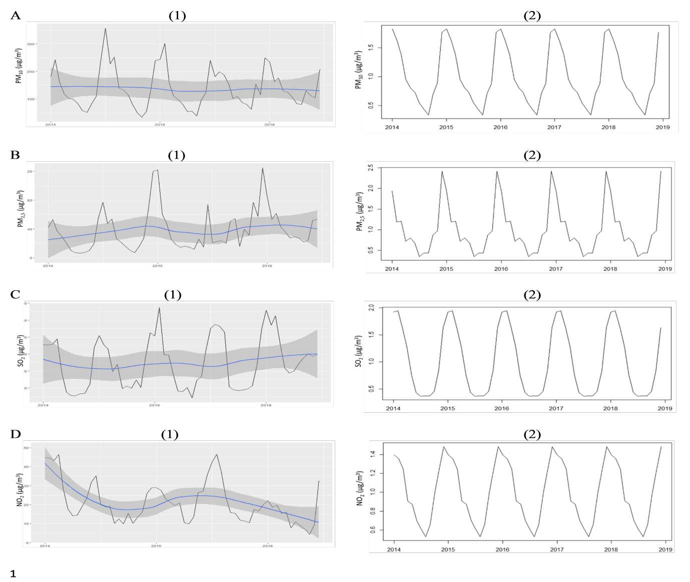

Figure 1: Monthly variation (raw series+trend (1) and seasonality (2)) in PM_{10} (A), $PM_{2.5}$ (B), SO_2 (C) and NO_2 (D) between 2014-2018.

Comparison of annual averages to regulatory values

Figure 2 presents the annual averages of pollutants and on the other hand the exceeding values compared to the guideline values. Annual values vary as follows: 14.46 $\mu g/m^3$ and 30.31 $\mu g/m^3$ (NO_2), 20.23 $\mu g/m^3$ and 32.73 $\mu g/m^3$ (SO_2), 126.52 $\mu g/m^3$ and 151.22 $\mu g/m^3$ (PM_{10}), 24.90 $\mu g/m^3$ and 44.94 $\mu g/m^3$ ($PM_{2.5}$). The highest values were recorded in 2014 (NO_2), 2015 (PM_{10}), 2017 ($PM_{2.5}$) and 2018 (SO_2). Moreover, except for SO_2, the annual levels are all above the guideline values.

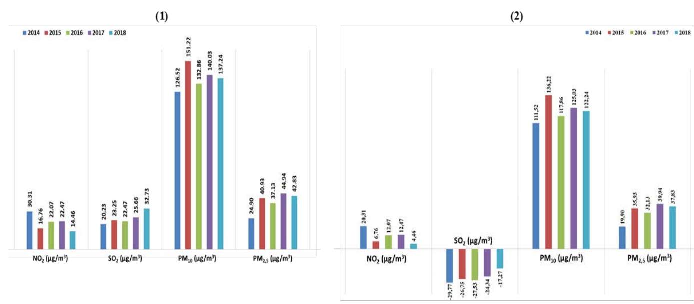

Figure 2: Annual averages in Dakar, between 2014-2018 in PM_{10}, $PM_{2.5}$, SO_2 and NO_2) (1) and WHO standard exceedance values (2).

Hospital admission and mortality

Over the period 2016–2018 and based on available values, hospital admission in Dakar is estimated at 168,939 patients. Of these, a total number of 10305 patients admitted for respiratory diseases can be estimated using Sylla's study. This work has also made it possible to estimate the number of patients admitted for respiratory diseases aged over 65 (927 patients) and those in the age range (8025 patients). Regarding mortality, 4237 cases were reported for 2017 [13]. Among the latter, a total number of 3798 adults (over 30 years old) is estimated by subtracting pediatric hospitals from the count. As for exposure, the calculated averages over the period 2016-2018 are: 19.67 ug/m^3 (NO_2), 26.95 ug/m^3 (SO_2), 136.71 ug/m^3 (PM_{10}) and 41.63 ug/m^3 ($PM_{2.5}$); 2017: 22.47 ug/m^3 (NO_2), 25.66 ug/m^3 (SO_2), 140.03 ug/m^3 (PM_{10}), 44.94 ug/m^3 ($PM_{2.5}$). Table 1 reports the number of admission and mortality cases attributable to short-term exposure to levels of pollutants above the threshold of 10 ug/m^3. For all ages combined, 1379 (13.38%) cases of hospital admission for respiratory diseases can be attributed to short-term exposure to PM_{10}. The latter is also the underlying cause of 315 (7.48%) non-accident deaths noted in 2017.

Table 1: Number of respiratory hospital admissions (between 2016 and 2018) and all-cause mortality (in 2017) attributable to short-term exposure above 10 $\mu g/m^3$.

Pollutants	Age range	RR	IC-95	Admissions		
				N	IC-95	%

SO_2	15-64 years old	1,00,20	(0,998-1,005)	27	(-27–67)	0,34
	>65 years old	1,00,40	(1,001-1,009)	6	(2–14)	0,67
PM_{10}	All age	1,01,14	(1,0062-1,0167)	1379	(776–1951)	13,38
NO_2	15-64 years old	1,002	(0,997-1,007)	15	(-23–54)	0,19%
	>65 years old	1,004	(0,996-1,012)	4	(-4–11)	0,39%
SO_2	All age	1,011	(1,005-1,017)	Mortality		
				72	(33–110)	1,7
PM_{10}	All age	10,06	(1,004-1,008)	315	(214–417)	7,48
$PM_{2.5}$	>30 years old	1,06	(1,02-1,11)	269	(94–468)	7,07
NO_2	All age	1,010	(1,007-1,013)	41	(28–51)	0,96

DISCUSSION

This study aimed to describe ambient air pollution in Dakar and estimate its health impact. It supports the existing documentation on air pollution in Dakar and could stimulate the implementation of policies to reduce population exposure [14].

The annual averages for airborne particles ($PM_{2.5}$ and PM_{10}) and NO_2 above guideline values. Regarding particles, they can be emitted directly into atmosphere (primary airborne particles) or formed there secondarily as a result of physico-chemical reactions (secondary airborne particles). Natural primary particles come mainly from soil erosion, especially in desert regions, sea spray, plants and volcanic eruptions. The main anthropogenic activities emitting primary particles are agriculture, manufacturing industry (construction and quarrying in particular), the residential sector (especially biomass and fossil fuels combustion and household waste incineration) as well as road traffic (mainly emissions from diesel engines). On average, annual levels over the study period ranged from 24.90 µg/m^3 to 44.94 µg/m^3 ($PM_{2.5}$) and from 126.52 µg/m^3 to 151.22 µg/m^3 (PM_{10}). Higher PM2.5 levels have been documented in West African cities such as Enugu (Nigeria) (78 µg/m^3), Ouagadougou (Burkina Faso) (46 µg/m^3) and Accra (Ghana) (93.30 µg/m^3) while in Benin and Gambia, lower levels were respectively found in Cotonou (10 µg/m^3) and Kanifing (21 µg/m^3). Higher levels are also found in Central Africa (Douala (Cameroon): 116 µg/m^3), East Africa (Addis Ababa (Ethiopia): 818 µg/m^3) and North Africa (Shobra (Egypt): 216 µg/m^3). As for PM_{10}, higher levels are found in Sapele (Nigeria) (434 µg/ m^3), Accra (Ghana) (322 µg/m^3) and Shobra (Egypt) (360 µg/m^3) while in Addis Ababa (Ethiopia), a lower level (80 µg/m^3) is reported. Annual levels for these pollutants are also above those recorded in recent years in America and Europe, where levels below 50 µg/m^3 (PM_{10}) and 25 µg/m^3 ($PM_{2.5}$).

For Nitrogen Oxides (NO_x), they result from the combination of oxygen and nitrogen during high temperature combustion processes. NO is predominantly emitted, but quickly oxidized to NO_2. Emissions into outdoor air come mainly from the use of fossil fuels in road traffic and industry (thermal power plants and cement factories in particular). NO_2 can also be produced during natural processes such as thunderstorms and volcanic eruptions. However, road traffic (diesel cars in particular) is the main contributors to atmospheric emissions. The annual averages in this study range from 14.46 µg/m^3 to 30.31 µg/m^3. Levels in this range are also reported in other West African cities: Abidjan (Côte d'Ivoire) (23.5 µg/m^3) and Bamako (Mali) (24.4 µg/m^3). Slightly higher levels were found in Yaoundé (Cameroon) (34.21 µg/m^3) and Cotonou (Benin) (32.5 µg/m^3), while in North Africa, a significantly higher level was recorded in Ben Arous (Tunisia) (178 µg/m^3). Moreover, in contrast to airborne particles, NO_2 levels are well below those observed in recent years in America and Europe.

Like the previously mentioned pollutants, SO_2 also comes from natural and anthropogenic sources. Volcanic eruptions are the main natural source while anthropogenic emissions come mainly from industrial processes of sulfuric acid and pulp production, petroleum refining as well as combustion of sulfur-containing fossil fuels in domestic heating installations and diesel-powered cars. In contrast to above-mentioned pollutants, annual averages of SO_2 are below guidelines values and range from 20.23 µg/m^3 to 32.73 µg/m^3. Significantly lower levels are also recorded in Bamako (14.41 µg/m^3) as well as in Cotonou, Yaoundé and Abidjan, where levels ranged from 2.096 µg/m^3 to 3.4 µg/m^3. In addition, higher levels are reported for North Africa, particularly in Cairo (Egypt) (69 µg/m^3) and Ben Arous (Tunisia) (104 µg/m^3).

In Africa, pollution has increased in recent years. Rapid urbanization and population and economic growth in large cities is coupled to high demand for energy, transportation, food and other amenities [15]. This situation has led to an increase in the number of car owners, greater use of solid fuels for cooking and heating as well as poor waste management practices, which combined to industrial activities and unpaved roads in several localities, is responsible for a high degradation of air quality.

Our study also reveals a seasonal variation of air pollution, which peaks always observed in December-January-February quarter, while the lowest levels are recorded in July-August-September quarter. The latter corresponds to wet season in Senegal while the former is part of dry season [16]. Similar variations are previously reported in Africa and in Dakar in particular. During dry season in Dakar, emissions tend to be maximum, due to intense car traffic and climatic conditions, harmattan in particular, favorable to continental aerosols transportation from northeast of Senegal. As for wet season, it is associated to monsoon favoring precipitation and wet deposition. The low levels of airborne particles could be explained by a direct effect of rain on them, while the low levels of gases result from their trapping by precipitation. In addition, wet season coincides to school vacations in Dakar and therefore less car traffic.

As regards exposure to air pollution and its health impact (hospital admission and mortality in particular); the link has long been documented by several studies in Europe and America. This link is confirmed by several other more recent studies. In view of the evidence, some countries like France have developed a methodological guide that they regularly update to facilitate estimation of air pollution health impact. In order to harmonize the approach, the WHO has developed a conceptual framework for this purpose. Thus, many countries regularly carry out estimation of air pollution health impact. Our study, which aimed to provide a pilot estimation for Dakar (Senegal), revealed 13.38% (1379) of hospital admission for respiratory diseases attributable to PM_{10} exposure between 2016 and 2018 for all ages combined. In addition, this pollutant is also the underlying cause of 7.48% (315) of non-accidental deaths recorded in 2017. There is a lack of documentation relating to air pollution health impact in sub-Saharan Africa, making it difficult to compare our results to those from others studies. This could be explained by poor access to health care services, poor management of health data and lack of air quality monitoring. This situation also reflects underestimation of air pollution health impact in African countries. There is therefore a need to improve this situation for a better estimation of air pollution health impact, especially as projections in Africa predict a greater impact if nothing is done.

The study has a number of limitations that should be taken into account for a better appreciation of the results. The health data used come from Senegal's health and social statistics yearbooks. Much information essential to air pollution health risks assessment is not documented, in particular the age structure of patients and causes of hospital admissions and mortality. In addition, some of the criteria necessary to ensure homogeneous exposure in the study area (demography, topography, climate, population's commuting patterns, presence of stationary sources of air pollution) are not rigorously verified due to the pilot aim of the study [17].

CONCLUSION

Air pollution is a real problem in Dakar in view of the level of indicators. Indeed, except for SO_2, levels of indicators are above the guideline values. With regard to their health impact, more exhaustive and more robust estimation would be very useful for better exposure reduction policies. To this end, air quality monitoring and health data management could be improved. In addition, climatic, topographical and demographic criteria, as well as population's commuting patterns and presence of stationary sources of air pollution, must be rigorously verified to ensure homogeneous exposure of population.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTION STATEMENT

Study conception and design: Mouhamadou Lamine DAFFE, Salimata THIAM and Mamadou FALL; Data analysis: Mouhamadou Lamine DAFFE; Interpretation and manuscript preparation: Mouhamadou Lamine DAFFE, Mamadou FALL, Salimata THIAM, Jackline YESSA, Fatoumata BAH and Awa NDONG. Mouhamadou Lamine DAFFE, Salimata THIAM, Fatoumata BAH, Awa NDONG, Jackline YESSA, Mathilde Cabral, Cheikh DIOP, Aminata TOURE, Absa LAM, Aminata MBOW-DIOKHANE, Mamadou FALL reviewed the results and approved the final version of the manuscript

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CONSENT FOR PUBLICATION

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

None sought.

COMPETING INTERESTS

No competing interests.

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