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Impact of Air Pollution on Ventilatory Function in Urban Population in a Sub-Saharan African Country

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Abstract

Background/Objective: Air pollution is a major public health issue, particularly in sub-Saharan African megacities. Diamniadio, an emerging urban and industrial hub in Senegal, has recently recorded alarming air quality levels linked to important road traffic, extensive construction activity, and intense industrial operations. The aim of this study was to evaluate the ventilatory function in population exposed to air pollution in Diamniadio. **Material and Methods:** A cross-sectional descriptive and comparative study was conducted in Diamniadio in April 2024. Participants aged 16 years and older were recruited following representative sampling across 17 neighborhoods of the municipality. Sociodemographic and clinical data were collected, and baseline spirometry was performed in all participants, measuring Forced Vital Capacity (FVC), Forced Expiratory Volume in One Second (FEV1), Tiffeneau ratio (FEV1/FVC) and mix-expiratory flow ($FEF_{25\%-75\%}$). **Results:** A total of 140 participants were enrolled, with a sex ratio of 0.75. The mean age was 47.02 ± 17.91 years. Mean measures of FVC, FEV1, $FEF_{25\%-75\%}$ were below predicted reference values, while FEV1/FVC was elevated. Ventilatory disorders (VD) were identified in 40.72% of the population study (n = 57), with obstructive VD being the most common (16.43%), followed by restrictive VD (12.86%) and mixed VD (11.43%). The majority of ventilatory impairments (91.23%) were observed among residents of neighborhoods located in close proximity to major road axes and industrial zones. **Conclusion:** This study highlights the impact of urban and industrial pollution on the development of VD in exposed populations. The geographic distribution of disorders suggests a close link with environmental exposure, underscoring the need to strengthen air quality monitoring and to implement respiratory health alert and prevention strategies in rapidly expanding urban areas in Senegal.

Keywords

One Health, Pollution, Spirometry, Senegal

1. Introduction

Air pollution is defined by the World Health Organization (WHO) as the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that alters the natural characteristics of the atmosphere [1]. According to [2], more than 99% of the world's population breathes air exceeding WHO pollutant thresholds, contributing to approximately 4.7 million deaths per year [2]. This phenomenon disproportionately affects low- and middle-income countries in Africa deaths from exposure to outdoor air pollution, disproportionately affecting low- and middle-income countries in Africa [3], such as Senegal, where the annual per capita average reached 63.7 μg/m^3 in 2019, representing 12.7 times the WHO recommended value [2]. Urban populations in Senegal are increasingly exposed to high levels of particulate matter (PM) and gaseous pollutants, yet comprehensive evidence on associated respiratory health outcomes remains fragmented. Recent air quality measurements (2024) were performed in Diamniadio-Sebikhotane, a rapidly expanding urban and industrial hub characterized by growing residential density, developing transport networks, and increasing industrial activity. Using an inertial impactor and a series of collection filters, these measurements revealed, along the Diamniadio-Sebikhotane corridor, pollution levels at least four times higher than the thresholds enforced in France, driven notably by PM > 1 μm, Total Carbon (TC) and Elementary Carbon (EC), iron [4]. In this context, the present study aimed to assess ventilatory function in population exposed to air pollution in Diamniadio.

2. Methodology

2.1. Study Design

We conducted a cross-sectional descriptive and comparative study in April 2024 in Diamniadio, Senegal.

2.2. Study Population

The study population comprised individuals aged 16 years and older, of both sexes, who had been residing for at least one year in one of the 17 neighborhoods of the megacity of Diamniadio. The sample size was calculated using Schwartz's formula for populations exceeding 10,000 inhabitants: $n = (\varepsilon^2 \times p \times q)/i^2 * 2$, with a 95% confidence level (ε = 1.96), an expected prevalence of 50% ($p = q = 0.5$), and a precision of 5% ($i = 0.05$), yielding a minimum sample of 380 participants for the parent study, which covered both the Sebikhotane and Diamniadio communes, based on the 2013 general census of populations. For the Diamniadio locality specifically, 146 participants were allocated proportionally across its 17 neighborhoods (21,049 inhabitants; 1163 households; 2045 concessions).

Household identification was carried out using cadastral maps of Diamniadio's neighborhoods. The 146 participants from these households were selected by random draw, conducted in the presence of the research team, neighborhood delegates, community elders, and community health workers.

Non-inclusion criteria were voluntary refusal to participate in the study, any medical condition contraindicating the performance of spirometry. and a duration of residence in the locality of less than 12 months. Exclusion criteria were poor cooperation during spirometry and/or non-interpretable spirometry data.

2.3. Study Protocol

A questionnaire was administrated to all participants through the KoboCollect platform to collect sociodemographic data (age, sex, place of residence), personal and family medical history, and smoking status. Anthropometric measurements (weight, height) were obtained using *Omron BF 511* bioelectrical impedance scales and *Fazzini* mechanical stadiometer. Body mass index (BMI) was calculated using the Quetelet formula: weight (kg)/height^2 (m). A physical examination was also performed, with particular emphasis on the respiratory system.

Baseline spirometry was carried out using the *Spirobank II Advanced* spirometer, regularly calibrated and interfaced with a computer running *MIR Spiro 1.1.* data analysis software. Prior to each test, detailed explanations and demonstrations were provided to ensure optimal participant cooperation. Measured parameters included Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), Tiffeneau ratio (FEV1/FVC) and mix-expiratory flow ($FEF_{25\%-75\%}$). All results underwent quality control and correction before analysis.

Spirometry data were interpreted using the GLI-2012 "Black" reference equations with the African-American ethnicity category, in accordance with recommendations for epidemiological studies and case finding in asymptomatic subjects. A Z-score < −1.96 (lower limit of normal, 2.5th percentile) was considered abnormal [5]; obstructive ventilatory disorder (OVD) was defined by FEV1/FVC and FEV1 Z-scores < −1.96, restrictive ventilatory disorder (RVD) by an FVC Z-score < −1.96 with a normal or ≥1.96 FEV1/FVC Z-score [5]; and mixed ventilatory disorder (MVD) by concomitant FVC and FEV1/FVC Z-scores < −1.96.

Severity grading was performed in accordance with the 2022 update of the European Respiratory Society (ERS) and American Thoracic Society (ATS) recommendations, which revised their 2005 standards and incorporated severity thresholds for pulmonary function impairment [6]. For all spirometric measurements, a three-level system to assess the severity of lung function impairment using Z-score values was used; Z-scores > −1.645 are normal, Z-scores between −1.65 and −2.5 are mild, Z-scores between −2.51 and −4 are moderate, and Z-scores < −4.1 are severe [6].

2.4. Statistical Analysis

Sociodemographic data were collected via KoboCollect and spirometry results were entered using *Microsoft Excel* 2023. Statistical analysis was performed using *IBM SPSS Statistics version* 31. Quantitative variables were expressed as means and standard deviations. Categorical variables were described as percentages and summarized using frequency tables. A paired Student's t-test was used to compare each participant's measured spirometric values with their individually predicted GLI reference values. Statistical significance was set at $p < 0.05$. A comparison of VD frequency between the two groups (high versus low exposure areas) was also conducted.

2.5. Ethical Considerations

The protocol was approved by the Senegalese National Ethics Committee for Health Research (CNERS): *Protocol SEN23/42*, *Opinion n°0000329MSAS/CNERS/SP*. All participants provided free and informed consent by signing a written consent form. They were assured of the anonymity and confidentiality of the information collected throughout the data collection, analysis and dissemination process, in accordance with the principles of the Declaration of Helsinki.

3. Results

3.1. General Characteristics

Of the 146 individuals initially drawn by random sampling, 140 (95.9%) completed the survey and were included in the final analysis; 6 participants were excluded due to poor cooperation during spirometry and/or non-interpretable spirometry data. Among the 140 participants enrolled, the male-to-female sex ratio was 0.75. The mean age was 47.02 ± 17.91 years (range: 16 - 86 years). Mean weight, height, and BMI were 68 ± 14.91 kg, 1.70 ± 0.09 m and 23.52 ± 5.50 kg/m^2, respectively. The majority of participants were non-smokers (85.7%), while current and former smokers accounted for 3.6% and 10.7%, respectively. Among participants, 74.28% reported at least one comorbidity, with arterial hypertension, respiratory allergies (19.29%; n = 27) and asthma (10.71%; n = 15) being the most prevalent conditions.

Based on a municipal cadastral map, neighborhoods were classified into high pollution risk (Group 1) or low pollution risk (Group 2) categories depending on their proximity to major pollution sources (**Figure 1** and **Figure 3**). Group 1 neighborhoods directly host or sit adjacent to a dense network of major infrastructure, including extensive transport axes (roads, tracks, lanes, highways, and railways), at least seven established industrial complexes in the urban hub, including Diamniadio

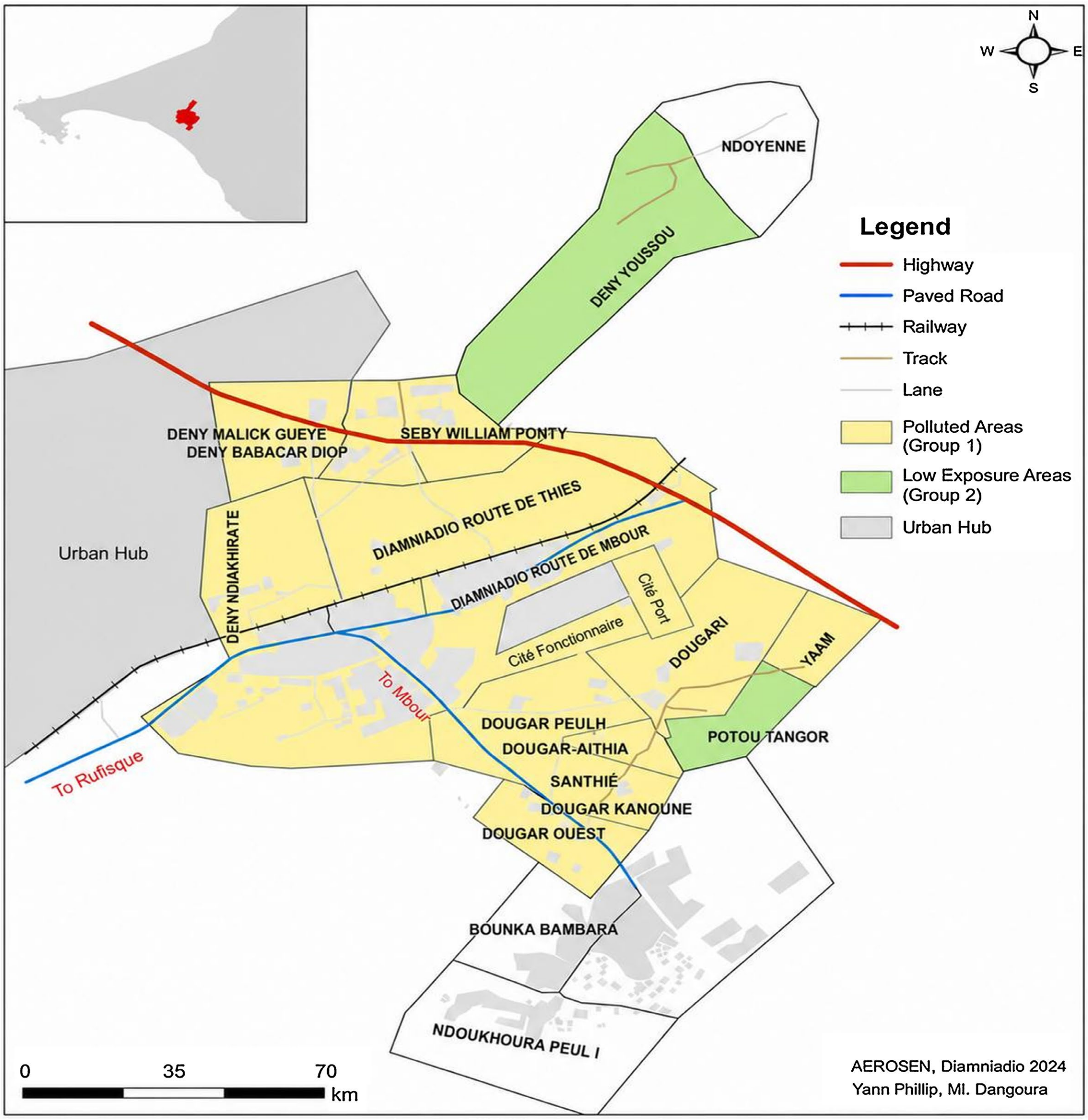

Figure 1. Neighborhoods and pollution exposure.

International Industrial Park and Integrated Special Economic Zones, also large public facilities and ongoing residential construction. Conversely, Group 2 consists of the neighborhoods located away from these heavily polluted areas. Geographically, the neighborhoods in Group 2 were located more than 5 kilometers from the sources of pollution, unlike the neighborhood constituting Group 1.

Among the 140 participants, 130 (92.9%) were from Group 1 (high pollution-risk neighborhoods, n = 15) and 10 (7.1%) were from Group 2 (low pollution-risk neighborhoods, n = 2). The distribution of participants across the 17 neighborhoods is presented in Table 1.

3.2. Spirometric Parameters

Table 2 presents the predicted and measured spirometric values recorded in the

Table 1. Distribution of the 140 included participants across the 17 neighborhoods of Diamniadio, by pollution exposure group.

N°	Neighborhood	Exposure group	Included participants (n)
1	Diamniadio Route de Thies	Group 1 (high-risk)	20
2	Citédes Fonctionnaires	Group 1 (high-risk)	18
3	Sebi William Ponty	Group 1 (high-risk)	17
4	Diamniadio Mbalibor	Group 1 (high-risk)	13
5	Cité du Port	Group 1 (high-risk)	11
6	Deny Ndiakhirate	Group 1 (high-risk)	11
7	Deny Malick Gueye	Group 1 (high-risk)	9
8	Dougar Lossa	Group 1 (high-risk)	7
9	Dougar Peulh	Group 1 (high-risk)	5
10	Yam	Group 1 (high-risk)	4
11	Dougar Aithia	Group 1 (high-risk)	4
12	Deny Babacar Diop	Group 1 (high-risk)	3
13	Deny Demba Codou	Group 1 (high-risk)	3
14	Dougar Ouest-Bounka Serere	Group 1 (high-risk)	3
15	Dougar Kanoune-Santhie	Group 1 (high-risk)	2
16	Deny Youssou	Group 2 (low-risk)	7
17	Potou Tangor	Group 2 (low-risk)	3
	Total	**Group 1:** 130 (92.9%) **Group 2:** 10 (7.1%)	**140**

Table 2. Spirometric parameters.

Spirometric parameters	Predicted values (mean ± SD)	Measured values (mean ± SD)	p-value	t	df
FVC (L)	3.70 ± 0.83	2.76 ± 0.80	$p < 0.001$	−18.42	139
FEV1 (L)	3.05 ± 0.72	2.40 ± 0.75	$p < 0.001$	−14.26	139
FEV1/FVC (%)	82.04 ± 3.57	87.37 ± 10.00	$p < 0.001$	6.26	139
$FEF_{25\%-75\%}$ (%)	3.48 ± 0.85	3.12 ± 1.31	$p < 0.001$	−3.62	139

study population, along with the results of the paired Student's t-test. Measured values of FVC, FEV1, and $FEF_{25\%-75\%}$ were significantly lower than their respective predicted reference values, while the measured FEV1/FVC ratio was significantly higher than predicted ($p < 0.001$ for all four parameters).

3.3. Frequency of Ventilatory Disorders

Figure 2 presents the frequency of VD identified among participants. Overall, 40.72% of the study population exhibited a VD (n = 57), with OVD being the most prevalent pattern (16.43%; n = 23), followed by RVD (12.86%; n = 18) and MVD (11.43%; n = 16).

Female participants were more frequently affected by OVD (50%) whereas male participants exhibited equal proportions of MVD (34%) and RVD (34%). Among the 23 cases of OVD identified across both sexes, obstruction was equally distributed between proximal and distal localizations (9 cases each), with 5 cases classified as diffuse obstruction.

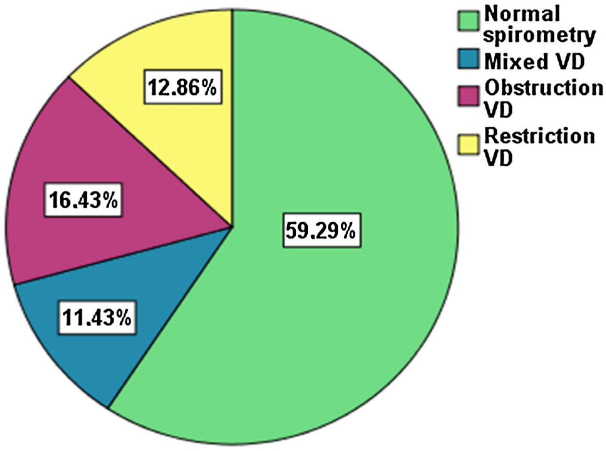

Figure 2. Frequency of ventilatory disorders.

3.4. Geographic Sources Pollution and Distribution of Ventilatory Disorders

Neighborhoods with the highest number of participants presenting VD were those comprising Group 1, which accounted for 91.23% (n = 52) of all 57 identified ventilatory abnormalities. The most represented were Diamniadio Route de Thies and Cité des Fonctionnaires, which together accounted for 28.08% of all VD, followed by Diamniadio Mbalibor (12.28%) and Sebi William Ponty (8.77%).

These areas are characterized by their proximity to National Road Number 2 (RN2), the old and new train railway lines and several industrial facilities, including fish processing plants, agri-food industries, a concrete batching plant and brickworks (Figure 3).

4. Discussion

Air pollution remains as a significant public health concern, especially because of the combined health risks linked to simultaneous exposure to multiple air pollutants [7]. Our findings reveal a notable impairment of ventilatory function, with an overall frequency of VD of 40.72%. The documentation of such functional abnormalities through spirometry addresses a largely underexplored field in sub-Saharan Africa, where, as reported by Katoto *et al.* (2019) and Glenn *et al.* (2022), objective epidemiological data on the respiratory effects of outdoor air pollution remain particularly scarce [3] [8]. Functional assessment indeed revealed a statistically

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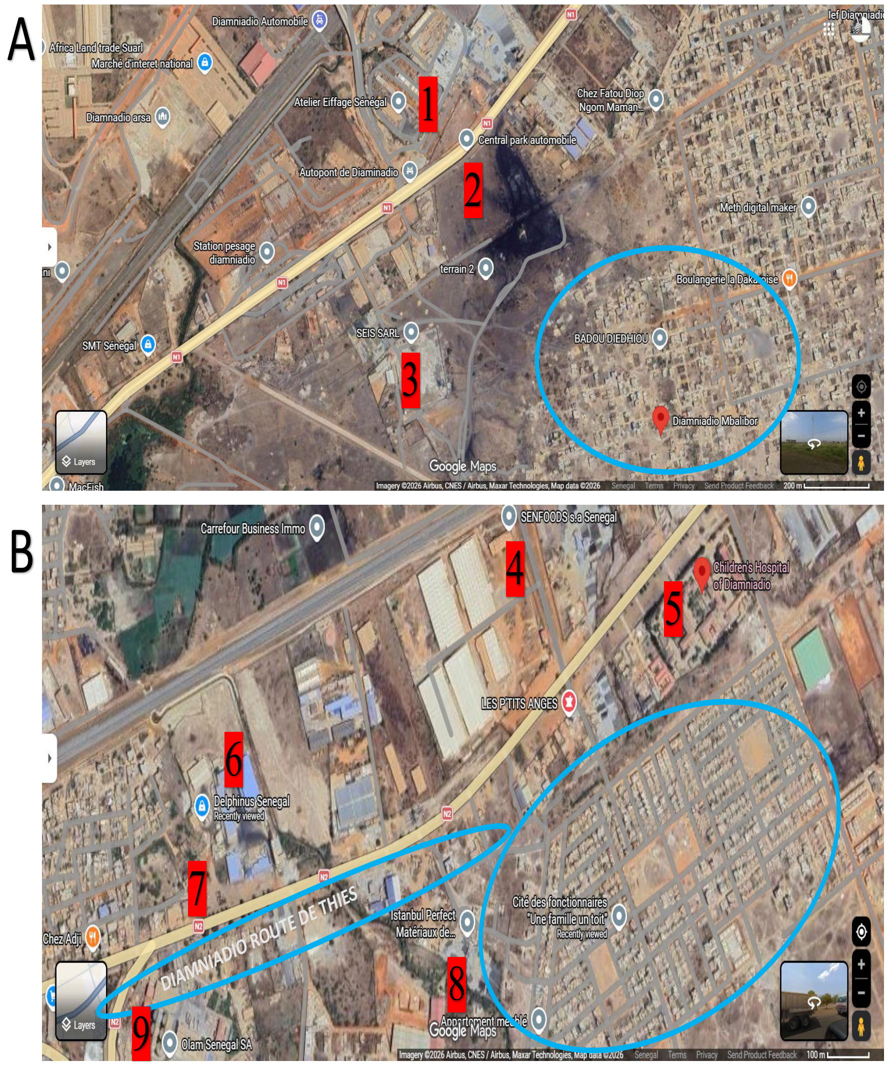

Figure 3. Geographic distribution of pollution sources. (A) Diamniadio Mbalibor neighborhood: 1) Eiffage Senegal, a concrete batching plant; 2) Central Park Automobile, car garage, land clearing and burning; 3) SEIS SARL, paper factory. (B) Cité des Fonctionnaires and Diamniadio Route de Thies neighborhoods: 4) SENFOODS, agri-food industry; 5) Children's Hospital, fumes from biomedical waste incineration; 6) Delphinus Senegal, fish processing plant; 7) National Road No.2, RN2; 8) Istanbul Perfect, brick and paving stone manufacturing plant; 9) Olam Senegal SA, wheat processing and distribution plant.

significant reduction ($p < 0.001$) in measured values of FVC, FEV1 and $FEF_{25\%-75\%}$ compared to the predicted reference values of the Global Lung Initiative (GLI) [5]. The predominant pattern was OVD (16.43%), followed by RVD (12.86%) and MVD (11.43%), findings consistent with those reported by Bopaka *et al.* (2021) conducted in Congo-Brazzaville among mechanics occupationally exposed to urban pollution [9]. Reference [10] demonstrated in a comparative study that the ventilatory function test of the urban population group exposed to air pollution was markedly declined when compared with the control group, which was statistically significant. It was also found that the mean values of parameters like FVC, FEV1, FEV1/FVC, $FEF_{25\%-75\%}$, were statistically different in <30 years and >30 years among urban-exposed population and control group.

Air composition analyses previously conducted in the area of Diamniadio-Sebikhotane by Delville *et al.* (2024) identified elevated levels of particulate matter (PM > 1 µm), Total Carbon (TC), elemental carbon and iron; pollutants commonly found in rapidly expanding urban environments [4]. The particulate matter (PM10) is considered as the criteria parameter for assessing the quality of air that we respire as it is known to produce a significant impairment in ventilatory function, leading to respiratory diseases, including bronchial asthma and chronic obstructive pulmonary disease [10]. These contextual data suggest that the ventilatory function impairment observed in our participants may be related to chronic exposure to these airborne pollutants. Furthermore, the predominance of OVD suggests a potential impact of chronic environmental exposure. Indeed, previous studies [11] [12] have demonstrated that prolonged inhalation of airborne PM and pro-allergenic or toxic pollutants is likely to induce oxidative stress and chronic airway inflammation, leading to a long-term reduction in expiratory flows and the subsequent development of ventilatory abnormalities.

This suggestion of an environmental origin is further supported by the general characteristics of our sample. The mean age of participants was 47.02 years, and the vast majority were non-smokers (85.7%), with current smokers accounting for only 3.6%. This very low smoking rate allows tobacco use to be ruled out as the primary confounding factor, redirecting attention toward exogenous determinants related to the urban and industrial living environment. The considerable proportions of respiratory allergies (19.29%) and asthma (10.71%) further suggest that air quality may act as an exacerbating or unmasking factor in individuals with pre-existing pulmonary susceptibility or atopy, as supported by the study conducted by prior data in Ivory Coast (West Africa) [13].

Furthermore, the diversity of ventilatory disorder profiles according to sex suggests distinct exposure patterns. Female participants were predominantly affected by OVD (50%). This could be explained by greater anatomical susceptibility, characterized by narrower airways [14], combined with the proximity or domestic exposures linked to indoor pollution from biomass combustion smoke, a pattern previously described among Senegalese women [3] [15].

Descriptive spatial analysis revealed that 91.23% of VD were concentrated among residents of Group 1 neighborhoods, particularly Diamniadio Route de Thies, Cité des Fonctionnaires and Diamniadio Mbalibor. Conversely, populations residing in Group 2 neighborhoods, Deny Youssou and Potou Tangor, displayed markedly lower prevalences, accounting for 8.77% of VD. This pronounced geographic gradient suggests a close association with the proximity to the megacity's major anthropogenetic infrastructures. The most affected neighborhoods are indeed located in close proximity to National Road Number 2 (RN2), along which approximately 12,000 vehicles circulate daily [4], the old and new train railway lines, as well as several active industrial sites, including concrete batching plants, brickworks and agri-food processing facilities. Previous evidence shows that in West Africa, road traffic associated with an aging vehicle fleet and emissions from anthropogenic activities had a negative impact on pulmonary function [3].

Air pollution in African megacities presents a growing public health emergency and despite the rising PM2.5 levels, only 17 of the 54 African countries have established ambient air quality standards [16]. The urgency for enhanced air quality management in these growing urban areas cannot be overstated [17]. Over 80% of air quality control strategies in Africa focus on household air pollution, while only 17% focus on ambient sources of air pollution, yet these industrial, traffic, and trash-burning sources are increasing as urbanization increases [16]. Whilst air quality control strategies in many high-income cities take a multifaceted approach that accounts for sources, emissions, chemical transformations, and meteorological effects, these elements remain underutilized and poorly understood in the fast-growing, unevenly expanding cities of emerging economies. This gap in failing to put knowledge into action underscores the importance of improving air quality frameworks to mitigate the adverse health effects of atmospheric pollution in these regions and raises questions about the burden of diseases from exposure to air pollution in the sub-Saharan African countries.

This study is subject to certain limitations, however. The absence of direct and individualized measurement of pollutant exposure constrained us to rely on previously conducted air quality measurements carried out in the area. The cross-sectional design additionally precludes long-term temporal monitoring evolution of participants' ventilatory function parameters.

5. Conclusion

This study reveals a high frequency of VD in urban population, heavily concentrated in areas in close proximity to major road axes and industrial facilities. Together with previously conducted air pollution measurements in the area, these findings suggest a close association between urban expansion and the alteration of ventilatory function in sub-Saharan African context. In light of these observations, the adoption of a One Health approach is essential, requiring the implementation of continuous air quality monitoring and strict regulatory frameworks to reconcile ecological urbanization with the improved population outcomes.

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Author Contributions

Conceptualization, Tastevin, Y.-P., Diaw, M. and Sar, F.B.; methodology, Tastevin, Y.-P., Diaw, M. and Sar, F.B.; software, Djite, M., Coly, M.S. and Tastevin, Y.-P.; validation, Tastevin, Y.-P., Diaw, M., Mbengue A., and Sar, F.B.; formal analysis, Djite, M., Coly, M.S. and Sar, F.B.; investigation, Djite, M., Diop, E.D., Diallo, B.M., Fall, M., Tastevin, Y.-P. and Sar, F.B; resources, Tastevin, Y.-P. and Sar, F.B.; data curation, Djite, M., Tastevin, Y.-P., Diaw, M., Sow, A.K., Mbengue A., and Sar, F.B.; writing-original draft preparation, Djite, M. and Coly, M.S.; writing-review and editing, all authors; visualization, Djite, M., Coly, M.S., Mbengue, A., and Sar, F.B.; supervision, Diaw, M., Mbengue A., Ba, A., Tastevin, Y.-P. and Sar, F.B.; project administration, Tastevin, Y.-P., Diaw, M. and Sar, F.B.; funding acquisition, Tastevin, Y.-P. and Sar, F.B. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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