Original Article

Indoor and Outdoor Air Quality Concentration Levels in Selected Hospital Environments in Kigali, Rwanda

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Abstract

Background

Exposure to polluted air is a significant cause of negative health effects. Air quality is crucial in hospital environments as patients and healthcare workers spend more time in such settings for treatment where they experience prolonged and repetitive exposure; however, comprehensive studies on air quality in hospital environments in Rwanda are scarce.

Objective

This study aimed to determine the indoor and outdoor air quality concentration levels in selected hospitals and investigate potential sources of air pollution.

Methods

This descriptive cross-sectional study was conducted in two public and two private hospitals in Kigali that were randomly selected using a simple random sampling technique. Real-time particulate matter (PM), $PM_{2.5}$ and PM_{10} were measured using calibrated Purple Air PA-II sensors. An observation checklist was used to identify potential sources of air pollution. One way ANOVA and t-tests were performed.

Results

Air quality levels in selected hospitals exceeded acceptable limits. The daily average indoor $PM_{2.5}$ concentration ranged from 23.52 µg/m³ to 121.60 µg/m³, and the PM_{10} levels varied from 25.98 µg/m³ to 131.17 µg/m³. In all hospitals, the difference in average indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations were not statistically significant.

Conclusion

All recorded concentrations exceeded the WHO air quality guidelines. The study calls for strategies to improve air quality in hospitals.

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Keywords: air quality, air pollution, hospital, Rwanda

Introduction

Air quality is essential for human health and well-being as humans depend on a healthy environment with good air quality.[1,2] Air pollution has become a global concern as exposure to polluted air contributes to significant diseases that result in poor health outcomes, including hospital admissions and deaths.[3–6] For example, in 2019, the WHO reported 4.2 million deaths worldwide due to exposure to air pollution from fine particle air pollution.[7] The majority (89%) of those premature deaths occurred in the low and middle income countries, including Africa.[7] This pollution is the result of traditional energy sources on this continent and the notable increase in vehicles, most of which rely on fossil fuels, and inadequate waste management practices.[8] A series of studies highlight several air pollutants, including particulate matter (PM), carbon monoxide, and nitrogen dioxide.[3,5]

The PM can harm human health and varies widely in concentration and composition.[9] PM is divided into different categories based on the size of the particles. $PM_{2.5}$ (fine particles with aerodynamic diameters of less than or equal to 2.5μm) is the category with the greatest negative impact on human and environmental health as it can enter the lungs, damage lung tissue, and spread throughout the body through blood circulation.[10,11] PM_{10} are particles with aerodynamic diameters of less than or equal to 10μm.[10,11] The WHO reports that PM is likely to cause 6.7 million deaths annually.[3,7] Specifically, in 2019, exposure to PM was reported to be responsible for more than 4 million deaths.[12,13] Episodes of asthma, severe bronchitis, and increased susceptibility to respiratory infections can all be caused by short-term exposure to PM for hours or days.[14] Living for a long time in a region with high concentrations of PM is known to cause impaired lung function, other diseases, and early death.[6,13, 14] The situation worsens for people with pre-existing health conditions, especially patients in healthcare facilities with poor air quality.[17] Human and nonhuman activities contribute significantly to the increased level of environmental pollution. Scholars illustrate that factors such as industrialization, rapid urbanization, and natural phenomena contribute to environmental degradation, including changes in air quality.[18] Industries release emissions containing air pollutants such as volatile organic compounds, PM, and other air pollutants because of inappropriate waste management.[19,20] It is not only industrialization but also other human activities, such as rapid urbanization,[21] that contribute to air pollution as it is directly related to the construction of industries; increased transport, which releases emissions containing air pollutants; deforestation; changes in land use; and the notable increase in the use of air conditioning.[14] Natural phenomena such as volcanic eruptions and wildfires also contribute to air pollution because they emit air pollutants such as sulfur dioxide, carbon monoxide, and harmful fine particulates known as $PM_{2.5}$ into the atmosphere and affect air quality once the concentration of these pollutants is above acceptable limits.[9,22]

Air quality guidelines differ from country to country. Many countries have established national air quality guidelines to control environmental pollution. For example, in the UK, the annual average of PM_{10} (should not exceed 40 μg/m^3 and for $PM_{2.5}$ it should not exceed 10 μg/m^3, and the acceptable daily average for PM_{10} is 50 μg/m^3.[23] The acceptable daily mean concentration for $PM_{2.5}$ is 25 μg/m3 in Australia, 35 μg/m3 in the United States, and 30 μg/m3 in Canada.[24] The WHO established globally acceptable limits to guide other countries to have global guidelines.[25] The WHO Air Quality guidelines state that the acceptable daily mean concentration for $PM_{2.5}$ should not exceed 15 μg/m^3 and for PM_{10} it should not exceed 45 μg/m^3. Compared to the annual concentration, WHO indicates that acceptable limits for $PM_{2.5}$ are 5 μg/m^3 and for PM_{10} it is15 μg/m^3.[25] According to the Rwanda Environmental Management Authority (REMA), air pollution in Rwanda is beyond acceptable national air quality guidelines.[26]

Rwanda, a low-income country, is characterized by high urbanization rates, economic growth, and a transportation system highly dependent on fossil fuels.[27] This scenario increases levels of air pollution, particularly in urban centers such as Kigali City. The data show that the average ambient $PM_{2.5}$ in Kigali was 52 µg/m³ from March 2017 to July 2018, significantly exceeding the interim target of the WHO.[3,28] In 2021, the REMA reported $PM_{2.5}$ as the main air pollutant in Rwanda.[26] High levels of pollution have been linked to thousands of premature deaths reported annually in Rwanda.[28] Moreover, REMA reported that the level of air pollution in most parts of the country is higher than the safe limits.[26] Despite this, there is a paucity of studies on air pollution in Rwanda, especially in healthcare settings where people spend a long time looking for health services. This research gap led to the present study that determined the levels of indoor and outdoor air quality concentrations in selected Kigali hospitals and investigated potential sources of air pollution in these settings.

Materials and Methods

The study was carried out in Kigali, the capital of Rwanda. Kigali is located in the center of Rwanda, and covers an area of 730 km². It experiences an annual average high temperature of 27 °C and a low temperature of 16 °C. Kigali is divided into three administrative districts, namely Gasabo, Kicukiro, and Nyarugenge.[15] The city was chosen for the study due to its heavy industrial activity, traffic, and population density. A descriptive cross-sectional study was conducted in selected hospitals to assess air quality within the facilities. To determine the study locations, a simple random sampling technique was used to select two public hospitals (Hospitals C & D) and two private hospitals (Hospitals A & B). The selected hospitals are in the district hospital category. Air sampling stations were randomly chosen in the hospitals.

The air sampling process was carried out using calibrated Purple Air PA-II sensors to measure the concentration of particles (PM_{10} and $PM_{2.5}$) in real time. Purple Air PA-II's calculations of PM_{10} and $PM_{2.5}$ mass concentrations are based on particle counts.[29,30] The Air Quality Sensor Performance Evaluation Center indicates that these air sensors have high precision and accuracy.[31,32] These sensors use memory cards to record air quality data and must be connected to electricity. Data collection was carried out during the beginning of the rainy season from 7 to 21 February 2023. Air quality was evaluated for 8 hours from 8:00 am to 4:00 pm, seven days a week. In addition to sensor data, the adopted observation checklists were used to identify potential sources of air pollution within the hospitals. The checklists were adapted from existing standards of operation procedure on air quality in the Department of Environmental Health Sciences at the University of Rwanda. Air sensors were mounted at a height of between 1.5 and 1.8 meters within the breathing zone opposite the windows and doors in different services, such as hospitalization, consultation rooms, maternity, and laboratory services, to measure indoor concentrations. Additional sensors were installed outside to assess outdoor PM_{10} and $PM_{2.5}$.

Data analysis

Quantitative data were extracted from the memory card and analyzed using Microsoft Excel, and the observation checklist data were entered in excel and we used STATA for analysis. Analysis of Variance (ANOVA) test was performed to compare the means of $PM_{2.5}$ and PM_{10} between the hospitals at level of significance of less than 5%. Similarly, independent t test was also performed to compare the difference between indoor and outdoor $PM_{2.5}$ as well as indoor PM_{10} and outdoor PM_{10}. The findings were then summarized in tabular form.

Ethical consideration

The Institutional Review Board (IRB) of the College of Medicine and Health Sciences granted ethical clearance for the research (Ref: CMHS/IRB/034/2023). Additionally, the management of each hospital offered permission for data collection. The study's objectives, methods, duration, significance, and confidentiality measures were explained to hospital management.

The hospital management agreed to participate voluntarily and provided access to different hospital sampling stations.

Results

The daily mean indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations at each of the four hospitals are presented in Figure1.

The results reveal that on day 6 hospital C encountered a maximum daily mean of 121.60 μg/m³ for $PM_{2.5}$ (indoors) and 131.17 μg/m³ for PM_{10} (outdoors), which exceed the thresholds established by WHO.[25]

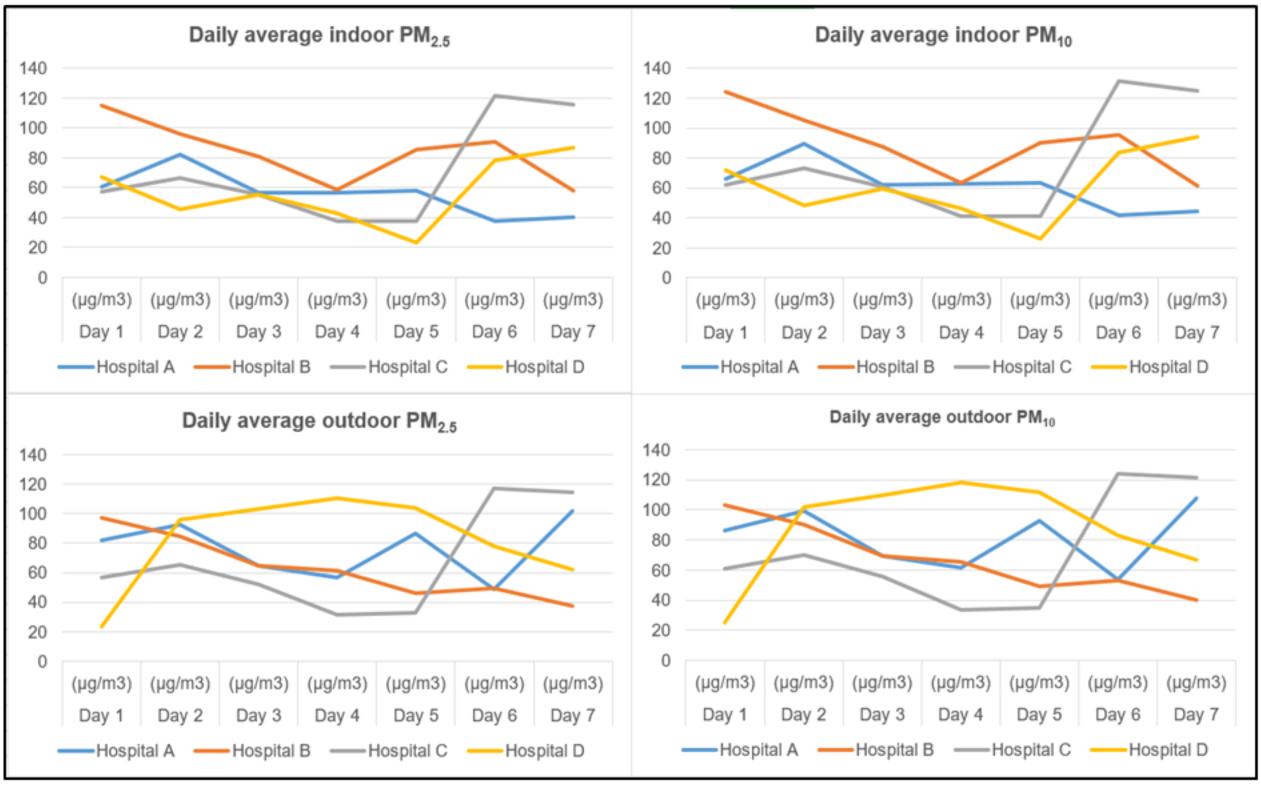

Figure 1. Daily averages of indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations per hospital

Table 1, shows that the indoor mean concentrations of both $PM_{2.5}$ and PM_{10} in the sampled hospitals were not statistically significantly different. Similar results were found in the outdoor sampling sites for both $PM_{2.5}$ and PM_{10}, which did not differ significantly between the hospitals.

Table 1. Comparison of the means of indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations between hospitals

Variable	Hospital	Mean	Std. Dev.	f	df	P value
Indoor $PM_{2.5}$	Hospital A	56.03	14.55	2.01	3	0.138
	Hospital B	83.52	20.34			
	Hospital C	70.27	34.61			
	Hospital D	57.22	22.08			
Indoor PM_{10}	Hospital A	61.55	15.84	1.92	3	0.153
	Hospital B	89.76	22.15			
	Hospital C	76.27	37.18			
	Hospital D	61.57	23.61			
Outdoor $PM_{2.5}$	Hospital A	76.05	19.52	0.71	3	0.557
	Hospital B	62.97	21.51			
	Hospital C	67.12	35.38			
	Hospital D	82.46	30.97			
Outdoor PM_{10}	Hospital A	81.57	20.37	0.75	3	0.533
	Hospital B	67.15	22.56			
	Hospital C	71.47	37.39			
	Hospital D	88.23	33.07			

Table 2 shows that the mean concentrations of outdoor $PM_{2.5}$ and PM_{10} are slightly higher compared to indoor $PM_{2.5}$ and PM_{10}. However, the difference is not statistically significant since the p-value for indoor $PM_{2.5}$ and outdoor $PM_{2.5}$ is greater than 0.05 (p=0.3762). Similarly, the p-value for indoor PM_{10} and outdoor PM_{10} is greater than 0.05 (p = 0.4579).

Table 2. Comparison of the means between indoor and outdoor $PM_{2.5}$ and indoor and outdoor PM_{10}

Variable	Mean	Std. Dev.	t	P value
Indoor $PM_{2.5}$	66.76496	25.36121	-0.899	0.376
Outdoor $PM_{2.5}$	72.1775	27.20849		
Indoor PM_{10}	72.2875	27.18236	-0.753	0.457
Outdoor PM_{10}	77.10714	28.81469		

Table 3 highlights the weekly average, minimum, and maximum indoor concentrations of $PM^{2.5}$ and PM_{10} within the chosen medical facilities. The table shows that the highest indoor mean $PM_{2.5}$ concentration calculated in the selected hospitals was 83.52 μg/m³, and the highest mean PM_{10} concentration observed was 89.75 μg/m³. Additionally, the table highlights the weekly average outdoor $PM_{2.5}$ and PM_{10} concentrations in selected hospitals. This table illustrates that the highest outdoor mean concentrations of $PM_{2.5}$ and PM_{10} were 82.46 μg/m³ and 88.23 μg/m³, respectively.

Table 3. Concentration of weekly average indoor and outdoor $PM_{2.5}$ and PM_{10} in selected hospitals

Variables	Hospital	Sampling hours	Mean (μg/m³)	Min (μg/m³)	Max (μg/m³)
Indoor $PM_{2.5}$	Hospital A	56	56.03	15.61	218.85
	Hospital B	56	83.52	8.45	172.07
	Hospital C	56	70.27	20.35	158.35
	Hospital D	56	57.22	9.32	133.35
Indoor PM_{10}	Hospital A	56	61.55	17.30	253.25
	Hospital B	56	89.75	9.85	188.48
	Hospital C	56	76.27	22.28	170.2
	Hospital D	56	61.56	12.09	145.52
Outdoor $PM_{2.5}$	Hospital A	56	76.14	17.56	176.78
	Hospital B	56	62.97	19.53	157.72
	Hospital C	56	67.12	16.09	166.50
	Hospital D	56	82.46	8.06	609.96
Outdoor PM_{10}	Hospital A	56	81.56	19.94	193.30
	Hospital B	56	67.15	21.17	168.11
	Hospital C	56	71.47	18.06	176.64
	Hospital D	56	88.23	8.069	704.04

Table 4 shows that all selected hospitals are located near the main road with high traffic, and that some have construction work being done on their buildings. The table shows that all hospital windows are open, which can contribute to an increase in the concentration of indoor air pollution. In addition, restrooms are near hospitalization rooms, which can increase air pollutants from cleaning materials.

Table 4. Possible sources of air pollution in hospitals and characteristics of hospitals

Variables	Hospital A	Hospital B	Hospital C	Hospital D
The hospital is close to industrial areas or nearby industries.	-	-	-	-
The hospital is located near the bus station.	-	-	-	-
The hospital is close to busy roads with a significant flow of vehicles.	+	+	+	+
Is construction activity currently underway on hospital premises or its surroundings?	+	-	-	+
At this time, demolition works are underway within the hospital.	-	-	-	-
Burning sites or burning activities within or around the hospital	-	-	-	-
The windows are open during the day.	+	+	+	+
Ventilation units, such as windows and doors, operate properly.	+	+	+	+
The hospital uses an incinerator that releases smoke through chimneys.	-	-	-	-
The patient restrooms and bathrooms are located close to the hospitalization wards.	+	+	+	+

Abbreviations: + = Yes, - = No

Discussion

This study assessed air pollution levels in selected hospitals in Kigali, specifically focusing on $PM_{2.5}$ and PM_{10}. The results revealed that the concentration of these pollutants in all selected hospitals significantly exceeded the acceptable limits established by the WHO.[3] The daily average indoor concentration of $PM_{2.5}$ ranged from 23.52 to 121.60 μg/m3, and PM_{10} ranged from 41.04 to 131.17 μg/m^3. These measurements significantly exceed the 24-hour guidelines set by the WHO, which suggest a limit of 15 μg/m^3 for $PM_{2.5}$ and 45 μg/m^3 for PM_{10}. These results mirror findings from a similar study conducted in two urban hospital sites in Kashan, Iran, that show average concentrations for $PM_{2.5}$ and PM_{10} of 45.5 μg/m^3 and 162.7 μg/m^3, respectively.[33] A study conducted in Greece further corroborates these results and report 24-hour average concentrations of $PM_{2.5}$ and PM_{10} exceeding WHO recommended limits.[3,34] Furthermore, our results correspond with a research investigation into indoor air quality in a large university hospital in Al-Khobar City, Saudi Arabia, where PM concentrations surpassed WHO recommended limits.[3,35]

Additionally, our findings are supported by the REMA report of 2021, which affirm that indoor and outdoor air are slightly above the safe limits of WHO.[26] Exposure to excessive $PM_{2.5}$ can lead to a number of adverse health effects including inflammatory responses, oxidative stress generation and genotoxicity with associated organ malfunctions, and eventually death.[36,37,38]

The inspection of the hospital locations provided further context for these results. All selected hospitals are close to busy roads and some are surrounded by ongoing construction activities. This observation aligns with the established scientific literature that vehicle emissions contribute significantly to the concentration of airborne PM in various settings, including hospitals.[39] A previous study confirmed a high probability of finding a high concentration of air pollutants, especially PM, in institutions near busy roads as vehicle emissions inevitably infiltrate hospital environments, thus increasing the PM concentration.[40] Furthermore, our study showed that the wards are often near bathrooms where cleaning and disinfectant products are frequently used. Previous studies provide evidence that the use of these products has the potential to raise levels of suspended PM in healthcare facilities,[34,35,40] although other research findings counter this argument by asserting that detergents do not significantly affect the levels of suspended PM indoors within hospital settings,[39]and this difference could be associated with many factors such as types detergents, concentrations, interaction with other cleaning agents among others. Calling conducting further investigation in our setting.

The construction activities observed on some hospital premises could further contribute to the increased levels of air pollution. Maintenance and construction work within hospitals have been recognized in the literature as factors that contribute to elevated levels of air pollution in such settings.[40]

Limitations

Despite the valuable information provided by this study, certain limitations must be noted. Firstly, the research was conducted within only four selected hospitals in the city of Kigali. This means that our findings may not be fully representative of all clinical settings in Rwanda. More research is needed in other hospitals and locations throughout the country to provide a complete understanding of air quality in Rwandan health facilities. This study was conducted at the beginning of the rainy season, and the data were collected over seven days. The study did not perform a statistical analysis to test the correlation between hospital air quality and associated factors.

Conclusion

The findings of this study provide valuable scientific insight into the concentrations of PM2.5 and PM10 in selected hospitals, illustrating that their levels exceed the acceptable air quality limits established by the WHO. Given these elevated concentrations, patients and healthcare providers, particularly those with existing health conditions, are potentially at an increased risk of experiencing negative health effects. Therefore, it is imperative to consider the establishment of routine air quality monitoring systems within hospitals. Short- and long-term strategies to improve air quality within these settings should also be developed. Such initiatives will improve patient safety and well-being and create a safer working environment for healthcare providers.

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Conflict of Interest

All authors report that there are no conflicts of interest.

Authors' Contribution

SM, JCK and CD wrote the proposal and collected data. NK and PK wrote the first draft of the manuscript. DP, FRK, EM, JM, FI, and CB provided critical input, review, and editing.

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