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Research article

Patterns and disparities in indoor particulate matter levels in selected primary schools in Kigali, Rwanda

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A B S T R A C T

Air pollution is a global environmental and public health challenge. There is limited evidence about the air quality in Rwanda, and the concentrations of particulate matter (PM), namely $PM_{2.5}$ and PM_{10} in schools have not been well documented. This study evaluated patterns and disparities in indoor PM levels in selected primary schools in Kigali, Rwanda.

The study collected $PM_{2.5}$ and PM_{10} concentrations from six classrooms in six selected primary schools during the regular school study period in the dry season. Data were collected using mobile air sensors (purple air/PA–II–SD air quality) and an observation checklist. A Kruskal-Wallis test was performed to assess the difference in $PM_{2.5}$ and PM_{10} concentrations between the six schools. The post-hoc Mann-Whitney test was used to compare all group pairs.

The results indicated a significant difference in both the indoor $PM_{2.5}$ concentration (H (5) = 41.01, $p < 0.001$) and the indoor PM_{10} concentration (H (5) = 38.5, $p < 0.001$). The maximum concentration observed was 133.6 μg/m^3 for $PM_{2.5}$ and 158.5 μg/m^3 for PM_{10}. Schools in highly exposed areas tended to have higher concentrations of PM than schools in moderately exposed areas. Specifically, the daily average concentration of $PM_{2.5}$ in schools located in highly exposed areas ranged from 39 μg/m^3 to 118 μg/m^3, while PM_{10} levels ranged from 44.0 μg/m^3 to 126 μg/m^3. In contrast, schools in moderately exposed areas had daily $PM_{2.5}$ average concentrations ranging from 32.0 μg/m^3 to 111.0 μg/m^3 and daily PM_{10} average concentrations ranging from 38.0 μg/m^3 to 119 μg/m^3.

Overall, the recorded values for both $PM_{2.5}$ and PM_{10} in all sampled schools were higher than the World Health Organization air quality guidelines. Indoor air quality is poorer in schools situated in highly exposed areas. This study suggests interventions to improve school air quality for the benefit of school communities.

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1. Introduction

Air pollution in the school environment, particularly high concentrations of particulate matter (PM), is an important public health problem. It can have a negative impact on children, teachers, and other staff who usually spend more than 30 % of their time in these environments [1]. PM is a type of air pollutant consisting of suspended particles of varying sizes, such as $PM_{2.5}$ and PM_{10}. These particles originate from both human activities and natural sources [2–4]. Exposure to elevated PM concentrations in various settings, including schools, has been linked to poor health outcomes, including diseases such as asthma, cardiovascular disease, tuberculosis, pneumonia, lung cancer, reduced lung function, and seasonal allergies [5–15]. Beyond its health effects, air pollution in schools can result in increased absenteeism among both students and teachers and can negatively impact academic performance [16,17]. A study conducted by the Department of Atmospheric Sciences at the University of Utah revealed the association between air pollution and school absence, showing that exposure to $PM_{2.5}$ resulted in poor performance and school attendance. The study showed that a slight increase in $PM_{2.5}$ was associated with an increase in school absences the next day [18].

In Africa, the literature indicates that $PM_{2.5}$ and PM_{10} are the main pollutants that affect indoor and outdoor air quality, with significant consequences for the health of school children [19–21]. In sub-Saharan Africa, it is reported that exposure to $PM_{2.5}$ and PM_{10} is responsible for 700 000 premature deaths per year [22]. A study done in Kenyan primary schools on the concentration of $PM_{2.5}$ indicated that the concentration of $PM_{2.5}$ ranged from 17.7 μg/m^3 to 52.4 μg/m^3 [23]. A study in Uganda illustrated that the concentration of $PM_{2.5}$ in schools in Kampala ranges from 14 μg/m^3 to 110 μg/m^3 [24]. A recent study on air quality in Rwanda found that $PM_{2.5}$ concentrations in Kigali were 52 μg/m^3, which exceeded the World Health Organization (WHO) acceptable $PM_{2.5}$ limits [25]. The WHO air quality guidelines stipulate that the 24-h average of $PM_{2.5}$ should not exceed 15 μg/m^3 and PM_{10} should not exceed 45 μg/m^3 [26]. Literature explains how PM concentrations increase on school premises and their adverse health effects on school children [16,27].

The understanding of PM in schools and its impact was built upon a theoretical framework supported by three primary perspectives, namely environmental science, epidemiological studies, and research on indoor air quality. Environmental perspectives suggest that the levels of PM in school settings are affected by numerous factors such as geographical location, meteorological conditions, cleaning materials, and the frequency of cleaning [28,29]. Research on indoor air quality report the role of ventilation systems, occupancy ratio, student activities inside classrooms, and building characteristics as factors that also influence the concentration of PM in a school environments [30,31]. Epidemiological studies established the linkage between exposure to PM and some respiratory problems among school children [23,30,32]. Therefore, it is crucial to understand the importance of indoor air quality in school settings in order to protect children's health [8].

Several researchers assessed school air quality and identified high levels of air pollution on many school premises [33,34]. Some factors contributing to elevated levels of air pollutants in schools have been documented and include the school's geographical location, the materials used in constructing the building, the design of the building itself, the occupancy ratio, the type of ventilation system employed (whether it is natural or mechanical), and the combustion processes occurring within the vicinity [16,35,36]. Literature indicates that the concentrations of air pollutants can be highest in schools near busy roads, industries, and other places such as markets and garages [37]. Other factors that can impact the air quality in classrooms include the construction materials, types of chalk and writing materials used, the use of air conditioning and heating systems, unpaved playgrounds, and the orientation of the windows [34,38,39]. Scholars also reveal that printers, photocopiers, cleaning materials, furniture, wall paints, and student playing activities at schools are factors that increase the mass concentration of PM in school buildings [34,37].

Children in schools are particularly vulnerable to air pollutants because of their repetitive and prolonged exposure on school premises [5,29,40,41]. Scholars reveal the association between exposure to PM and respiratory problems among children in schools [23,42]. A study conducted in Iran show elevated concentrations of PM in schools, in particular an indoor $PM_{2.5}$ concentration of 115.8 μg/m^3 in schools located near busy roads [43]. Another study in Uganda illustrate that the concentrations of $PM_{2.5}$ in four public primary schools in Kampala ranged from 9 μg/m^3 to 110 μg/m^3, which are higher than the WHO guidelines [24]. Janssen et al. conducted a study in primary schools in Wageningen City in the Netherlands and found that the schools' $PM_{2.5}$ concentrations ranged from 14.1 μg/m^3 to 35.2 μg/m^3 per day [44], which were lower than those collected in Iran and Uganda. These findings highlight the risk of adverse health effects from exposure to poor air quality in school environments and the need for more data, especially in African regions, since the latest review of air pollution in schools revealed limited information on air quality in African countries [45].

Available studies on air pollution in Rwanda predominantly focus on testing air quality within households, and there is only a single

Table 1
School/classroom characteristics.

Variable	School 1	School 2	School 3	School 4	School 5	School 6
Year of construction	1954	1962	1979	1967	1964	1950
Class size (m^2)	52.4	61.8	39.7	56.4	47.2	54.7
Average temperature (°C)	25.9	26.1	23.1	23.2	24.6	24.9
Average relative humidity (%)	39.8	39.7	48.8	50.0	43.7	43.5
Classroom adjacent to the playground	–	+	+	+	–	+
Chalkboard chalk dust inside classrooms	+	+	+	+	+	+
Smoke from school kitchens &residential houses near schools	+	+	+	+	+	+
Windows adjacent to the street	–	+	–	–	+	+

Notes: + = Yes; - = No.

Table 2
Mean levels of $PM_{2.5}$ and PM_{10} per primary school in Kigali (N = 144).

Variables	Schools	Location	Mean rank	Mean	SD	Minimum	Maximum
Indoor $PM_{2.5}$	School 1	M	61.0	64.0	25.0	30.0	120.0
	School 2	H	79.0	77.5	38.0	14.0	134.0
	School 3	H	112.0	100.5	19.5	55.0	129.5
	School 4	M	80.0	78.0	36.0	20.0	129.0
	School 5	M	37.0	49.0	11.0	26.0	66.0
	School 6	H	65.0	65.0	12.0	36.0	81.0
Indoor PM_{10}	School 1	M	62.0	74.0	23.5	39.0	127.5
	School 2	H	76.5	84.0	40.0	15.5	141.0
	School 3	H	112.0	109.0	23.5	59.5	158.5
	School 4	M	81.0	87.0	39.0	22.0	141.5
	School 5	M	42.0	60.0	12.0	32.0	75.0
	School 6	H	61.0	70.0	12.0	43.0	87.0

Notes: H = Highly exposed area; M = Moderately exposed area.

Table 3
Descriptive statistics of the daily average of $PM_{2.5}$ and PM_{10} per school (N = 144).

Variables	Schools	Sampling hours	Average day 1	Average day 2	Average day 3
Daily average indoor $PM_{2.5}$	School 1	24	91.0	52.0	45.0
	School 2	24	39.0	75.9	118.0
	School 3	24	96.0	88.5	117.0
	School 4	24	32.0	92.0	111.0
	School 5	24	40.5	44.0	62.0
	School 6	24	71.0	60.0	63.0
Daily average indoor PM_{10}	School 1	24	96.0	58.5	59.0
	School 2	24	44.0	80.0	124.0
	School 3	24	103.9	98.2	126.0
	School 4	24	38.0	102.5	119.0
	School 5	24	50.5	57.0	72.0
	School 6	24	76.0	63.9	70.5

Patterns and variations in $PM_{2.5}$ and PM_{10} concentrations between the studied schools.

study that focus on air quality in schools [22,46]. This has left a significant research gap regarding air quality in school settings. From an environmental science standpoint, it is important to note that although no research has been conducted to validate this assertion, certain schools in Kigali City may be encountering environmental challenges that could lead to compromised air quality because of their locations as some schools are situated in urban areas and others in suburban regions and are exposed to various sources of pollution. The primary sources of emissions that have the potential to impact air quality in these schools are emissions from vehicles on busy roads, emissions from garages, markets, and the combustion processes in residential houses near the schools.

This study was carried out because previous studies on air quality assessment in Rwanda focus on households and the concentration of PM in school settings remains inadequately researched. The objective was to evaluate the patterns and disparities in the levels of PMs in the selected primary schools in Kigali, Rwanda, to provide evidence on the disparities in PM levels and to guide the development of policies and strategies aiming to promote a healthier school environment.

2. Materials and methods

2.1. Study setting

The research was conducted in six public primary schools situated in three districts of Kigali, Rwanda. Despite Kigali's reputation as a clean city in East Africa, it is currently experiencing rapid economic growth, industrialisation, increased busy roads, and expansion in urbanisation. While these developments bring benefits, they also pose environmental challenges such as heightened energy demands, air pollution, and diminished green spaces. These factors can influence the levels of PM within different settings, including schools. Therefore, the schools in Kigali were chosen for the purpose of evaluating air pollution levels on their premises. The schools were categorised based on their proximity to sources of pollution, distinguishing between highly exposed areas and moderately exposed areas. In this study, a highly exposed area were defined as a location near busy roads (0.5–1 km) with a high volume of vehicles, or nearby factories, markets, and commercial establishments. On the other hand, moderately exposed areas were characterised by lower levels of development, including fewer vehicles and buildings, a distance of at least 1 km from main roads, an absence of bustling markets, and no industrial facilities.

2.2. Design and sampling methods

The study used a cross-sectional design. The Directorate of Education at City of Kigali level provided two lists of schools that formed

Table 4
Kruskal-Wallis test results.

Variables	N	Test statistics	Df	P-value
Indoor $PM_{2.5}$ concentration	144	41.017	5	0.000
Indoor PM_{10} concentration	144	38.503	5	0.000

A pairwise comparison of indoor $PM_{2.5}$ and PM_{10} concentrations among schools.

Table 5
A pairwise comparison of indoor $PM_{2.5}$ and PM_{10} concentrations among schools (N = 144).

Sample 1–sample 2	Indoor $PM_{2.5}$			Indoor PM_{10}		
	U	S. E	P-value	U	S. E	P-value
School 1–School 2	21.958	12.042	1.000	−19.292	12.042	1.000
School 1–School 3	−26.375	12.042	0.428	20.5	12.042	1.000
School 1–School 4	40.417	12.042	**0.012**	34.625	12.042	0.061
School 1–School 5	41.250	12.042	**0.009**	39.33	12.042	**0.016**
School 1–School 6	73.000	12.042	**P < 0.001**	69.75	12.042	**P < 0.001**
School 2–School 3	−4.417	12.042	1.000	1.208	12.042	1.000
School 2–School 4	−18.458	12.042	1.000	15.33	12.042	1.000
School 2–School 5	−19.292	12.042	1.000	20.042	12.042	1.000
School 2–School 6	−51.042	12.042	**P < 0.001**	50.458	12.042	**P < 0.001**
School 3–School 4	14.042	12.042	1.000	−14.125	12.042	1.000
School 3–School 5	14.875	12.042	1.000	−18.833	12.042	1.000
School 3–School 6	46.625	12.042	**0.002**	−49.25	12.042	**0.001**
School 4–School 5	−0.833	12.042	1.000	−4.708	12.042	1.000
School 4–School 6	−32.583	12.042	0.102	−35.125	12.042	0.530
School 5–School 6	31.750	12.042	0.126	30.417	12.042	0.173

Notes: Bold: significant at 0.05 level; significance values have been adjusted by the Bonferroni correction for multiple tests.

two strata based on exposure levels. One list included schools in highly exposed areas based on the criteria used for the current study, and the other consisted of schools in moderately exposed areas. A simple random sampling technique was used to select schools from each strata. We selected six study sites (six public primary schools), and three of these selected schools were in highly exposed areas, and three were in moderately exposed areas. The same sampling technique was applied to select one classroom at school level. The inclusion criteria for classrooms were that they should be class-level III classrooms in a primary school and should have electricity.

2.3. Air quality monitoring

Real-time air quality measurements (concentration of $PM_{2.5}$ and PM10) in classrooms were collected using mobile air sensors (PurpleAir/PA–II–SD air quality). These sensors measure PM, temperature, and relative humidity [47]. In the literature, PurpleAir is reported to be a real-time air quality sensor that measures $PM_{2.5}$ and PM_{10}, and these sensors have two optical sensors, channel A and channel B. The data reported by the instrument are the average of both channels [48]. The sensors require calibration to give an accurate air quality index [48], and were calibrated by technicians in the laboratory of the School of Science at the University of Rwanda. Before using these air samplers, technicians cleaned the laser counters of PurpleAir with canned compressed air. They also installed high-accuracy air quality monitors (AQmesh) with air sensors (PurpleAir) at the same locations and with the same background for reference.

Sensors were placed in breathing zones for children at a height of between 0.8 m and 1.5 m, near the wall facing away from the blackboard and 1 m from the window. The sensors reported the concentration of $PM_{2.5}$ and PM_{10} at 2-min intervals. Data were collected concurrently in all selected classrooms during the regular school study time from 8:00 a.m. to 4:00 p.m. for three sequential days during the last week of June. The last week of June was considered suitable for conducting the research as it is the hottest week of the month. The mean measured parameters were calculated hourly for 8 h a day. Therefore, 24 samples were collected from each classroom, meaning 144 air samples were collected from the six primary schools. Air quality monitoring followed the procedure described in the study and assessed the level of PM_{10} and $PM_{2.5}$ and respiratory health in schoolchildren in Kenya [23]. The values obtained for $PM_{2.5}$ and PM_{10} were compared with the WHO air quality guidelines.

2.4. Onsite observations

A walk-through inspection, using a well-structured observation checklist, was done for each school to collect data on school and classroom characteristics and maintenance activities at the schools or their surroundings. The checklist was adapted from the Healthy Schools Environmental Assessment Checklist because it provides a comprehensive framework for assessing environmental factors that affect children's health [49]. Data on classroom location were collected particularly to determine whether the classrooms and windows are adjacent to the playground or street. In addition, data were collected on dust entering from unpaved playgrounds and the presence of other possible sources of pollution, such as smoke resulting from combustion processes at school kitchen or from residential houses surrounding the school. Finally, the size of each classroom was measured using a tape measure, and data related to the year the schools were built were also collected from the archives of the schools.

2.5. Statistical analysis

Statistical Package for the Social Sciences (SPSS) was used to analyse the data and perform descriptive and inferential statistics. Firstly, Kolmogorov–Smirnov tests were used to verify the normal distribution of the data. Next, the mean, standard deviation, and minimum and maximum values of indoor $PM_{2.5}$ and PM_{10} concentrations were calculated to describe the concentrations in primary schools. A Kruskal-Wallis test was conducted to evaluate the difference in the concentration of $PM_{2.5}$ and PM_{10} between the six schools. Furthermore, Mann-Whitney post-hoc tests were used to compare all pairs of groups. Data from observation checklists were analysed using Microsoft Excel.

2.6. Ethical considerations

The Institutional Review Board of the Faculty of Medicine and Health Sciences, University of Rwanda, provided ethical approval (Notice No. 108/CMHS 110/2021) for the study. Administrative clearance was obtained from the Kigali City Management (Ref No: 1277). It should be noted that the study did not involve human or animal subjects.

3. Results

3.1. School/classroom characteristics

The data in Table 1 show that most of the classrooms of the sampled schools (level III classrooms in a primary school) are old and adjacent to the playground. The findings of the inspections indicated that all the schools sampled (100 %) are close to other potential sources of pollution, such as smoke from cooking activities at schools that rely on traditional wood burning and residential houses surrounding the schools, dust from unpaved playgrounds, and chalk dust from chalkboards inside the classrooms.

3.2. Indoor levels of $PM_{2.5}$ and PM_{10} in selected primary schools

Table 2 shows the concentration of indoor $PM_{2.5}$ and PM_{10} in schools. It shows that the maximum indoor concentrations of $PM_{2.5}$ and PM_{10} observed in the selected schools were 134.0 $\mu g/m^3$ and 158.5 $\mu g/m^3$, respectively. The highest average calculated for indoor $PM_{2.5}$ concentration was 100.5 $\mu g/m^3$, and the highest average measured indoor PM_{10} concentration was 109.0 $\mu g/m^3$. Table 2 shows that schools in highly exposed areas tend to have higher levels of PM than those in moderately exposed areas.

3.3. Daily average concentration of $PM_{2.5}$ and PM_{10} per school

Table 3 illustrates the daily average concentration of $PM_{2.5}$ and PM_{10} per school. The table shows that the highest daily average was 118.0 $\mu g/m^3$ for $PM_{2.5}$ and 126.0 $\mu g/m^3$ for PM_{10}, respectively.

Table 4 shows the results of the Kruskal-Wallis test. The test compared the concentration of both indoor $PM_{2.5}$ and PM_{10} between six schools. The table shows that the indoor $PM_{2.5}$ concentration ($H (5) = 41.01$, $p = 0.000$) and the indoor PM_{10} concentration ($H (5) = 38.50$, $p = 0.000$) were significantly different between the schools sampled.

Table 5 shows the results of the Mann-Whitney *U* test performed for multiple comparisons. According to the results of the Mann-Whitney *U* test, there was a significant difference in $PM_{2.5}$ concentrations between School 1 and School 4 ($U = 40.41$, $P = 0.012$), School 1 and School 5 ($U = 41.25$, $P = 0.009$), School 1 and School 6 ($U = 73.0$, $P < 0.001$), School 2 and School 6 ($U = -51.042$, $P < 0.001$), and School 3 and School 6 ($U = 46.625$, $P = 0.002$). Furthermore, the results of the Mann-Whitney *U* test also showed that there was a significant difference in PM_{10} concentration between School 1 and School 5 ($U = 39.33$, $P = 0.016$), School 1 and School 6 ($U = 69.75$, $P < 0.001$), School 2 and School 6 ($U = -50.458$, $P = 0.000$) and School 3 and School 6 ($U = -49.25$, $P = 0.001$).

4. Discussion

This study examined patterns and disparities in indoor concentrations of PM in selected primary schools in Kigali, Rwanda. The average recorded values of $PM_{2.5}$ ranged from 32 $\mu g/m^3$ to 118 $\mu g/m^3$, exceeding the WHO recommended air quality thresholds. The results for PM_{10} showed that only two schools had an average daily (38 $\mu g/m^3$ and 44 $\mu g/m^3$ per day) under the WHO air quality guidelines, and the other four schools ranged from 50.5 $\mu g/m^3$ to 126 $\mu g/m^3$ per day. The results of this study are consistent with the results of other studies on air quality in primary schools around the world [23,32,42,50–53]. For example, a study conducted in Lahore, Pakistan, showed average summer concentrations of PM_{10} and $PM_{2.5}$ as 1365.4 $\mu g/m^3$ and 284.4 $\mu g/m^3$ for PM_{10}, and 137.8 $\mu g/m^3$ and 44.5 $\mu g/m^3$ for $PM_{2.5}$, respectively [35]. In a similar study in Munich, Germany, PM_{10} and $PM_{2.5}$ were estimated at 71.7 $\mu g/m^3$ and 13.5 $\mu g/m^3$, respectively [54]. In a study conducted in Tehran, Iran, the mean concentrations of PM_{10} and $PM_{2.5}$ were 274 $\mu g/m^3$ and 42 $\mu g/m^3$, respectively [55]. The PM_{10} and $PM_{2.5}$ concentrations for schools in Germany were lower than those for Iran and Pakistan. According to the WHO air quality guidelines, the daily average concentration of $PM_{2.5}$ and PM_{10} should not exceed 15 $\mu g/m^3$ for $PM_{2.5}$ and 45 $\mu g/m^3$ for PM_{10} [26].

Additionally, a study carried out in India to investigate air quality in Hamirpur primary schools illustrate that the indoor values of $PM_{2.5}$ ranged from 145 μg/m^3 to 564.67 μg/m^3 [50]. In Europe, the findings of a study done in schools located in urban settings in the coastal region in Spain indicate that the levels of indoor PM_{10} ranged from 65 μg/m^3 to 186 μg/m^3 in urban areas, 21 μg/m^3 to 322 μg/m^3 in the industrial zone, and 16 μg/m^3 to 169 μg/m^3 in rural areas [32]. A study that assessed the state of air quality in schools in Serbia revealed that the concentration of PM_{10} ranged from 37.32 μg/m^3 to 103.14 μg/m^3, and the concentration of $PM_{2.5}$ ranged from 26.88 μg/m^3 to 63.92 μg/m^3 [51]. According to these findings for Serbia, schools located in industrial and urban zones experience higher concentrations of PM_{10} than those located in rural settings.

Similarly, a study carried out in some schools in California, USA, indicate that PM_{10} and $PM_{2.5}$ range from 17.6 μg/m^3 to 61.5 μg/m^3 and 6.3 μg/m^3 to 23.7 μg/m^3, respectively [52]. These findings show that the concentrations of PM in California tend to meet the WHO standards. Furthermore, research conducted in Brazilian schools indicate that the level of $PM_{2.5}$ ranged from 6.39 μg/m^3 to 99.91 μg/m^3 [42]. All these findings highlight the need to improve air quality in school environments to protect the health and well-being of school children.

The current study found that all selected schools are built in locations with potential sources of pollution, such as burning activities, dusty unpaved playgrounds, chalk particles inside the classrooms, smoke from school kitchens, residential houses near the schools, and high traffic near some schools. Such factors could explain the high concentration of PM in the selected primary schools. These findings align with those of a previous study conducted in Pakistan, which illustrate that the high concentration of PM in schools can be attributed to their location as those located near busy roads had a higher mass concentration of PM compared to those located far from busy roads [35]. Furthermore, these findings are supported by a study conducted in Iran, that reveal that outdoor activities and school children activities in classrooms are the sources of the high concentration of PM in classrooms [55]. Additionally, our findings align with the results of other investigations that reveal that the location of schools, dust from outside the classroom, vehicle emissions, road dust, insufficient ventilation, building materials, and the age of buildings could impact the concentrations of PM in school premises [13,28,38,55–63].

The elevated values of $PM_{2.5}$ and PM_{10} indicate the poor quality of air in sampled schools. Exposure to these PM concentrations poses significant health risks and has a negative impact on the well-being of the school occupants. The literature examined the impact of PM exposure in schools [64–66], and various factors must be considered to effectively address and control the levels of PM in school settings. These factors include the pathways through which PM enter the school environment, outdoor sources such as emissions from surrounding areas, indoor factors like the use of chalkboards, inadequate ventilation, and the design and materials of the school building. All of these factors contribute to the exacerbation of PM levels within school premises. It is important to prioritise air quality management in schools, as school communities are particularly vulnerable to the detrimental effects of air pollution. Consequently, policies and strategies should be developed to address this problem. These initiatives may include upgrading from traditional chalk to dust-free chalk or whiteboards, transitioning from wood burning to cleaner-burning technologies and implementing air quality awareness programs aimed at educating school communities about simple measures to reduce exposure, such as planting trees and other community-based environmental protection initiatives.

5. Conclusions

Our findings showed that the indoor concentration values of $PM_{2.5}$ and PM_{10} in schools Kigali, Rwanda, are beyond WHO air quality thresholds, suggesting that the indoor air quality in these schools is poorer than what is considered safe. Schools in highly exposed areas often have higher levels of PM than those in moderately exposed areas. Variations in the concentration of PM between selected schools can be attributed to factors such as emissions in neighbouring environments, ageing school buildings, and outdoor pollutants. The study recommends address this problem through actions and strategies to improve school air quality and establishing prevention measures. These strategies include shifting from traditional chalk to whiteboards, transitioning from wood burning at schools to cleaner energy sources, and implementing air quality education, among other measures. This study adds knowledge about air quality in Rwandan schools to the existing body of literature. However, the limitations of this study cannot be completely ignored. The study did not examine the relationship between the modes of transportation from and to school for students and exposure to PM_{10} and $PM_{2.5}$. It is important to note that the study only investigated air quality in schools located in urban settings and that it did not extend to rural areas. Lastly, the study was limited by a short investigation period, and it did not collect data on ambient air. Therefore, further studies are needed to assess the characteristics of PM in schools in relation to seasonal variability and to expand its scope to rural settings.

Data availability

The data set is available and can be shared upon request.

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CRediT authorship contribution statement

Noel Korukire: Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Ana Godson:** Writing – review & editing, Supervision. **Judith Mukamurigo:** Writing – review & editing, Supervision. **Akanbi Oyiza Memunat:** Writing – review & editing. **Josias Izabayo:** Formal analysis. **David Bashaija:** Writing – review & editing. **Theoneste Ntakirutimana:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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