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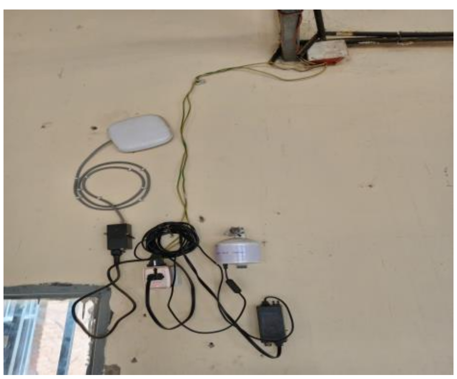
MASTER'S PROGRAM IN BIODIVERSITY CONSERVATION AND NATURAL RESOURCES MANAGEMENT

CHILDREN'S EXPOSURE TO INDOOR AIR POLLUTION IN SCHOOLS IN KIGALI CITY, RWANDA



A thesis submitted in partial fulfillment of the requirements for the degree of Master in Biodiversity Conservation and Natural Resources Management

By

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Kigali, October 2024

DECLARATION

I, ISHIMWE Marie Eudoxie, declare that this master's dissertation ''**Children's Exposure to Indoor Air Pollution in Schools in Kigali City, Rwanda**'' is the result of my own work in partial fulfillment of the requirements for the award of a master's degree in Biodiversity Conservation and Natural Resource Management at the University of Rwanda, College of Science and Technology and has not been submitted for any other degree at the University of Rwanda or any other institution. All sources I have used or quoted have been indicated and acknowledged in the references.

Date:

Signed by:

ISHIMWE Marie Eudoxie, 221027747

APPROVAL

I certify that this research project entitled " **Children's exposure to indoor air pollution in schools in Kigali City, Rwanda"** was done under my supervision and has been submitted for examination with my approval.

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May God bless you all

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LIST OF ACRONYMS AND ABBREVIATIONS

F: Fahrenheit

HVAC: Heating, Ventilation, and Air Conditioning

Hum: Humidity

IAQ: Indoor air quality

m^3: Cubic meter

µg: Microgram

PM: Particulate matter

PM_{10}: Particles that are 10 micrometers in diameter or less

$PM_{2.5}$: Particles that are 2.5 micrometers in diameter or less

RH: Relative humidity

R: Correlation

WHO: World Health Organization

R: Correlation

Temp: Temperature

ABSTRACT

Children are particularly vulnerable to indoor air pollution, which leads to high premature death rates. This is particularly true in Africa, where school air pollution emissions are high and data is lacking. In Africa, Schoolchildren spend more than 6 hours in the classroom; thus, understanding classroom air quality is vital for their health, academic performance, and well-being. The present thesis has examined children's exposure to indoor air pollution in both rural and urban schools in Rwanda. Particulate matter air pollution with an aerodynamic diameter of less than 2.5µm ($PM_{2.5}$) and less than 10µm (PM_{10}) was collected over two months from four schools in Rwanda using real-time Purple Air low-cost air quality sensors. The results showed that the mean concentrations of $PM_{2.5}$ in rural and urban schools were varying between 52.99 ± 23.09 µg/m³ and 53.64 ±22.76 µg/m³, respectively. The mean concentration of PM_{10} levels in rural and urban areas were varying between 57.89±24 µg/m³ and 59.01±24.22 µg/m³, respectively. The $PM_{2.5}$ and PM_{10} concentration levels in urban and rural schools in Rwanda exceeded the 24-hour mean of the World Health Organization (WHO) air quality standards of 15 µg/m³ and 45µg/m³, respectively. Although the concentration of $PM_{2.5}$ and PM_{10} were higher in urban than rural schools, the Wilcoxon test showed no significant difference in $PM_{2.5}$ and PM_{10} concentration levels. It was also found that there is no significant association between meteorological conditions and air pollution. This study underscores the urgent need for interventions to improve indoor air quality in Rwandan schools. Despite the short duration of the study and the limited sensor sample size; the findings provide preliminary results for future research to improve children's health in educational settings.

CHAPTER 1. INTRODUCTION

1.1 Background and Problem Statement

Schools are fundamental to fostering an optimal environment for children's learning and development, as students spend a significant amount of their time indoors. The quality of indoor air is a critical concern, particularly in densely populated classrooms, which are essential to students' social and educational growth. Ensuring excellent indoor air quality (IAQ) is imperative because it profoundly influences the physical and mental well-being, academic performance, focus, and overall comfort of students and teachers (Mendell & Heath, 2005).

Air pollution is a significant global environmental challenge, posing a substantial threat to human health. Children are particularly vulnerable to the adverse effects of air pollution due to their developing lungs, higher respiratory rates, and closer proximity to the ground, which increases their exposure to pollutants. This is especially concerning in school environments, where children spend a considerable portion of their day (Grimsrud et al., 2003). Both rural and urban areas are experiencing rising levels of air pollution due to rapid urbanization, industrialization, and agricultural activities. A survey conducted in France from 2009 to 2011 on indoor air quality in educational institutions highlighted how common cleaning practices and the chemicals in cleaning products could increase indoor air pollution, particularly affecting vulnerable occupants such as children (Wei et al., 2016). Exposure to air pollution in classrooms can have serious health implications for children, including respiratory and cardiovascular diseases, cognitive impairment, and developmental problems.

In Rwanda, schoolchildren spend about eight hours a day in densely populated urban areas at schools located near major roads (Kalisa et al., 2023). This proximity to traffic significantly contributes to their exposure to air pollution from vehicle emissions, which contain harmful pollutants (Zhang and Batterman, 2013). Particularly in Kigali, where many primary schools are situated within 100-200 meters of major roads, there is concern because air pollution levels tend to be elevated within approximately 100-400 meters of such roads (Kalisa et al., 2023). Chronic exposure to traffic-related pollution has been linked to various adverse health effects in children

(Wood et al., 2015). Consequently, schoolchildren in urban areas face a considerable risk of exposure to harmful traffic and urban air pollution.

The pressing need for the assessment of children's exposure to indoor air pollution in both urban and rural schools of Rwanda is underscored by several alarming factors. Given the detrimental impacts of indoor air pollution on children's health and academic performance, understanding the extent of exposure in both urban and rural school environments is paramount. This study is essential not only for addressing immediate health concerns but also for informing targeted interventions and policy initiatives aimed at safeguarding the well-being of Rwanda's youth and fostering a healthier educational environment for future generations.

Kalisa et al. (2023) found that the yearly average levels of Particles that are 2.5 micrometers in diameter or less ($PM_{2.5}$) in both classroom and outdoor school environments in urban areas exceeded the World Health Organization's safe thresholds by more than eightfold. Exposure was highest in classrooms after drop-off hours. Classrooms in both urban and rural areas have poor ventilation and high levels of indoor air pollution, with urban schools being more polluted due to high traffic and industrial activities nearby (Sadrizadeh et al., 2022).

Exposure to ambient air pollution is a global concern, affecting both urban and rural areas. Epidemiological studies have shown an association between Particulate matter (PM) exposure and respiratory diseases such as lung cancer, asthma, and chronic obstructive pulmonary disease (Arias-Pérez et al., 2020). In 2016, air pollution contributed to 4.2 million premature deaths worldwide, with nearly 300,000 of these fatalities involving children under five years old. Alarmingly, 93% of all young children, roughly 630 million globally, are exposed to elevated levels of fine particulate matter that surpass World Health Organization guidelines (WHO, 2018).

A study by Kalisa et al. (2023) found that outdoor air pollution accounted for up to 25% of indoor PM levels in classrooms in Kigali, Rwanda's capital city. The sources of both indoor and outdoor pollution, their dilution, and their removal by ventilation all affect classroom air quality. The type of ventilation system and air distribution inside the classroom also impact air quality. In urban areas with high traffic emissions, outdoor air pollution can significantly infiltrate classrooms.

This study aims to investigate children's exposure to air pollution in classrooms in rural and urban areas of Rwanda. It will assess the level of indoor air pollution and identify the sources of pollutants in schools. The findings of this study are expected to provide valuable insights into the current state of indoor air quality in classrooms. They will inform decision-making and interventions to protect children's health.

In Rwanda, indoor air pollution in schools is an emerging issue, and there is limited research on the levels of $PM_{2.5}$ and PM_{10} in classrooms (Sadrizadeh et al., 2022). Most research has concentrated on urban schools, resulting in a scarcity of data concerning rural regions. Additionally, there has been limited exploration of comparisons between urban and rural schools, despite clear disparities in environmental and social factors that could affect indoor air quality.

Therefore, this research aims to understand indoor air quality in Rwandan schools better. This study seeks to contribute to improving students' health and performance. It will be the first study to compare air quality between urban and rural schools in Rwanda, providing relevant data to the Rwanda Environmental Management Authority (REMA) and other decision-makers to implement control measures for air pollution in typical urban and rural school settings.

1.2 Objectives

1..2.1 Main objective of the study

The main objective of this thesis is to investigate children's exposure to indoor air pollution and predict how meteorological factors contribute to air pollution levels in Kigali City.

1.2.2 Specific objectives

1. To determine the levels of $PM_{2.5}$ and PM_{10} in classrooms in urban and rural schools.
2. To compare the levels of $PM_{2.5}$ and PM_{10} between urban and rural schools.
3. To model the influence of meteorological factors (such as temperature and humidity) on $PM_{2.5}$ and PM_{10} levels in Kigali City

1.3 Research questions

1. What are the average concentrations of $PM_{2.5}$ and PM_{10} in classrooms in urban and rural schools in Kigali City?

2. Are there significant differences in the levels of $PM_{2.5}$ and PM_{10} between classrooms in urban and rural schools?

3. How do temperature and humidity affect $PM_{2.5}$ and PM_{10} levels in urban and rural classrooms?

1.4 Hypotheses

Higher levels of $PM_{2.5}$ and PM_{10} will be found in classrooms located in urban areas compared to those in rural areas. Additionally, it is hypothesized that indoor air pollution in classrooms will be influenced by meteorological factors (temperature and relative humidity).

1.5. Scope of the Study

As this study centers on evaluating indoor air quality, specifically focusing on $PM_{2.5}$ and PM_{10}, in both urban and rural schools in Kigali City, it will present the following notable contributions:

- This will serve as a valuable resource for literature reviews for fellow students and researchers studying air pollution in schools, its impact on children, and its effects in Rwanda's urban and rural areas.
- This will help to predict how temperature and humidity influence air pollution levels in Kigali City.
- The study's outcomes hold practical utility for government authorities in advancing the sustainability of air quality standards.

CHAPTER 2. LITERATURE REVIEW

2.1. Particle Matter (PM)

PM is a major component of indoor air pollution in classrooms and greatly concerns children's health. $PM_{2.5}$ and PM_{10} are the two most frequently measured PM types, with $PM_{2.5}$ particles being smaller and more harmful to human health. Rural and urban areas in Kigali City are experiencing high levels of PM pollution due to various sources such as traffic, biomass burning, and industrial activities. Several studies have been conducted to assess PM (PM_{10}, $PM_{2.5}$, and ultrafine particles) in indoor environments in schools in terms of concentration and chemical composition. (Chen *et al.*, 2015; Trompetter *et al.*, 2018).

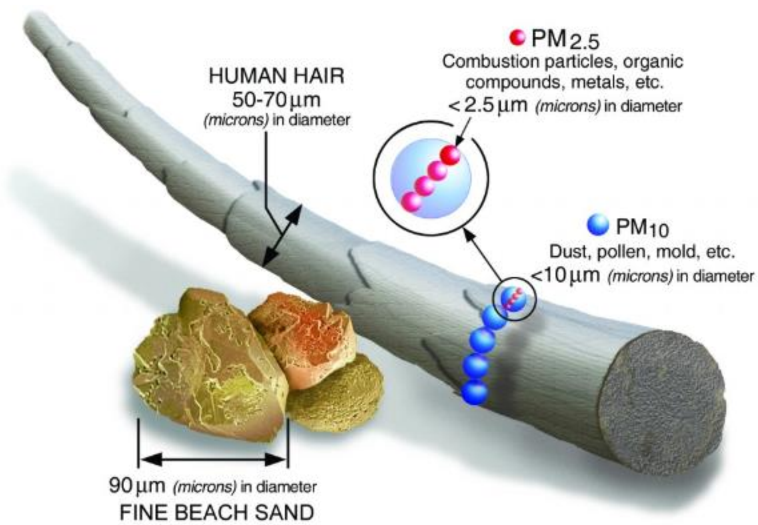

Figure 1: Size comparisons for PM particles (Source: United States Environmental Protection Agency)

Global assessments of ambient air pollution alone suggest between 4 million and 9 million deaths annually and hundreds of millions of lost years of healthy life, with the most significant disease burden seen in low- and middle-income countries (Burnett *et al.*, 2018; Vohra *et al.*, 2021). The impact of air pollution is mainly seen on vulnerable individuals with more significant exposure levels and susceptible individuals with chronic conditions (such as asthma, diabetes, heart failure, pregnant women and children included (WHO, 2021; Burnett *et al.*, 2018; Yang *et al.*, 2020). In addition, this burden of disease and mortality caused by ambient air pollution also impedes the reduction of inequities and progress toward achieving full human rights and the UN SDGs (WHO, 2021).

Sadrizadeh *et al*. (2022) found that exposure to indoor air pollution in schools in developing countries can lead to decreased lung function in children. Indoor air quality in schools is characterized by; 1) insufficient ventilation, 2) infrequent and inadequate cleaning of indoor surfaces, and 3) a large number of pupils per classroom area and volume with constant re-suspension of particles pollution from room surface alongside suspension of soil materials from activities done by children (Trompetter *et al*., 2018).

Children spend much time of their days at school and on the way to and from school, this is where they meet with poor indoor air quality which is linked with a variety of health problems, which range from coughing and wheezing to more serious conditions such as asthma and cancer.

The researchers analyzed the dust from classrooms in populated areas and found that they contained several types of molds. They also discovered mold levels in classroom dust often exceeded levels of mold found in dust collected from local homes (Baxi *et al*.,2013). When children breathe this polluted air, it harms their academic performance. If a child or student gets sick, he/she misses school, and again, the studies show that poor classroom air quality reduces cognitive ability.

A correlation between school $PM_{2.5}$ concentrations and an elevated risk of high blood pressure was found in a cross-sectional survey conducted in China with 53,289 participants aged 6 to 18 (Wang *et al*., 2019). Prior research has linked children's higher systolic blood pressure to the daily ambient air pollution at schools. According to data from China (Chen *et al*., 2015), bettering indoor air quality lowers blood pressure in Chinese college students. It has been demonstrated that healthy children's development of lung function is reduced by elevated exposure to ambient air pollution. Children between the ages of 10 and 18 are most likely to have a positive attitude toward learning, according to two-stage regression research of 1759 fourth-graders from elementary schools in 12 southern California cities (average age, 10 years) (Chen *et al*., 2015).

Epidemiological studies have been conducted and results showed that health implications caused by atmospheric particle pollution and found that there is a correlation between the concentration of particle pollution and the number of deaths from cancer, cardiovascular, and respiratory diseases (Pope III *et al*., 2002). The large number of children suffering from bronchial hyper-responsiveness, positive allergic sensitization to common allergens, or both were identified in schools that are close to vehicle roads with many traffic jams than in schools closer to vehicle roads with low traffic (Janssen *et al*., 2003).

2.2. Status of particulate matter globally with emphasis on Africa

Air pollution is a significant issue worldwide, affecting both developed and developing nations. Africa, with its vast land area spanning both hemispheres, is particularly notable in this context. The continent's emission of pollutants, such as trace gases and aerosols, is influenced by its diverse climatic conditions (Piketh and Walton, 2004). Africa's variety of climatic regions means that climate variables can significantly impact air particle levels. For example, in countries with distinct wet and dry seasons, noticeable changes in dust and sea spray levels occur (Querol et al., 2009). Additionally, (Naidja et al. 2018) noted that the emission of air particles is linked to both human activities and natural sources.

Studies have shown that particulate matter (PM) levels in Africa often exceed the annual and 24-hour guidelines set by the World Health Organization (WHO). Nigeria, in particular, reports very high PM levels, with a significant contribution from the large number of vehicles in Lagos (Adeleke et al., 2011). High PM concentrations have also been noted in other West African countries. In East Africa, Uganda, and Rwanda recorded the highest PM levels (Kirenga et al., 2015; Kalisa et al., 2018), whereas Tanzania had the lowest mean PM levels recorded, though these still surpassed WHO's 24-hour PM_{10} guidelines (Mkoma et al., 2010).

High PM concentrations are also prevalent in parts of North and South Africa. Research by Bouchlaghem and Nson (2012) indicated that the highest dust emissions originated from the Saharan desert, and cities in Egypt also reported high levels of air particles. Additionally, a study by Xu et al. (2019) in Southern West Africa found that various human activities emitted air pollutants, exposing people to these harmful substances.

2.3 Some studies about air pollution levels in schools in Africa

Various studies conducted in different regions have revealed that levels of particulate matter (PM) in schools often exceed the World Health Organization (WHO) guidelines. For example, studies indicate high $PM_{2.5}$ levels in Kenya (Were et al., 2020) while South Africa experiences comparatively lower $PM_{2.5}$ levels (Engwa et al., 2023). Additionally, studies have shown that Palestine has high levels of PM_{10} (Elbayoumi et al., 2013), whereas South Africa continues to exhibit lower $PM_{2.5}$ levels in comparison (Engwa et al., 2023). The Figure 2 shows the levels of $PM_{2.5}$ and PM_{10} found in different countries.

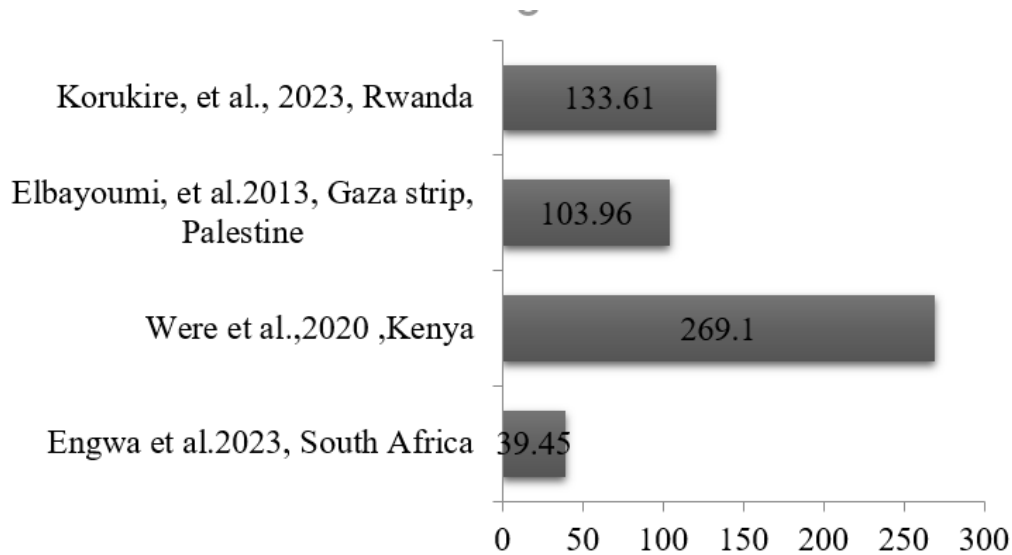

Figure 2:Different studies showing the level of $PM_{2.5}$ ($\mu g/m^3$) in schools in different areas

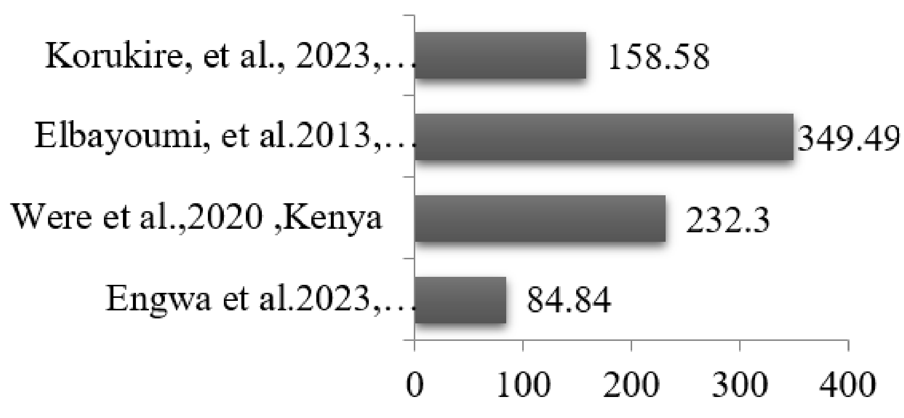

Figure 3: Different studies showing the level of PM_{10} ($\mu g/m^3$) in schools in different areas

Growing populations, increasing urbanization, and resource-intensive activities have made African cities significant sources of pollution. African urban growth rates are among the highest in the world, ranging from 3.1% to 3.8% annually (World Bank, 2017). WHO estimates that the annual median concentration of $PM_{2.5}$ exceeds 26 µg/m³ in more than half of the African continent, significantly above the WHO's recommended yearly average limit of 5 µg/m³ for healthy outdoor air (WHO, 2021). Despite these concerning pollution levels, air quality monitoring in Africa is lacking. Among the 47 countries in sub-Saharan Africa, only six can provide long-term data on airborne particulate matter (PM), covering just 16 cities (Abera et al.,2021). This scarcity of data hinders the development of effective policies and interventions to address air pollution, leaving many regions without the necessary information to protect public health.

2.4 Research gaps related to pollution of particulate matter in Rwanda

Research on PM pollution in Kigali City has revealed significant gaps in air quality management. Henniger (2009) underscored that air pollution in Kigali had reached critical levels, with pollutant concentrations exceeding WHO guidelines. He advocated for comprehensive air pollutant measurements both covering dry and rainy seasons within a year. Additionally, he emphasized the necessity for multiple air monitoring devices at various locations in Kigali and nationwide to improve the accuracy of the findings.

REMA (2018) conducted a study highlighting that air pollution in rural areas is largely due to the extensive use of solid biomass for burning. The study suggested that improving infrastructure and technology for alternative cooking methods, such as electric or pellet stoves, could significantly reduce emissions and mitigate negative impacts on human health and the environment.

DeWitt (2016) pointed out that while natural events like wildfires and wind can elevate PM levels, human activities such as burning wood and coal contribute significantly to higher emissions of $PM_{2.5}$ and PM_{10} in urban areas. Emissions from traffic and industrial development contribute to environmental pollution (Irankunda and Ishigaki, 2020). Kalisa et al. (2018) found that air pollutant levels in Kigali City exceeded WHO guidelines. Similarly, rural areas were reported to suffer from high indoor air pollution due to burning materials during cooking (Irankunda, 2021).

To address these issues, there is a pressing need to invest in long-term solutions such as liquefied petroleum gas or biogas and to increase the number of paved roads in urban and rural areas to reduce air particle emissions, especially during the dry season. Implementing air filters on chimneys and providing training on converting waste into valuable materials, such as fertilizers, are necessary to improve air quality.

Kalisa et al. (2018) further identified that the levels of $PM_{2.5}$ and PM_{10} in urban areas of Rwanda were significantly higher than in rural areas, primarily due to traffic emissions and industrial activities. In rural areas, biomass burning for cooking and heating was a major contributor to indoor air pollution. Wei et al. (2016) also found that using cleaning products containing bleach and ammonia in schools resulted in high levels of $PM_{2.5}$ and PM_{10}.

In conclusion, air pollution is a significant problem in rural and urban areas worldwide and in Rwanda, with higher levels observed in urban areas. PM sources are varied and complex, necessitating targeted interventions to improve indoor air quality in schools and protect children's health.

CHAPTER 3. MATERIALS AND METHODS

3.1. Location and characteristics of schools involved in the study

The study was conducted in four schools in Kigali City, the capital of Rwanda. Kigali covers an area of 730 km² and is divided into three districts: Kicukiro, Nyarugenge, and Gasabo. The city has a population of 1,745,555, with a population density of 2,391 people per square kilometer, and 32.2% of its residents are children aged 0 to 14 years (NISR, 2022). The selected schools for the study included Remera Catholic Primary School II and Muhima Primary School, representing urban schools, and Groupe Scolaire Masaka I and Ecole Primaire Bweramvura Catholique, representing rural schools. These are illustrated in Figure 2 and summarized in Table 1.

Remera Catholic Primary School I is located in an area intersected by three main tarmac roads, conveniently situated 1.6 km from Kimironko bus park and market to the east. To the southwest lies Remera bus park. At the time of the study, a driving school was operating just 20 meters from the school. The school has no trees or vegetation and is surrounded by buildings. Muhima Primary School is located in an area served by two major bus parks. Nyabugogo bus park, an area with numerous vehicles, is 0.6 km to the south. To the north, the school is near Cartier Commercial and Downtown bus parks. Tarmac roads and many buildings surround the school.

Groupe Scolaire Masaka I is situated near Paroisse Sts Pierre and Paul in an area with fewer buildings and is adjacent to a non-tarmac road. The surroundings still include some agricultural activities and small forests. Located near the northern province, Ecole Primaire Bweramvura Catholique is in an area with fewer buildings and near a non-tarmac road. There are still some agricultural activities and small forests around the school.

The schools were selected based on their easy accessibility, availability of electricity, ability to charge equipment and security to prevent the theft of the sensors. Moreover, the selected urban schools are in areas with many buildings and traffic jams, while the rural schools are far from the city and major centers. All the selected schools were public schools.

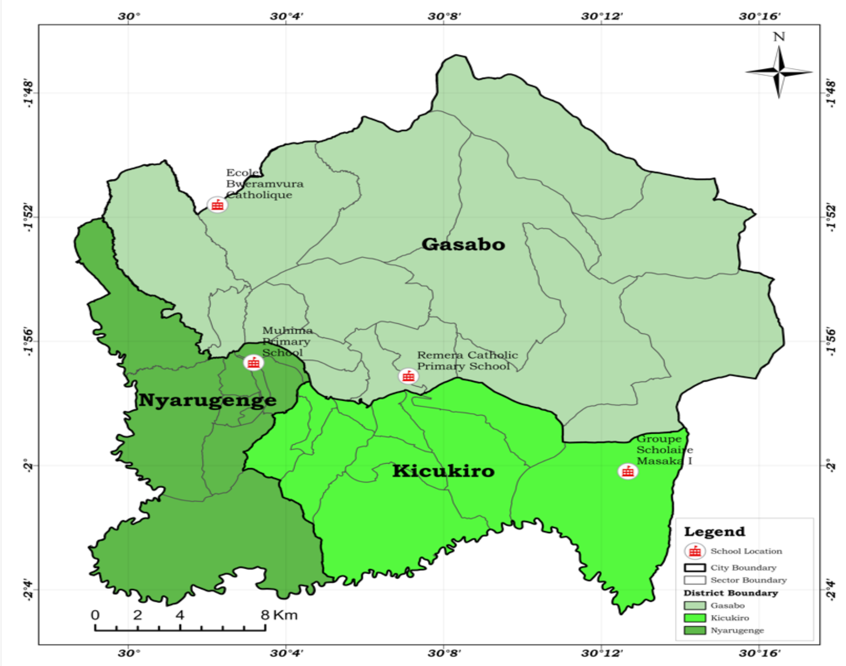

Figure 4:Location of schools involved in the study

Characteristics of monitored schools.

Table 1: Table showing Characteristics of Schools characteristics, location, and number of school children

School name	School location type	Districts	Coordinates	Number of students
Muhima Primary School	Urban	Nyarugenge	-1.94472016, 30.0529908	1682
Remera Catholic Primary School II	Urban	Gasabo	-1.95199742, 30.11843651	1021
Ecole Primaire Bweramvura catholique	Rural	Gasabo	-1.86000981, 30.03773056	1347
Group Scholaire Masaka I	Rural	Kicukiro	-2.00313007, 30.21122316	1222

3.2 Collecting $PM_{2.5}$ &PM_{10}, temperature and current humidity

The real-time data of PM ($PM_{2.5}$, PM_{10}) and meteorological factors (temperature and humidity) were collected using low-cost air quality sensors (Purple Air PA-II-FLEX Sensors) over two months. One sensor was installed in one classroom of each school in this study simultaneously. They were located 1m from the window and there well recording at the same time PM, humidity, and temperature every two seconds. During data collection windows were open. Schools were visited on weekends to check if they were still recording, and all data were taken at the same time from the sensor to the computer and analyzed by R studio and Excel software.

Table 2:Table showing the period of data collection for each school

School name	**Start date**	**End date**
Muhima Primary School	10th May 2023	9th July 2023
Remera Catholic Primary School II	9th May 2023	9th July 2023
Ecole Primaire Bweramvura catholique	9th May 2023	9th July 2023
Group Scholaire Masaka I	9th May 2023	31st June 2023

Figure 5: Photo showing the installation of the Purple Air Sensor. (Source: Photograph, 2023)

3.3. Data analysis

The PM and meteorological data were exported into Excel to be cleaned. Excel was used to analyze the correlation between meteorological data, PM levels, and daily variation. Additionally, R version 4.4.1 was employed to produce box plots and analyze variations, as well as to determine significant differences using p-values. Wilcoxon test was used to test for significance between the sites at a significance level of 5% and compare the means of PM concentrations between urban and rural schools.

CHAPTER 4: RESULTS

4.1 Descriptive statistics

Table 3: Weather conditions and PM concentrations on an average of 24 hours at sampling sites in two months.

Measured parameters	N	Site Type	Min	Mean	Max
$PM_{2.5}$ (µg/m^3)	60	Rural	30.37	52.11	79.38
PM_{10} (µg/m^3)	60	Rural	35.09	56.14	83.28
Temperature (^{0}C)	60	Rural	26.85	29.87	33.63
Relative Humidity (%)	60	Rural	23.48	40.47	48.86
$PM_{2.5}$ (µg/m^3)	60	Urban	37.70	53.78	88.39
PM_{10} (µg/m^3)	60	Urban	42.79	59.51	95.37
Temperature (^{0}C)	60	Urban	26.18	29.91	31.50
Relative Humidity (%)	60	Urban	23.31	40.99	56.21

Prediction of $PM_{10} = PM_{2.5} + 0.05$ hum + 0.45temp -3.6

4.2. Comparison of $PM_{2.5}$ and PM_{10} between rural and urban areas

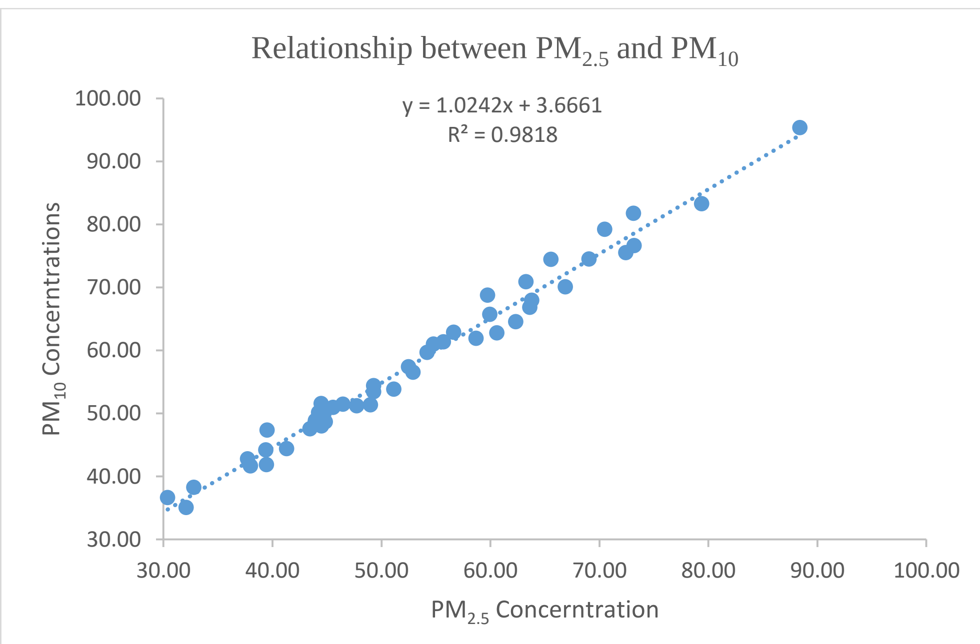

Figure 6: Relationship between $PM_{2.5}$ and PM_{10}

Table 4: The P value of the level of PM2.5 and PM10 at different sampling sites

Pollutants	**PM_{10} (µg/m^3)**	**$PM_{2.5}$(µg/m^3)**

School location	**Rural**	**Urban**	**Rural**	**Urban**
Average(Mean ± SD)	57.89±24	59.01±24.22	52.99±23.09	53.64±22.76
P-value (Wilcoxon test)	0.27		0.42	

Table 5: Correlation between $PM_{2.5}$ & PM_{10} and Metrological factors

	Temp_C	Hum	$PM_{2.5}$	PM_{10}
Current_Temp_C	1			
Current_Hum	-0.490	1		
$PM_{2.5}$	0.269	-0.324	1	
PM_{10}	0.285	-0.329	0.990	1

4.3. To model the influence of meteorological factors on $PM_{2.5}$ and PM_{10} levels in Schools

Table 6: Regression Statistics

Regression Statistics	
Multiple R	0.991623706
R Square	0.983317573
Adjusted R Square	0.982180135
Standard Error	1.804521249
Observations	48

ANOVA

	df	*SS*	*MS*	*F*
Regression	3	8445.225617	2815.075206	864.5019968
Residual	44	143.2770653	3.256296938	
Total	47	8588.502682		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-11.89472177	8.037352325	-1.479930366	0.146016878
Current_Temp_C	0.457426694	0.227378512	2.011741087	0.050395957
Current_Hum	0.057153152	0.049701713	1.14992318	0.256387419
$PM_{2.5}$	1.015902225	0.023490483	43.24739654	1.08175E-37

From this regression the table PM_{10} can be predicted to be = Equation 1: PM10= PM2.5+0.45temp+0.05 Hum -3

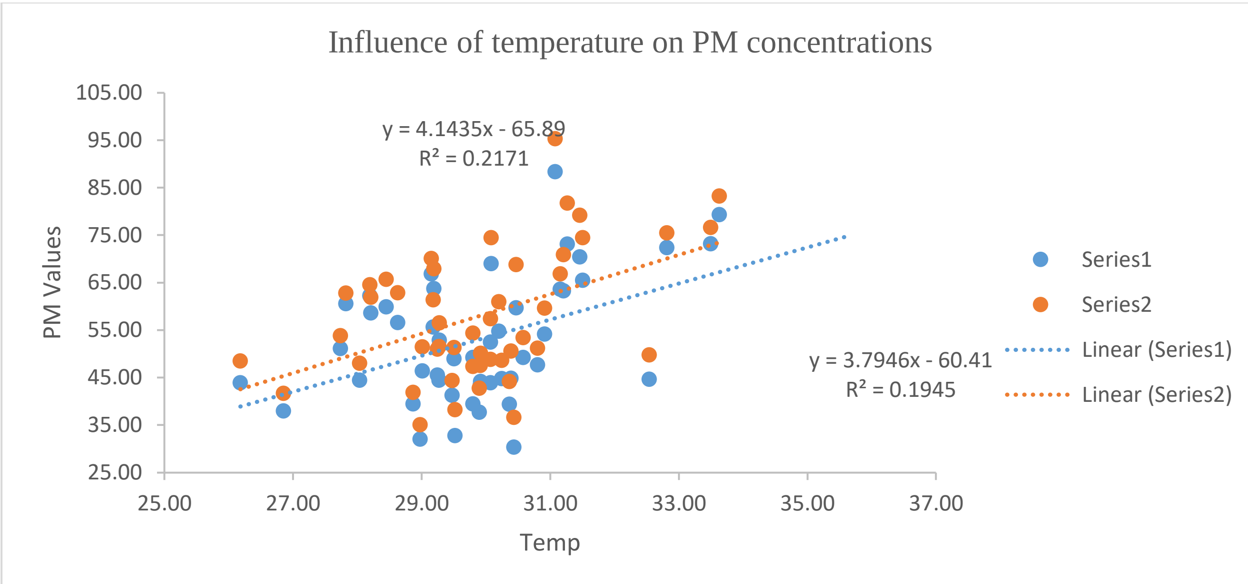

Figure 7: Influence of temperature on PM concentrations using linear regression

CHAPTER 5: DISCUSSION

5.1. The daily mean concentrations of $PM_{2.5}$ and PM_{10} vary in schools involved in the study

The concentrations of air pollutants at the sampling sites are summarized in Table 3. The 24-hour average concentrations of $PM_{2.5}$ and PM_{10} in urban schools in Kigali were 52.11µg/m³ and 56.14µg/m³, respectively. These levels exceeded the World Health Organization (WHO) standards of 15µg/m³ for $PM_{2.5}$ and 45µg/m³ for PM_{10} (WHO, 2021). In contrast, lower concentrations of $PM_{2.5}$ and PM_{10} were observed in rural areas compared to urban Kigali, likely due to reduced emissions from fewer traffic sources. This finding aligns with studies by Irankunda (2019) and Nduwayezu et al. (2015), which identified fuel combustion, motor vehicle emissions, and waste decomposition as major sources of air pollutants in Kigali. However, a 2018 study by REMA indicated that human activities such as agriculture, construction, and biomass burning in rural areas also contribute to air pollution. Across all sites, the lowest $PM_{2.5}$ and PM_{10} concentrations were recorded in rural areas (30.37µg/m³ and 35.09µg/m³, respectively), while the highest concentrations were found in urban areas (88.39µg/m³ and 95.37µg/m³, respectively). Additionally, relative humidity and temperature were measured during the sampling period, with daily averages of 29°C and 40% for both urban and rural locations.

5.2 Comparison of $PM_{2.5}$ and PM_{10} between rural and urban areas

Table 4 shows the pollutant concentrations measured across urban and rural areas. The results indicate that $PM_{2.5}$ and PM_{10} levels in rural sites were relatively consistent. According to Table 5, the Wilcoxon test revealed a P-value of 0.27 for PM_{10}, indicating no significant difference between urban and rural areas. For $PM_{2.5}$, the concentrations were higher in urban areas than in rural ones, with a P-value of 0.42. These findings are consistent with Branco et al. (2019) and Kalisa et al. (2018), who found elevated PM levels in urban areas due to vehicle emissions, a major source of air pollution. Urban children, in particular, are more vulnerable as they spend more time near traffic, increasing their exposure to pollution (Zhang and Batterman, 2013).

Figure 6 shows a strong correlation between $PM_{2.5}$ and PM_{10}, with an increase in one leading to an increase in the other across all sites, with a 99% confidence level. Additionally, Figure 7 indicates that temperature had a 20% influence on PM levels.

Despite no statistically significant difference in pollutant levels between rural and urban schools, all sites exceeded WHO air quality guidelines. The high PM concentrations suggest that local activities may be contributing to increased emissions. This aligns with Monn et al. (1997), who found that anthropogenic activities are key contributors to PM formation. As all the schools are located in Kigali, they likely share similar pollution sources, as supported by studies from Kalisa et al. (2018) and DeWitt et al. (2019), which found that both urban and rural areas in Rwanda are affected by common emission sources and environmental factors. Barnes et al. (2009) further emphasized that exposure to air pollution poses global health risks, leading to diseases and premature deaths.

Although this study found no significant differences in $PM_{2.5}$ and PM_{10} levels between urban and rural areas, with P-values of 0.42 and 0.27, respectively, it suggests that vehicle emissions are likely the main source of particulate matter in schools. However, the pollutant concentrations at all sites exceeded WHO standards.

Table 5: Levels of PM concentration of this study and other studies conducted in Rwanda Study Site

Study	Site(Kigali)	Pollutant	Level(µg/m³)
This study	Urban		56.14 & 59.51
	Rural		52.11&53.78
Kalisa et al., 2018	Urban	$PM_{2.5}$ & PM_{10}	185.3 & 214.0
	Rural		6.4 & 17.5
REMA, 2018	Urban		8.5 & 19.5
Korukire et al.,2023	Urban		133.61 & 158.58

Table 5 compares the 24-hour mean concentrations of particulate matter measured in this study with findings from other studies in Rwanda. The results show that air pollution levels in both rural and urban areas exceed the WHO air quality guidelines for $PM_{2.5}$ and PM_{10}. Although lower than concentrations reported by Kalisa et al. (2018) in urban roadside areas, this study's results are consistent with findings by Korukire et al.,2023 and Subramanian et al. (2020), which reported high pollution levels in Kigali. In contrast, REMA (2018) found lower particulate matter concentrations in Kigali’s urban background, likely due to differences in monitoring conditions. Overall, air quality in Kigali’s rural and urban areas is unsafe for human health in all studies.

5.3 Meteorological influence on $PM_{2.5}$ and PM_{10} levels in Schools

This study reveals significant correlations between PM2.5, PM10, temperature (T), and relative humidity (RH) when analyzed at each study site. A positive correlation was observed between PM2.5 and PM10 concentrations, indicating that an increase in one led to an increase in the other, as shown in Figure 7. This suggests that meteorological factors did not significantly influence PM concentrations across the sites, as weather conditions remained relatively stable throughout the sampling period. These findings are consistent with Zhou et al. (2016), who reported a strong relationship between PM2.5 and PM10, as both pollutants often originate from the same emission sources. This could be due to additional pollution sources at the study sites, such as dust from unpaved roads and fuel combustion.

Similar results were observed by Arkouli et al. (2010), who found high correlations between PM2.5 and PM10, suggesting that the pollutants shared common sources and behaved similarly, even with short-term changes in weather conditions. However, a negative correlation was noted between temperature and relative humidity, as shown in Table 5, indicating that when temperature increased, RH decreased, and vice versa. This inverse relationship has been linked to the potential for heavy precipitation in the future (Denson et al., 2021). While some studies, such as Elminir (2005), have suggested that higher relative humidity can increase ambient particulate matter concentrations, this study did not observe the same effect.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This research aimed to assess the variation of $PM_{2.5}$ and PM_{10} and meteorological factors in classrooms in both rural and urban areas of Rwanda. The findings demonstrate that urban and rural schools experience no difference between $PM_{2.5}$ and PM_{10} concentrations. Consequently, students in both urban and rural areas are subjected to pollutant concentrations that exceed the WHO's recommended 24-hour average exposure levels. The simultaneous increase in PM levels with temperature, coupled with the decrease in relative humidity, underscores the impact of meteorological conditions on air quality.

The elevated PM concentrations in urban areas can be largely attributed to traffic emissions and industrial activities. In contrast, rural areas face pollution from road construction (dust) and increased vehicle use. These findings underscore the urgent need for targeted interventions to address the sources of air pollution and mitigate its impact on children's health and academic performance.

6.2. Recommendations

Urgent interventions are needed to improve indoor air quality in schools across Rwanda. Implementing measures to enhance ventilation in classrooms can significantly reduce indoor air pollution. This includes the use of air purifiers, ensuring natural ventilation, and maintaining HVAC systems regularly. Additionally, creating green spaces with vegetation around schools can serve as natural barriers, helping to filter out pollutants before they enter the classroom environment.

It is crucial for different institutions, including government bodies, schools, and community organizations, to collaborate in efforts to reduce exposure to air pollution. Joint initiatives could focus on reducing vehicle emissions in the vicinity of schools, regulating nearby industrial activities, and promoting the use of cleaner energy sources. Such coordinated efforts can lead to substantial improvements in air quality and protect the health of schoolchildren.

Further research is necessary to thoroughly understand the sources of air pollution affecting both rural and urban schools. Future studies should involve larger sample sizes and extended observation periods to account for seasonal variations and other contributing factors. Additionally, it is important to investigate the health impacts of air pollution on students in Rwanda. This will provide critical data that can inform evidence-based recommendations for improving school air quality.

Policy development is essential to enforce air quality standards in educational institutions. This includes regularly monitoring indoor air quality, setting strict limits for pollutants, and ensuring compliance with WHO guidelines. Policies should also promote cleaner transportation options and improve urban planning to minimize traffic congestion and emissions around schools. By implementing these recommendations, it is possible to create a healthier learning environment for students and safeguard their well-being.

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