Heliyon 9 (2023) e18450

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Exposure to indoor and outdoor air pollution in schools in Africa: Current status, knowledge gaps, and a call to action

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ARTICLE INFO

Keywords:
Schoolchildren
Indoor air pollution
Outdoor air pollution
Particulate matter
Africa

ABSTRACT

Chronic exposure to indoor and outdoor air pollution is linked to adverse human health impacts worldwide, and in children, these include increased respiratory symptoms, reduced cognitive and academic performance, and absences from school. African children are exposed to high levels of air pollution from aging diesel and gasoline second-hand vehicles, dusty roads, trash burning, and solid-fuel combustion for cooking. There is a need for more empirical evidence on the impact of air pollutants on schoolchildren in most countries of Africa. Therefore, we conducted a scoping review on schoolchildren's exposure to indoor and outdoor $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 µm and PM_{10} (particulate matter with an aerodynamic diameter less than 10 µm) in Africa. Following PRISMA guidelines, our search strategy yielded 2975 records, of which eight peer-reviewed articles met our selection criteria and were considered in the final analysis. We also analyzed satellite data on $PM_{2.5}$ and PM_{10} levels in five African regions from 1990 to 2019 and compared schoolchildren's exposure to $PM_{2.5}$ and PM_{10} levels in Africa with available data from the rest of the world. The findings showed that schoolchildren in Africa are frequently exposed to $PM_{2.5}$ and PM_{10} levels exceeding the recommended World Health Organization air quality guidelines. We conclude with a list of recommendations and strategies to reduce air pollution exposure in African schools. Education can help to produce citizens who are literate in environmental science and policy. More air quality measurements in schools and intervention studies are needed to protect schoolchildren's health and reduce exposure to air pollution in classrooms across Africa.

1. Introduction

Africa's population is expected to double between 2010 and 2050 [1] and to remain the world's fastest-growing population. Due to

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https://doi.org/10.1016/j.heliyon.2023.e18450
Received 23 May 2023; Received in revised form 4 July 2023; Accepted 18 July 2023

this rapid demographic growth and lack of clean-energy infrastructure, Africa is the region most affected by air pollution worldwide [2]. For instance, $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 μm) and PM_{10} (particulate matter with an aerodynamic diameter less than 10 μm), are the primary contaminants affecting indoor and outdoor air quality and students' health. High levels of $PM_{2.5}$ and PM_{10} air pollution in sub-Saharan Africa are estimated to result in more than 700,000 premature deaths per year [3]; more than the combined effects of unsafe water, poor sanitation, and childhood malnutrition [4]. Deaths attributed to outdoor air pollution exposure in Africa increased by nearly 60% between 1990 and 2017 [4].

Children are vulnerable to air pollution because of their developing respiratory, nervous, and immune systems. Children also inhale more particles per unit of body mass than adults because of their higher oxygen consumption rates [5,6]. In addition, children do less nasal breathing, reducing particle deposition in the nasal airways and increasing deposition in the lower respiratory tract [7]. Children of school age in cities worldwide spend most of their time indoors, with 6–8 h of their day being spent at school and ~2 h in transit to or from school [8,9]. Indoor and outdoor air pollution affects millions of schoolchildren in Africa and other low-income regions. For instance, 12.6 million people die yearly because of pollution, representing 23% of human deaths for all ages but 26% of deaths for children [10]. Africa has the world's youngest population, with 40% of its population aged between 0 and 15 years, compared to the global average of 26% [11]. However, there is a lack of empirical evidence on the effect of air pollutants on schoolchildren in most countries of Africa.

Five of the world's top ten countries with the highest population-weighted average annual exposures to $PM_{2.5}$ are in Africa: Niger, Nigeria, Egypt, Mauritania, and Cameroon [12]. PM consists of ultrafine particles (UFPs), fine particles ($PM_{2.5}$) and coarse particles (PM_{10}), which are smaller than 0.1 μm 2.5 μm and 10 μm in aerodynamic diameter, respectively. UFPs and $PM_{2.5}$ can penetrate and deposit deep within the pulmonary region of the lungs, where gas exchange occurs. UFPs can also readily penetrate cellular membranes, eventually reaching the circulatory system and beyond. Particulate matter contains many potentially toxic species, including inorganic ions (e.g., sulfates and nitrates), organic compounds (e.g., polycyclic aromatic hydrocarbons (PAHs), nitro-polycyclic aromatic hydrocarbons (NPAHs), quinones, transition metals (e.g., Cu, Pb, Cd, Zn), elemental (or black) carbon, and biological compounds (e.g., vegetative detritus, viruses, bacteria, and fungi) [13]; such compounds and species are not frequently measured by countries' monitoring networks or included in air quality standards in Africa. In addition, several PM constituents (e.g., PAHs and NPAH) are linked to cancer and asthma even when the levels are low or do not exceed the mass concentration air quality guidelines [14], and little is known about their occurrence in the African school environment. Our recent study in Africa showed that low-volume

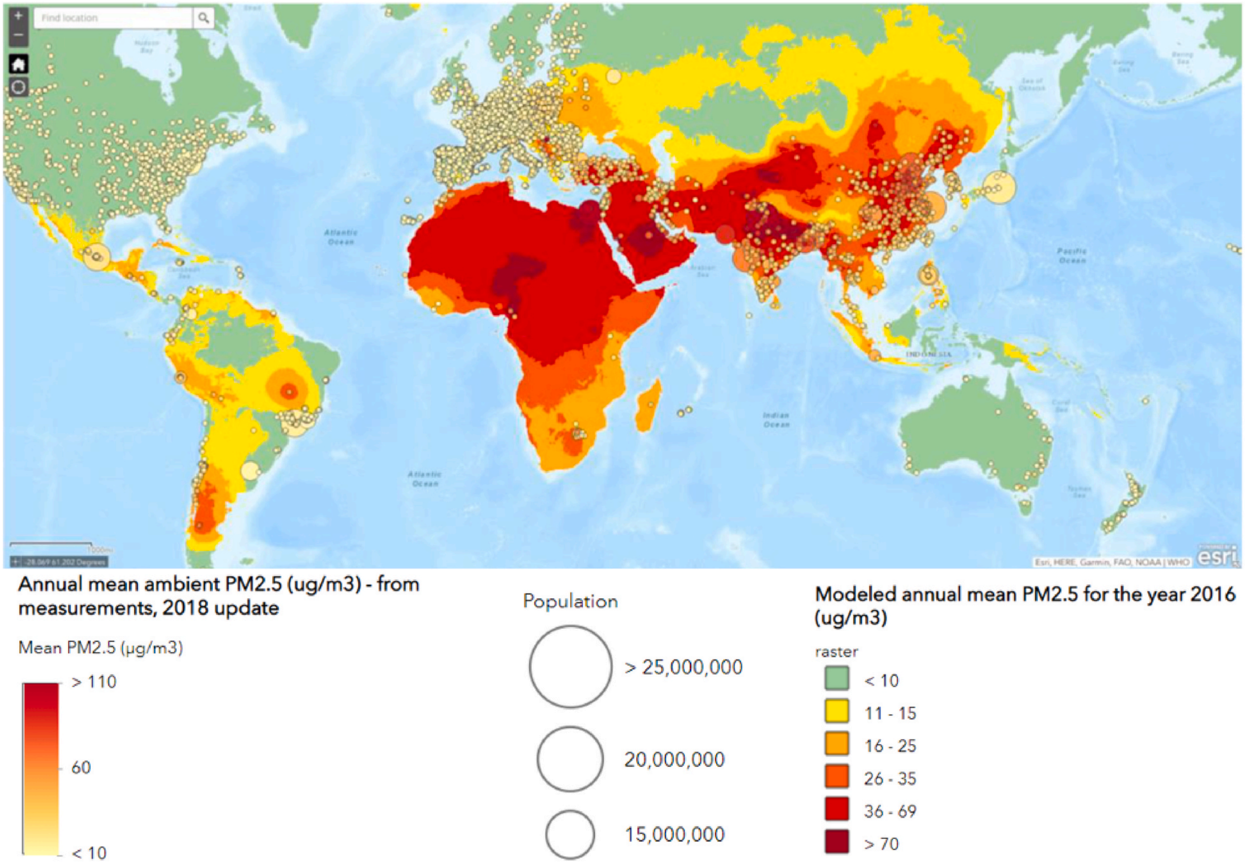

Fig. 1. Map showing worldwide fine particulate air pollution ($PM_{2.5}$) (from worst = red to best = green) and national air monitoring network locations (circles) [24]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

air samplers, which are more cost-efficient than high-volume air samplers, can be used to characterize particulate matter chemical and biological composition and fill the existing research gap in atmospheric aerosol characterization in Africa [15].

Particulate matter air pollutants are emitted into the atmosphere through primary emission sources (biomass burning, road dust, and traffic emissions are dominant sources of PM_{10} and $PM_{2.5}$ in Africa [13,16–19]), and through the secondary formation of PM via photochemical oxidation of volatile and semi-volatile gases. Economic growth in Africa will likely lead to increased PM emissions over time [20]. The concentration of $PM_{2.5}$ in African countries is more than ten times higher than the annual exposure limits recommended by the WHO (5 $\mu g\ m^{-3}$) [21]. In addition, most African cities have high levels of ambient PM [2,3,17,22,23]. Despite these estimates, knowledge about air pollution and its impact on human health is not well-advanced in most African countries. This lack of knowledge is partly due to the lack of reliable PM monitoring at ground level [15,24] – an expensive endeavor, as reference-grade air quality monitoring networks can cost millions of dollars to establish and maintain each year. As a result, government funding for air quality monitoring is low to nonexistent in Africa [23,24]. For example, only seven of 54 African countries have continuous monitoring stations, and most ambient air quality stations are located in South Africa [4]. Fig. 1 from the World Health Organization presents air-monitoring stations overlaid with global air quality estimates, demonstrating a clear lack of sufficient monitoring in many of the locations estimated to be the most polluted, globally.

A recent global review of indoor and outdoor air pollution at schools stated that only two studies were identified from Africa (both in South Africa) at the time of that review [8]. Our assessment sought to expand upon their work by summarizing the state of the science from the last few years, including the two studies identified by Oliveira et al. From a scoping review perspective, we summarized published studies on air pollution levels and exposure in African indoor and outdoor school environments. We also compared the findings of studies conducted in Africa with those undertaken in high-income countries. We provided evidence across the literature

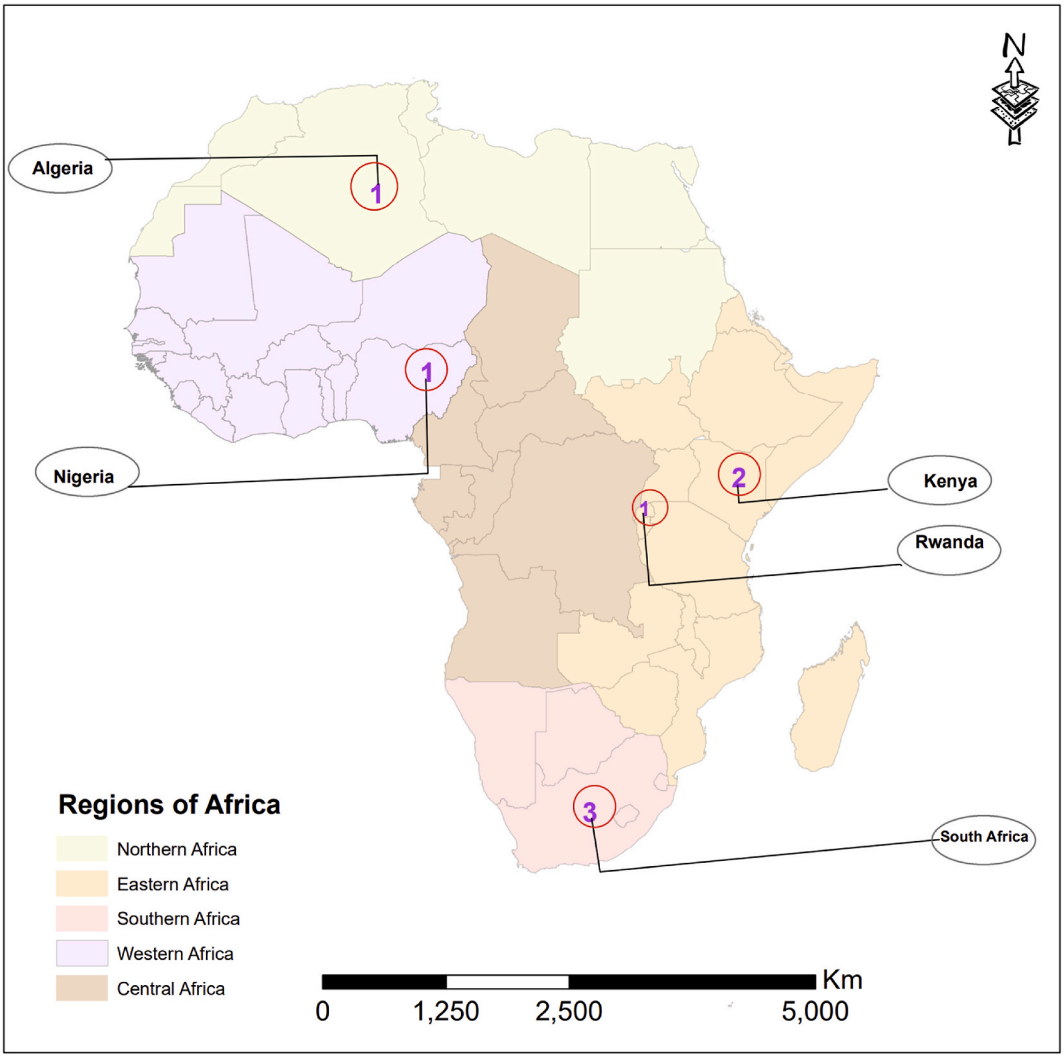

Fig. 2. The number of studies included per country for review across five regions of Africa: Eastern Africa (Kenya, Rwanda), Northern Africa (Algeria), Western Africa (Nigeria) and Southern Africa (South Africa).

Table 1

Findings of studies conducted on schoolchildren's exposure to indoor and outdoor PM in Africa.

City, Country	Methodology	Notes	Location type	Pollutants -Indoor	Mean ± SD [µg/m^3]	Pollutants -Outdoor	Mean ± SD [µg/m^3]	Conclusion	References
Kigali, Rwanda	Purple Air low-cost sensor, Annual average (2020–2021)	1 Primary school, Aged 5-10	Urban	$PM_{2.5}$	41 ± 10	$PM_{2.5}$	45 ± 8	$PM_{2.5}$ levels in classrooms were above the WHO's air quality guidelines.	Kalisa et al. [37].
Durban, South Africa	TEOM (24 h average), 12 weeks: The sampling year 2003–2004	7 Primary schools (n = 129, grade 4: 9–11 ages)	industrial	na	na	PM_{10}	86 ± 1.1	Correlation was observed between air pollutants and respiratory diseases was observed in schoolchildren.	Reddy et al. [34]
Durban, South Africa	TEOM; (24 h average), (continuous eight months). Sampling year: nr	Four Primary schools, n = 341, grades 3–6	Industrial	PM_{10} & $PM_{2.5}$	51 ± 25.2 & 20 ± 15.0	na	na	Correlation between air pollution and respiratory diseases (asthma) was observed in schoolchildren in industrial areas	Naidoo et al. [52]
Tiaret City, Algeria	Dekati® PM10 impactor, Finland), (8 h average), Sampling year: 2016–2017	23 primary schools)	Roadside	na	na	$PM_{2.5}$	33 ± 3.27	$PM_{2.5}$ was elevated in the classroom with the presence of students	Khadidja et al. [36]
Nairobi, Kenya	Particle counter Sampling (Annual average), year:2016–2017	4 Schools n = 578) students (9–14) years old, dry/wet season	Industrial	na	na	PM_{10} & $PM_{2.5}$	56-59 & 11-13	Low-cost sensors can collect school data, addressing poor air quality and filling data gaps.	DeSouza et al. [53].
Nairobi, Kenya	Ecotech Microvol 1100. (8 h average) Sampling year: 2018	Five primary schools/(n = 578) students of age 9–14. 8 h (Dry season)	Industrial Suburban	PM_{10} & $PM_{2.5}$	60–269 & 28–75	na	na	PM in classrooms exceeds the WHO limit value.	Were et al. [54].
Akwa Ibom, Nigeria	Fluke 985 Particle Counter (UK), (2 months average), Sampling year: 2018.	Two schools (n = 35 and 34) Dry and wet season	Industrial	PM_{10}	47–59	na	na	PM levels are higher in schools located in industrial areas than in schools in urban areas.	Ite et al. [55].
Gauteng, South Africa	AEROQUAL, New Zealand (8 h average), Sampling year: 2012	Five schools, 13–14-year-old, n = 100	Industrial Mining	na	na	PM_{10}	16.42 ± 3.67	Children with asthma are exposed to air pollution from dust emissions.	Nkosi et al. [55].

na: Not Applicable; nr: Nor reported; TEOM: Tapered element oscillating microbalance; PM2.5 and PM_{10} particulate matter les 2.5 and 10 µm in diameter, respectively WHO: World Health Organization.

database, searching published articles relating to schools in African countries, and focusing on PM because PM is the most measured air pollutant in schools in tropical countries, most of which are in Africa [25]. Our research was motivated by the lack of data on exposure to air pollution at school in Africa. The present review aimed to provide an overview of the current evidence on the topic and provide a list of recommendations and approaches to reduce air pollution exposure in African schools. We also used satellite data to assess exposure to $PM_{2.5}$ from 1990 to 2019 in 54 countries in Africa grouped into five regions (Northern, Eastern, Central, Southern, and Western).

2. Methods

This review used PRISMA scoping review guidelines [26] to summarise the state of knowledge on schoolchildren's air pollution exposure in Africa. The PRISMA method involves four main steps: identification, screening, eligibility, and inclusion [27–29]. We identified potential publications with the following online databases: PubMed, African Index Medicus, Web of Science, Scopus, and ScienceDirect. Further, we included citation and reference chaining from selected African studies to increase the number of published papers to be considered in the scoping review. Due to the limited number of African air quality studies, there was no restriction regarding the publication date or study period. This study focused on PM air pollution in database searches, using the following terms: "PM" OR "particulate matter," OR "fine particles" OR "coarse particles" OR "PM_{10}" OR "$PM_{2.5}$" AND "school OR classroom OR children OR schoolchildren," AND "indoor school" OR "outdoor school" OR "air pollution at school in Africa." We also considered reports published on government websites or from recognized organizations by searching "indoor and outdoor air pollution at school in Africa." These terms were sometimes combined with the name of an African country or region. Studies were considered eligible for inclusion in the review if their abstract and methods sections reported findings from measurement studies in classrooms or outdoor schools in Africa. We excluded studies conducted outside Africa. To highlight current knowledge on the exposure of schoolchildren and to generalize these findings to air pollution exposure in African schools, we compared schoolchildren's exposure to PM levels in Africa with those in high-income countries [8].

We summarized annual ambient $PM_{2.5}$ levels (1990–2019) for the following five African regions: North Africa, South Africa, East Africa, Central Africa, and West Africa [12]. We contrasted these levels with existing guidelines from the World Health Organization (WHO), the United States Environmental Protection Agency (US-EPA), and European Union (EU) air quality guidelines.

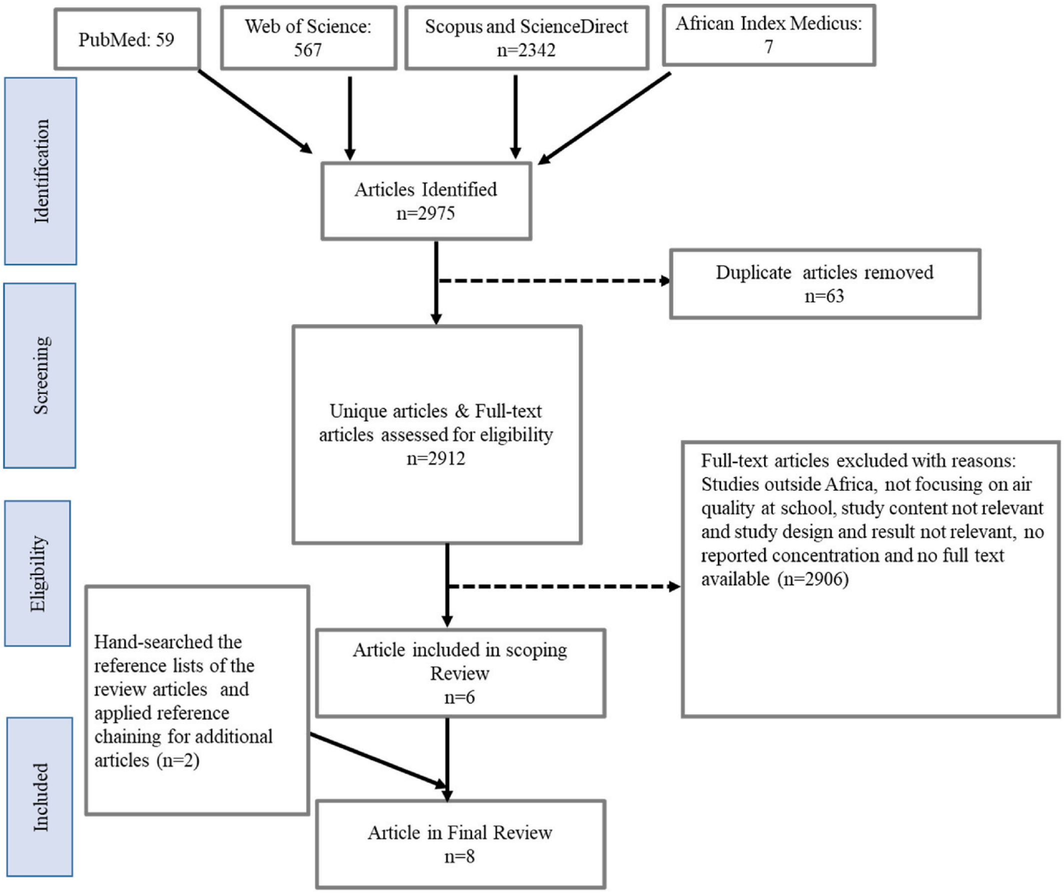

Fig. 3. Using a modified PRISMA framework selected, eight studies were included in the review.

3. Results

The geographic distribution of the studies from the scoping review is shown in Fig. 2. These included three studies conducted in South Africa, two conducted in Kenya, one in Nigeria, one in Rwanda, and one in Algeria. Table 1 lists the eight papers that were considered. Fig. 3 summarizes the modified PRISMA approach that was used for this review.

To the best of our knowledge, no review has summarized the scientific literature on levels of air pollution in African schools or discussed policy implementation relevant to such exposures. A global review published in 2019 included only two South African studies [8]. The need for more information from African schools is evident from Fig. 2 and Table 1. The key findings from existing studies are summarized as follows. Indoor PM_{10} concentrations in schools in Kenya and Nigeria ranged between 43 and 269 μg m^{-3} [30,31], and indoor concentrations of $PM_{2.5}$ ranged between 20 and 76 μg m^{-3} [30,32], respectively. The outdoor concentrations of PM_{10} in schools in South Africa ranged from 16 to 86 μg m^{-3} [33,34], while the outdoor exposure levels for $PM_{2.5}$ ranged between 11 and 33 μg m^{-3} [35,36]. (**Table 1**). Only one study in Rwanda investigated schoolchildren's indoor and outdoor exposure to PM in Africa, with data collected simultaneously [37]. Kalisa et al. found $PM_{2.5}$ concentrations of 41 μg/m^3 in classrooms in Kigali, Rwanda, and school playground concentrations were 45 μg/m^3. Only two studies (one from South Africa and one from Kenya) assessed the exposure levels of children to both PM_{10} and $PM_{2.5}$ at school [31,32]. Overall, limited studies have been conducted simultaneously in the African continent in both classrooms and outdoor school environments.

3.1. *Comparison of PM levels measured at schools in Africa to other regions of the world*

We compared the average concentrations reported in Africa to those already described worldwide in indoor classrooms or outdoor schools by Oliveira et al. (2019). Although we anticipated within-region heterogeneity in PM levels measured indoors and outdoors in schools, our goal was to present the current evidence for general comparisons. Levels of $PM_{2.5}$ in Asian schools ranged from 17 to 163 μg m^{-3} indoors and 15.3–242 μg m^{-3} outdoors [8]. For European schools, the levels of $PM_{2.5}$ ranged from 5 to 100 μg/m^3 indoors and 6–115 μg m^{-3} outdoors [8]. Levels of $PM_{2.5}$ in North American schools ranged from 8 to 10.2 μg m^{-3} indoors and 9–17 μg m^{-3} outdoors. Levels of $PM_{2.5}$ in Central America ranged from 20 to 27 μg m^{-3} in indoor classrooms compared to 17.5–31.1 μg m^{-3} in outdoor schools. Levels of PM_{10} in schools in South America varied from 17 to 24 μg m^{-3} [38]. Indoor PM_{10} levels were 105 μg m^{-3} for

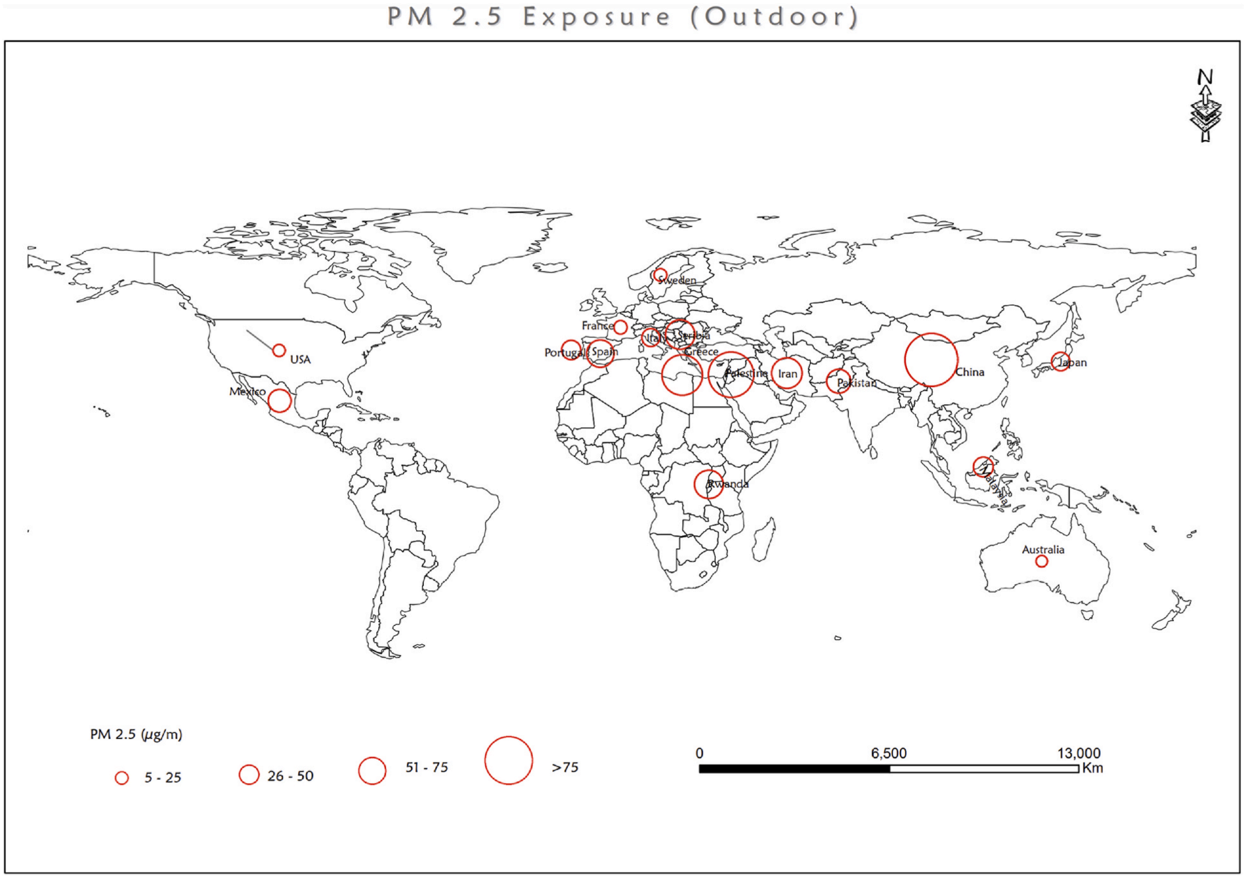

Fig. 4. Geographical distribution of studies on children's exposure to mean concentrations of $PM_{2.5}$ as reported in studies in indoor classrooms.

schools in Europe, 86 μg m^{-3} for schools in Asia, and 35 μg m^{-3} for schools in America [8]. The mean concentration of outdoor PM_{10} levels was 74 μg m^{-3} for schools in Asia, 47 μg m^{-3} for schools in America, and 47 μg m^{-3} for schools in Europe [8]. In Africa, indoor and outdoor PM_{10} concentrations in schools ranged from 43 to 269 μg m^{-3} and 16–86 μg m^{-3}, respectively (Table 1). The indoor and outdoor exposure levels for $PM_{2.5}$ in Africa ranged from 21 to 76 μg m^{-3} and outdoor exposure levels for $PM_{2.5}$ ranged from 11 to 41 μg m^{-3} (Table 1).

In this review, we also compared studies in Africa to other studies conducted worldwide that had analyzed air pollution data collected in classrooms and ambient air in the school environment (simultaneously). Figs. 4 and 5 show the spatial variation of the concentrations of $PM_{2.5}$ measured simultaneously indoors and outdoors in schools worldwide. There was only one study conducted in Africa (Rwanda). The annual average level of $PM_{2.5}$ air pollution measured in the classroom and outdoors at schools in Africa (Rwanda) [37] was comparable to that found in studies in Iran and Serbia [39] but higher than those reported in the US and Mexico [40], Japan [41], Pakistan [42], France [43], Portugal [44], Spain [45,46], Sweden [47], Italy [48], and Australia [49] and lower than China [50] and Palestine [51] (Figs. 4 and 5).

Overall, limited studies have been conducted simultaneously in the African continent in both classrooms and outdoor school environments. The available study indicated that average levels of $PM_{2.5}$ measured simultaneously in indoor or outdoor schools followed the same distribution profiles within continents, with higher levels measured in Asia and Africa than in Europe, Oceania, and the US.

3.2. Satellite-based $PM_{2.5}$ levels across Africa: 1990–2019

Satellite data can provide relatively reliable estimates of outdoor $PM_{2.5}$ trends in Africa, despite the need for long-term surface monitoring across the continent. However, satellite estimates are only reliable as annual means without continuous ground-based monitoring. Using satellite data from 1990 to 2019 [12] (Fig. 6), we found that the mean yearly $PM_{2.5}$ levels in all five regions of Africa (64 ± 26 μg m^{-3}) exceeded the WHO annual air quality guideline value limits of 5 μg m^{-3} [56], European Union (25 μg/m^3) [57] and USEPA (12 μg/m^3) [58]). However, these estimates should be interpreted with caution because satellite estimates likely have increased error in areas lacking ground-level air quality monitoring. From 1990 to 2020, the average $PM_{2.5}$ level was higher in West African (89.36 ± 20.23 μg m^{-3}), followed by Middle African (69.9 ± 16.24 μg m^{-3}), North African (60.54 ± 22.37 μg m–3, East

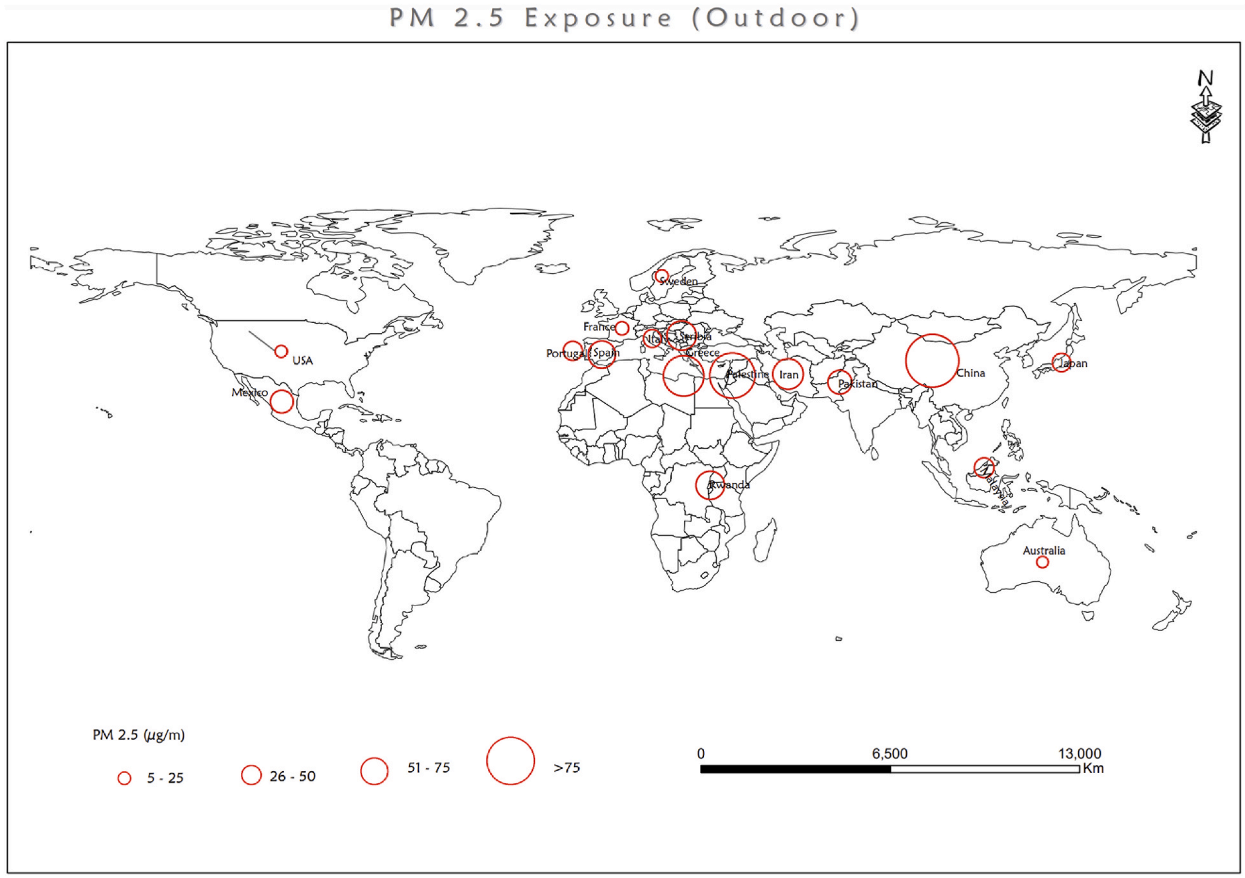

Fig. 5. Geographical distribution of studies regarding children's exposure to mean concentrations of $PM_{2.5}$ as reported in studies in outdoor environments.

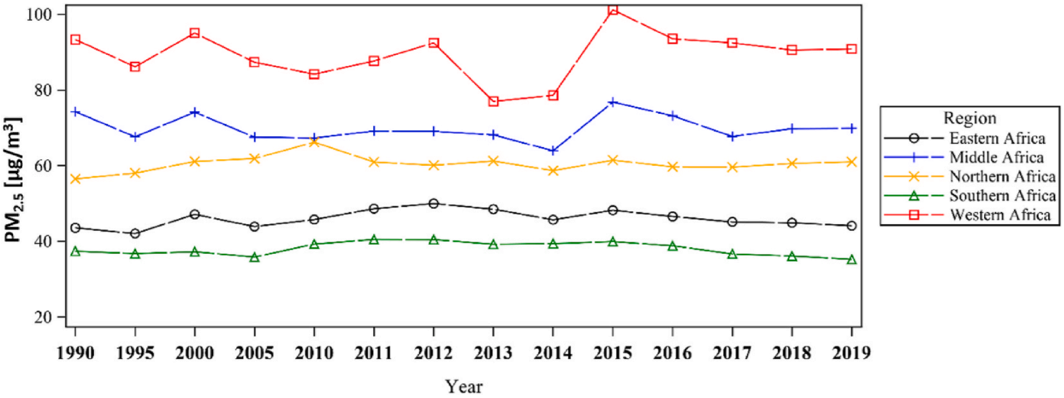

Fig. 6. Temporal changes in ambient $PM_{2.5}$ levels in Africa region from 1990 to 2019. State of Global Air 2020. The data source is the Global Burden of Disease Study 2019 [12].

African (46.04 ± 18.22 μg m^{-3}), and South African (38.10 ± 3.96 μg m^{-3}) regions (Fig. 6). The average concentration levels recorded in the five African regions were significantly higher than most of the other world regions and exceeded the annual mean proposed by the WHO (5 μg m^{-3}). We found that Djibouti (76 μg m^{-3}), Eritrea (72 μg m^{-3}), and Rwanda (68 μg m^{-3}) had the highest levels of $PM_{2.5}$ in the East African region between 1990 and 2019 [12]. We recorded the lowest concentrations in this region in Mauritius, Seychelles, and Comoros. The highest concentrations of $PM_{2.5}$ were found in West Africa in Niger, Mauritania, and Nigeria, while in North Africa, the level of $PM_{2.5}$ was high in Egypt, with high levels also observed in Lesotho in the Southern African region.

4. Policy implications

Many high-income countries have established policies and guidelines to improve air quality in indoor and outdoor school environments. For instance, the European Commission developed a project to improve classroom air pollution in kindergartens [59]. In Europe, 39% of all countries have established national standards for schools for some air pollutants such as VOCs, chemical indoor air pollutants and asbestos [59]. In the US, the USEPA created a schools kit to help schools assess and improve indoor air quality [60]. The kit provides information resources, low-cost sensors, air monitors, and a list of activities that will reduce air pollution in classrooms and outdoor school environments to prevent future indoor air quality problems. In Canada, the Ontario Public Health Association (2005) developed policies to locate schools in less polluted areas, monitor school air pollution, and install ventilation in classrooms to allow filtration of classroom air [61]. However, Africa lacks policies to protect schoolchildren and others from air pollution.

4.1. Ways to reduce children's exposure to air pollution at schools in Africa

4.1.1. Implement school siting policies in Africa

Studies have indicated that schoolchildren are exposed to air pollution from parents' vehicles idling during drop-off and pick-up times [62]. Most school playgrounds in Africa are located adjacent to the "kiss-and-ride" drop-off area. Given the proximity of many schools in Africa to major roads and highways and the fact that schoolchildren are in the classroom when traffic pollution is at its peak, air pollution exposure risks can be high during the daytime. Additionally, diesel school buses are used in Africa, which often idle on the school grounds and emit substantial quantities of diesel-related air pollutants [37]. Some school play areas are located downwind from major roads, residential areas, and industrial activities that can contribute to worsening air quality by mid-range transport of toxic air pollutants. Studies have indicated that children who spend more time outdoors tend to be more physically active, and due to their high respiration rates, they can inhale large amounts of air pollutants [63]. Studies on children's exposure to air pollution at school have generally focused on outdoor air quality as the critical determinant of exposure. However, schoolchildren spend a significant fraction of their time in indoor locations.

Children in outdoor play areas are exposed to a mixture of air pollutants from private vehicles and diesel-fueled school buses. The USEPA has published guidelines for school siting and indicated that a classroom's location affects student safety and the environment [64]. This guide showed that building a safe school that allows parents, teachers, students, and other community members to easily walk or cycle there helps to reduce school traffic and air pollution and improves children's health. In Europe, studies have established school siting guidelines, such as the inclusion of urban vegetation for new schools located around busy streets and highways [59]. However, no African country has legislation determining the distance of schools from polluting sources, such as busy roads. Thus, there is a need to locate schools in Africa away from sources of outdoor pollution. For existing schools, African governments should work with schools to establish green buses (electric buses) and bicycle paths leading to schools, along with measures to facilitate walking to schools, anti-idling campaigns on school premises, and car-free zones around schools. Schools could also add green infrastructure like 'barrier plants' along busy roads and playgrounds to help filter smoke and reduce traffic pollution.

4.1.2. Improve air quality monitoring

The recent design of air quality monitoring devices such as low-cost air quality sensors and wearable devices allows air quality sampling at higher spatial resolution [65,66]. Wearable air quality monitors used for personal monitoring are an inexpensive and direct approach to investigating individual exposure to air pollution for schoolchildren [67]. Many previous studies used real-time mobile monitors embedded with Global Positioning Systems (GPSs) that provide tracking to investigate schoolchildren's exposure to air pollutants in various environments, such as at home, at school, while outdoors, while recreation, and during commuting [68,69].

The WHO in Europe published software to measure the effects of exposure to air pollutants on human health [8]. The software relies on the findings of a review of available studies up to 2013. The data from that review on the concentrations of indoor PM_{10} and $PM_{2.5}$ in schools in America, Asia, and Europe served to estimate how exposure to PM affects the health of schoolchildren. However, Africa and Oceania were not included in the estimation because data were scarce for these continents [8]. In addition, for all continents, available data were on the effects of exposure to PM on children aged 6–13 years; few studies exist for younger children [8]. However, younger children may be more susceptible to exposure to PM. Children are likely exposed to indoor and outdoor PM at school regardless of age. Another critical limitation of previous studies is that nearby fixed monitoring station data are used to represent individual exposure, assuming that air quality is homogeneous at schools located around air quality monitoring sites installed at hundreds of kilometers [68]. Since air pollution in urban ecosystems is spatially and temporally heterogeneous and schoolchildren travel to or from school in different ways, data from modelling, fixed and mobile air quality monitoring, and personal air quality monitoring are the most appropriate approaches to determine the exposure of children to outdoor air pollutants. However, there are a few studies on commuting microenvironments as potential contributors to schoolchildren's total daily exposure [46,70]. One study estimated that schoolchildren commuting to or from school receive ~20% of their daily black carbon intake during their commute [46]. Higher exposure of schoolchildren to $PM_{2.5}$ on their way to school negatively affects their cognitive development [71]. In another study, students who spent 5% of their daytime traveling received 12% and 10% of their daily intake of black carbon and ultrafine particles respectively during that time [72]. Similarly, Buonanno et al. estimated that schoolchildren allocated 4% of their day to transport, but they accumulated 11% of their ultrafine particle intake during this time [73]. Thus, there is a need to determine schoolchildren's exposure to PM during their commutes between home and school.

Future studies in African schools should focus on simultaneously investigating both PM_{10} and $PM_{2.5}$ to identify the primary sources of PM and suggest strategies to reduce schoolchildren's exposure to air pollution at home and when commuting. To reduce air pollution in schools, there is a need to increase awareness in school communities, including among children, parents, and teachers [74], of the health effects of air pollutants on children. Students should be motivated to replace private with public transportation to and from school, use cleaning products that emit fewer air pollutants while cleaning classrooms with windows and doors open, and play on non-sandy playgrounds [74]. It is also essential to determine the relationship between the means of transportation used by students to get to and from school and their exposure to PM_{10} and $PM_{2.5}$. To investigate whether these suggested policies will be effective, continuous air quality monitoring at schools is required in African countries. It will promote air pollution education and awareness, to reduce air pollution exposure.

4.1.3. Develop standards or adopt guidelines for air pollution levels in schools

Air quality standards serve many roles in the public interest. For example, they may be used to inform the public about health risks related to air quality, and they allow populations to know which areas do not comply with the set standards. They can help individuals modify their behavior to mitigate emissions and exposures. To date, governments in several high-income developed countries have established air quality standards, which enable those countries to devise sustainable air quality policies. However, such programmes do not exist in Africa (sub-Saharan African region) [75,76]. Despite many discussions about the expansion of air quality monitoring in Africa, only five countries (Eswatini, Kenya, Rwanda, Senegal, and South Africa) [77] have set up air quality guidelines (Table 2). However, as stated above, efforts are also needed to monitor ambient air pollution in Africa, identify its primary sources, and mitigate adverse health effects by imposing legislation, especially for schoolchildren.

4.1.4. Conduct outreach to educate African schoolchildren

Solutions to improve air quality must account for social and cultural factors, which often play a role in environmental problems such as air pollution. Therefore, closely examining the complex relationship between people and air pollution is necessary. Air pollution emissions and exposure may be related to challenging lifestyles, cultural norms, and other behaviors; thus there is a need to distinguish between essential human needs (e.g., energy for cooking, lighting, heating/cooling, and transportation) and luxuries/

Table 2
Countries in Africa with standards for ambient particulate matter air pollution [78].

Pollutant (μg m^{-3})	Average time	Kenya	Rwanda	Senegal	South Africa	Eswatini
$PM_{2.5}$	One year	35	35	na	20	40
	24 h	70	70	na	40	na
PM_{10}	One year	50	50	80	40	75
	24 h	75	150	260	70	na
Enforced		YES	NO	NO	YES	YES

na: information not available.

behaviors that exacerbate environmental problems. There is also a need to increase public awareness about the causes and effects of pollution, and policies that lead toward more sustainable development. Producing an environmentally literate citizenry capable of solving the issues of air pollution and other environmental problems is essential. Thus, comprehensive and meaningful education is a promising way to equip schoolchildren to identify potential solutions to environmental issues, such as air pollution in Africa. An excellent policy involves the public, and education is a part of such a policy. Awareness of clean air at school and children's workshops on air pollution in Africa will help the government to communicate the benefit of implementing an anti-idling policy at schools, using electric school buses, and planting green vegetation for schools located on busy roads and by industries.

5. Conclusion and recommendations

Children are more vulnerable to air pollution and must be protected against exposure both indoors and outdoors. Though developing countries face the most significant challenges regarding air pollution, and their urban populations are increasing annually by 1–18% [79], schoolchildren's exposures to indoor and outdoor air have rarely been assessed in schools in Africa. It is important to know the concentrations of ambient and indoor pollutants in African schools. Previous studies have relied on data from nearby fixed stations to determine personal exposure to air pollutants, as if air quality is homogeneous within distances to monitoring station and people do not move out of that area. However, air pollution is spatially and temporally heterogeneous in urban ecosystems. Findings from the current scoping review have revealed the following.

- Schoolchildren in Africa are frequently exposed to $PM_{2.5}$ and PM_{10} levels exceeding the air quality guidelines recommended by the World Health Organization.
- Major knowledge gaps persist, and the total number of studies conducted on indoor and outdoor air pollution at school are low in Africa compared to higher-income regions.
- The few studies investigating children's exposure to air pollution in schools in Africa have rarely examined simultaneous exposure to both PM_{10} and $PM_{2.5.}$ Both PM_{10} and $PM_{2.5}$ threaten human health. There is thus a need to look at schoolchildren's exposure to both large and small particles of air pollutants and their chemical and biological compositions in atmospheric PM.
- Students travel between home and school using different means: walking, by car, bus, bicycle, or motorcycle. To accurately measure schoolchildren's exposure to ambient and indoor air pollution, future studies should combine personal monitoring, air quality modeling and air quality monitoring data.
- This review does not consider schoolchildren's exposure to air pollutants during transport to and from school or their exposure at home, but both are important sources of daily pollution intake. Thus, future studies in Africa and elsewhere should also consider children's exposure to classroom air pollutants during their travel to and from school.
- Walking and cycling will require proper pedestrian walkways and lanes for cyclists.
- Current evidence indicates that the use of commercial air purifiers in a school classroom reduced aerosol concentration by 90% just during first 30min of its operation [80]. Thus, air purifiers are likely effective and may be affordable options [81]. Similarly, face masks (N95), [82,83] may be options in African schools to reduce children's exposure (i.e., reducing indoor air pollution levels below WHO guidelines and reducing airborne transmission risk of Covid-19) [84]. Further evaluations should be conducted to determine if these interventions can improve health and improve academic performance [85].
- Finally, in Africa and other developing countries, epidemiological studies are needed to determine how schoolchildren's health and school performance are associated with exposure to air pollution. There is a need to promote education and inform schoolchildren of the choices they can make to reduce their exposure to air pollution on their way to and from school.

This review provides a basis for research and policy to establish mitigation measures to control the effects of air pollution in African schools.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data will be made available on request.

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.

Acknowledgment

E.K. acknowledges funding from the National Institute of Health as part of the Global Emerging Leadership Award (5 K43 TW 011954-01).

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