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REVIEW ARTICLE



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Release and health outcomes of exposure to chalk particles in classrooms: a systematic literature review

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ABSTRACT

This systematic review explores the release and health outcomes of exposure to chalk particles in classrooms. A literature search was conducted on Scopus, Google Scholar, and the Web of Science. Chalk particles contribute significantly to poor indoor air quality in classrooms. Higher concentrations of PM_{2.5} chalk particles were found in the front row (14.25 µg/m³) and near the chalkboard (19.07 µg/m³). Inhalation and dermal are significant exposure routes; hence, teachers and learners are at risk of developing respiratory and skin disorders. Inhalation of chalk particles correlates with reduced lung function in teachers and learners. The release and size of chalk particles depend on the activities, type of chalk sticks, and texture of the chalkboards. Wiping the chalkboard releases more chalk particles of smaller size (3.85–9.3 µm) than writing (10.57–92.91 µm). A shift from chalk sticks and chalkboards in classrooms is necessary to mitigate the associated health risks.

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KEYWORDS

Particulate matter; chalkboard; chalk sticks; erasable whiteboards; indoor air quality; spirometry

Introduction

Education is fundamental to developing children's numeracy and literacy skills, which are important for decision-making, empowerment, and good health and stability (United Nations 2016). Chalk sticks of different colours have long been popular tools for writing and drawing on blackboards in classrooms (Czerniewicz et al. 2020). Despite the increasing introduction and use of digital technologies in the education sector, teachers in many primary and secondary schools still rely on chalk sticks and chalkboards to convey information and engage learners (Lin et al. 2015). Chalk sticks are predominantly used in low-to-middle-income countries (LMICs) because of their cost-effectiveness (Goel et al. 2017). Most public schools in LMICs cannot afford digital technologies, whereas countries such as the Republic of South Africa (RSA) are affected by theft (Macupe 2019) and frequent power outages (Mbazima et al. 2022). However, the use of chalk sticks and chalkboards releases particulate matter (PM) in the form of chalk particles of different sizes and shapes, which contributes to poor indoor air quality (IAQ) in classrooms (Lin et al. 2015).

The amount and size of particles released mainly depend on the activities (i.e., writing or wiping) (Majumdar et al. 2012). When writing, the number and size of particles released are influenced by factors such as the type of blackboard and chalk sticks, writing style, applied

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force, and angle (Thakur et al. 2017). The quality of chalk is dependent on the amount of calcium carbonate (CaCO_3) and carboxyl methylcellulose (CMC), and chalks containing less than 6% CMC are dusty; thus, they release more PM when used (Maruthi et al. 2017). Dustless chalk sticks have been created to improve IAQ in classrooms; however, their price can be 5–10-fold higher than that of dusty chalk sticks (Goel et al. 2017). Poor IAQ is a subject of research interest because people spend most of their time in indoor microenvironments such as offices, homes, and classrooms (Wargocki 2011), where they are likely to be exposed to a mixture of indoor and outdoor pollutants (Mbazima et al. 2021). For example, teachers and learners can spend between 5 and 8 h per day and between 175 and 220 days per year in classrooms (Andrews et al., 2007), where they are potentially exposed to chalk particles mainly through the inhalation and dermal routes (Maruthi et al., 2017).

Exposure to chalk particles, even at low concentrations, is associated with short and long-term health effects such as respiratory disorders (Szász et al. 2017), skin (Corazza et al. 2012), eye, throat, and nose irritation (Sekar et al. 2021), and symptoms such as coughing and wheezing (Mishra et al. 1992). These symptoms can be particularly problematic for individuals with pre-existing respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), and allergies (Mendell and Heath 2005). Such health implications negatively impact the performance and productivity of learners and teachers (Mendell and Heath 2005; Annesi-Maesano et al. 2013) and lead to absenteeism among both teachers and learners (Wargocki 2011). Exposure to chalk particles can be exacerbated by confined spaces in classrooms, overcrowding, poorly constructed and maintained buildings, and a lack of ventilation (Madureira et al. 2009). For example, small-sized indoor microenvironments, such as classrooms, lack ventilation and allow easy accumulation and less dilution, transformation, and dispersion of chalk particles (Ilacqua et al. 2007; Nazaroff 2008). Therefore, it is important for teachers, learners, and policymakers to be aware of the potential health risks associated with the use of chalk sticks and chalkboards and to take steps to reduce exposure to chalk particles in classrooms.

Systematic reviews have been conventionally used to map the literature in various disciplines (Pahlevan-Sharif et al. 2019). Systematic reviews are important because they provide researchers, scholars, policymakers, and practitioners in various disciplines with evidence from the existing literature and advocate for future research, policy formulation, and the implementation of interventions (Pahlevan-Sharif et al. 2019). The objective of this systematic review was to provide a comprehensive overview of the research conducted on chalk particles. To the best of our knowledge, no systematic review focusing on research conducted on chalk particles has yet been conducted.

The main contributions of this systematic review are the identification of research gaps and future research on chalk particles. The study further highlights the risks and health outcomes associated with the release and exposure to chalk particles in classrooms and creates awareness among teachers, learners, parents, and policymakers in the education sector. Therefore, the results of this review will help policymakers understand the factors that lead to the release of chalk particles, and the health risks and outcomes associated with exposure to chalk particles in classrooms. The results will further help policymakers in the education sector to implement effective mitigation measures to improve IAQ in classrooms, thus protecting the health and safety of teachers and learners and improving their productivity. Furthermore, providing a healthy and comfortable workplace environment is an investment in the future of any country. This study is important, given that chalk sticks and chalkboards will be used for longer because they are cost-effective and easy to attain, particularly for LMICs that cannot afford to implement advanced technological teaching and learning equipment.

Methods and materials

Protocol

To achieve the objectives of this study, a literature search was conducted following the updated checklist items in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Page et al. 2021). The main research question of this review was, “What is the current state of scientific knowledge regarding the release and exposure to chalk particles in classrooms and their potential health effects on teachers and learners?”

Search strategy

A literature search was conducted to identify original peer-reviewed articles published in English focusing on the release and exposure of chalk particles in classrooms. Two databases were selected to locate peer-reviewed articles: the Web of Science (WoS) core collection from Clarivate Analytics and Scopus from Elsevier. These databases were chosen because they are updated frequently, cover a wide range of scientific subjects, and provide useful features that can be used to refine results (Chadegani et al. 2013). The WoS core collection provides subscription-based access to various academic databases with comprehensive citation information for various academic disciplines (Abas 2021). Furthermore, with the WoS core collection, manuscripts undergo a rigorous peer review and editorial process to ensure that quality articles are published to sustain the impact factor for the journal indexed in the WoS core collection. Another advantage is that the WoS core collection covers the publication index in the Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Conference Proceedings Citation Index-Science, and Emerging Sources Citation Index (Ranjbari et al. 2021). Scopus is a source-neutral abstract and citation database that provides a broad range of academics in many disciplines (Ranjbari et al. 2021).

Literature was searched using a combination of keywords and Boolean functions. Specifically, in Scopus, the “All fields” were searched, (ALL (chalk AND particles OR dust AND exposure AND classroom) AND NOT TITLE-ABS-KEY (gym*)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (DOCTYPE, “ar”)) which can be found at Scopus – Document search results | Signed in (wits.ac.za). In the WoS; chalk particles OR dust AND exposure AND classroom* AND school AND blackboard OR chalkboard (Topic) NOT gym* OR polycyclic aromatic hydrocarbons OR water OR geolog* OR endotoxin OR phthalate* OR pesticides OR flame retardant OR pesticides OR polybrominated diphenyl ethers OR polybrominated dibenzo-p-dioxins/furans (Topic) NOT miner* OR nitrification OR ocean OR poly* OR sport OR rock OR clay OR *water OR combust* OR soot OR aqui* OR sand* (Topic) NOT plume OR seismic OR radio* OR vivo OR vitro OR iso* OR *stone OR fuel OR layer OR fluid OR liqui* OR porous OR sedimen* OR ion* OR atmos* (Topic) and English (Languages) and Article (Document Types) and Proceeding Paper (Exclude – Document Types), <https://www.webofscience.com/wos/woscc/summary/4d59d6f9-7c52-451e-9993-a799f9b4f6bd-71a080c2/author-ascending/1>. The literature search was conducted on 10th August 2022, and the last comprehensive search was conducted on 14th February 2023. Date restrictions were not applied to cover all published studies. Furthermore, Google Scholar was used to search for citations for studies that might have been missed on Scopus and in the WoS core collection.

Study selection

Retrieved articles were transferred to a Microsoft Excel spreadsheet (Redmond, Washington, USA), where they were independently reviewed by two authors (S.J.M. and R.M.). Disagreements between the two authors on which articles to exclude or include were resolved by extensive discussion, and where an agreement could be reached, the third author (J.S.J.) was consulted for further discussion

and a final decision. Filters were applied to detect duplicate studies, which were then removed. The remaining articles were reviewed by reading their titles and abstracts to determine whether they met the inclusion criteria shown in Table 1. For articles without abstracts, the full text was downloaded to reach a consensus. The full texts of studies that met the inclusion criteria were downloaded into version 1.19.8 of Mendeley Desktop (Elsevier, London, UK), where they were further reviewed.

Study eligibility criteria

The inclusion and exclusion criteria (Table 1) for this systematic review were formulated by the authors before the literature search to ensure consistent identification of relevant.

Results

Figure 1 shows the process followed in the literature search, the selection of studies, and the number of studies included in the systematic review. Of the 192 studies identified during the literature search, only 11 met the inclusion criteria stipulated in Table 1.

Table 1. Inclusion and exclusion criteria used to assess the eligibility of identified studies.

Inclusion criteria	Exclusion criteria
Studies published in English	Studies not published in English
Studies conducted in classrooms	Studies conducted at higher institutions
Studies focussing specifically on chalk particles	Review articles, books, book chapters, book reviews, commentaries, editorials, notes, newsletters, conference articles, dissertations, case studies and theses
Original articles	Studies focussing on general particulate matter

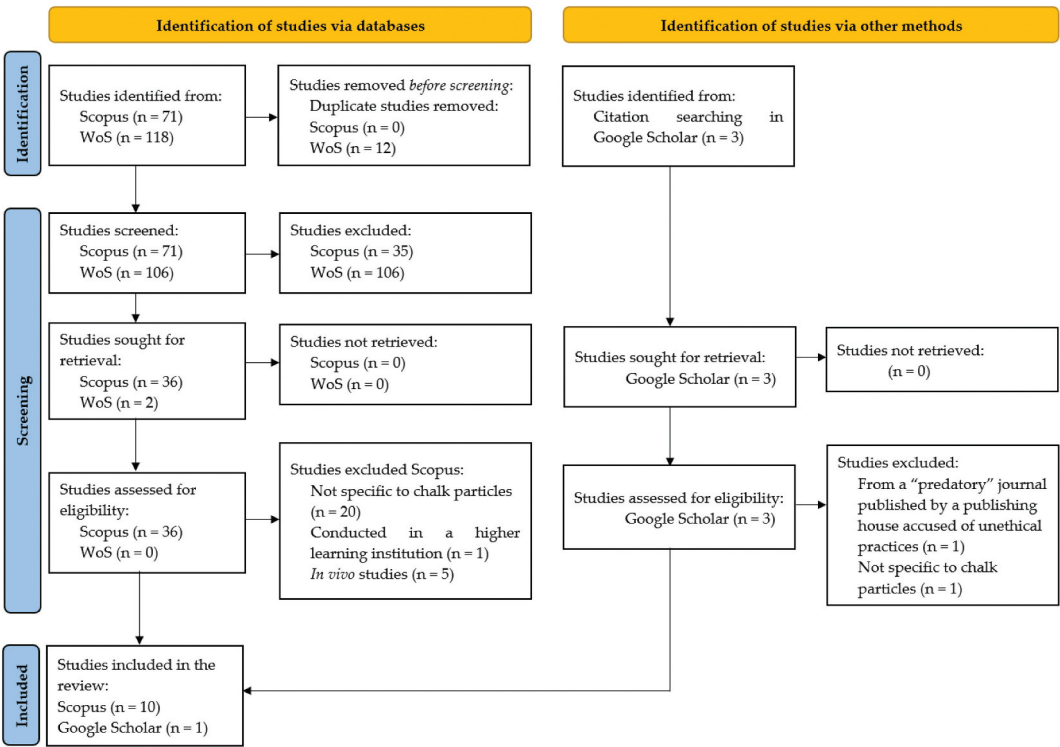


Figure 1. PRISMA statement flow diagram used in the systematic review.

Figure 2a shows the number of published studies per year focussing on chalk particles in classrooms, whereas Figure 2b shows the subject area of the studies. From Figure 2a, it can be noted that a minimum of one study and a maximum of three studies are published per year in this research area. It should be noted that research on chalk particles is unsatisfactory, despite the heavy reliance on chalk sticks and chalkboards and the health implications of exposure to chalk particles. Figure 2b shows that the most researched subject area was medicine, followed by environmental science and multidisciplinary. The least researched areas were chemistry, biochemistry, immunology and microbiology, social sciences, engineering, earth, and planetary science. Most of the published studies were conducted in India, followed by Nigeria (Figure 2c) and the leading author was Majumdar D (Figure 2d).

Table 2 presents a summary of the studies on chalk particles conducted. Most studies assessed exposure to chalk particles and potential health effects. Other studies investigated the knowledge, attitudes, and practises of teachers regarding chalk particles, whereas others investigated the factors influencing the release of chalk particles and their physicochemical properties. Most of the studies (70%) were conducted in India, a country that relies heavily on chalk sticks and chalkboards for teaching (Sekar et al. 2021).

Table 3 summarises the studies conducted on human subjects. These human subject studies assessed the pulmonary function of teachers and learners exposed to chalk particles in classrooms. Two of the three studies that conducted lung function tests focussed only on teachers, whereas one focussed on both teachers and learners exposed to chalk particles in classrooms. As shown in Table 3, two of the studies were conducted in Nigeria.

Discussion

This systematic review analysed original peer-reviewed articles from multiple databases to identify research trends on chalk particle exposure and check whether research on chalk particles has

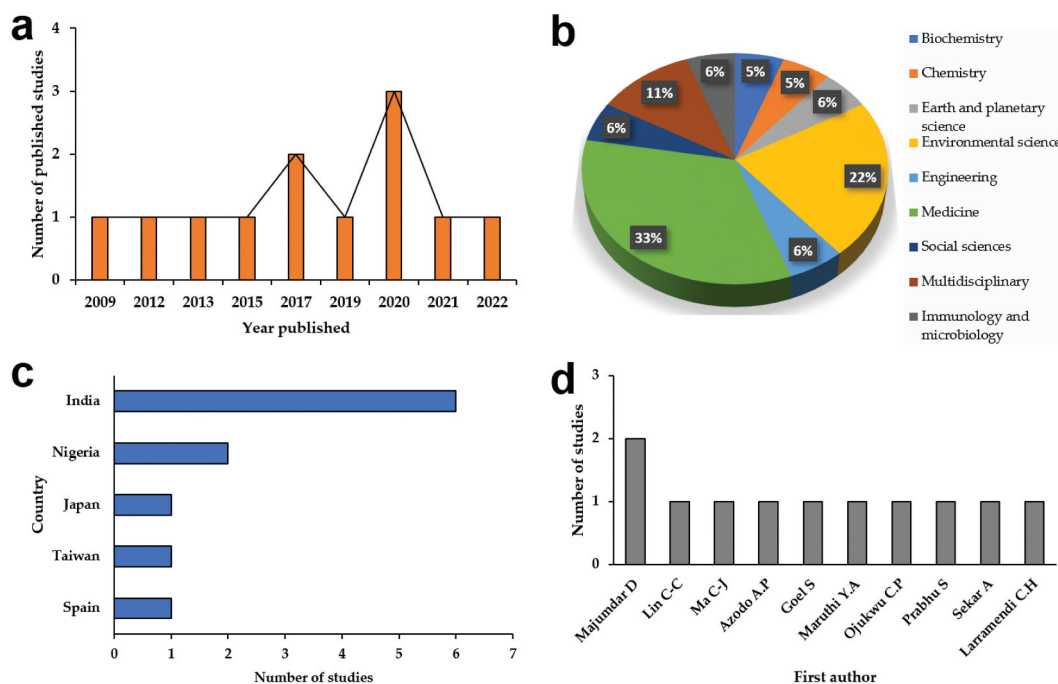


Figure 2. Number of studies published per year focussing on chalk particles in classrooms (a), subject area of the published studies (b), number of studies published per country (c), and number of studies published per first author (d).

Table 2. Summary of studies investigating the release and exposure to chalk particles in classrooms.

Study	Country	Methodology	Key findings	Recommendations
(Majumdar and SPMP 2009)	India	Dusting and non-dusting chalk sticks were used to write on smooth and rough chalkboards. Writing on the chalkboard was conducted by 10 different people. Chalk particles were collected using glass Petri plates placed 3 m from the chalkboards. The final weight of the chalk used was subtracted from the initial weight to obtain the amount of dust generated in 30 min. Scanning electron microscopy coupled with electron dispersive X-ray (SEM-EDX) was used to analyse the morphology of the particles. The size distribution of the chalk particles was also analysed. The strength and breaking behaviour of the dust and non-dusting chalk sticks were determined.	Dusting chalk sticks contributed more to the mass concentration of chalk particles, particularly when writing on rough chalkboards. More chalk particles were also released when writing on rough chalkboards. Dusting chalk sticks produced higher numbers of smaller chalk particles when writing on smooth chalkboards. Compared with rough chalkboards, writing on smooth chalkboards released lesser chalk particles <4.5 µm and <11 µm. Overall, dusting, and non-dusting chalk sticks released a higher number of smaller chalk particles when writing on smooth chalkboards. Non-dusting chalk sticks generated higher smaller particles compared to dusting chalk particles. More than 50% of the chalk particles generated by non-dusting chalk sticks were PM_{2.5}. Many of the chalk particles released by non-dusting chalk sticks when writing on the smooth and rough chalkboard were <4.5 µm. Particles from dusty chalk sticks had an elongated and random shape indicating that dusty chalk sticks tend to break into a rod shape. Both dusty and non-dusting chalk sticks showed flocs. Non-dusty chalk sticks also broke into random shapes; however, elongated chalk particles were not observed. Non-dusting chalk sticks showed a higher compressive strength relative to dusty chalk sticks, indicating the to hold their integrity when pressed against boards during writing.	Health effects of exposure to chalk particles in classrooms must be conducted

(Continued)

Table 2. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Majumdar et al. 2012)	India	Writing and wiping experiments were conducted on cement chalkboards to compare three varieties of white chalk sticks (local gypsum, abroad quality, and clean write). The experiment was conducted in a classroom with dimensions $7.6 \times 4.25 \times 3 \text{ m}^3$ and a series of five windows ($1.2 \times 0.9 \text{ m}^2$) located on each side. The experiment was conducted in the absence of learners and teachers, and the doors and windows were closed. The chalk sticks were weighed before and after writing to estimate the weight loss per unit of time. A standard paragraph was written for 15 min by one person. The wiping of the chalkboard was also performed by one person, and each writing and wiping experiment was performed in triplicates. Real-time monitoring of airborne chalk particles was conducted using a portable aerosol spectrometer (Grimm 1.109, Germany). Long paper sheets ($50 \text{ cm} \times 150 \text{ cm}$) were used to collect settling chalk particles at the base of the chalkboard during writing and wiping. A particle size analyser (CILAS 1180) that provided the cumulative particle size distribution (PSD) in percentages for particles between 0.04 and $2 \text{ 500 } \mu\text{m}$ was used to determine the volumetric PSD.	The average mass concentration of chalk particles increased slightly when writing on the chalkboard. Regarding dust fall, all chalks released fine particles when wiping compared with writing on the chalkboard. The concentrations of airborne chalk particles were lower when writing on the chalkboard than when wiping. The mean diameter of chalk particles collected below the chalkboard when writing was $92.91 \mu\text{m}$ for the local gypsum chalk sticks, $15.86 \mu\text{m}$ for the abroad quality and $10.57 \mu\text{m}$ for clean-write. After wiping, the mean diameter was $9.3 \mu\text{m}$ for the local gypsum chalk sticks, $4.53 \mu\text{m}$ for the abroad quality and $3.85 \mu\text{m}$ for the clean-write. Ten per cent of the chalk particles collected below the chalkboard were fine (clean write: $0.5 \mu\text{m}$), (abroad quality: $0.67 \mu\text{m}$) and (local gypsum: $1.15 \mu\text{m}$). At 50%, the chalk particles were also fine (abroad quality: $5.12 \mu\text{m}$), (clean write: $6.36 \mu\text{m}$), and (local gypsum: $77.65 \mu\text{m}$). Clean write released the lowest number of chalk particles per unit time (PM_{10}: 0.33 g/h; $\text{PM}_{2.5}$: 0.58 g/h and PM_{5}: 0.86 g/h). Clean write chalk sticks wasted less per unit of time compared with the other types (clean write: 1.92 g/h; local gypsum: 5.12 g/h and abroad quality 3.04 g/h). The chalk sticks were dominated by calcium carbonate and calcium sulphate but contained no toxic metals.	Thorough studies investigating the health implications of exposure to chalk particles on teachers and learners.

(Continued)

Table 2. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Lin et al. 2015)	Taiwan	Teachers' and learners' exposure to chalk particles (PM_{10} and $PM_{2.5}$) was conducted in a windowless classroom (L = 890 cm, W = 837 cm, and H = 450 cm) for an hour, which was equivalent to one teaching session. Exposure to chalk particles was conducted under different ventilation modes [(i) closed doors, (ii) closed doors + air conditioner on, (iii) closed doors, air conditioner on + ceiling fans on, (iv) opened doors, and (v) opened doors, + ceiling fans on]. A total of 126 grids (24 × 22 cm) were drawn on the chalkboard by one person using white anti-chalk sticks and then wiped. The experiment was performed in triplicates. Chalk particles near the chalkboard were collected at 1.7 m to represent the breathing zone of a standing teacher using a scanning mobility particle sizer (TSI 3080, USA) coupled with an electrostatic classifier and a condensation particle counter (TSI 3022A, USA). A Grimm dust monitor (Grimm 1.109, Germany) was used to collect representative samples of PM_{10} and $PM_{2.5}$ at 26 locations in the classroom at 1.2 m to represent the breathing zone of seated learners.	Writing on the chalkboard increased the number of chalk particles near the chalkboard. The mass concentration of chalk particles was higher than the background concentration regardless of the ventilation mode. Higher mass concentrations of chalk particles were recorded in the teaching area during ventilation mode (i), implying that teachers were at a higher risk of exposure when the doors were closed. The highest mass concentration of chalk particles was recorded during ventilation mode (iv), whereas ventilation modes (ii), (iii), and (vi) showed elevated dispersion of chalk particles in the classroom. Higher PM_{10} mass concentration levels were observed when the doors were opened, and the ceiling fans were on compared with when the doors were opened. Ceiling fans caused turbulence, which slowed the settling of coarse chalk particles and increased their retention time. Chalk particles ranging from 2.5–10 μm were dominant in all ventilation modes. Chalk particles near the chalkboard were less than 7 μm when writing and wiping without any form of ventilation. The mass concentration of chalk particles was lower when writing compared with wiping the chalkboard. Wiping the chalkboard released a higher number of inhalable and thoracic chalk particles. Chalk particles were a significant source of ultrafine particles in classrooms.	Teachers must wear personal protective equipment such as face masks when teaching. Doors should be kept open during lessons to prevent the accumulation of chalk particles in classrooms. There must be a significant distance between the chalkboard and the first row where learners are sitting. Classrooms must be cleaned frequently to prevent the re-suspension of settled chalk particles.

(Continued)

Table 2. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Goel et al. 2017)	India	Low dust, dustless, moulded and dust-free chalk sticks were used to write on wooden and ceramic chalkboards. A standard paragraph was written by three different people for an hour in the absence of learners and teachers. The chalkboards were wiped using a dry duster, and windows, doors, and all openings were closed. The classroom was deep cleaned before the experiment. A respirable dust sampler (Envirotech, APM: 460) coupled with a cyclone was used to sample PM₁₀ and total suspended (TSP) at a flow rate of 54–90 m³/h. A fine dust sampler (Netel, FDS 2.5 µ A) coupled with a WINNS impactor was used to sample PM_{2.5} at a flow rate of 1 m³/h. PM_{2.5} and PM₁₀ airborne chalk particles were collected during the writing and wiping of the blackboards using air samplers, and the settling particles below the chalkboard were collected using paper sheets. A respirable dust sampler coupled with a cyclone housing a Whatmann glass fibre filter with a filter area of 25.4 × 20.3 cm (pore size: 0.1 mm; and 99% collection efficiency) was used to collect PM₁₀ particles. PM_{2.5} particles were collected using a fine dust sampler coupled with Whatmann PTFE filters (pore size: 2 µm, diameter: 46.2 mm). The filters were conditioned at 22°C and weighed on a microbalance scale. Sampling of PM in classrooms was done twice for each type of chalk, and the average MC was used. The morphology of the collected chalk particles was investigated using SEM, and the chemical properties were investigated using EDS.	Low dust and dustless chalk sticks generated less fraction of chalk particles when writing on the wooden blackboard relative to the ceramic blackboard. However, the moulded and dust-free chalk sticks generated more chalk particles when writing on the wooden blackboard than on the ceramic. Low dust chalk sticks generated less chalk particles when wiping on the ceramic blackboard, whereas the other three chalk types generated more particles. Dustless chalk sticks emitted the highest concentrations of PM_{2.5}, PM₁₀, and TSP chalk particles of the three chalk types when writing on both ceramic and wooden chalkboards. Dustless chalk sticks generated the lowest PM_{2.5} and TSP mass concentrations, whereas dustless chalk sticks generated the lowest PM₁₀ mass concentration during writing. Writing on the chalkboards generated less particles than wiping for all the chalk stick types. Chalk sticks constituting gypsum generated approximately 20% more chalk particles than calcium carbonate-based chalk sticks when writing and wiping. EDS showed that calcium, carbon, and oxygen were the main constituents in low dust and dustless chalk sticks, indicating that they were created from CaCO₃ (calcite). Magnesium, aluminium, and silicon, which are also used to manufacture chalk sticks, were also detected. EDS also showed that sulphur, calcium, and oxygen as the main constituents for dustless and moulded chalk sticks, indicating that the chalk sticks were made from CaSO₄ (gypsum).	Not provided

(Continued)

Table 2. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Maruthi et al. 2017)	India	Airborne chalk particles were collected near chalkboards using a fine dust sampler (Envirotech APM550) at a height of 1–2 m from selected classrooms during workdays from morning until evening. Petri plates were placed 3 m from the chalkboard for 30 min to collect settling chalk particles. Inductively coupled plasma-mass spectrometry (ICP-MS) (Agilent Technologies, Tokyo, Japan) was used to determine the elemental composition of the chalk particles. SEM was used to analyse the morphology of the chalk particles. A human health risk assessment was conducted for adults and children according to the United States Environmental Protection Agency (USEPA) guidelines.	Chalk particles generated from dusty chalk sticks remained suspended relative to particles from dustless chalk sticks. Aluminium, manganese, and iron were the elements with the highest average concentrations in airborne and settled chalk particles. The concentration of trace elements was higher in airborne chalk particles than in settled chalk particles. The concentration of trace elements was higher in airborne chalk particles than in suspended ones, and all SEM images showed elongated chalk particles. Chalk particles with fibrous shapes were found for dustless chalk sticks, whereas dusty chalk sticks showed circular and aggregated chalk particles. Dermal contact was found to be the major route of exposure for teachers, followed by inhalation and ingestion.	Not provided
(Ma et al. 2019)	Japan	The spatial distribution of chalk particles in a model classroom was measured using two optical particle counters (HHPCP3+, HACH Co) and a PM_{2.5} monitor (PM_{2.5}, TSI Co) in the presence of learners. The measuring instruments were placed 1.5 m from the chalkboard. A silver foil placed on a passive dust collector was used to collect settling chalk particles. Activities conducted included writing on the board, wiping the board, and operating a blackboard eraser. Each class duration was 50 min. A control experiment was conducted using a whiteboard. SEM (JEOL JSM-5400) coupled with EDX (Phillips, EDAX DX-4) was used to investigate the elemental composition and morphology of the chalk particles. The number of PM_{2.5} chalk particles deposited in the respiratory tract of teachers and learners was calculated.	A significant number of PM_{2.5} chalk particles were released when chalk sticks were used. However, there was no elevation of PM_{2.5} when using the whiteboard and eraser during the activities. The concentration of chalk particles was significantly lower furthest from the blackboard when going to the back of the classroom. Learners sitting in front of the chalkboard are at a higher risk of exposure. SEM showed chalk particles of different sizes with random shapes. Major elements found were in the decreasing order of calcium, carbon, and oxygen. Based on the classroom concentration, the potential deposited dose in the interstitial alveolar region of 10-year males and females doing light work was 3.69 µg. The deposited doses for adult males and females doing light work were 18.12 and 15.10, respectively.	Formulation of policies to prevent exposure to chalk particles in classrooms must be prioritised.

(Continued)

Table 2. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Sekar et al. 2021)	India	Real-time sampling of chalk particles was conducted for 1 h from the breathing zone of teachers using a mini laser aerosol spectrometer (Grimm 11-R, Germany). Variation between normal and dustless chalk sticks was investigated during writing, dusting, and de-dusting. SEM (Hitachi SU6600, Japan) was used to analyse the morphology of the chalk sticks. A Fourier transform infrared spectrometer with attenuated total reflectance (FTIR-ATR) (Perkin Elmer-Spectrum 2) sampling accessory was used to determine the elemental composition of the chalk sticks. FTIR-ATR was coupled with spectral databases from L60002 Polymer & Polymer additives, S.T. Japan-Europe GmbH, and the Fulka library. The deposition of chalk particles in the respiratory tract was determined using version 3.04 of the multi-path particle dosimetry model (MPPD) (Applied Research Associates Inc.) An online self-administered questionnaire was used to gather information on exposure to chalk dust, teaching methods, and associated health effects.	Approximately 55% of the teachers spent 3–5 h in the classroom, and 38% of them used two chalk sticks per day. Approximately 42% of the teachers washed their hands after lessons, while 29% washed both their hands and face. Teachers who used less chalk sticks per day had fewer health issues than those who used a higher number. Teachers teaching theoretical subjects were vulnerable to eye irritations, pulmonary disorders, and skin infections and irritation relative to those teaching numerical subjects. Ninety-three per cent of the teachers used masks to reduce exposure to chalk particles. No correlation was found between age and associated health effects; however, the number of teaching hours was correlated with health effects. Teachers who used dust-free chalk sticks reported less health issues than those using normal chalk sticks. The concentration of fine chalk particles was slightly higher in dustless chalk sticks than in normal chalk sticks. The mass concentrations of PM_{10}, $PM_{2.5}$ and PM_{10} showed no statistically significant difference when the teachers wrote above the head, with the head and below. De-dusting, which was performed by tapping the duster against the wall, released a higher number of chalk particles than writing and wiping the chalkboard. The mass concentration of fine particles was higher for dustless chalk. A statistically significant difference was found between writing and de-dusting and between dusting and de-dusting. However, no difference was found between writing and dusting for normal chalk sticks. The main chemical constituents of the chalk sticks were calcium sulfate and ground calcium carbonate. The highest total deposition factor was for PM_{10} compared with $PM_{2.5}$ and PM_{10}. The deposition of PM_{10}, $PM_{2.5}$, and PM_{10} were in decreasing order of head (H), tracheobronchial (TB), and pulmonary (P) regions. The deposition of chalk particles in the head region was lower for female teachers than for males; however, it showed opposite results for the TB and P regions.	Awareness of exposure to chalk particles is required, including precautionary measures to prevent exposure.

Table 3. Summary of human-based studies on chalk particles and their associated health effects.

Study	Country	Methodology	Key findings	Recommendations
(Larramendi et al. 2013)	Spain	Allergy to cow's milk protein (CMP) was investigated in a group of 14 children after a 2-year-old body developed a reaction to the first dose of an iron compound containing casein. Chalk sticks (Giotto Robercolor, Italy) were bought, and the proteins contained in the chalk sticks were extracted overnight at 50% (wt/vol) in 0.1 M sodium hydroxide. The extracts were centrifuged at 10 000 g, dialysed against pure water with 3 500-Da membranes (Pierce, Rockford, Illinois), sterilised through a filter (Millipore, Bedford, Massachusetts), and freeze-dried. The chalk extracts were used for skin prick tests (SPTs) and in vitro assays. To conduct the SPTs, the extracts were adjusted to 0.2 mg/mL of total protein (Bradford method) in phosphate-buffered saline with 50% phenolated glycerin. Specific IgE levels were measured using an enzyme allergosorbent test on cyanogen bromide-activated paper disks. The IgE titer to casein and chalk was compared with a serum pool from patients allergic to olive pollen titrated by the CAP system FEIA (Pharmacia AB, Uppsala, Sweden), which was used as an in-house reference standard. Normal serum samples were used as controls. The extracts were analysed on discontinuous gels at 15% acrylamide, and protein bands were detected using silver stain or transferred to nitrocellulose membranes for immunoblotting. Serum samples were tested at 1/5 dilution medium with 0.1% gelatin. Bound IgE antibodies were detected using a biotinylated mouse monoclonal antibody to human IgE (Operon, Zaragoza, Spain) followed by streptavidin-peroxidase and the ECL Plus System (Amersham, Uppsala, Sweden). Basal spirometry tests were performed on four subjects using a Vmax22 spirometer (Sensor Medics Co, Yorba Linda, CA). Methacholine tests were conducted using a Methacholine chloride (Provocholine, Methapharm Inc, Brantford, Ontario, Canada) following the American Society Protocol. After basal spirometry tests and clinical evaluation of nose and eye symptoms, the subjects were placed in a closed clean room (25 m³) where writing and erasing on a chalkboard were performed.	Alkaline extraction with 0.1 N sodium hydroxide produced an extract with a protein content of 0.05 mg/mL, equivalent to 0.1 mg of protein per gram of chalk. SDS-PAGE and silver staining revealed protein bands at approximately 30 and 37 kDa. Skin tests were positive in five (three non-exposed and two exposed) of the 12 subjects, and all chalk-positive subjects tested positive for casein. The tested subjects had specific IgE to casein (kU/L) [mean (19.4), SD (43.8), range (0.58–156.2 kU/L)] and chalk (kU/L) [mean (13), SD (30), range (1.2–109.9)]. Elevated levels of IgE to casein and chalk were detected in the index case (E-1) before school age, indicating the presence of specific IgE to chalk before exposure. The positive sample produced a pattern of IgE binding to chalk a blurred pattern where a significant band could be identified at approximately 30 kDa. Pre-incubation with casein produced strong inhibition of IgE binding to the band. Basal spirometry tests were normal in four subjects and methacholine line challenge tests were positive in three of the four subjects, whereas chalk use results were positive in two cases. Subject E-1 developed rhinorrhea and sneezing, coughing, and wheezing with a 32% decrease in FEV₁. After inhaling a cumulative dose of 4 g of chalk particles, subject E-2 was coughed after 35 min of exposure to an estimated cumulative dose of 6.5 g of chalk particles and had a 22% decrease in FEV₁. Subjects E-3 and E-4 had no symptoms or changes in FEV₁ during exposure to 9 g of chalk particles for 50 min.	The health risks of continuous exposure to casein-containing chalk for children allergic to milk cannot be neglected, and the health effects must be thoroughly investigated.

(Continued)

Table 3. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Azodo et al. 2020)	Nigeria	Chalk particles were dispersed in a multidirectional turbulent flow, releasing doses of 1 g in 5 min, 3 g in 15 min and 5 g in 30 min. Chest, nose, and eye symptoms were monitored after each writing and wiping activity. Two-hundred and forty participants consisting of 120 exposed learners and 120 controlled groups were recruited from 5 schools. The exposed group consisted of learners who sat in the first three front rows in the classrooms, whereas the control group was randomly selected from a school that used marker boards instead of chalkboards. The sociodemographic data of the participants were obtained through interviews. A questionnaire was administered to determine learners suitable for the study, and a stadiometer was used to measure the anthropometry of the participants. Smoking and drinking participants and those with pulmonary disorders were excluded from the study. The anthropometric data and age of the participants were entered on the Contec SP-10 digital spirometer (Contec Medical Systems Co. Ltd., China) used to conduct spirometry tests. Spirometry tests [forced expiratory volume (FEV), forced vital capacity (FVC)] were conducted at 2–3-min intervals. The relationship between the peak expiratory flow rate (PEFR) and FEV₁ of the exposed group was determined using the Pearson correlation ($\alpha = 0.05$).	The average PEFR of the exposed group (2.92 ± 1.36 L/s) was statistically lower than that of the control group (3.9 ± 1.37 L/s). The FVC of the exposed group (1.98 ± 0.99 L) was statistically higher than that of the control (2.05 ± 0.71 L). The FEV₁ of the exposed group (1.48 ± 0.81 L) was statistically lower than that of the control group (1.74 ± 0.48 L). The average PEFR (2.92 ± 1.36 L/s) of the exposed group was statistically lower than that of the control group (3.9 ± 1.37 L/s). A significant positive correlation ($r = 0.436$; $p < 0.05$) was found between PEFR and FEV₁. The FEV₁ and FEV tests indicated that both the exposed and control groups had healthy lungs, however, the FEV₁ and FEV of the exposed group were statistically lower than those of the control group. The exposed group had a FER of 0.80 ± 0.25 while that of the control group was 0.89 ± 0.17 and a statistically significant difference was not found. The FER% indicated that both the exposed and control groups had healthy lungs, however, a decline was observed in the lung function of the exposed group. The exposed group had an average FER of $79.35 \pm 23.37\%$, which was lower than that of the control group (88.13 ± 17.32).	Chalk sticks and chalkboards must be replaced with marker boards

(Continued)

Table 3. (Continued).

Study	Country	Methodology	Key findings	Recommendations
(Prabhu et al. 2020)	India	The PEFR of 40 teachers and non-school teachers (control group) was assessed. The included teachers used chalk sticks and chalkboards as the primary mode of teaching for 15 h per week or a year, with no history of respiratory disorders in the 2–3 months and were between the ages of 20 and 60 years. Non-teachers included individuals who had never practised as teachers, were not exposed to chalk particles, had no history of respiratory disorders and were between the ages of 20–60 years. PEFR was measured in 40 teachers and 40 non-teachers in a sitting position using a mini bell PEFR instrument. Three measurements were taken, and the average was calculated. A chronic obstructive pulmonary disorder assessment test (CAT) was administered to both groups. Unpaired t-tests were used to compare the results between the exposed groups and the control group	Thirty teachers scored normal to level in the CAT, nine scored medium-level, and one scored high-level impact. All subjects in the control group scored normal to low impact in the CAT. There was a statistically significant difference between the CAT scores of the exposed and control groups. The PEFR of teachers was higher than that of the control group, suggesting a problem with the respiratory airways. The average PEFR score for the exposed group was 340 ± 68.12 whereas that of the control group was 345 ± 46.40 and a statistically significant difference was found between the PEFRs of the two groups. Teachers exposed to chalk particles for 5 or more h per day either had low PEFR or high CAT scores.	Not provided
(Ojukwu et al. 2022)	Nigeria	Pulmonary function of teachers and associated risk factors were assessed. Pulmonary functions measured included forced vital capacity (FVC), forced expiratory volume in a second ($FEV_{1.1}$), FVC/FEV_1 ratio, FVC prediction, and expiratory flow (PEFR). The subjects comprised 101 females and 20 males below the age of 65 years who worked in 11 private schools and eight government-funded schools. Subjective data on the demographics, work details, exposure to chalk particles, and characteristics of the living environment were collected using a self-administered questionnaire. The pulmonary function of the teachers was measured using a spirometer in triplicate and the average value was used. Anthropometric data were also collected. One-way analysis of variance (ANOVA) was used to compare the measured pulmonary tests.	Close to 51% of the teachers had teaching experience between 16 and 30 years, and about 53% of them were teaching in public schools. Approximately 83% of teachers used chalk sticks and blackboards as the primary mode of teaching and worked more than 6 h per day. There was a statistically significant difference between employment period, school category, teaching hours, the type of chalkboard, previous occupation, and school grade taught. Teachers who have been teaching for 16–30 years had higher pulmonary values suggesting that the duration of exposure is linked with pulmonary function. Compared with a normal population, the FVC, FEV_1, FVC/FEV_1 ratio, FVC prediction, and PEFR values of teachers who used chalk sticks and chalkboards were higher.	Formulation of policies promoting a safe working environment for teachers.

received sufficient attention. Numerous studies on chalk particles have been conducted in recent years, however, research on chalk particles is not growing. Most of the studies were conducted in India, which is one of the countries reported to heavily rely on chalk and chalkboards for teaching in most schools (Sekar et al. 2021). The limited research conducted on the release and health outcomes of exposure to chalk particles in classrooms is a concern given the number of countries, particularly LIMCs that rely heavily on chalk sticks and chalkboards for teaching and the health implications associated with exposure to chalk particles. Four main themes were identified from the synthesis of the reviewed studies: (i) exposure assessment, (ii) exposure and health, (iii) physical and chemical properties, and (iv) task analysis.

Exposure assessment

Most studies investigating exposure to chalk particles were conducted in model or actual classrooms. Studies in actual classrooms were conducted either in the presence or absence of teachers and learners. The inhalation route of exposure received more attention than dermal and ingestion. This is because inhalation is regarded as the most harmful and common route of entry (Oberdörster and Kuhlbusch 2018). For example, fine particles can penetrate deeper into the alveolar (Geiser et al. 2005), and even deposit directly into the brain (Tsuda et al. 2013). Many studies focussed on airborne and settled chalk particles in classrooms. Airborne chalk particles were collected at a constant flow rate using air samplers. Representative samples around the classroom were collected at 1.2 m to represent sitting learners (Maruthi et al. 2017), whereas, chalk particles near the chalkboard were collected at 1.7 m to represent standing teachers (Lin et al. 2015). Settling chalk particles were collected below the chalkboard using paper, aluminium foil, or Petri dishes (Maruthi et al. 2017). To estimate the concentration of chalk particles to which teachers were exposed while teaching, breathing zone measurements were conducted. Collecting exposure concentrations from the breathing zone of receptors is encouraged in many exposure assessment studies because it provides a better estimate of exposure relative to representative samples collected near the receptors or around the classroom (Haynes et al. 2012).

Findings from this theme showed that airborne chalk particles are a significant contributor to poor IAQ in classrooms. Higher concentrations of chalk particles were found near the chalkboard (Lin et al. 2015; Ma et al. 2019). This implies that teachers and learners sitting in the front row are at higher risk of exposure. However, teachers are at higher risk of exposure compared to learners since they are nearer to the chalkboard and frequently talk, resulting in an increased breathing rate; hence, they gasp for air (Majumdar et al. 2012). An increased breathing rate and gasping of air result in teachers breathing through the mouth and nose simultaneously (oronasal breathing), which decreases the filtering efficiency of particles, subsequently leading to the deposition of more particles in the pulmonary and tracheobronchial regions of the lungs (Miller 2000; Sracic 2016). The deposition of chalk particles in the pulmonary lung is of concern because this is where gas exchange occurs between air and blood through the alveoli (Hofmann 2011). This is more concerning for smaller particles because they are not easily cleared; hence, they can be retained for longer periods (Mbazima 2022), penetrate the bloodstream, and even translocate to other vital organs such as the heart (Schwarze et al. 2006).

Exposure and health

The exposure and health theme (Table 3) had three sub-themes. The first sub-theme is spirometry test studies (Larramendi et al. 2013; Azodo et al. 2020; Ojukwu et al. 2022), which were conducted to measure the rate of change in lung volume during forced expiration and inspiration to determine how effectively and quickly the lungs can be emptied and filled (Pierce et al. 2005). Spirometry tests can be used to diagnose obstructive (e.g. asthma and chronic obstructive pulmonary disorders) and restrictive (e.g. pulmonary fibrosis and asbestosis) lung disorders (Soriano et al. 2009), and to track

the progression of disorders or the effectiveness of prescribed medications in individuals already diagnosed with lung disorders (Barreiro and Perillo 2004).

The common matrix of measure is the FEV₁/FVC ratio, which can be used to identify individuals with airway obstruction characterised by reduced FVC. The FEV₁/FVC ratio also identifies the cause(s) of the reduction in FEV₁ (Liou and Kanner 2009). The lungs of healthy individuals can expel more than 80% of their total volume within 6 s or less (Barreiro and Perillo 2004). When taken as an absolute value, the FEV₁/FVC ratio can be used to differentiate between obstructive and restrictive lung disorders (Barreiro and Perillo 2004). Although some studies (Azodo et al. 2020; Prabhu et al. 2020) found that teachers and learners had healthy lungs, their lung function was lower than that of the control groups, indicating that exposure to chalk particles does affect pulmonary function. The decline in lung function of teachers exposed to chalk particles was evidenced by a reduced FEV₁ and FEV₁/FVC ratio. Larramendi et al. (2013) found that the FEV₁ of learners significantly decreased shortly after they were exposed to chalk particles. The reduced FEV₁ of teachers and learners exposed to chalk particles in classrooms is evidence that exposure to chalk particles through the inhalation route can cause lung dysfunction. Therefore, teachers and learners must take precautions when in classrooms.

The second sub-theme was skin tests for children between 2–7 years who were allergic to casein – a milk protein often used in dustless chalk sticks because of its adhesive and compact properties (Larramendi et al. 2013). However, the chalk sticks release chalk particles of smaller sizes which act as a vehicle for the casein which may induce symptoms in milk-allergic learners after inhalation (Larramendi et al. 2013) (Larramendi et al. 2013). found that skin tests conducted on 12 subjects were positive for casein in five of the 12 subjects. Therefore, parents must seek medical attention to assess what their children are allergic to before sending them to school. This is important for children who attend schools that use chalk and chalkboards for teaching. This proactive approach will help schools take precautionary measures in the classroom. For example, children allergic to casein can be enrolled in schools that do not use chalk sticks and chalkboards for teaching. If not possible, the allergic learners can be placed in the back rows of the classroom to minimise exposure to chalk particles potentially containing casein. This is important because asthma and allergy allergies are common in children (Maziak et al. 2003).

Teachers are also prone to occupational airborne contact dermatitis because a significant amount of chalk particles settles on uncovered areas such as the face, neck, hands and arms (Corazza et al. 2012). Contact dermatitis in teachers can occur because of the frictional and chemical properties of the particles (Lachapelle 2006). It is unclear if the physical properties of the particles (i.e. shape and size) affect the development of contact dermatitis and its severity (Lachapelle 2006). However, factors such as temperature, relative humidity, atopic status and sweating contribute to the development of contact dermatitis (Lachapelle 2006). A 17-year-old female learner with a childhood history of atopic dermatitis developed localised oedema after coming into contact with chalk particles from white Crayola chalk sticks manufactured by Binney & Smith, Easton, PA (Moreau et al. 2006). Open and prick tests were conducted on the volar aspect of the right arm of the learners which was never exposed to chalk particles. The open and prick tests were conducted for chalk particles and CMC in aqueous. The learner immediately reacted to the open tests with the chalk and with CMC (10%) indicating that absorption happens through unblemished skin (Moreau et al. 2006). The prick tests were also positive for CMC (0.1%) but negative for higher concentrations of CMC. The authors hypothesised that the reason the learner reacted more strongly to the chalk particles than pure CMC was because absorption was exacerbated by the abrasiveness of calcium carbonate (Moreau et al. 2006).

Chemically induced dermatitis occurs when the particles in contact with the skin are enriched with chemicals which then react with the skin (Lachapelle 2006). For example, bilateral erythematous-oedematous periorbital dermatitis and itching were present in a 40-year-old female primary school teacher (Corazza et al. 2012). Furthermore, the teacher's distal apex of the thumbs and second finger of the right hand were affected by fissured periorbital dermatitis (Corazza et al. 2012).

A chemical analysis of 6 chalk sticks of different colours used by the teachers was conducted and it was concluded that nickel was responsible for the teacher's periorbital dermatitis and hand eczema (Corazza et al. 2012).

The third sub-theme was the use of models to determine the deposition dose of chalk particles into the human lungs. For example, Ma et al. (2019) calculated the deposition doses of chalk particles in the alveolar interstitial region of male and female learners (10 years) and adult male and female teachers during light behaviour and sitting. This is important because the activities of an individual influence the exertion rate which determines the number of particles deposited into the lungs (Salma et al. 2002). Sekar et al. (2021) used the MPPD model to predict the deposition of PM₁, PM_{2.5} and PM₁₀ chalk particles in the respiratory tract of adult and elderly male and female subjects.

Models were also used to determine the potential for developing non-carcinogenic and carcinogenic health effects among teachers and learners exposed to chalk particles. The risk of developing non-carcinogenic health effects was determined by calculating the hazard quotient and hazard index. A hazard quotient greater than 1 indicates a risk of developing non-carcinogenic health effects due to exposure to one chemical, whereas a hazard index value greater than 1 indicates a risk of developing non-carcinogenic health effects due to exposure to multiple or a mixture of chemicals (Calderón et al. 2003). The risk of developing carcinogenic health effects was determined by calculating the cancer risk. A cancer risk value greater than the recommended lower limit (1×10^{-4}) and upper limit (1×10^{-6}) indicates a significant and unacceptable cancer risk (Demirel et al. 2014). For example, Maruthi et al. (2017) conducted a health risk assessment following the USEPA guidelines using inhalation, dermal, and ingestion routes to determine the potential for developing carcinogenic non-carcinogenic health effects among teachers. There was a risk of developing non-carcinogenic health effects because of exposure to chalk particles in classrooms, however, no cancer risk was found.

Although health risk assessment and particle deposition models are probabilistic and depend on assumptions and default values, however, they can help policymakers implement risk management strategies based on informed and determine which population or age group must be prioritised (Mbazima 2022, 2023). For example, Sekar et al. (2021) found the highest total particulate matter deposition in elderly females and the highest deposited mass per unit area for PM₁, PM_{2.5} and PM₁₀ in adult females. This implies that adult and elderly female teachers must be prioritised when implementing risk management strategies. Thus, policy-makers in the education sector can implement risk management strategies based on the results from the health risk assessment studies conducted in classrooms to prevent exposure to chalk particles and the risk of developing carcinogenic and non-carcinogenic health effects.

Physical and chemical properties

The characterisation of chalk particles is an important aspect of exposure assessment and can help determine effective mitigation measures to prevent exposure. It was initially believed that the health effects of particles were due to the mass concentration, hence it was commonly used as the exposure matrix (Ramachandran et al. 2011). However, studies have shown that the shape, size, elemental composition, surface area (Frampton et al. 1999), and number concentration (Peters et al. 1997) of the particles determine the toxicity of the health effects. For example, smaller particles can penetrate deeper into the alveolar region (Schwarze et al. 2006) and occupy a larger surface area, thereby causing adverse health effects. Moreover, smaller particles are not easily cleared, hence, they can be retained longer (Mbazima 2022). Furthermore, smaller particles can remain suspended for a longer time and travel a distance from the point of release (Goel et al. 2017). Therefore, knowing the size of particles is important in determining the type of masks that can be used to effectively filter particles.

To analyse the physical properties of chalk particles, many studies collected chalk particles on paper filters using air samplers. The air samplers were coupled with a cyclone that separated large and small particles. The paper filters were cut, and the physical properties of chalk particles, such as

the shape and size were analysed using SEM coupled with EDS. EDS was used to determine the elemental composition of the chalk particles. However, EDS is semi-quantitative, and its results are not conclusive in most cases. To overcome the limitations of SEM, other studies used ICP-MS or Fourier transform infrared spectrometer with attenuated total reflectance to determine the elemental composition of the chalk particles. Based on EDS results, Ma et al. (2019) found that chalk particles from white chalk sticks manufactured by Nihon Hakuboku Industry Co mainly comprised calcium (45.06%), carbon (32.27%) and oxygen (18.58%). Using EDS, Goel et al. (2017) found that the main constituents of four chalk types were in the decreasing order of oxygen > calcium > carbon and minor constituents such as magnesium, aluminium, and silicon. Based on ICP-MS results, Maruthi et al. (2017) found aluminium, chromium, manganese, iron, cobalt, nickel, silicon, and lead in both airborne and settled chalk particles. However, the concentrations of these trace elements were higher in airborne chalk particles than in settled (Maruthi et al. 2017).

Based on SEM images, Ma et al. (2019) observed chalk particles with random shapes while Maruthi et al. (2017) observed chalk particles with an elongated shape. The fibrous nature of the chalk particles was associated with non-dusty chalk sticks while aggregated chalk particles were linked to dusty chalk sticks (Maruthi et al. 2017). Based on SEM images Goel et al. (2017) and Sekar et al. (2021) observed that chalk particles from chalk sticks made of calcium carbonate are compact compared to those made of calcium sulphate, hence they release chalk particles of smaller sizes. The difference in the morphological and elemental properties of the chalk particles can be attributed to the different types of chalk sticks used. Therefore, it can be concluded that the elemental composition of chalk sticks depends on the type of chalk, manufacturer, and country.

Task-based monitoring

Task-based monitoring was conducted to determine the size, number, and mass concentration of chalk particles released by chalk sticks of different colours and properties when used to write on different chalkboards (Majumdar and SPMP 2009; Majumdar et al. 2012; Goel et al. 2017). A standard paragraph was written on rough, smooth, wooden, and ceramic chalkboards using different types of chalk sticks to determine how their texture influences the release of chalk particles. The standard paragraph was written by more than one person to eliminate bias. This is important because the angle, pressure, and writing style determine the number of chalk particles released (Thakur et al. 2017).

The types of chalk sticks used to write on the different types of chalkboards were white or coloured, dustless, moulded, low dust, dust-free and dusty. This kind of information is important because it identifies the types of chalk sticks that release more or fewer chalk particles and their sizes when used on various types of chalkboards. For example, Majumdar and SPMP (2009) found that dusting chalk sticks contributed significantly to the mass concentration when they were used to write on rough chalkboards. On the other hand, dustless chalk sticks released a higher quantity of smaller particles ($<5\text{ }\mu\text{m}$). Sekar et al. (2021) also found that dustless chalk sticks released fine chalk particles that significantly contributed to the mass concentration. Based on this information, schools that cannot afford alternative teaching equipment such as erasable whiteboards can procure chalk sticks that release fewer particles and install chalkboards that do not influence the release of a higher number of fine chalk particles.

Task-based monitoring was also conducted during different activities such as writing, wiping the chalkboard, and de-dusting to determine which activities release more chalk particles (Goel et al. 2017; Sekar et al. 2021). Statistical analysis, either analysis of variance or a student's t-test, was then employed to determine if there was a significant difference between the chalk particles released during the different activities. This information is important because it can inform which activities release more chalk particles, their sizes, and the type of interventions needed to prevent exposure. For example, Majumdar et al. (2012) and Sekar et al. (2021) found that wiping the chalkboard released more particles of smaller sizes compared to writing; implying that caution must be

practised when wiping the chalkboard. For example, the chalkboard can be wiped with a wet cloth to prevent the high releases of chalk particles thus preventing exposure.

Control of exposure to chalk particles in classrooms

Some studies provided recommendations to prevent exposure to chalk particles in classrooms. To effectively prevent exposure, the source of the hazard must be eliminated. In this regard, chalk sticks and chalkboards must be eliminated and replaced with markers and whiteboards, as most studies recommended. However, such an intervention would not be feasible for LMICs where most public schools operate on limited budgets, while those with sufficient budgets do not use the funds efficiently (World Bank and UNESCO 2023). For example, in many African countries, education is allocated little budget and a higher budget is allocated to sanitation and the control and prevention of infectious diseases (Fuller and Amegah 2022). Meanwhile, erasable whiteboards and markers are expensive, therefore, eliminating chalk sticks and chalkboards will not be easy and quick in many public schools in LMICs. While planning to eliminate chalkboards and chalk sticks, precautions must be taken to prevent exposure to chalk particles in classrooms.

Ventilation was also recommended as an effective way of reducing the concentration of chalk particles in classrooms, thus reducing exposure. However, natural ventilation should be used instead of mechanical. This is because mechanical ventilators re-suspended settled chalk particles. For example, Lin et al. (2015) found that the mass concentration of PM_{2.5} chalk particles in a classroom was reduced by 3.6-fold when doors were opened coupled with ceiling fans (9.88 µg/m³) compared to when doors were closed coupled with air condition system and ceiling fans (35.58 µg/m³). Therefore, the best ventilation mode to reduce the concentration of chalk particles in classrooms is the opening of doors coupled with ceiling fans. Other studies recommended frequently cleaning classroom floors. Although the studies did not specify which methods must be used for cleaning; Wilson and VanSnick (2017) recommend cleaning the floors with water and microfiber mops and vacuuming with a high-efficiency particulate filter. Frequent cleaning of classrooms is required to prevent the re-suspension of settled chalk particles by movement of people (Stranger et al. 2008), this is important for public school classrooms which are usually overcrowded. Implementing effective and efficient interventions to reduce and prevent exposure to chalk particles in classrooms should start from the design and inception of the school building. Classrooms must be installed with extractor fans above the chalkboards to prevent the spread of chalk particles. However, there are also costs related to this type of intervention. Furthermore, most LIMCs in Africa, such as RSA, experience frequent planned and unplanned power outages which might render the intervention ineffective (Mbazima et al. 2022).

Ma et al. (2019) found less PM_{2.5} particles when using erasable whiteboards and markers compared to when using chalk sticks and chalkboards. This implies that chalk sticks and chalkboards are a significant contributor of PM_{2.5} particles in classrooms and should be replaced with alternatives such as erasable whiteboards and markers. However, it should be noted that the replacement of chalk sticks and chalkboards with erasable whiteboards and markers is a precursor to other hazards and potential exposure. Compelling evidence from studies has shown that the use of markers releases volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (Castorina et al. 2016; Sabina et al. 2018). For example, Dorizas et al. (2015) found that using markers increased the concentrations of VOCs and carbon monoxide in classrooms. Most of the VOCs released by markers in classrooms are categorised as carcinogens, irritants, and developmental and respiratory toxicants (Castorina et al. 2016). Therefore, the use of electronic devices and PowerPoint presentations must instead be used for teaching. However, most African countries still lack access to electricity, while those that have access to electricity experience frequent and long power outages (Mbazima et al. 2022). As such, schools willing to implement electronic devices for teaching must be equipped with solar panels that will power the electronic devices.

Key findings of the review, research gaps, and future research priorities

There is a lack of interventional studies on exposure to chalk particles in classrooms. A few studies have assessed the importance of ventilation and how it can be used to control chalk particles in classrooms. Knowledge, attitudes, and practises (KAPs) studies on chalk particles in classrooms are also lacking. Most task-based monitoring studies focussed only on the mass concentrations of the chalk particles. Only one study investigated the number concentration and particle size distribution of chalk particles. However, studies have shown that larger particles account for most of the mass concentration, whereas smaller particles account for more of the number concentration (See and Balasubramanian 2006). Therefore, using only mass concentration might not be a good measure, especially when considering the health effects. Meanwhile, mass concentrations can be used for regulatory or compliance purposes. Future task-based monitoring studies must consider the number concentration and PSD of chalk particles released during different activities and when using different chalk sticks on different types of chalkboards. This information will provide an in-depth understanding of the deposition of chalk particles in the respiratory tract.

The spirometry test results from the teachers were not compared to any baseline data to check if there was a decline in lung function. This is due to the unavailability of baseline data to compare against. Furthermore, Spirometry tests were not correlated with the exposure concentration of chalk particles. Therefore, future studies conducting spirometry tests must correlate the results with the obtained exposure concentration, preferably measured from the breathing zone. There were limited studies specifically investigating the effects of chalk particles on the skin despite that many chalk particles settle on the skin of teachers and sometimes learners. There is a lack of exposure assessment studies on chalk particles in classrooms, particularly in Africa. No studies have assessed exposure to chalk particles in classrooms in the African continent. This is concerning given that most African countries heavily depend on chalk sticks and chalkboards for teaching and that classrooms are overcrowded. The lack of exposure assessment studies in African countries can be attributed to a lack of funding.

Schools that use chalk sticks and chalkboards must implement entry-level medical examinations on teachers that include compulsory spirometry tests as part of employee wellness. The initial spirometry test results obtained from the entry medical examinations will then serve as baseline data. Thereafter, spirometry tests must be conducted as part of periodic medical examinations, and the results can be compared with the baseline data to check if there is a shift in the lung function of the teachers. Furthermore, the living style (i.e. smoking) and living conditions of the teachers must be captured as part of the entry and periodic medical tests. Periodic lung function tests will help identify lung disorders at an early stage, and action can be taken to lessen the severity and progression of the disorder. Retiring teachers and those changing professions must also be subjected to exit medical tests. Ohtsuka et al. (1995) showed that teachers can develop pulmonary disorders after teaching. Spirometry test records can also be used in the teachers' compensation for occupational illnesses and injuries (Nevitt et al. 1994). This is important given that many compensation claims are rejected because of a lack of historical medical records, such as spirometry tests, that can be used as evidence.

KAP studies are needed, they can help raise awareness among teachers so that they can take precautionary measures regarding chalk particles in classrooms. KAP studies are important and recommended because they can identify factors that influence the behaviour of teachers and their competence to prevent exposure to chalk particles in classrooms. Future bioassay studies investigating the toxicity of chalk particles should use the concentration of chalk particles collected in the classroom during actual writing or wiping of the chalkboard instead of pulverising chalk sticks and exposing alveolar macrophages to the chalk particles. Longitudinal studies are required so that effective control measures can be implemented to prevent the re-occurrence of the health implications of exposure to chalk particles. Future studies should also focus on the effects of chalk particles on the skin. This is important given that most of the chalk particles settle on the hands, arms, and

faces of teachers when writing and wiping the chalkboard. Future health risk assessment studies must use deposition models to predict the absorbed dose instead of the exposure concentration. Mbazima (2022) and Chalvatzaki et al. (2019) showed that using the exposure concentration in the health risk assessment overestimates the risk. Therefore, using the absorbed dose gives a better estimate than using the exposure concentration. This approach is preferred since adverse health effects occur because of the internal dose rather than the exposure concentration.

No studies focused on the resuspension of settled chalk particles in classrooms due to the movement of people. Future studies must investigate the effect of the movement of people on the resuspension of settled chalk particles. This is important since most classrooms are overcrowded meaning the movement of learners might have significant effects on the resuspension of settled chalk particles. All the experiments were conducted using white chalk sticks, none of the studies investigated coloured chalk sticks. As a result, information on the size, shape, elemental composition and health effects of chalk particles released by coloured chalk sticks is unknown. Therefore, future studies must investigate the release of chalk particles in classrooms using coloured chalk sticks.

Strengths and limitations of this review

To the best of our knowledge, this is the first comprehensive systematic review focusing on the release and health outcomes of exposure to chalk particles in classrooms globally. In this systematic review, timeframes were not applied to capture all relevant studies. Two of the most reputable and rich databases (Scopus and WoS core collection) were searched and Google Scholar was also searched to identify any documents not indexed both in Scopus and the WoS. Furthermore, the snowball effect was used to identify any relevant documents that might have been missed during the initial literature search. The literature search, selection of studies, and synthesis were conducted by two and at times three authors to limit bias and error. The limitation of this systematic review is that the quality and reporting of the studies used were not graded.

Conclusions

A systematic literature review of the release and health outcomes of exposure to chalk particles in classrooms was conducted to identify the current research trends and identify knowledge gaps. Findings from this systematic review can be used to create awareness among teachers, learners and parents and prompt policymakers in the education sector to implement risk management strategies. Numerous studies have been conducted in this research area and can be summarised into four main themes: (i) exposure assessment, (ii) exposure and health, (iii) physical and chemical properties and (iv) task-based monitoring. However, the research progress on the release and health outcomes of exposure to chalk particles in classrooms is not satisfactory, particularly in LMICs such as those in Africa where chalk sticks and chalkboards are still used predominantly for teaching. Evidence from this systematic review showed that a minimum of one study and a maximum of three studies are published per year in this research area. The evidence from the reviewed studies showed that chalk particles are a significant contributor to poor IAQ in classrooms and a significant health hazard to both teachers and learners, particularly through inhalation and dermal routes. Natural ventilation in classrooms is recommended to reduce the concentration of chalk particles and wearing of face masks is encouraged to prevent exposure via inhalation. There is a need to increase research on chalk particles and funding for future studies, particularly in African countries where there are few studies and subsequently limited data. Most importantly, there is an urgent need to adopt and implement alternative teaching methods which do not pose a threat to the health and safety of teachers and learners in the classroom.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, (S.J.M) upon reasonable request.

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