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Published: 15 February 2023

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Air Quality, Atmosphere & Health (2023) Cite this article

#### Abstract

A healthy indoor environment is critical for children due to the severe effect of poor indoor air quality (IAQ) on their overall well-being. Day-care centres (DCCs) are important indoor microenvironments for children apart from their homes. Therefore, monitoring IAQ in this microenvironment is vital because of the vulnerability of the occupants. This review gives a global overview of the predominant indoor chemical pollutant levels monitored in DCCs, compares their concentration with available regulations for IAQ, evaluates the sources and health risk effects of chemical pollutants and proposes strategies for enhancing IAQ in DCCs. Thirty-seven (37) articles were used based on specific stated inclusion and exclusion criteria. Continents like Europe and Asia have the most published studies in indoor DCCs. The decreasing trend of pollutants examined in most studies include particulate matter > carbon dioxide > formaldehyde > carbon monoxide > total volatile organic compounds > volatile organic compounds > nitrogen dioxide > ozone > benzene > sulphur dioxide = radon. Particulate matter in the size and mass concentration range of PM<sub>10</sub> (0.116–1920.71 µg/m<sup>3</sup>) > PM<sub>2.5</sub> (0.279.2–260.74 µg/m<sup>3</sup>) was the most investigated pollutant. While nitrogen dioxide, radon and carbon monoxide were consistent with the existing national and international reference values for IAQ across the continents, exceedances occurred in other pollutants. The limited number of

indoor chemical pollutant studies suggests the need for more comprehensive studies on IAQ in DCC globally. Further studies should highlight the availability of low-cost sensors and mobile analytical equipment that will promote affordable ground-level data accessibility.

## Introduction

A healthy environment is vital for efficient and impactful learning, especially for children vulnerable to air pollution (Masekela and Vanker 2020). Over time, it has been proven that a clean-air environment increases a child's attention rate and leads to better and improved participation in the learning and development process of the child (Clark et al. 2020; Adaji et al. 2020; Michelot et al. 2013; Agbo et al. 2021). Therefore, it is vital to always ensure that the environment is clean and health-promoting. The environment is categorized into two divisions: indoor and outdoor environments. There have been numerous studies on ambient air pollution/quality. Still, very few studies have been conducted on indoor air quality (IAQ), particularly in children's public spaces such as day-care centres (DCCs), preschools, nurseries and kindergartens (Annesi-Maesano et al. 2013; Zhang et al. 2021; Manuel et al. 2021). There are many definitions for IAQ (Cincinelli and Martellini 2017); for this context, IAQ has been defined as the air quality within and around a building, which can affect the general well-being of its occupants (Soreanu 2016; USEPA 2022). Two major parameters are used in assessing IAQ, namely, infiltration of outdoor contaminants and thermal conditions such as temperature, relative humidity and airflow (Cincinelli and Martellini 2017; WHO 2021a). Indoor air pollution in children's learning spaces is associated with types of indoor activities, infiltration of outdoor pollutants into the indoor environment, nature of building structures, interior decorations, emission of pollutants from building materials, cleaning chemicals, geographical conditions and the nature of ventilation system in use (natural, mechanical or a combination of the two) (Branco et al. 2014; Mannan and Al-Ghamdi 2021; Oliveira et al. 2019; Salthammer et al. 2016; Valderrama-Ulloa et al. 2020; WHO 2021b).

Air quality in an indoor environment is critical because it has been scientifically proven that we spend approximately 70–90% of our time indoors (UNICEF 2019). According to WHO, about five hundred thousand (500,000) children under the age of 5 died in 2016 due to respiratory tract diseases induced by indoor air pollution (IAP) (WHO 2017). Given the health relevance of IAQ, unhealthy IAQ has been assessed as the eighth (8th) most critical environmental risk factor and is responsible for 2.7% of death cases globally. Based on the foregoing, the United Nations Sustainable Development Goal (UNSDG) 3.9 focuses on drastically reducing deaths and illnesses caused by air pollution. As a result, there is an urgent need to navigate research interests to this

area.

Some of the indoor chemical pollutants that thrive in children learning environments include particulate matter (PMs) (Guak et al. 2021; Sara et al. 2020; Kalimeri et al. 2016), carbon monoxide (CO) (Masekela and Vanker 2020), nitrogen dioxide (NO<sub>2</sub>) (Holgate et al. 2021; Nunes et al. 2016), (ozone (O<sub>3</sub>) (Vu et al. 2019; WHO 2021b), sulphur dioxide (SO<sub>2</sub>) (Kotzias 2021), phthalate esters (PAEs) (Li et al. 2021, Anake and Nnamani 2022), polycyclic aromatic hydrocarbons (Vardoulakis et al. 2020; Wang et al. 2021), benzene (C<sub>6</sub>H<sub>6</sub>) (Siwarom et al. 2017; Vu et al. 2019), formaldehyde (HCHO) and volatile organic compounds (VOCs) (Almeida et al. 2011; Zhang et al. 2021). In order to protect public health from the adverse effects of exposure to these indoor chemical pollutants, standards and guidelines values have been provided by governments in different countries and worldwide organisations. Table 1 outlines the criteria for chemical pollutant set limits by the two internationally recognized regulatory bodies across the globe: the United States Environmental and Protection Agency (USEPA) and World Health Organization (WHO).

Table 1 Air quality standards for criteria air pollutants by the USEPA and WHO

Full size table

Previous study report shows that the effect of elevated levels of these indoor chemical pollutants on a child is more than that of an average adult (Olaoye et al. 2021; Canha et al. 2016). A review conducted by Zhang et al. (2021) on indoor air pollution levels and its associated environmental and behavioural factors in nurseries was able to highlight the thermal comfort, ventilation rate and exposure of children to measured pollutants (biological and chemical) in nursery environments. Their study examined work done between 1992 and 2018 in nurseries of children in the age bracket of 3 months to 10 years in Europe, Asia and North America except for Africa. Overall, inadequate ventilation evidenced in the increased levels of CO<sub>2</sub> above recommended standards was observed. Also, IAQ in nurseries often exceeded current guidelines; as such, the IAQ performance was declared unacceptable. In this article, we have provided a global overview of the predominant indoor chemical pollutant levels monitored in DCCs from reported studies, compare their concentration with available regulations for IAQ and health protection, evaluate the sources and health risk effects of chemical pollutants on children's health and propose strategies for enhancing IAQ in DCCs. Furthermore, to the best of the authors' knowledge, this review is the first to provide information on monitored indoor chemical pollutants in DCCs on the African continent.

Keywords

Chemical pollutants

Day-care centres

Indoor air quality

Health effects

Particulate matter

SDGs

Springer Nature

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