Heliyon 9 (2023) e16419

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Physico-chemical characterization of indoor settled dust in Children's microenvironments in Ikeja and Ota, Nigeria

Winifred U. Anake *, Esther A. Nnamani

Department of Chemistry, College of Science and Technology, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria

ARTICLE INFO

Keywords:
Indoor dust
Children
Preschool
Chemical exposure
SDGs
SEM-EDX

ABSTRACT

Indoor dust is a collection of particles identified as a major reservoir for several emerging indoor chemical pollutants. This study presents indoor dust particles' morphology and elemental composition in eight children's urban and semi-urban microenvironments (A-H) in Nigeria. Samples were collected using a Tesco vacuum cleaner and analyzed with scanning electron microscopy coupled with an energy-dispersive X-ray (SEM-EDX). The morphology results confirm the presence of alumino silicates, mineral particles and flakes, fly ash and soot, and soot aggregates deposited on alumino silicate particles in the sampled microenvironments. These particles may trigger serious health concerns that directly or indirectly affect the overall well-being of children. From the EDX analysis, the trend of elements (w/w %) in the dust particles across the sampled sites was silicon (386) > oxygen (174)> aluminium (114) > carbon (34.5) > iron (28.0) > calcium (16.7) > magnesium (14.2) > sodium (7.92) > potassium (7.58) > phosphorus (2.22) > lead (2.04) > manganese (1.17) > titanium (0.21). Lead (Pb), a toxic and carcinogenic heavy metal, was observed in locations A and B. This is a concern without a safe lead level because of the neurotoxicity effect on children. As a result, further research on the concentrations, bioavailability, and health risk assessment of heavy metals in these sampled locations is recommended. Furthermore, frequent vacuum cleaning, wet moping and adequate ventilation systems will significantly reduce the accumulation of indoor dust–bound metals.

1. Introduction

The World Health Organization (WHO) has classified air pollution as a major environmental concern [1]. More importantly, it has been scientifically validated that indoor environments are two-five times more polluted than outdoor environments, and most people across the globe are exposed to poor indoor air quality [2,3]. Dust particles are everywhere and represent chemical use in an indoor environment [4,5]. This is because most indoor chemicals are semi-volatile organic compounds (SVOCs) which exist in the gas and condensed phases and redistribute from their original point source, partitioning between indoor air, dust, and surfaces. As a result, SVOC exposure in the indoor environment may occur through air, dust, or dermal absorption [6]. Dust particles are present in almost all indoor environments, making them one of the most common sources of indoor air pollution [7]. Settled dust represents an indoor chemical reaction primarily from combustion sources, heating and ventilation systems, building characteristics and occupants' behavioural patterns. The human body sheds about 10 g of skin scales daily, contributing to indoor dust particles [6]. Additionally, indoor dust is a sink for various inorganic, organic and emerging indoor chemical contaminants [8]. One of the most common ways

* Corresponding author.
E-mail address: winifred.anake@covenantuniversity.edu.ng (W.U. Anake).

https://doi.org/10.1016/j.heliyon.2023.e16419
Received 30 January 2023; Received in revised form 12 May 2023; Accepted 16 May 2023
Available online 19 May 2023
2405-8440/© 2023 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

children are exposed to these indoor chemical pollutants is via ingestion [9,10]. Dust ingestion is an important entry point for many chemical contaminants in young children due to their frequent hand-to-mouth activities [9,11].

Furthermore, children's increased exposure to dust particles in an indoor environment, combined with their developing physiology, can lead to serious health problems like wheezing, sneezing coughing, and asthma [12]. Certain constituents in indoor dust, such as pollen grains, soot, coarse mineral particles and alumina, have some health consequences, such as asthma, bronchitis, coronary heart diseases and cancer [13–15]. A high concentration of skin cells in a dust sample, for example, could indicate a malfunctioning or insufficient heating, ventilation, and air conditioning (HVAC) filtering system in an indoor environment [16]. Dust characterization can be useful and important for a snapshot evaluation of indoor air quality [17]. Typically, dust components can be broken into four major categories: human and animal activities (skin scales, dandruff, human hair and cellulose fibre), food particles (salt, sugar and starch), combustion products/sources (ash, carbon, soot and iron ore), building constituents (fibreglass, gypsum, calcites and paints) and other non-classified miscellaneous sources such as rubber, plastics, natural soil and air distribution system debris [16,18–20]. There are several techniques for dust characterization [20]. Polarized light microscopy [PLM] is the most commonly used method because it is simple to set up, fast and inexpensive [20,21]. However, it does not provide information on the elemental compositions of the dust particles, and it is difficult to identify very tiny particles, especially at trace concentrations [21].

As a result, more advanced techniques, such as Scanning electron microscopy or Transmission electron microscope coupled to an energy-dispersive X-ray, have been developed [22]. These techniques reveal a detailed morphology, surface elemental composition, and possible sources of indoor chemical pollutants in indoor dust particles [23–26]. Some studies on using scanning electron microscopy-energy dispersive X-ray (SEM-EDX) for indoor dust characterization have been published in India [17], with some of the study locations including children's microenvironments. The SEM micrograph revealed tiny aggregates, sharp edges, crystalline spores, and spherical particles, mostly minerals, fly ash, and soot particles. These conglomerates are found in indoor dust particles due to dust resuspension from outdoor construction and traffic activities. The presence of fly ash particles in the SEM micrograph, which is spherical in shape, contains Si and Al predominantly. Another related study was conducted in northern Nigeria, a region known for its harsh weather conditions during the harmattan (cold, dry, strong, and dusty winds). The SEM micrograph revealed rectangular, sharp-edged oxygen, silicon, and aluminium particles [23]. The Shanghai study [27] discovered flake-like, fibrous, rod-like, and spherical particles. The most abundant elements in the surface elemental analysis were carbon, oxygen, and nitrogen. In Sweden,

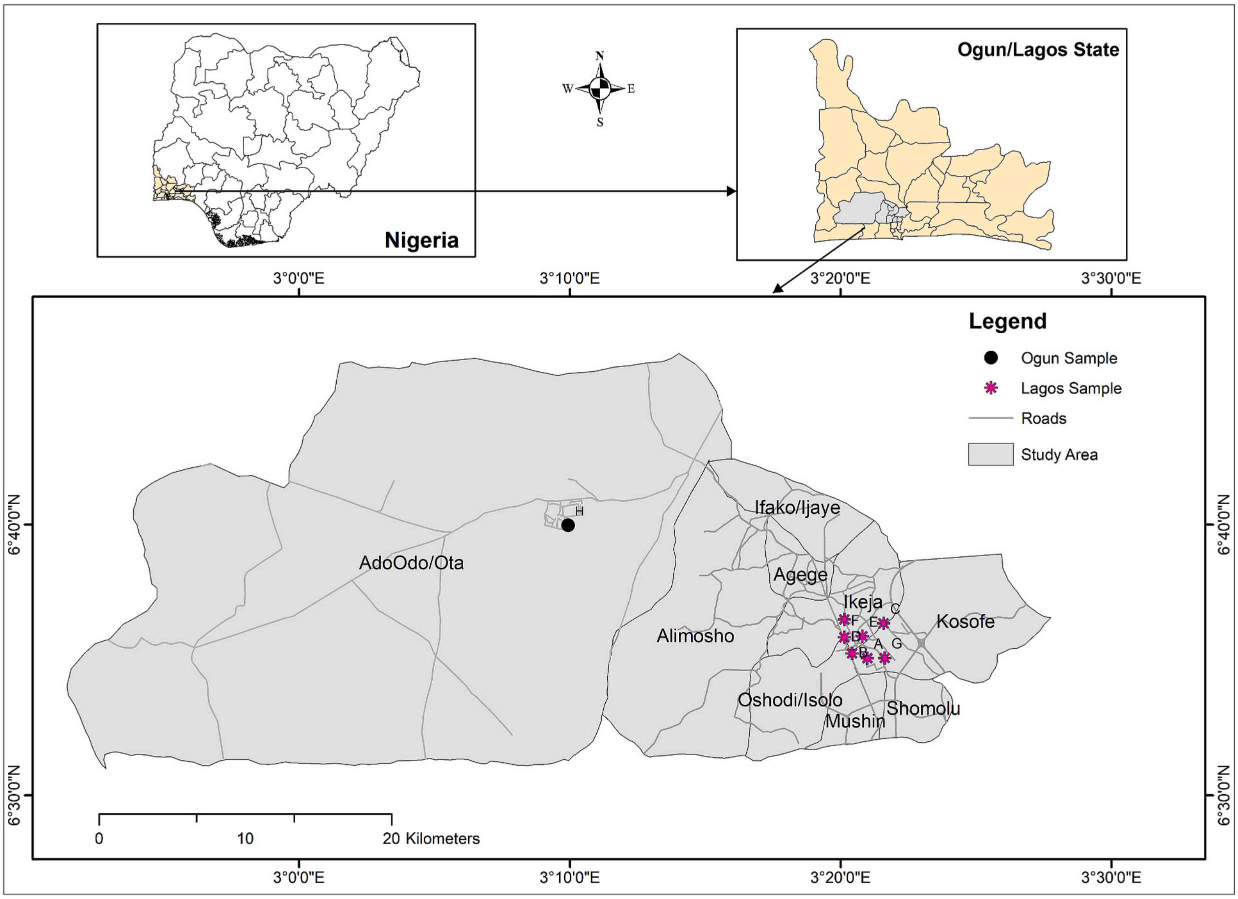

Fig. 1. Map of the study locations.

Gustafsson et al. [6] investigated residential homes, the SEM micrograph showed the respirable dust fraction containing larger flakes with smaller particles adhered to them while eight [8] elements were detected, with carbon (78%), oxygen (15.7%), and nitrogen (2.4%) being the most abundant.

Also, in another study conducted in Dhanbad, the coal capital of India and a densely populated area. The SEM micrograph confirmed that most of the dust particles were symmetrical, with only a few having complicated morphology. Additionally, the dust samples contained metallic elements Fe, Mg, Al, Si, Ca and Na and non-metallic ones like C and O in varying ration [28]. It is critical to note that morphological analysis of indoor dust in children's microenvironments using SEM-EDX is very limited, and more published studies in this area are needed. The elemental analysis provided by the EDX instrumental technique coupled with the SEM equipment is important because it provides information on potential sources of these indoor dust particles and their associated health risks. There have been few studies on indoor dust characterization in other microenvironments such as homes (3, 5, 19, 22, 27), dormitories (18), a classroom and a laboratory of a technical institution (16) except in a preschool indoor environment. This study is very imperative as the study's sample was choosen only from children's microenvironments (children's bay in an office environment, children's ward in a hospital, and preschool indoor environments). The research's findings will help policymakers design children's microenvironments that will not be health-threatening years later. Furthermore, the study is consistent with the United Nations Sustainable Development Goals (SDGs) 3, 7, 11, and 13 for significantly reducing air pollution. To the best of our knowledge, this is the first study on indoor dust characterization in African children's microenvironments using SEM-EDX. As a result, the findings of this study will serve as a foundation for future research on indoor dust characterization in children's microenvironments. Therefore, the objectives of this study were to (i) assess the morphology of indoor dust, which may indicate the source of the dust particles, and (ii) determine the prevalent surface elemental composition of indoor dust in children's microenvironments.

2. Materials and methods

2.1. Description of the study area

The research was conducted in major urban and semi-urban cities, namely Ikeja in Lagos State and Ota in Ogun State, Nigeria. Ikeja is Nigeria's commercial centre (60 31′ 46″N; 30 21′ 48″ E), home to big private cooperation. The biggest computer software and hardware market is also in Ikeja, while Ota is Nigeria's heavily industrialized centre (latitude 6° 32′N, longitude 2° 57′E). Several multinational corporations and companies have factories or assembly plants in Ota. They have engaged in several industrial processes, including the manufacturing of chemicals, pharmaceutical products, cooking utensils, galvanized pipes, steel bars (rods), roofing sheets, melting of aluminium and recycling of metal scraps. Six pre-schools and a pediatric section of an office environment were sampled in Ikeja, Lagos state while a children's ward in a hospital microenvironment was sampled in Ota, Ogun state. Fig. 1 depicts a map of the study locations. Both study sites are known for heavy vehicular traffic and various anthropogenic activities. Also, information on the major activities, age of the building and the ventilation type in the different children's microenvironments is shown in

Table 1
Description of the study locations.

S/N	Sample Location Code	Ventilation Type	Age of the Building	Major Activities	Mass Collected (g)	Area Coordinate
1.	A	Mechanical [fan] and natural ventilation	26	The school is near a busy road and a mini construction site. The sampled classrooms were about 100 m away from the gate; the entire compound is unpaved, so the classrooms are dusty.	8.98	6° 35′ 48″ N; 3° 20′ 50″ E
2	B	Mechanical ventilation	24	The pediatric area of the office is located behind the trash cans. It is located near a busy road and a supermarket.	4.17	6° 35′ 11″ N; 3° 21′ 28″ E
3.	C	Mechanical [fan] and natural ventilation [although the window is small]	10	The school is near a major road.	4.08	6° 35′ 48″ N; 3° 20′ 43″ E
4.	D	Mechanical [fan] and natural ventilation [although the window is small]	27	The school is located in a residential apartment complex, close to the road, and near a busy restaurant.	6.67	6° 35′ 57″ N; 3° 20′ 47″ E
5.	E	Mechanical [air conditioner] and natural ventilation [the windows are big]	16	The children's home is located in a large compound about 100 m from the road. The environment is relatively calm.	11.86	6° 35′ 39″ N; 3° 20′ 41″ E
6.	F	Mechanical [fan] and natural ventilation	18	The sampled classrooms are near the restroom.	5.56	6° 35′ 52″ N; 3° 20′ 48″ E
7.	G	Mechanical [fan and air conditioner] and natural ventilation	16	The daycare centre's location is large. The school is located near a busy road	9.51	6° 35′ 57″ N; 3° 20′ 51″ E
8.	H	Mechanical [air conditioner] and natural ventilation.	6	The pediatric section of the medical centre is situated near a higher institution along a major road leading to the border of another country [Benin Republic].		6° 40′ 05″ N; 3^0 09′ 19′″ E

Table 1.

2.2. Dust collection and preparation

A Tesco VCBL17 vacuum cleaner was used to collect indoor dust samples from December 2021 to January 2022 during the peak of the dry season. Indoor dust samples were collected from classrooms, playrooms, children's ward floors, walls, curtains, window and door frames, shelves, and heating and ventilation system surfaces of each location [29]. The list of samples collected is presented in Table 1. All sample locations were divided into four strata, and composite samples from each of the different strata were merged, wrapped in labelled aluminium foil and sealed in an airtight ziploc bag in preparation for analysis. The vacuum brush was pre-cleaned with methanol before and after the collection of samples to avoid cross-contamination of samples and ensure the integrity of the results [27]. Since most floor polishing products contain corrosive metals and non-metals like Fe and Si, it was verified that they were not utilized throughout the sampling time to prevent a deceptive portrayal of the sampled areas. Afterwards, the samples were transported to the laboratory and sieved with a $<$150 μm mesh sieve to remove all unwanted substances. The particle diameters of $<$150-μm mess size were used because the fine fractions (e.g. $<$ 150 μm or $<$63 μm) adhere more easily to exposed body parts (e. g children's hands) due to their frequent hand-to-mouth activities and are more likely to be dissolved, increasing their capabilities to pass through the gastric mucosa (11, 23, 28). To prepare for SEM-EDX analysis, 2 g of the sieved indoor dust samples were weighed precisely using a pre-calibrated analytical weighing balance and stored in an ice chest bag in the freezer at -20 °C to prevent thermal degradation, microbial activities and evaporation of volatile components before further analysis [9,29].

2.3. SEM-EDX analysis of indoor dust particles

The scanning electron microscopy with energy dispersive x-ray [JOEL-JSM 7600F SEM-EDX] was used to determine the morphology and elemental composition of settled indoor dust in children's microenvironments. Exactly, 2 g of the sieved dust sample was placed on adhesive tape and mounted on the specimen stubs, and a 10 nm platinum coating with an electrically conducting material was deposited on the sample by low vacuum sputter coating. This was done to improve vacuum durability and conductivity. The SEM instrument places the specimen in a relatively high-pressure chamber where the working distance is short, and the electron optical column is differentially pumped to keep the vacuum sufficiently low at the electron gun. SEM analysis was carried out by scanning the electron beam [20–30 kV accelerating voltage] with a beam current of 10 μA over the sample and observing the secondary

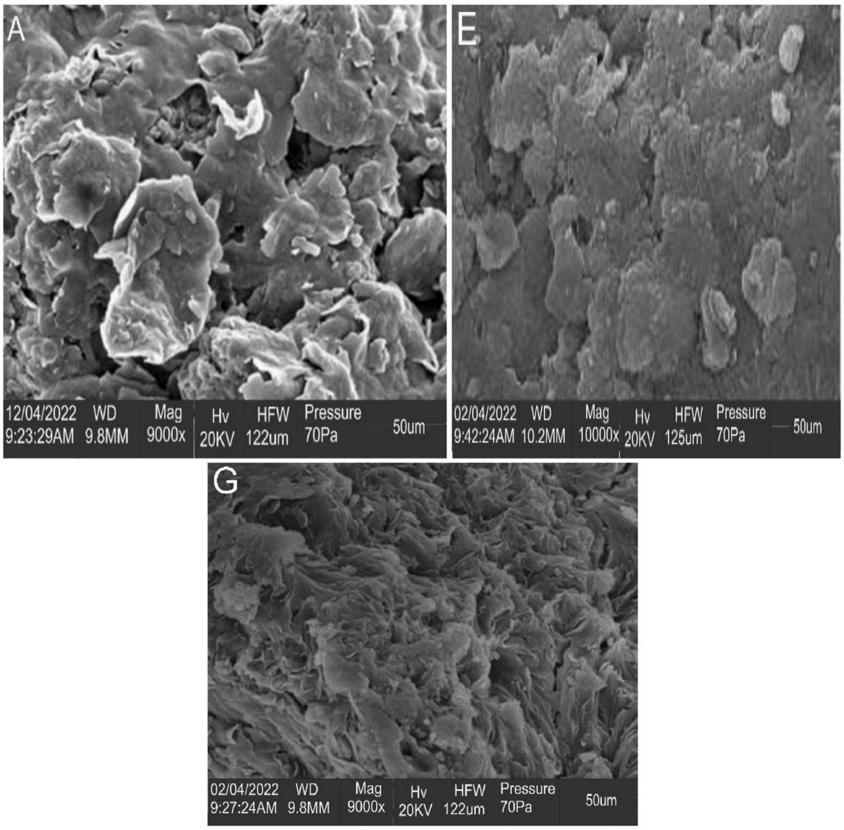

Fig. 2a. Morphology of indoor dust particles in locations A, E & G: alumino silicates.

or backscattered signals generated. Coated specimens were observed as they were placed in the corner of the SEM-EDX chamber, and three unique images were captured with magnifications of 8000X, 9000X, and 10000X. EDX spectra with peaks of various elements were obtained and identified using the computer software programming's quantifying function for further elemental composition interpretation [17,24].

3. Results and discussion

3.1. Indoor dust morphology

The morphological analysis of indoor dust particles is presented in Fig. 2a–d. The detailed SEM micrograph of indoor dust samples collected from the investigated locations (A–H) revealed miniature collections, sharp edges, crystalline structures, spores, and irregular and regular mineral particle shapes. Other studies have reported similar results [4,17,24]. According to the indoor dust characterization result, four categories of particles were found, detailed as follows:

1. **Alumino silicate:** Locations A, E and G as shown in Fig. 2a indicated the presence of alumino silicate. The primary makeup of alumino silicate includes aluminium, silicon and oxygen, and they are usually in irregular form. This result corroborates other research findings [17,24,27]. Typically, aluminium-silicon-oxygen comes from two sources: natural such as soil (irregular-shaped fly ash particles) and anthropogenic (spherical-shaped fly ash particles) [27]. Previous research shows that indoor dust particles are mainly a result of infiltration from outdoor sources and road dust resuspension caused by vehicular and traffic activities. The sources of alumino silicates in these study areas may be attributed to outdoor infiltration due to the location of the study sites near unpaved and busy roads.
2. **Mineral particles and flakes [irregular and coarse large particles] :** Locations B, C, and D (Fig. 2b) have both natural sources of irregular and regular mineral particles as well as skin-flaked-like particles. The presence of mineral particles may be from the infiltration of outdoor dust particles and the resuspension of soil dust in an indoor environment. Anthropogenic activities such as building construction, building characteristics, and automobile emission all contribute to the presence of mineral particles in indoor environments [17,21]. In addition, the occurrence of silica and mineral particles in an indoor environment is primarily attributed to building constituents and flooring patterns [20,29,30]. This result corroborates with research findings from a technical institution classroom indicating the presence of irregular or roughly spherical particles [17]. Also, Kolluru et al. [30] documented irregularly shaped and elongated mineral particles that form from natural and secondary reactions in the atmosphere, respectively.
3. **Fly ash and soot:** Location F comprises fly ash and soot particles as shown in Fig. 2c. Fly ash particles have spherical shapes and are primarily composed of Si and Al. They are typically generated from synthetic sources such as incomplete coal combustion and

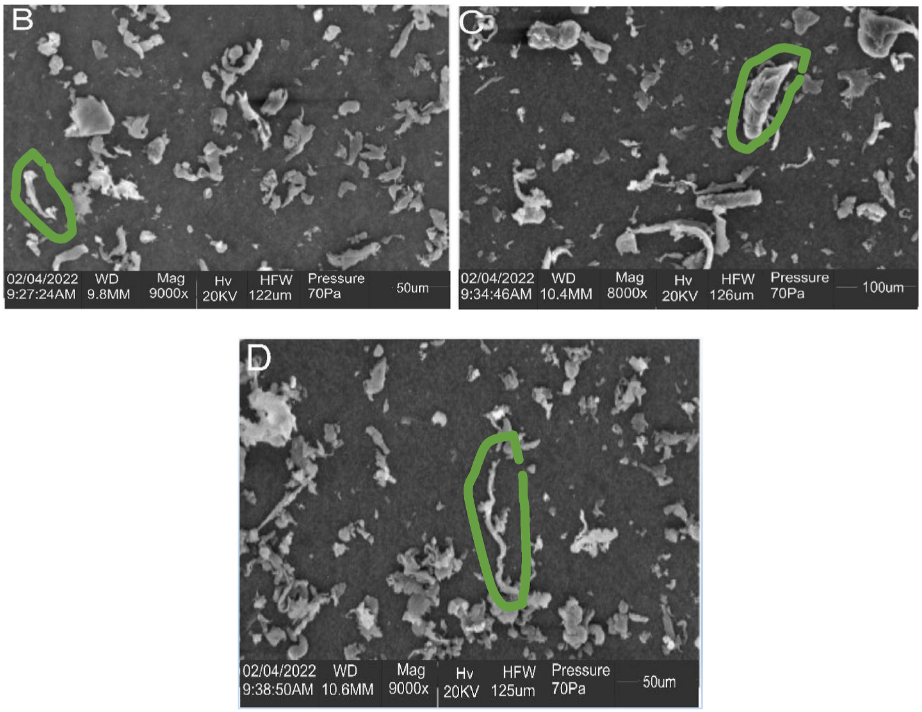

Fig. 2b. Morphology of indoor dust particles in locations B, C & D: mineral particles and flakes.

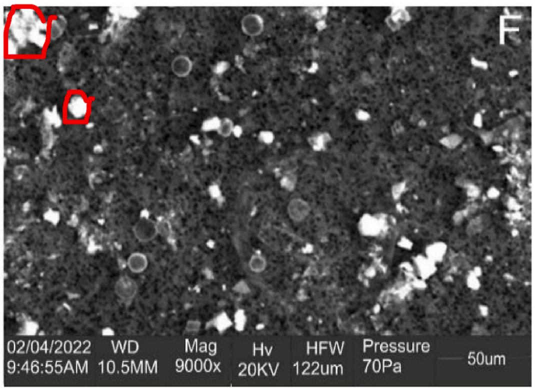

Fig. 2c. Morphology of indoor dust particles in location F: fly ash and soot.

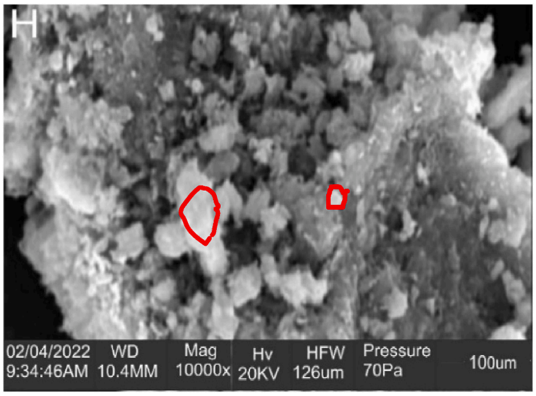

Fig. 2d. Morphology of indoor dust particles in location H: soot aggregates deposited on alumino silicate particles.

vehicular and traffic activities [17,24]. Soot particles in this location are largely emitted from automobile discharge and incomplete combustion of diesel and fuel oil used in powering generators [16,31]. Also, a previous study on the exposure of fly ash in children's homes by Zierold et al. [32] describes fly ash particles as being smoothly spherical and characterized by silicon, sulphur, potassium, calcium and iron [33]. The soot particles indicated in Pietras's [14] work had elongated and branched shapes that are different from this study's micrograph. This variation in the micrograph of the soot particles depends on the type and source of fuel used, the combustion process, and smog reactions in the atmosphere [14].

4. **Soot aggregates deposited on alumino silicate particles:** The SEM micrograph in location H (Fig. 2d) indicates the presence of soot aggregates mixed with alumino silicate particles containing 0.21%, 20.5%, and 40% by weight of Ti, Al and Si. Location H is near a higher institution located in an industrialized area along a major road leading to the border of another country (Benin Republic) and near a very busy café in the University. The occurrence of alumino silicate could be due to the breakdown of flooring materials (tiles), dust infiltration, and transboundary atmospheric particles. Also, vehicular emissions and coal combustion have been identified as precursors of soot particles, and the sampled location has a very high rate of automobile emission [3,17]. Isaxon et al. [34] reported that soot particles resulting from vehicular emission may contribute to the development of aggregates on silicate particles, while Bharti et al. [26] identified alumino silicates in every of their study sites, and documented that they mainly composed of Si and Al with a variable amount of Na, K, Mg, Ca, Fe and Ti. These corroborate with the presence of soot and the elements reported in the morphology of location H, thus attesting to the presence of soots and alumino silicate particles in location H.

3.2. Elemental analysis of indoor dust particles

The EDX spectra peaks for location A to H depicted in Fig. 2e as Edx A to Edx H and Table S1 show the elements and their atomic percentages in various children's microenvironments. From the EDX result, the ascending trends for the elements in the dust particles were Si > O > Al > C > Fe > Ca > Mg > Na > K > P > Mn > Pb > Ti. Six elements (Si, O, Al, C, Fe, and Ca) were identified in all the sampled locations (A-H). The abundance of Si, O, C, and Ca in various sample locations indicates the presence of silica, calcite, and clay minerals [35,36]. Aluminium and silicon make up 72% of the earth's layer, since Si and Al were the two most abundantly detected elements in all of the locations, they could be attributed to particles of crustal origin due to infiltration from the ambient surrounding

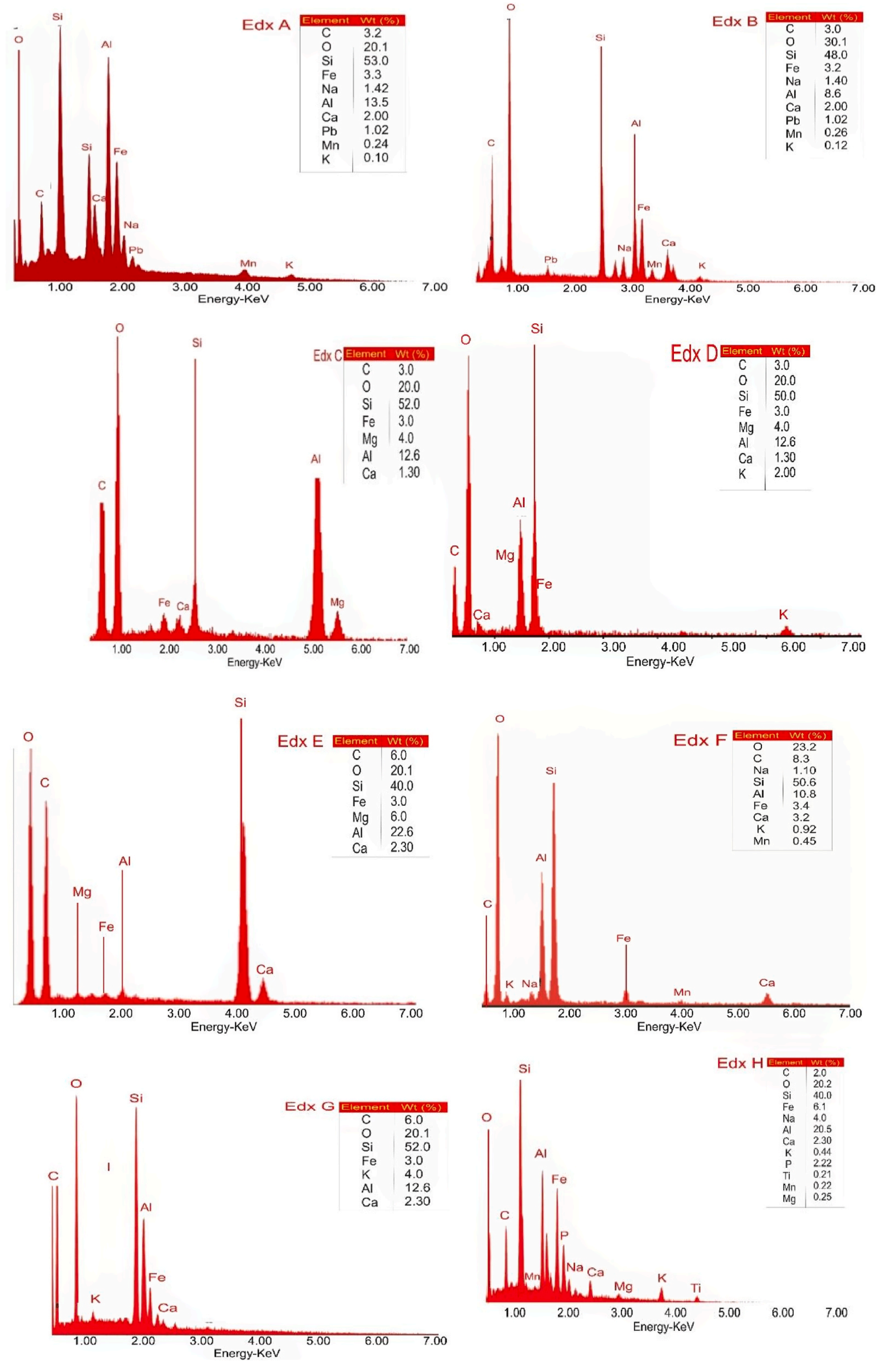

Fig. 2e. EDX spectra for elemental composition (in wt. %) of different indoor dust samples from locations A (Edx A) to H (Edx H).

and household indoor materials [16,30]. Moreover, Al, Si, and Ca particles are clay and can also come from construction and road-paved dust [37]. A previous work by Gustafsson et al. [6] highlighted talc, paints and geological materials as possible sources of aluminium in the indoor environment. Ca indicates the presence of gypsum and cement on the wall and floor surfaces from all sampled locations and the usage of gypsum materials such as chalkboards in location A [5,17,18]. Carbon and oxygen are major elements present in polymers used in the production of plastic [38]. Table S2 presents information on the observed indoor characteristics and materials which account for the high usage of plastic materials [toys, chairs and tables] in all sampled locations. Hence, the abundance of carbon and oxygen can be attributed to the abrasion of plastic materials and the emission from agricultural soil [29,35,38].

The main contributing elements in locations A to H were Si, O, and Al. It is worth noting that in locations A and B, sampled classrooms were located near the school playground, which was filled with quartz sands for construction purposes. Locations C, D, E, F and G were due to their proximity to a major road with heavy automobile emission, infiltration of outdoor dust, and the use of a fossil-fuelled generator as an alternative source of power, while location H's contribution was as a result of infiltration of outdoor dust, vehicular emission, and human-induced activities due to industrial presence. This finding is consistent with recent studies which employed SEM-EDX to observe different indoor dust particles [33]. The presence of Fe could be attributed to natural and anthropogenic sources such as dust from the unpaved road, infiltration of iron impurities from coal or fossil fuel burnt in the outdoor environment and incomplete combustion from automobiles [3,5,17]. An increased percentage of elemental Al and Fe in location H is associated with anthropogenic origin, as reflected in Fig. 2e. This is attributed to the emission of Al and Fe from industrial processes such as cooking utensils, galvanized pipes, steel bars (rods), roofing sheets, melting of aluminium and recycling of metal scraps.

Titanium and phosphorus were only recorded in location H (the hospital's pediatric section). This can be attributed to dust re-suspension and the alloy materials used in the production of medical devices [16,35]. Other studies from Saudi Arabia and India have reported Ti–burdened particles in household indoor dust as a function of certain alloys from domestic practices and also linked it with infiltration of outdoor soil [26,32].

Also, potassium and magnesium were present only in locations A, B, D, F, G, H and C, D, E, and H, respectively. This is attributed to some geological materials in the building stemming from the building materials and characteristics such as paints, soil and cement [17,18,36]. In addition, the cleaning materials (detergents and liquid soap) used in these locations could account for the presence of Mg. Mg and Ti are the crustal elements used as tracers for soil dust. However, a higher concentration of Ti is an indication of anthropogenic contribution [39]. Only locations A, B, F and H recorded Na and Mn. Natural sources, such as soil constituents in construction materials and anthropogenic sources, including Mn in steel and cement, maybe the probable sources. An earlier report by Emenike [40] attributed the emission of Mn in Ota to anthropogenic contributions from industrial processes such as plastics and metalliferous extraction. Isley et al. [5] have equally reported higher Mn concentrations in detached homes due to soil track-in, smoke, and the use of Mn as an additive to steel and concrete floors. Lead (Pb), one of the ubiquitous toxic metals, was found in locations A and B. This may be associated with vehicular emission and the chipping of lead-based paint from the wall surfaces as these preschool centres are very old buildings [36,41,42]. The age of the sampled locations (buildings) is shown in Table 1. This study's results corroborate other indoor dust results for Pb in older homes [5,43–45]. Lead is highly toxic and non-degradable, exposure to lead, even at trace levels, can result in neurodevelopmental disorders (NDDs) in children [28,46–48]. As such, the service of a certified professional to carry out proper renovation of these facilities is required [5].

In an attempt to improve the health and education outcomes of children, the United States Environmental Protection Agency (USEPA) has made a substantial effort to reduce lead-burdened dust in homes, schools and childcare facilities through a progressive downward review of the standard lead levels in the dust on floors and window sills [43,44]. Furthermore, it is worth noting that excessive exposure to some of the elements in the sampled locations may result in mild to severe adverse health outcomes such as lung diseases, sinusitis, coughing, wheezing, nose irritation, shortness of breath, slowed growth and development in children [48–53]. Comparatively, there are scanty research publications in the studied microenvironments [preschool centres, office and hospital] at the time of this write-up. As such most comparison is done with studies in other indoor environments, such as homes or residential areas. Although sulphur [S] was recorded in Stockholm and Södertälje in Sweden [6], this study did not contain any S. On the contrary, while C was the most abundant across the indoor residential areas, Si was the most abundant across all sampled indoor microenvironments in this study. Additionally, this study reported more elements, including Ti, P, Mg, Mn, Pb, and Fe than were identified in the Swedish study.

Some limitations of this study that should be considered are as follows: the number of sample locations was small due to difficulties in securing approval from daycare centres administrators; only indoor dust was examined, subsequent analysis of both outdoor and indoor dust from the same microenvironment to understand the influence of the outdoor pollutants on the indoor air quality is suggested; and for precise quantification of the elements, more sensitive detection approaches should be used. The major strength of this study is that it is the first study to measure and identify children's indoor exposure to fly ash and soots, alumino silicates, mineral particles and flakes and soot aggregates deposited on alumino silicate particles and surface elemental composition (Si > O > Al > C > Fe > Ca > Mg > Na > K > P > Mn > Pb > Ti) in different children's microenvironments (preschool centres, office and hospital) in Africa.

4. Conclusion and recommendation

In this study, SEM-EDX was used to characterize the morphology and elemental composition of indoor dust in various microenvironments. The finding from this study reveals the presence of fly ash and soots, alumino silicates, mineral particles and flakes and soot aggregates deposited on alumino silicate particles in different children's microenvironments, a pointer to some health consequences. Gypsum from classroom materials and building features such as wall decoration and paints has been identified as a probable source of indoor chemical pollutants. All the examined study areas revealed the presence of C, O, Si, Fe, Al and Ca, with Si being the most detected element across all the sampled locations. Lead, a toxic and carcinogenic heavy metal, was observed in locations A and B. This outcome calls for further investigation of the concentrations, bioavailability and health risk assessment of heavy metals in these sampled locations using a more sensitive analytical instrument to ascertain the concise levels of exposure and health implications. Also, a consistent cleaning pattern, including frequent vacuum cleaning, wet moping and adequate ventilation systems will significantly reduce the build-up of dust particles in an indoor environment. Furthermore, effective regulatory measures should be enacted and enforced to ensure the appropriate use of building materials during the construction process, as it will significantly reduce the emergence of indoor chemical pollutants from indoor dust particles.

Author contribution statement

Anake Winifred U: Conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

Nnamani Esther A: Performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Funding

This research received financial support covering sample collection and laboratory analysis from Global Corp Ltd.

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.

Acknowledgement

The authors are grateful to the proprietors and directors of the sampled preschools, hospital and office for agreeing to have their places of business activities sampled. We also applaud Covenant University's administration for fostering a supportive laboratory environment for this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16419.

References

[1] S. Guak, K. Kim, W. Yang, S. Won, H. Lee, K. Lee, Prediction models using outdoor environmental data for real-time PM10 concentrations in daycare centers, kindergartens, and elementary schools, Build. Environ. 187 (2021), 107371, https://doi.org/10.1016/j.buildenv.2020.107371.

[2] I. Oghenovo, N. Benson, A. Adedapo, O. Fred-Ahmadu, Assessment of particulate matter [$PM_{2.5}$] in residential staff quarters of covenant university, Nigeria, J. Phys. Conf. Ser. 1299 (2019) 1, https://doi.org/10.1088/1742-6596/1299/1/012101.

[3] Y. Bouchriti, B. Kabbachi, M.A. Haddou, A. Achbani, R. Amiha, H. Gougueni, Household dust from a city in Morocco: characterization by scanning electron microscopy, Pollution 8 (2) (2022) 513–527, https://doi.org/10.22059/poll.2021.330823.1190.

[4] M. Caban, P. Stepnowski, Determination of bisphenol A in size fractions of indoor dust from several microenvironments, Microchem. J. 153 (2020), 104392, https://doi.org/10.1016/j.microc.2019.104392.

[5] C. F Isley, K. L Fry, X. Liu, G.M. Filippelli, J.A. Entwistle, A.P. Martin, M. Kah, D. Meza-Figueroa, J.T. Shukle, K. Jabeen, A.O. Famuyiwa, International analysis of sources and human health risk associated with trace metal contaminants in residential indoor dust, Environ. Sci. Technol. 56 (2) (2021) 1053–1068, https://doi.org/10.1021/acs.est.1c0449.

[6] Å. Gustafsson, A. M Krais, A. Gorzsás, T. Lundh, P. Gerde, Isolation and characterization of a respirable particle fraction from residential house-dust, October 2017, Environ. Res. [Internet] 161 (2018) 284–290, https://doi.org/10.1016/j.envres.2017.10.049.

[7] D.S. Samaradiwakara, H.M.T.G. A Pitawala, Extent of air pollution in Kandy area, Sri Lanka: morphological, mineralogical and chemical characterization of dust, Ceylon J. Sci. 50 (4) (2021) 475, https://doi.org/10.4038/cjs.v50i4.7946.

[8] X. Fan, G. P Katuri, A.A. Caza, P.E. Rasmussen, C. Kubwabo, Simultaneous measurement of 16 bisphenol A analogues in house dust and evaluation of two sampling techniques, Emer. Contam. 7 (2021) 1–9, https://doi.org/10.1016/j.emcon.2020.12.001.

[9] X. Li, W. Zhang, J. Lv, W. Liu, S. Sun, C. Guo, et al., Distribution, source apportionment, and health risk assessment of phthalate esters in indoor dust samples across China, Environ. Sci. Eur. 33 (2021) 1, https://doi.org/10.1186/s12302-021-00457-3.

[10] W. U Anake, E.A. Nnamani, A brief review on emerging indoor chemical pollutants, IOP Conf. Ser. Earth Environ. Sci. 1054 (2022), 012022, https://doi.org/10.1088/1755-1315/1054/1/012012.

[11] Y. Li, E. Padoan, F. Ajmone-Marsan, Soil Particle Size Fraction and Potentially Toxic Elements Bioaccessibility: A Review vol. 209, Ecotoxicology and Environmental Safety, 2021, 111806.

[12] C. Yang, S. A Harris, L.M. Jantunen, J. Kvasnicka, L.V. Nguyen, M.L. Diamond, Phthalates: relationships between air, dust, electronic devices, and hands with implications for exposure, Environ. Sci. Technol. 54 (13) (2020) 8186–8197, https://doi.org/10.1021/acs.est.0c00229.
[13] D.C. Vu, T.L. Ho, P.H. Vo, G. Carlo, J.A. McElroy, A.N. Davis, et al., Determination of volatile organic compounds in child care centers by thermal desorption gas chromatography-mass spectrometry, Anal. Methods 10 (7) (2018) 730–742, https://doi.org/10.1039/C7AY02570J.
[14] B.G. Pietras, The origin of dust particles in atmospheric air in krakow [Poland] [atmospheric background], Land 11 (2022), https://doi.org/10.3390/land11020155 [2].
[15] J. Zhang, C. Sun, R. Lu, Z. Zou, W. Liu, C. Huang, Associations between phthalic acid esters in household dust and childhood asthma in Shanghai, China, Environ. Res. 200 (2021), 111760, https://doi.org/10.1016/j.envres.2021.111760.
[16] G. Simonetti, P. Di Filippo, C. Riccardi, D. Pomata, E. Sonego, F. Buiarelli, Occurrence of halogenated pollutants in domestic and occupational indoor dust, Int. J. Environ. Res. Publ. Health 17 (11) (2020) 1–16, https://doi.org/10.3390/ijerph17113813.
[17] V. Sahu, S.P. Elumalai, S. Gautam, N. K Singh, P. Singh, Characterization of indoor settled dust and investigation of indoor air quality in different micro-environments, Int. J. Environ. Health Res. 28 (4) (2018) 419–431, https://doi.org/10.1080/09603123.2018.1481498.
[18] F. Dubocq, A. Kärrman, J. Gustavsson, T. Wang, Comprehensive chemical characterization of indoor dust by target, suspect screening and nontarget analysis using LC-HRMS and GC-HRMS, Environ. Pollut. 276 (2021), https://doi.org/10.1016/j.envpol.2021.116701.
[19] N. Ali, N. A Alhakamy, I.M. L Ismail, E. Nazar, A.S. Summan, S.A.M.A.S. Eqani, et al., Exposure to phthalate and organophosphate esters via indoor dust and pm10 is a cause of concern for the exposed saudi population, Int. J. Environ. Res. Publ. Health 18 (4) (2021) 1–15, https://doi.org/10.3390/ijerph18042125.
[20] P. Rostkowski, P. Haglund, R. Aalizadeh, N. Alygizakis, N. Thomaidis, J.B. Arandes, et al., The strength in numbers: comprehensive characterization of house dust using complementary mass spectrometric techniques, Anal. Bioanal. Chem. 411 (10) (2019), 1957–77, https://doi.org/10.1007/s00216-019-01615-6.
[21] D. Yaparla, S.M.S. Nagendra, S.N. Gummadi, Characterization and health risk assessment of indoor dust in biomass and LPG-based households of rural Telangana, India, J. Air Waste Manag. Assoc. 69 (12) (2019), 1438–51, https://doi.org/10.1080/10962247.2019.1668874.
[22] S. Abbasi, B. Keshavarzi, F. Moore, A. Turner, F.J. Kelly, A.O. Dominguez, et al., Distribution and potential health impacts of microplastics and microrubbers in air and street dusts from Asaluyeh County, Iran, Environ. Pollut. 244 (2019) 153–164, https://doi.org/10.1016/j.envpol.2018.10.039.
[23] F.S. Mohammed, Characterization of indoor/outdoor settled dust and air pollutants in damaturu, Nigeria, Int. J. Eng. Technol. 5 (1) (2013) 104–108, https://doi.org/10.7763/IJET.2013.V5.521.
[24] W.U. Anake, G.R.E. E Ana, N. U Benson, Study of surface morphology, Elemental Composition and Sources of Airborne Fine Particulate Matter in Agbara Industrial Estate, 2016, pp. 881–890, 11[4].
[25] W.U. Anake, K.D. Oyeyemi, G.R.E.E. Ana, Fine particulate matter-based air quality index: a case study, Int. J. Mech. Eng. Technol. 9 (8) (2018) 1321–1328.
[26] S. K Bharti, D. Kumar, S. Anand, S. Poonam, S.C. Barman, N. Kumar, Characterization and morphological analysis of individual aerosol of PM10 in urban area of Lucknow, India, Micron 103 (2017) 90–98, https://doi.org/10.1016/j. micron.2017.09.004.
[27] L. Li, Y. Qiu, Å. Gustafsson, A. M Krais, J.M. Weiss, T. Lundh, et al., Characterization of residential household dust from Shanghai by particle size and analysis of organophosphorus flame retardants and metals, Environ. Sci. Eur. 31 (2019) 1, https://doi.org/10.1186/s12302-019-0279-9.
[28] USEPA, EPA and HUD Announce New Lead Dust Standards to Protect Children's Health, U.S. Environmental Protective Agency, 2019. Retrieved from, https://www.epa.gov/newsreleases/epa and-hud-announce-new-lead-dust-standards-protect-childrens-health.
[29] S. Kumar, M.K. Jain, Characterization and morphometric study of household settled dust: a case study in Dhanbad, the coal capital of India, Appl. Geochem. [Internet] 144 (July) (2022), 105398, https://doi.org/10.1016/j.apgeochem.2022.105398.
[30] S.S.R. Kolluru, A.K. Patra, P. Kumar, Determinants of commuter exposure to PM2.5 and CO during long-haul journeys on national highways in India, Atmos. Pollut. Res. 10 (2019) 1031–1041, https://doi.org/10.1016/j.apr.2019.01.012.
[31] A.A. El-Zahhar, A.M. Idris, K.F. Fawy, M. Arshad, SEM, SEM-EDX, µ-ATR-FTIR and XRD for urban street dust characterisation, Int. J. Environ. Anal. Chem. 101 (7) (2021) 988–1006, https://doi.org/10.1080/03067319.2019.1674849.
[32] K.M. Zierold, C.G. Sears, A.N. Hagemeyer, G.N. Brock, B.J. Polivka, C.H. Zhang, L. Sears, Protocol for measuring indoor exposure to coal fly ash and heavy metals, and neurobehavioural symptoms in children aged 6 to 14 years old, BMJ Open 10 (11) (2020), e038960, https://doi.org/10.1136/bmjopen-2020-038960.
[33] Y.N. Chanchangi, A. Ghosh, S. Sundaram, T. K Mallick, An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material, Sol. Energy [Internet] 203 (December 2019) (2020) 46–68, https://doi.org/10.1016/j.solener.2020.03.089.
[34] C. Isaxon, A. Gudmundsson, E.Z. Nordin, L. Lönnblad, A. Dahl, G. Wieslander, M. Bohgard, A. Wierzbicka, Contribution of indoor-generated particles to residential exposure, Atmos. Environ. 106 (2015) 458–466, https://doi.org/10.1016/j. atmosenv.2014.07.053.
[35] B.S. Tawabini, T.T. Lawal, A. Shaibani, A.M. Farahat, Morphological and chemical properties of particulate matter in the Dammam metropolitan region: dhahran, Khobar, and Dammam, Saudi Arabia, Adv. Meteorol. (2017) 1–9, https://doi.org/10.1155/2017/8512146.
[36] P. Gupta, M. Satsangi, G.P. Satsangi, A. Jangid, Y. Liu, S. K Pani, R. Kumar, Exposure to respirable and fine dust particle over North-Central India: chemical characterization, source interpretation, and health risk analysis, Environ. Geochem. Health 42 (7) (2020) 2081–2099, https://doi.org/10.1007/s10653-019-00461-w.
[37] P.G. Satsangi, S. Yadav, A.S. Pipal, N. Kumbhar, Characteristics of trace metals in fine ($PM_{2.5}$) and inhalable (PM_{10}) particles and its health risk assessment along with in silico approach in indoor environment of India, Atmos. Environ. 92 (2014) 384–393, https://doi.org/10.1016/j.atmosenv.2014.04.047.
[38] L. Pires, M. Vaz, A. Carolina, C. De Oliveira, L. Falcon, M. Stella, et al., Capture and Reuse of Carbon Dioxide (CO2) for a Plastics Circular Economy : A Review, 2021, https://doi.org/10.3390/pr9050759.
[39] R. Zhao, B. Han, B. Lu, N. Zhang, L. Zhu, Z. Bai, Element composition and source apportionment of atmospheric aerosols over the China Sea, Atmos. Pollut. Res. 6 (2015) 191–201.
[40] C.P. Emenike, E.J. Okwuonu, I.T. Tenebe, D.O. Omole, M. Nwani, O.D. Afolayan, B.I. Oniemayin, Ecological risk estimation of heavy metal pollution in roadside dust of Ado-Odo Ota, Southwestern Nigeria, IOP Conf. Ser. Mater. Sci. Eng. 640 (2019), 012100.
[41] M. Omeje, M.M. Orosun, O.O. Adewoyin, E.S. Joel, M.R. Usikalu, O. Olagoke, E.O. Ehinlafa, U.A. Omeje, Radiotoxicity risk assessments of ceramic tiles used in Nigeria: the Monte Carlo approach, Environ. Nanotechnol. Monit. Manag. 17 (2022), 100618, https://doi.org/10.1016/j.enmm.2021.100618.
[42] S. Rylance, R. Nightingale, A. Naunje, F. Mbalume, C. Jewell, J. R Balmes, et al., Lung Health and Exposure to Air Pollution in Malawian Children [CAPS]: a Cross-Sectional Study, 74, Thorax, 2019, 1070–7, https://doi.org/10.1136/thoraxjnl-2019-214134, 11.
[43] J.H. Dingle, L. Kohl, N. Khan, M. Meng, Y.A. Shi, M. Pedroza-Brambila, C.W. Chow, A.W. Chan, Sources and composition of metals in indoor house dust in a mid-size Canadian city, Environ. Pollut. 289 (2021), 117867, https://doi.org/10.1016/j.envpol.2021.117867.
[44] I. Manisalidis, E. Stavropoulou, A. Stavropoulos, E. Bezirtzoglou, Environmental and health impacts of air pollution: a review, Front. Public Health 8 (2020) 1–13, https://doi.org/10.3389/fpubh.2020.00014.
[45] S. Cao, D. Wen, X. Chen, X. Duan, L. Zhang, B. Wang, N. Qin, F. Wei, Source identification of pollution and health risks to metals in household indoor and outdoor dust: a cross-sectional study in a typical mining town, China, Environ. Pollut. 293 (2022), 118551, https://doi.org/10.1016/j.envpol.2021.118551.
[46] K.D. Oyeyemi, A.P. Aizebeokhia, W.U. Anake, O. Asanuade, A.A. Akinsiku, O. M Olofinnade, H.O. Jonathan, W. A Ayara, Geospatial distribution of heavy metal contamination in Ewekoro Limestone, SW Nigeria, J. Phys. Conf. (2019), https://doi.org/10.1088/1742-6596/1299/1/012080.
[47] M.S. Abd Wahil, M.H. Ja'afar, Z. Md Isa, Assessment of urinary Lead [Pb] and essential trace elements in autism Spectrum disorder: a case-control study among preschool children in Malaysia, Biol. Trace Elem. Res. 200 (1) (2022) 97–121, https://doi.org/10.1007/s12011-021-02654-w.
[48] V.I. Naranjo, M. Hendricks, K.S. Jones, Lead toxicity in children: an unremitting public health problem, Pediatr. Neurol. 113 (2020) 51–55, https://doi.org/10.1016/j.pediatrneurol.2020.08.005.
[49] M. Bodor, A. Ceoromila, V. Bas liu, Morphological and chemical characterization of particulate matter from an indoor measuring campaign, Sustainability 14 (2022), 11621, https://doi.org/10.3390/su141811621.
[50] B. Zeb, K. Alam, A. Sorooshian, T. Blaschke, I. Ahmad, I. Shahid, On the morphology and composition of particulate matter in an urban environment, Aerosol Air Qual. Res. 18 (6) (2018 28) 1431–1447, https://doi.org/10.4209/aaqr.2017.09.0340.

[51] M.G. Kwata, S.J. Moja, Measurement and characterization of dustfall samples from Mpumalanga province, South Africa, WIT Trans. Ecol. Environ. 211 (2017) 111–120.
[52] W.J. Deng, N. Li, R. Wu, W.K.S. Richard, Z. Wang, W. Ho, Phosphorus flame retardants and Bisphenol A in indoor dust and PM2.5 in kindergartens and primary schools in Hong Kong, Environ. Pollut. 235 (2018) 365–371, https://doi.org/10.1016/j.envpol.2017.12.093.
[53] B.B. Neupane, A. Sharma, B. Giri, M.K. Joshi, Characterization of airborne dust samples collected from core areas of Kathmandu Valley, 6, Heliyon 1 (4) (2020), e03791, https://doi.org/10.1016/j.heliyon.2020.e03791.