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SPECTROSCOPIC AND MINERALOGICAL ANALYSIS OF INDOOR DEPOSITED PARTICLES AT KUET CAMPUS USING ATR-FTIR AND XRD TECHNIQUES

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ABSTRACT

Indoor air quality is a major concern today, as it directly affects human health. Particulate matter in indoor deposited dust plays a crucial role in indoor air quality. So it is important to assess, identify and characterize the indoor deposited dust to understand the exposure risks and to improve the indoor air quality. Indoor dust particles were intensively examined in this study. Functional groups and mineral contents were investigated through attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy and X-ray diffraction (XRD) technique. For testing, four indoor dust samples were collected from a five storied residential hall by using the gravity deposition method. Spatial variability was found in the deposition rates. It varies from 5.35 mg/m^2/day to 16.15 mg/m^2/day across different floors. From the ATR-FTIR analysis, a number of organic and inorganic key functional groups were identified, including hydroxyls, aldehydes, methyl groups, alkenes, aromatics, and aromatic amines, as well as silicates, carbonates, chlorides, and metal oxides. XRD analysis identified some crystalline minerals, which include quartz and calcite as primary mineral contents, and average crystallite sizes were found to be 19 nm and 12 nm for the two respective samples. Both the natural (such as soil and mineral dust) and anthropogenic (like building materials and combustion activities) sources produce these organic and inorganic substances. The results found in this study show that more research is needed on indoor air quality, especially in the institutional environment, to address the complexity of deposited particulate matter. A detailed assessment of indoor dust will support indoor air quality management, public health campaigns, and make it easier to create focused interventions to improve indoor air quality and overall human health.

Keywords: *Indoor Deposited Particles, Functional Groups, Mineral Content, ATR-FTIR, XRD*

1. INTRODUCTION

Indoor air pollution has become a major public health problem, especially in developing and rapidly urbanizing regions. People spend most of their day indoors—often 80% to 90% of their time—so indoor exposures can influence overall health risk more than short outdoor exposures (Firdaus & Ahmad, 2011). Therefore, the risks of short-term outdoor exposure are frequently outweighed by indoor particulate exposure. Particulate matter (PM), gases, and biological agents are examples of dangerous or irritating substances that can be found inside buildings and are referred to as indoor air pollution. PM is a complicated mixture of airborne solid and liquid particles. The U.S. Environmental Protection Agency (EPA) has linked indoor dust (PM) exposure to both short-term symptoms like eye and throat irritation, exhaustion, and lightheadedness, as well as long-term ailments like cancer, heart disease, and asthma. Because their organs and tissues are still developing and because they breathe more air per unit of body weight than adults, young children are especially vulnerable to indoor air pollution (Hou et al., 2015; Viegi et al., 2004).

The amount of exposure, the rate at which particles settle, their size, composition, and shape, how they interact with surfaces, whether they attract or repel water, and how they dissolve in their final locations are just a few of the many variables that interact to affect the health effects of particulate matter (Fubini & Areán, 1999; Pöschl, 2005). There are many different sources of indoor particulate matter in residential environments, which usually consist of both outdoor particles that enter the indoor environment and particles produced by daily indoor activities (cooking, cleaning, smoking, and fuel combustion for heating) (Zhang et al., 2021). Consequently, indoor concentrations can occasionally surpass outdoor levels, influenced by factors such as season, ventilation, and occupant behavior (Massey et al., 2011). Settled indoor dust serves as a dynamic reservoir. It accumulates more dust over time and can be reintroduced into the air. The composition of indoor dust frequently reflects a blend of origins. This includes organic compounds with mineral components and trace contaminants (Kumar & Rajkumar, 2014). In recent research, synthetic polymers (microplastics) have been found in indoor dust, highlighting hazardous microplastics exposure pathways through inhalation and resuspension (Islam et al., 2024).

Particulate matter can be divided into two types based on their aerodynamic diameter: fine ($PM_{2.5}$, ≤ 2.5 µm) and coarse (PM_{10}, ≤ 10 µm) (Introduction to Indoor Air Quality | US EPA, 2025). Ultrafine (UFPs, <0.1 µm) particles can be identified as the finer portion of $PM_{2.5}$. Fine and ultrafine particulates can travel hundreds or even thousands of miles from their source and remain in the atmosphere for days or weeks, depending on the circumstances (Tyagi, 2009). The World Health Organization (WHO, 2021) suggests annual guidelines of 5 µg/m³ for $PM_{2.5}$ and 15 µg/m³ for PM_{10}, with 24-hour values of 15 µg/m³ for $PM_{2.5}$ and 45 µg/m³ for PM_{10}. These values indicate that the finer particles are more hazardous than the coarser particles. Fine and ultrafine particulate matter ($PM_{2.5}$ and UFPs) can deeply penetrate the lungs, enter the bloodstream, and cause respiratory and cardiovascular diseases (Kim et al., 2014; WHO, 2021).

According to research from different regions, indoor and ambient dust are chemically diverse, highly dynamic, and influenced by both natural and human activities. It shows that South Asia ranks among the most severely affected regions in terms of particulate pollution, with cities in India, Pakistan, and Bangladesh frequently appearing at the top of global pollution indices (Writers, 2024). Global reviews highlight that particles range from nano to micrometer scales, combining organic materials with mineral components. It is also proven that if multiple techniques can be used together, such as microscopy, vibrational spectroscopy, and diffraction, it improves the reliability (Pöschl, 2005).

The application of ATR-FTIR and XRD techniques for the characterization of indoor deposited particles has been widely reported in international studies, but such investigations remain limited in the context of institutional indoor environments in Bangladesh. Most local studies lack the time-averaged burden from settled dust. In particular, there is a lack of baseline data on the spectroscopic and mineralogical analysis of indoor dust across different floor levels within the university residential facilities. They only focus on airborne particulate matter with short-term indoor-outdoor comparisons. In institutional contexts such as classrooms, residence halls, and dorms, indoor deposited dust has a poorly known deposition rate and composition. So that in this study, indoor deposited particles have been examined to understand the identity and the characteristics at a residential hall on a university campus.

These are the objectives of this study:

- To determine the deposition rate of indoor deposited dust over various floors of a residential hall
- To identify the functional groups of indoor deposited dust particles using ATR-FTIR spectroscopy
- To determine the mineral contents of indoor deposited dust particles using XRD analysis

The findings offer location-specific insights into indoor dust composition in a rapidly urbanizing and construction-intensive environment, contributing valuable baseline information for exposure assessment, health risk evaluation, and future indoor air quality management in similar institutional settings.

2. METHODOLOGY

The research plan was developed to maintain a standard for data collection, testing, and analysis in order to ensure accuracy and reliability of the results. To guarantee consistency and viability, each result was compared and cross-checked with previously published research (Mahmud & Mohiuddin, 2024).

2.1 Study Area

The selected study area was Khulna University of Engineering & Technology (KUET), which is situated in Fulbarigate, Khulna, Bangladesh. Khulna is located in the southwest coastal region of the country. The climate is humid in this region of Bangladesh, with consistently high relative humidity. Khulna is particularly vulnerable due to the dust accumulation along with the climatic factors. This vulnerability increases due to human and natural activities.

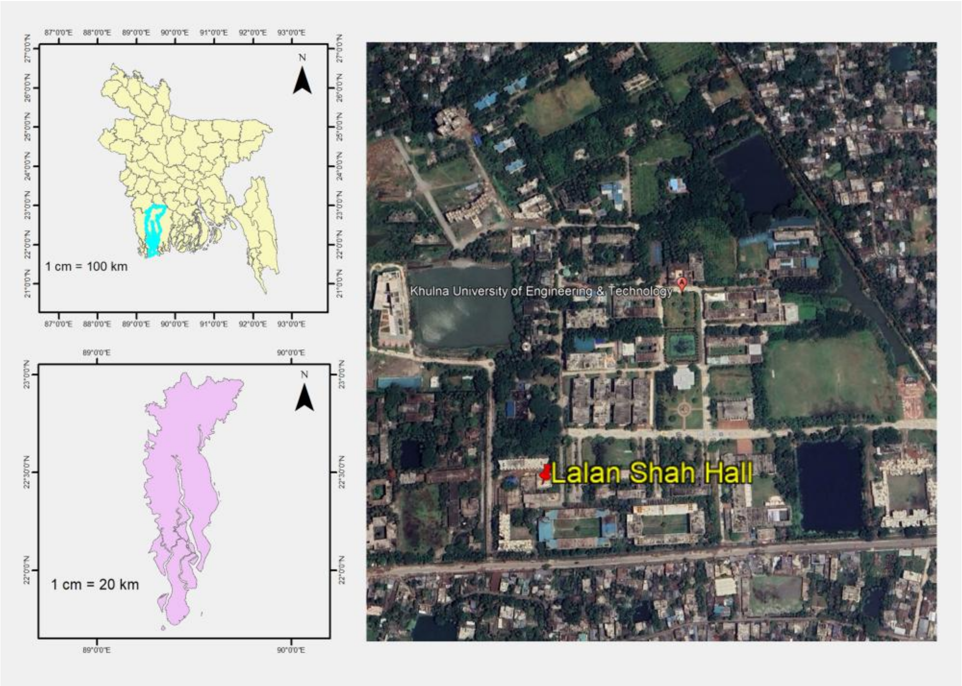

Figure 1: Study Area (Lalan Shah Hall, KUET)

The sampling site was Lalan Shah Hall (22°54′52″ N, 89°30′1″ E) for this study, a student residence on the KUET campus (Figure 1). There are about 250 students living in the five-story residence, creating a crowded interior space. A national highway, a local road, ongoing construction sites, a cooking facility, and adjacent brick fields are some of the potential particle sources that surround the KUET campus. The hall is a suitable place to study indoor particle deposition because of its poor ventilation, irregular window and door usage patterns, and high occupant activity. Additionally, the quantity and composition of deposited particles were probably impacted by outside factors like cooking techniques, construction activities, and resuspended road dust from the nearby street.

2.2 Sample Collection

Dust samples were collected by the passive gravitational settling method. This allows dust to accumulate naturally on surfaces without active airflow disturbance. To ensure consistency and comparability across the samples, rooms with similar orientation, occupancy pattern, and ventilation characteristics were selected on each floor. Four collection stations were set up at four rooms in the five-story dormitory, one on each of the first four floors. The fifth floor was not operational during the sampling period, so it was excluded. A flat plastic board measuring roughly 56.5 x 36 mm was installed at each station at a height of about 2.0 meters above the ground (Figure 2) which reduced the interference caused by occupant activity and near-floor resuspension. Sampling took place from January 8 to February 12, 2025, during the dry season. During this time of year, more dust accumulates from surrounding sources like construction and vehicular movement on the road, as there is less rainfall.

Figure 2: Sample collection setup

Figure 3: Collected sample after 35 days

Deposited dust was meticulously gathered at the conclusion of the collection period (Figure 3), moved into airtight plastic containers, labelled, and stored to avoid moisture absorption and cross-contamination. Collected samples were manually inspected, and all extraneous materials (e.g., spider webs, fibres, and large debris) were removed before conducting laboratory analyses to maintain sample purity and analytical precision.

2.3 Deposition Rate Measurement

Indoor deposition rate provides a quantitative measure of particle accumulation in enclosed environments. It is described as the flux of particulate matter that settles onto indoor surfaces per unit area over time and is expressed in mg/m²/day (Lai et al., 2017; Licina & Nazaroff, 2018). The gravimetric measurement method was used to quantify the deposition. In this analytical method, the net mass of deposited particles is calculated by weighing a sampling substrate both before and after particle collection (Hinds & Zhu, 2022). After 35 days, the deposited particles were carefully brushed into airtight plastic jars. Each jar was weighed before and after sample transfer using a milligram-sensitive digital balance, and the difference in weight was taken as the net sample mass. This process ensured precise measurement of deposited material while reducing the impact of ambient humidity. The deposition rate was then calculated using the equation (1).

$$\text{DR} = \frac{M}{A \times T} \tag{1}$$

Where

DR = Deposition Rate (mg/m²/day)
M = Net mass of deposited particles collected in the jar (mg),
A = Exposed surface area of the plastic board (m²), and
T = Sampling period (days).

This method is frequently used to study indoor particles, particularly in residential and institutional settings (Adams & Ford, 2001).

2.4 ATR-FTIR Spectroscopic Analysis

Fourier Transform Infrared (FTIR) spectroscopy provides information on molecular bonding through vibrational spectra and is a widely used tool for analysing the chemical composition of samples (Coates, 2000). In particular, attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) offers a rapid, non-destructive, and surface-sensitive method for characterizing particulate matter, enabling identification of both organic and inorganic functional groups (Pavia et al., 2014).

In this study, a Shimadzu IRTracer-100 spectrometer equipped with an ATR accessory (Figure 4) was used to identify the functional groups of indoor deposited dust obtained from Lalan Shah Hall, KUET. Samples were put directly on the ATR crystal without any pretreatment, and spectra were recorded at a resolution of 1 cm^{-1} in the 4000–600 cm^{-1} range with an average of 20 consecutive scans for each sample. OriginPro software (OriginLab, USA) was used to process and visualize the raw spectra.

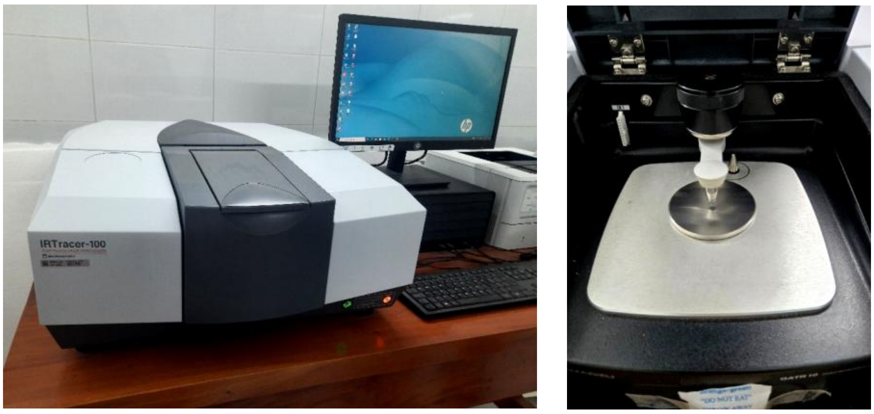

Figure 4: Shimadzu IRTracer-100 spectrometer (left) with ATR accessory (right)

Absorption bands from ATR-FTIR spectroscopy were matched with standard reference spectra and band tables from reliable databases and literature to assign functional groups (Nakamoto, 2009; Pavia et al., 2014; Chen et al., 2015; Libretexts, 2020). This method made it easy to identify important organic groups (such as hydroxyl, carbonyl, aliphatic hydrocarbons, and amines) as well as inorganic connections (such as silicates, carbonates, metal–oxygen bonds) with the use of their absorption bands.

2.5 XRD Analysis

Another popular analytical method used for describing crystalline materials is X-ray diffraction (XRD), which offers comprehensive details on crystal structure, mineralogical composition, and degree of crystallinity (Cullity & Smoluchowski, 1957). Minerals can be distinguished by their distinctive crystallographic patterns by measuring the X-ray diffraction at particular angles.

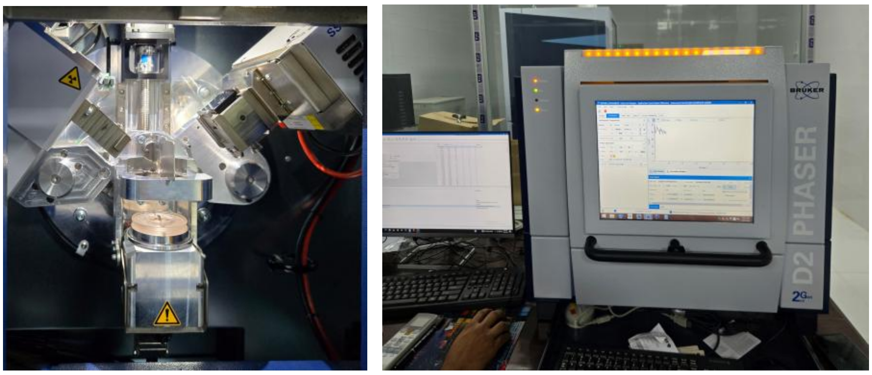

Figure 5: Bruker D2 Phaser diffractometer

Figure 6: Sample holder

In this study, a Bruker D2 Phaser diffractometer with a Cu Kα radiation source ($\lambda = 1.5418$ Å) was used to analyse the mineralogical composition and crystallite size of two indoor dust samples (F02 and F03) (Figure 5). The primary diffraction peaks of silicate, oxide, and other common mineral phases were covered by the scans, which were conducted over a 2θ range of 10° to 80°. In order to reduce preferred orientation effects, powdered dust samples were carefully mounted on a flat glass holder (Figure 6), and data collection was carried out under the standard operating conditions of the instrument.

X'Pert HighScore software (PANalytical, The Netherlands) was used to process and interpret the collected diffractograms. Phase identification was carried out by automated matching with standard reference patterns from the International Centre for Diffraction Data (ICDD) database. Additionally, diffraction angles (2θ values) and full width at half maximum (FWHM) were extracted for major peaks using the software. Average crystallite sizes were estimated by the Scherrer equation (2) using 2θ and FWHM values (Scherrer, 1912).

Scherrer equation for crystallite size (Å):

$$D = \frac{k\lambda}{\beta \cos\theta} \tag{2}$$

Where,

D = the crystallite size (Å)
K = shape factor (~0.9)
λ = Wavelength of the X-ray source (Å)
β = the peak full width at half maximum (radians) after instrumental correction and
θ = Diffraction angle (radians)

3. ILLUSTRATIONS

The results are organized according to the measured deposition rate, the identification of functional groups using ATR-FTIR spectroscopy, and the mineralogical analysis carried out using XRD. Each set of findings is interpreted to emphasize how the indoor environment affects the composition and accumulation of dust. Results are compared with previous campus work, especially Mahmud and Mohiuddin (2024), where applicable.

3.1 Deposition Rate

The gravimetric method was used to measure the indoor particle deposition rate at Lalan Shah Hall. The computed deposition rates (mg/m²/day) for the four floors during the 35-day study period are shown in Table 1.

Table 1: Deposition rate of indoor deposited particles at Lalan Shah Hall

Room No (Floor)	Sample ID	Sample Weight (mg)	Deposition Rate (mg/m²/day)
101 (Ground)	F01	38	5.35
201 (1st)	F02	115	16.15
301 (2nd)	F03	94	13.13
403 (3rd)	F04	46	6.42

The results show that the ground floor had the lowest deposition rate (5.35 mg/m²/day), while the second floor had the highest value (16.15 mg/m²/day). The increased deposition on the second and third floors is probably caused by increased exposure to outdoor particle entry, which is made possible by open windows and air flow, in addition to the effects of adjacent construction projects and car emissions. The lower deposition rates on the first and fourth floors might be the result of less ventilation and less air exchange with the outside world.

The deposition rates found in this study (5.35 mg/m²/day to 16.15 mg/m²/day) are comparable with the study of Mahmud and Mohiuddin (2024), who reported deposition rates of 18.5 mg/m²/day to 39.6 mg/m²/day across academic and residential buildings of KUET. However, they are significantly lower than the maximum reported for the New Academic Building (39.6 mg/m²/day). The residential hall is characterized by more stable conditions with resuspension primarily influenced by occupancy density and limited ventilation, whereas academic facilities experience greater pedestrian activity, outdoor dust intrusion, and air circulation. This difference probably reflects variations in building type and use.

3.2 ATR-FTIR Analysis

The functional groups in the deposited indoor dust samples were characterized using ATR-FTIR spectroscopy. Spectra obtained for the four samples (F01~F04) displayed a broad range of absorption bands (Figure 7~Figure 10) representing both organic and inorganic components (Table 2), confirming the chemically heterogeneous nature of the collected dust. Band assignments were made by comparing the observed spectra with established databases and standard references, including Introduction to Spectroscopy (Pavia et al., 2014), Infrared and Raman Spectra of Inorganic and Coordination Compounds (Nakamoto, 2009), and Infrared Spectroscopy Absorption Table. (Libretexts, 2020).

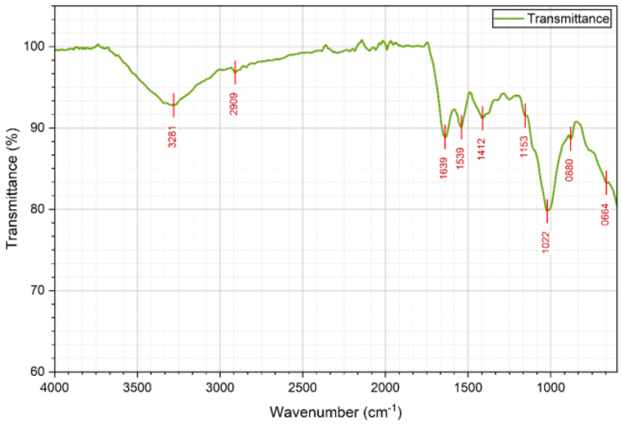

Figure 7: FTIR scan for air particles of sample F01

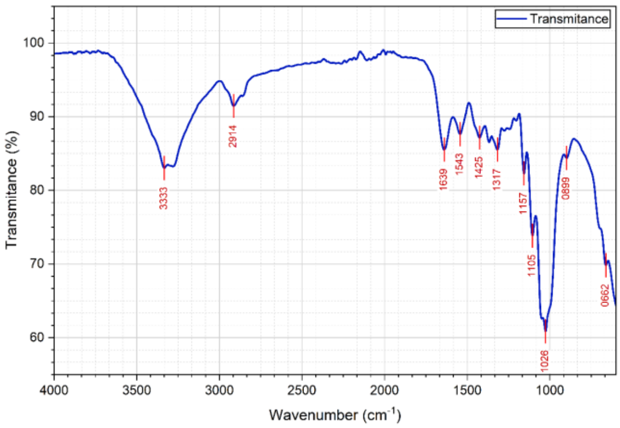

Figure 8: FTIR scan for air particles of sample F02

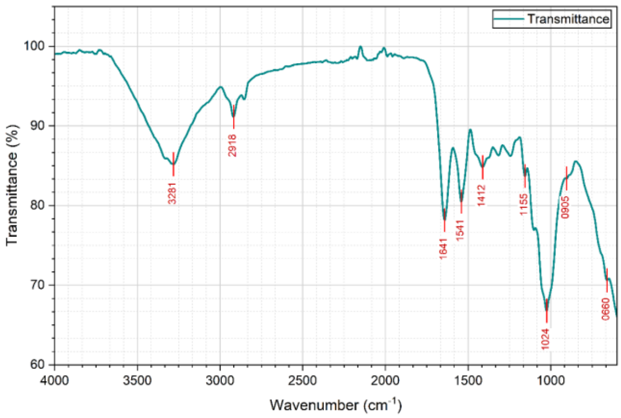

Figure 9: FTIR scan for air particles of sample F03

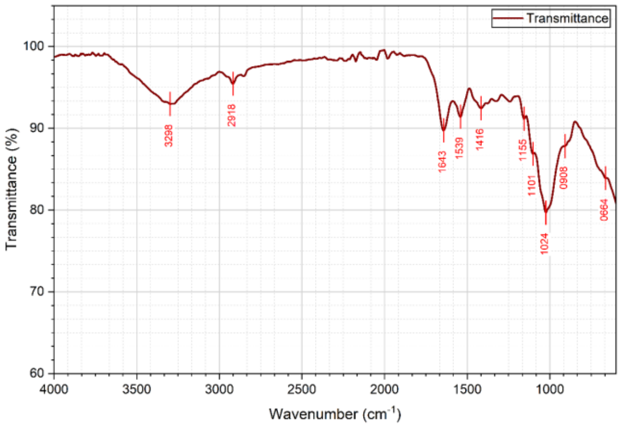

Figure 10: FTIR scan for air particles of sample F04

Table 2: Assigned functional groups for the bands

Sample ID	Wave No (cm-1) at which peak observed	Functional Group	Corresponding Class
Sample F01	3281	O-H (Stretching)	H-bonded
	2909	C-H	Aldehyde
	1639	C=C	Alkene
	1539	C=C	Aromatic
	1412	C-H (Bending)	-CH3
	1153	C-N	Aromatic Amines
	1022	Si-O	Silicate
	880	CO_3^{2-}	Carbonate
	664	C–Cl (Stretching), M–O	Chloride, Metal Oxide (Fe–O, Al–O etc.)

Sample ID	Wave No (cm-1) at which peak observed	Functional Group	Corresponding Class
Sample F02	3333	O-H	H-bonded
	2914	C-H	Aldehyde
	1639	C=C	Alkene
	1543	C=C	Aromatic
	1425	C-H (Bending)	-CH3 (Terminal)
	1317	O-H (Bending)	Phenol
	1157	C-N	Aromatic Amines
	1105	Si-O	Silicate
	1026	Si-O	Silicate
	899	CO_3^{2-}	Carbonate
	0662	C–Cl (Stretching), M–O	Chloride, Metal Oxide (Fe–O, Al–O etc.)
Sample F03	3281	O-H (Stretching)	H-bonded
	2918	C-H	Aldehyde
	1641	C=C	Alkene
	1541	C=C	Aromatic
	1412	C-H (Bending)	-CH3 (Terminal)
	1155	C-N	Aromatic Amines
	1024	C-N	Aromatic Amines
	905	CO_3^{2-}	Carbonate
	660	C–Cl (Stretching), M–O	Chloride, Metal Oxide (Fe–O, Al–O etc.)
Sample F04	3298	O-H (Stretching)	H-bonded
	2918	C-H	Aldehyde
	1643	C=C	Alkene
	1539	C=C	Aromatic
	1416	C-H (Bending)	-CH3 (Terminal)
	1155	C-N	Aromatic Amines
	1101	Si-O	Silicate
	1024	Si-O	Silicate
	908	CO_3^{2-}	Carbonate
	664	C–Cl (Stretching), M–O	Chloride, Metal Oxide (Fe–O, Al–O, etc.)

All four samples exhibited a similar suite of organic and inorganic functional groups, with minor variations in peak intensities between floors. The detection of Silicate (Si–O) bands and carbonate (CO3-) absorptions indicates substantial inputs from construction materials, road dust, and resuspended soil around the building. Aliphatic C–H and aromatic C=C characteristics most likely come from combustion-related sources, such car exhaust and potentially domestic cooking. Aromatic amines (C–N) may be a result of biogenic sources, plastic degradation, or organic contaminants. Iron and aluminum oxides are indicated by metal oxygen (M–O) vibrations, which are consistent with inputs from soil and building dust.

Whenever the quantities of many of these substances increase indoors, they may become dangerous. For example, aromatic compounds (C=C) and aromatic amines (C–N) have been linked to headaches and even liver or kidney damage after extended contact, whilst aldehydes (C–H) are known to irritate the eyes and respiratory system. On the inorganic side, metal oxides (M–O), particularly those containing iron, can cause siderosis in the respiratory system, silicates (Si–O) can cause significant lung disorders, including silicosis and lung cancer, and chlorides (C–Cl) can function as toxic irritants. These findings are in line with those of Mahmud and Mohiuddin (2024), who similarly found that the most prevalent functional groups in indoor dust were hydroxyl, aliphatic carbon, carbonyl, and amino groups.

3.3 XRD Analysis

3.3.1 Mineral Phases Identified

The XRD patterns revealed distinct crystalline phases and provided insight into the mineralogical composition of deposited particulates. XRD patterns along with their diffraction angle, full width at half maximum (FWHM), and mineral contents of two representative samples, F02 and F03, are presented in the following Figure 11~Figure 14.

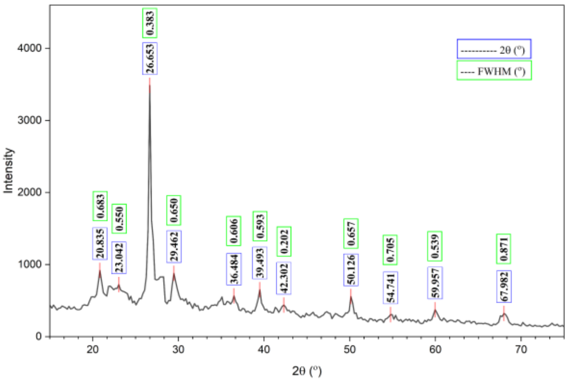

Figure 11: XRD spectra with their diffraction angle (2θ) and FWHM of sample F02

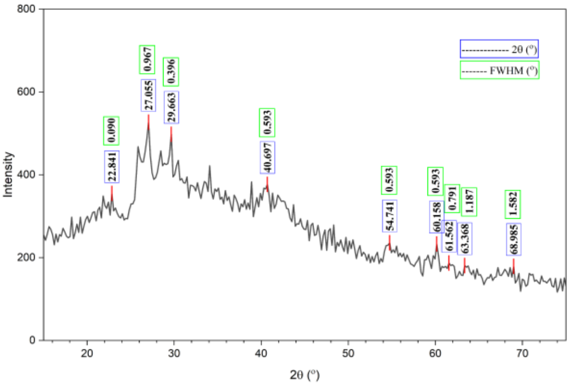

Figure 12: XRD spectra with their diffraction angle (2θ) and FWHM of sampleF03

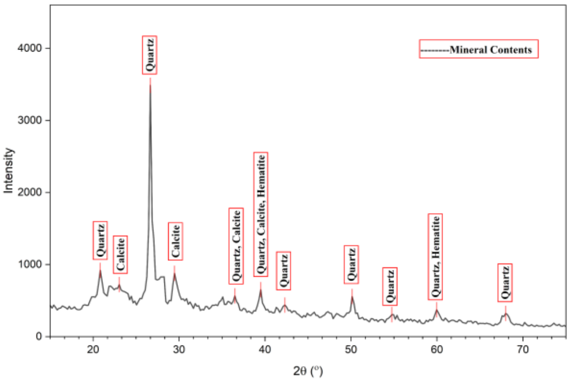

Figure 13: XRD spectra with their mineral contents of sample F02

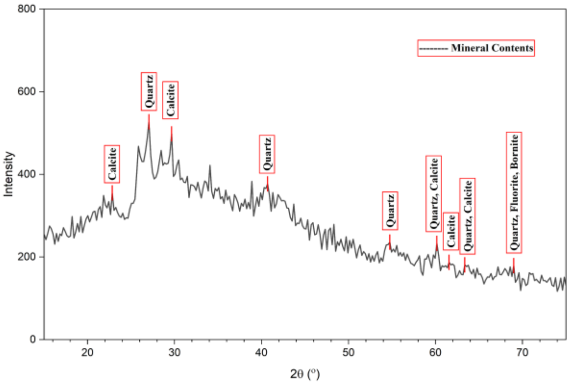

Figure 14: XRD spectra with their mineral contents of sample F03

Both analyzed samples showed similar mineralogical patterns, suggesting a uniform dust composition throughout the research location. The diffraction peaks between 15° and 75° (2θ) were typical of carbonate and crystalline silicate minerals that are frequently seen in dust from the environment. Using the ICDD database and X'Pert HighScore software, phase identification revealed that quartz (SiO_2) was the predominant mineral, followed by calcite ($CaCO_3$), with hematite (Fe_2O_3) and fluorite (CaF_2) making small contributions.

3.3.2 Crystallite Size Estimation

The average crystallite sizes, calculated from the full width at half maximum (FWHM) of the major diffraction peaks using the Scherrer equation (2), are presented in Table 3 and Table 4.

Table 3: Crystalline size of sample F02

Peak Position (°2θ)	FWHM (°2θ)	Crystalline Size (Å)
20.835	0.683	118
23.046	0.406	200
26.690	0.394	207
29.500	0.265	310

Peak Position (°2θ)	FWHM (°2θ)	Crystalline Size (Å)
36.490	0.535	156
39.536	0.593	142
42.355	0.206	414
50.180	0.791	111
54.180	0.652	137
60.022	0.493	186
67.979	0.948	101
Avg. Crystaline size(Å) =		189
Avg. Crystaline size(nm) =		19

Table 4: Crystalline size of sample F03

Peak Position (°2θ)	FWHM (°2θ)	Crystalline Size (Å)
22.841	0.090	84
27.055	0.967	84
29.663	0.396	208
40.697	0.593	143
54.741	0.593	151
60.158	0.593	155
61.562	0.791	117
63.368	1.187	79
68.985	1.582	61
Avg. Crystaline size(Å) =		120
Avg. Crystaline size(nm) =		12

Sample F02 had a mean crystallite size of 19 nm, whereas sample F03 had a somewhat smaller average size of 12 nm. Variations in sources, exposure, and usage circumstances may account for this discrepancy. The results of Mahmud and Mohiuddin (2024), who identified quartz as the predominant mineral phase in KUET indoor dust with crystallite diameters of 11.10~42.92 nm, are consistent with the predominance of quartz and other silicates in the current research.

These minerals are directly linked to road and soil dust resuspension, infiltration from outside sources, and construction activity on and around the KUET campus. The persistence of small crystalline particles indoors, which might endanger the health of student inhabitants, is further suggested by the nanoscale crystallite sizes. These results are consistent with the ATR-FTIR findings, which also identified silicates and carbonates as principal components, highlighting the combined influence of construction, soil resuspension, and combustion-related activities on indoor air quality at the study site.

4. CONCLUSIONS

The primary purpose of this study is to investigate the spectroscopic and mineralogical characteristics of indoor deposited particles at Lalan Shah Hall, KUET, through deposition rate measurements, ATR-FTIR, and XRD. It also includes general insights about the possible sources and associated health relevance for student residents. The main points of the overall findings are as follows:

- The results showed that the deposition rates of indoor dust varied significantly between floors. The first floor had the lowest value (5.35 mg m^{-2} day^{-1}), while the second floor had the highest deposition (16.15 mg m^{-2} day^{-1}).
- The indoor dust samples had both organic and inorganic functional groups. According to ATR-FTIR analysis, hydroxyl, aliphatic, alkenes and aromatic bonds, silicates, carbonates, amines, and chlorides/metal oxides were identified as the main absorbers.

- The XRD analysis showed that the predominant crystalline phase was quartz (SiO_2), with traces of hematite (Fe_2O_3), fluorite (CaF_2), and bornite (Cu_5FeS_4) as well as calcite ($CaCO_3$). Average values of roughly 19 nm and 12 nm were obtained from crystallite size estimation.

Overall, the ATR-FTIR and XRD findings show that indoor dust has a chemically varied composition that is influenced by both indoor human activity and outdoor infiltration. The identification of nanoscale crystalline particles and potentially hazardous substances like silica, aromatic hydrocarbons, and amines suggests potential health consequences for locals, particularly with prolonged exposure in a densely populated area.

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DECLARATION OF USE OF AI

The author declares that some of part of this part was written with the help of artificial intelligence. AI has been used only to make it grammatically correct and enhance the clarity, fluency of the manuscripts. No part of the information has been generated or manipulated using AI, which includes data collection, interpretation, and the results. All scientific information, findings, and conclusions presented in this work are entirely based on the author's original research and are accurate to the best of their knowledge.

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