Micro-Characterization of Indoor Deposited Particles Using FTIR, SEM-EDS, and XRD Techniques: A Case Study of a University Campus, Bangladesh

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ABSTRACT

Micro-characterization of indoor atmospheric particles is essential for understanding atmospheric particle consequences on human health. In this study, the atmospheric particles were collected from inside the different buildings of KUET campus. The samples underwent characterization through FTIR, SEM -EDS, and XRD techniques. Among the four sampled locations, the New Academic Building (NAB) had the highest rate of atmospheric particle deposition at 3.96 \( \mu \text{g cm}^{-2} \text{ day}^{-1} \). The FTIR analysis indicated that the primary functional groups present across all samples were organic, specifically hydroxyl (\(-\text{OH}\)), aliphatic carbon (\(-\text{CH}_2\)), carbonyl (\(-\text{CO}\)), and amino (\(-\text{NH}_2\)) groups. The morphological analysis by SEM depicted the shape of indoor particles as angular, micro-flake, cubic, and irregular with the major chemical compositions of C, O, Al, Si, Ca, Na, Fe, and Mg of which Si and Fe were dominant in CEC and CEL sites which most likely originated from construction activities and dust from paved and unpaved roads. The average crystallinity of studied atmospheric particles was found to be a minimum of 27.3% at RH and a maximum of 64.5% at NAB sites and the corresponding crystalline size was 11.10 nm and 42.92 nm respectively. Quartz mineral in the inorganic fraction of atmospheric particles was found predominantly in every sample which most likely originates from soil erosion, construction activities and vehicular emissions. The outcome of this study will enhance our understanding of organic and inorganic compounds in atmospheric particles and their significance regarding radiative forcing, health impacts, and policy considerations for atmospheric particle sources.

Keywords: Indoor air pollution, Crystalline silica, Microplastics, FTIR, SEM-EDS, XRD

1 INTRODUCTION

Air pollution stands out as a pressing global concern in the present world, notably owing to the increasing particulate matter (PM) pollution within urban centers, with a pronounced impact on developing nations where human exposure to PM has increased significantly (Tao et al., 2013; Huang et al., 2014). Especially, indoor air quality is a big environmental concern because it can seriously harm our health (Verriele et al., 2016). Indoor air quality is important for two main reasons. First, people spend most of their time indoors, about 90%. Second, indoor air pollution can build up quickly because there are many things that can cause pollution inside, and the air doesn’t move as much as it does outside (Gong et al., 2017; Pei et al., 2013). Inhaling indoor air particles has been tied to a variety of health difficulties, including chronic bronchitis, asthma, diabetes, strokes, cancer, and, ultimately, the loss of life (Kim et al., 2015; Brook et al., 2004). The impact of particulate matter on health is influenced by a complex interplay of factors, including the amount of exposure, how quickly particles settle, their size, their composition, their shape, how they interact with surfaces, whether they repel or attract water, and how they dissolve in the places they end up (Fubini and Otero Areán, 1999; Merget et al., 2002; Pöschl, 2005).

People encounter dust in three main ways: ingesting it, breathing it in and getting absorbed...
through their skin, and it depends on the deposition rate. The smaller the dust size the larger will be the deposition rate. The easiest way to measure how much dust particles deposit on a surface is to weigh that surface before and after the particles fall on it. This method helps to know how much dust has collected on the surface (Lai et al., 2017; Licina and Nazaroff, 2018). However, it’s not great for measuring really small amounts of particles, and there are guidelines in the ISO 15767:2009 standard to make sure to get accurate measurements, especially in workplaces with different air conditions. In places with a lot of dust, it’s been estimated that adults might ingest up to 100 milligrams of dust each day. Children typically have more contact with dust than adults because they play more in exposed environments (Ren et al., 2006; Leung et al., 2008).

Organic compounds found in atmospheric particles, which can come from natural and human-made sources, can harm human health, the environment, and the Earth’s radiation balance (Čupr et al., 2013; Hallquist et al., 2009; Ehn et al., 2014). Researchers use techniques like elemental analysis and gas chromatography-mass spectrometry (GC-MS) to study these compounds. These compounds behave differently depending on their bonding structure (Roos, 1997; Ghauch et al., 2006; Allen et al., 1994; Maria et al., 2002). The Fourier transform infrared (FTIR) technique can help identify and partially quantify the structural properties of both organic and inorganic compounds in these particles. This study is the first to utilize the FTIR technique for analyzing the bonding structure of particles collected from the indoor environment of a university campus in Bangladesh. The atmospheric particle’s shape, size, texture and elemental composition play an important role in the deposition rate of atmospheric particles. The Scanning Electron Microscope is a versatile tool that plays a crucial role in scientific research and industry by enabling the visualization and analysis of materials at the nanoscale, providing valuable insights into their structure and composition. Hence it is essential to visualize atmospheric particles’ shape, size, and texture by SEM and elemental composition by using energy-dispersive X-ray spectroscopy (EDS). In atmospheric particles, inorganic compounds can consist of both amorphous and crystalline materials. Analyzing the elemental composition of inorganic compounds within atmospheric particles solely yields the overall elemental composition, a combination that might arise from either amorphous or crystalline sources. For example, the silica content in atmospheric particles can result from both amorphous and crystalline silicate minerals like quartz and crystalline quartz. However, the behavior of these inorganic compounds depends significantly on the specific mineral phases present (Calvo et al., 2013). By studying the unique characteristics, such as how X-rays interact with crystalline atoms, the quantities of various minerals in atmospheric particles can easily be identified, whether they originate naturally or from human activities. Therefore, it is crucial to assess the mineral content of indoor atmospheric particles using the X-ray diffraction (XRD) technique.

This study collected the atmospheric particles from KUET to understand the nature of atmospheric particles in the indoor environment. The collection and analysis of studied samples were conducted with the focus on:

i. Estimation of the deposition rate of atmospheric particles in the indoor environment at KUET campus.

ii. Identification of the bonding structure of atmospheric particles using FTIR technique.

iii. Evaluation of particle morphology (size, shape, texture) and elemental composition by using SEM-EDS technique.

iv. Analyzing the mineral content of indoor atmospheric particles using XRD technique.

This study aimed to identify potentially harmful metallic elements, minerals, organic, and inorganic compounds in indoor atmospheric particles in Bangladesh. These substances could pose occupational health hazards if safety measures are not implemented. The result of this study will enhance our comprehension of organic and inorganic compounds found in atmospheric particles.

2 RESEARCH METHODS

2.1 Study Area

This study was carried out at the KUET campus, a renowned public university in Bangladesh, and the sample collected areas are visualized in Fig. 1 and are listed with their latitude and
Fig. 1. Sample collection areas in various locations of KUET campus.

<table>
<thead>
<tr>
<th>Sample Collection Location</th>
<th>Sample ID</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Area Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil Engineering Classroom</td>
<td>CEC</td>
<td>22°54'0.8&quot;N</td>
<td>89°30'9.9&quot;E</td>
<td>Academic</td>
</tr>
<tr>
<td>Civil Engineering Laboratory</td>
<td>CEL</td>
<td>22°54'1.2&quot;N</td>
<td>89°30'10.4&quot;E</td>
<td>Academic</td>
</tr>
<tr>
<td>Residential Hall</td>
<td>RH</td>
<td>22°53'53.7&quot;N</td>
<td>89°30'6.3&quot;E</td>
<td>Residential</td>
</tr>
<tr>
<td>New Academic Building</td>
<td>NAB</td>
<td>22°53'56.6&quot;N</td>
<td>89°30'7.7&quot;E</td>
<td>Academic</td>
</tr>
</tbody>
</table>

longitude in Table 1. KUET is located in Fulbarigate, a north-west section of Khulna metropolis, Bangladesh’s third largest south-western divisional city. The campus is approximately 15 kilometers from Khulna metropolis, which is well connected to major city centers via open and wide roads. The campus is broadly divided into two zones: academic zones and residential zones.

2.2 Collection of Atmospheric Particles and Deposition Rate

In the literature (Adams and Ford, 2001; Beaman and Kingsbury, 1984) a wide range of field methods for the collection of deposited atmospheric particles have been discussed. In this investigation, the passive sampling approach was used. The particles descended freely and settled upon a solid platform made of steel above which a wooden board having dimensions 20" × 31.5" was placed for some periods. The wooden board was selected as it did not absorb any atmospheric particles. This platform, positioned at a certain height above the existing ground...
Table 2. Details of indoor atmospheric sample collection in KUET campus

<table>
<thead>
<tr>
<th>Sampling location</th>
<th>Sample collection period</th>
<th>Sample collection duration (days)</th>
<th>Sampling height from EGL (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>16 June 2022–12 July 2022</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>CEL</td>
<td>06 July–03 August 2022</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>RH</td>
<td>14 April 2022–07 May 2022</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>NAB</td>
<td>01 October–27 October</td>
<td>26</td>
<td>25</td>
</tr>
</tbody>
</table>

level, served as the landing site for atmospheric particles that were eventually gathered on a dry and sun-drenched day, subject to any unforeseen disruptions, and details of sample collection are shown in Table 2. The deposited atmospheric particles were then collected in polyethylene bags so that the atmospheric particles did not absorb any moisture from the environment. The deposition rate of atmospheric particles at the four sampling locations was calculated by using Eq. (1).

\[
\text{Deposition Rate} = \frac{(\text{Final Weight} - \text{Initial Weight})}{\text{Surface Area} \times \text{Duration}}
\]  

2.3 FTIR Analysis

The Fourier transform infrared ray spectroscopy was employed as a method to identify and analyze the presence of functional groups within atmospheric particles (Coates, 2000; Mohiuddin et al., 2016). The FTIR spectroscopy was performed in the Chemistry Department by Shimadzu (IRTracer-100) in KBr mode. The samples were mixed with Potassium Bromide (KBr) at a ratio of 1:30. Pellets were then prepared, and the spectra were captured in the frequency range of 4000 cm\(^{-1}\) to 400 cm\(^{-1}\). The instrument scans these spectra 32 times per minute, with a resolution of ± 2 cm\(^{-1}\) and an accuracy of ± 1 cm\(^{-1}\). Origin Pro Software (Version 2018) was used to analyze the spectrum data, which included baseline adjustments, spectral normalization, and peak integration.

2.4 SEM-EDS Analysis

The utilization of the SEM-EDS technique is used for a comprehensive evaluation of the shape, size, and chemical composition of the atmospheric particles. By employing SEM, a profound understanding of the modifications in both the morphology and elemental configuration of the airborne samples was achieved. This knowledge contributes to a more nuanced comprehension of the origin of particles emitted through natural or human-induced processes (Bernabé et al., 2005; Petrovic et al., 2000). The scanning electron microscope (SEM) model JEOL JCM-7000 BENCTOP SEM, equipped with energy-dispersive X-ray spectroscopy (EDS), was employed to conduct the sample analysis. The SEM micrographs came to life as the samples were securely affixed onto aluminum stubs using double-sided sticky carbon tape. To optimize conductivity, a thin layer of gold was skillfully applied to the sample surface utilizing the DII-29030SCTR Smart Coater. Following the application of the gold coat, the sample stub was sequentially placed in a vacuum chamber to capture the digital image. The elemental composition of the samples was determined by detecting the X-rays emitted from the sample bulk. The scanning electron microscope (SEM) utilized a dry silicon drift detector with a 2504 cps acquisition rate and a 20 keV resolution. The detection limit of the detector was approximately 0.1% by weight.

2.5 XRD Analysis

The qualitative mineralogy of selected air dust samples was recorded to gather information about the mineralogical composition and analyze the crystalline nature of the minerals present in the atmospheric particles. For XRD analysis, the samples were carefully positioned within a ground glass depression housed within a sample holder. Subsequently, this ensemble was placed onto the D2 PHASER Benchtop X-ray Powder Diffraction instrument, enabling the commencement of the analysis process. The scan was conducted using a copper anode X-ray source with a wavelength of 1.54184 Å and fixed optics, including a graphite monochromator operating at 30 kV power and the data were collected within a Bragg angle 2θ range of 10\(^{\circ}\)–80\(^{\circ}\). The minerals present
in the samples were identified by comparing the peak positions at 2theta with appropriate d spacing using the International Center for Diffraction Data (ICDD) database as a reference. Additionally, some minerals were confirmed through literature reviews conducted by Alam and Mohiuddin (2023).

3 RESULTS AND DISCUSSION

3.1 Deposition Rate

The deposition is a characteristic of airborne particles that can settle on both indoor surfaces and human body surfaces, and the finer the particles greater will be the probability of deposition of airborne particles (Braakhuis et al., 2014). Higher deposition rate of atmospheric particles is more likely to cause different health issues ranging from irritation of eyes to death. The maximum deposition rate for this study was found as 3.96 $\mu$g cm$^{-2}$ day$^{-1}$ and the minimum deposition rate 1.85 $\mu$g cm$^{-2}$ day$^{-1}$ was shown in Table 3. The NAB site has the highest deposition rate of atmospheric particles among the selected sites due to its location near the KUET main road and the RH site has the lowest deposition rate as the site was managed by organized persons in regular interval.

3.2 FTIR Analysis

FTIR analysis, a powerful technique, unveils the chemical composition of atmospheric particles by gauging their unique ability to absorb infrared light across different wavelengths. The absorption frequencies of functional groups nestled within these particles serve as indicators of the validity of their chemical bonds. Vibrant bonds eagerly absorb higher frequency light, while weak bonds prefer to absorb on lower frequency light. In this investigation, a series of functional groups, namely hydroxyl (-OH), aliphatic carbon (-CH$_2$), carbonyl (-CO), and amino (-NH$_2$) groups found within atmospheric particles. These groups predominantly found through the advent of long-distance transported particles, sea spray, and combustion processes. The presence of organic chemicals, surrounded by carbonaceous and nitrogenous molecules, within atmospheric particles can cause detrimental effects on the balance of radiation, the environment, and human well-being (Dockery et al., 1993; WHO, 2003; Shah and Balkhair, 2011). Such substances arise from both human activities, such as industrial processes, car exhaust, and wood heaters, as well as natural occurrences like the formation of secondary organic particles from biogenic sources. Additionally, Fig. 2 showcases the spectrum of atmospheric particles collected from various locations on the KUET campus, consisting of the new academic building (NAB), residential hall (RH), civil engineering classroom (CEC), and civil engineering laboratory (CEL). The interpretation of these spectra particularly focused on discerning specific organic absorbance groups, as described below.

3.2.1 Aliphatic carbon (-CH$_2$) group

The vast amount of aliphatic carbon molecules encompasses a wide range of compounds, including n-alkanes, branching alkanes, carbonyl-containing molecules, alkanes, and aromatic aliphatic substituents. These compounds are composed of the foundational building blocks of -CH$_3$, -CH$_2$, and -CH carbon bonds, as illustrated by Roos (1997). In the group of saturated aliphatic species, the simple C-H stretching vibrations resonates within the frequency range of 2800–3000 cm$^{-1}$, while their corresponding bending vibrations gracefully vibrate between 1300 and 1500 cm$^{-1}$ (Pavia et al., 2014). It is the dominant -CH$_2$ asymmetric vibration that claims responsibility for the fascinating absorption peaks observed at 2862.36 and 2940 cm$^{-1}$ (Civil Engineering Classroom),

<table>
<thead>
<tr>
<th>Sampling location</th>
<th>Deposition rate ($\mu$g cm$^{-2}$ day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>3.10</td>
</tr>
<tr>
<td>CEL</td>
<td>3.60</td>
</tr>
<tr>
<td>RH</td>
<td>1.85</td>
</tr>
<tr>
<td>NAB</td>
<td>3.96</td>
</tr>
</tbody>
</table>
Fig. 2. FTIR spectrum of atmospheric particles at sample CEC, NAB, RH, CEL.

3.2.2 Carbonyl (-CO) group

Aldehyde (R-COH), ketone (R-CO-R), and carboxylic acid belong to the esteemed group of organic compounds that exhibit a similar planar geometry and associated with sp² hybridized carbon and oxygen atoms. These compounds bear the features of carbonyl group (R-COOH). This large group easily works with other groups, creating new groups with different features and behaviors. Depending on the specific functional group, such as amide or open-chain acid anhydride, the carbonyl group showcases its presence across a wide range of spectra, ranging from 1640 to 1850 cm⁻¹ at (Civil Engineering classroom, New Academic Building, and Residential Hall), adorned with distinctive peaks that found from lower to higher frequencies. In the sample IDs assigned to the residential...
hall and new academic building, the absorption bands observed at 1656.85 cm\(^{-1}\) and 1807.30 cm\(^{-1}\) aligned with reactive carbonyl compounds (acid halide and aryl carbonate), simple carbonyl compounds (ketone), and conjugated carbonyl compounds (conjugated ketone), respectively (Pavia et al., 2014).

### 3.2.3 Hydroxyl (-OH) group

Within the absorbance realm spanning 3250–3650 cm\(^{-1}\), the hydroxyl group reigns supreme, asserting its dominance. Noteworthy discoveries emerge as this study unravels the intriguing world of vibrations. Moderate to strong and delightfully broad stretching vibrations dance their way into the spotlight, captivating attention at frequencies of 3439.08, 3421.72, and 3419.79 cm\(^{-1}\) across sampling IDs CEC, NAB, RH, and CEL. These alluring vibrations gracefully embody the essence of both free OH entities and the captivating dance of hydrogen bonding within an alcohol functional group (Pavia et al., 2014). Furthermore, the surfaces of crystals boast the presence of hydroxyl groups, revealing their captivating vibrations that elegantly span between 3250 and 3650 cm\(^{-1}\). Notably, the hydroxyl group also makes its presence known at frequencies of 1600–1700 cm\(^{-1}\) and 3100–3600 cm\(^{-1}\), fueled by the remarkable capacity of aerosol salts to absorb copious amounts of water (Allen et al., 1994).

### 3.2.4 Amino (NH\(_2\)) group

Amino (-NH\(_2\)) groups which are derived from the ammonia (NH\(_3\)) have sp\(^3\) structural characteristics. Vibrations within the spectral ranges of 3300–3500, 1550–1650, and 660–900 cm\(^{-1}\) bear witness to the presence of the amino (-NH\(_2\)) group. An observation appeared as the robust O-H bond takes center stage at 3300–3500 cm\(^{-1}\), and seemingly disappeared the weak N-H bond which causing it to fade into the background. In addition to the distinctive IR bands exhibited by organonitrates, such as RONO\(_2\), which often absorb around 1631 cm\(^{-1}\), these organic compounds find their origins in primary amino compounds. This is evident through medium to strong bending vibrations at 1627.92, 1625.99 cm\(^{-1}\) accompanied by vibrations at 677.01, 682.80, 771.53, and 773.46 cm\(^{-1}\) (Pavia et al., 2014). The role of organonitrates in the formation of secondary organic aerosols has great contribution. Notably, this distinctive group primarily manifests itself in the particle samples collected across all four sampling locations CEC, NAB, RH, CEL shown in Fig. 2.

### 3.2.5 Functional group distribution

The understanding of the behavior of organic compounds in atmospheric particles relies on recognizing the strength, occurrence, and types of functional groups. The observed hydroxyl (-OH) group (in alcohol compounds, surface OH on crystals, salt hydrate), aliphatic carbon (-CH\(_2\)) group (in methylene compounds, n-alkane), carbonyl (-CO) group (in acid halide, aryl carbonate, ketone, conjugated ketone), and amino (-NH\(_2\)) group (in primary amino compounds such as n-butylamine) in atmospheric particles at CEC, CEL, RH, and NAB sites are predominantly from anthropogenic sources. These sources encompass diverse industrial activities, construction activities, motor vehicle exhaust, long-range transport particles, and microbiological processes from biogenic sources. Some inorganic functional group silicate ion Si-O symmetric stretching and Si-O symmetric bending, Fe-O stretching and carbonate ion CO\(_3\) stretching was also observed in atmospheric particles. These functional groups may attribute to atmosphere from the construction and demolition activities that were carried in KUET campus in the period of the study. A recent study carried by Patwary (2019) at the indoor environment of Jashore University of Science & Technology found the similar types of functional groups in atmospheric particles. The presence of Si-O, -CH\(_2\), Fe-O is a matter of concern for students health as long term exposure can cause silicosis, lung cancer, pulmonary tuberculosis etc. It is challenging to entirely avoid the presence of all functional groups, as they can arise from various natural and anthropogenic sources. However, efforts can be made to reduce their concentrations and associated environmental impacts. Implementing technologies and practices to control emissions from industrial processes can minimize the release of pollutants. Enforcing stricter emission standards for vehicles can reduce the release of pollutants from motor vehicle exhaust, which often contributes to atmospheric particles. Proper waste disposal and recycling practices should be ensured to reduce the breakdown of plastic
materials. The use of water sprays and wet methods can reduce dust during operations like cutting, grinding, or drilling into materials containing silica.

### 3.3 SEM-EDS Analysis

The SEM micrographs of the studied samples revealed particles with different shapes and sizes ranging from 0.1 to 75 µm as shown in Fig. 3. The EDS analysis detected various inorganic compounds such as Al, Cl, Si, Ca, Fe, Mg, S, K, and Na as well as organic compounds such as O and C, which is shown in Fig. 5. The sources of these elements could be from vehicular emissions, construction and demolition activities, and emissions from residential areas. The description of SEM micrographs was presented in Table 4. The SEM images revealed that most of the atmospheric particles were symmetrical with a lower aspect (width/height) ratio between 1 to 2.5. However, there were some particles with diverse morphology and a higher aspect ratio (width/height) greater than 2.5, including sheet-like particles with multiple microfibers with aspect ratios as high as 30. These types of particles can be classified as microplastics like polypropylene (PP) and polystyrene (PS) which was found in residential hall (RH) samples SEM micrographs Fig. 4(c). This observation is

![Fig. 3. (a–d) Morphology analysis of sample CEL.](image)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Description of SEM Micrographs</th>
</tr>
</thead>
</table>
| CEC       | • The observation of large-sized particles, irregular fracturing of particles, and the deposition of small-sized particles indicates the possibility of multiple pollution sources. These sources may include emissions from construction activities, vehicular traffic, and the presence of unpaved roads.  
• Additionally, irregular, non-crystalline particles also found |
| NAB       | • Presence of small-sized particles in a crystalline material indicates that fuel emissions from vehicle.  
• Presence of small and irregular deposition is indicative of soil erosion and the accumulation of ash from paved roads. |
| RH        | • Deposition of large, small-sized, and thick particles implies that aerosols are being emitted from paved roads, as well as from various student activities.  
• Deposition of microplastic in atmospheric particles may come from personal care products used by the student as tiny plastic beads found in cosmetics and personal care products, use of polyethylene bags that degrades and come in atmosphere. |
| CEL       | • Large particulates with irregular, angular, rounded shape have been coated with very fine aerosols due to the emissions from different machineries in the lab.  
• Small and irregular deposition illustrates that there may be soil erosion and ash coming from side roads and from different soil samples in the geotechnical engineering laboratory. |
consistent with a recent study on dust samples from Kathmandu Valley, which also found particles with diverse morphology and high aspect ratios and presence of microplastics (Rauniyar et al., 2018). The SEM morphology analysis of several samples, including RH and NAB, showed the presence of soot, carbonaceous particles, and aluminosilicates. The samples exhibited the presence of large crystal forms of particles, which is believed to be caused by the transportation of construction materials and the dispersion of very fine particles through vehicular movement. Additionally, small and irregular particle accumulations were observed as a result of soil erosion and the deposition of ash from cooking activities in the residential area. In samples CEC and CEL, there was a significant deposition of extremely fine particles due to the presence of silicon originating from paved roads. Through an EDS study, it was determined that the particles containing predominantly silica, such as quartz, were sourced from various locations including soil, old and new buildings, and crust formations (Pachauri et al., 2013; Ram et al., 2012). The presence of silica is ensured by the brighter zones in the SEM micrographs. The sample ID: CEC and CEL have been mapped in SEM to identify the elements present in it and shown in Table 5. The analysis of the sample shows that the most abundant inorganic element present in the atmospheric particles is silicon, followed by the presence of iron shown in Figs. 5(a–d). These two elements, i.e., silicon and iron are of particular concern to humans as excessive inhalation of these elements can lead to several health issues such as respiratory problems, skin irritation, eye irritation, and cardiovascular problems. Silicon, an element found abundantly in nature within rocks, soil, and sand, can be released into the air through natural erosion processes. However, human activities, such as construction and industrial processes (Dey et al., 2020; Zong et al., 2019; Kicińska and Bożęcki, 2018), can also contribute to its presence in the atmosphere. Inhalation of elevated levels of silicon particles over an extended period can lead to a severe respiratory condition known as silicosis, characterized by breathing difficulties and potential fatality. Similarly, iron, another naturally occurring element, can enter the atmosphere through diverse sources like soil dust, industrial activities, and vehicular emissions. Exposure to high concentrations of iron particles in the air can result in respiratory

![Fig. 4. (a–d) SEM micrographs of sample CEC, NAB, RH, CEL.](image)

**Table 5.** Semi-quantitative elemental analysis of samples by SEM-EDS technique.

<table>
<thead>
<tr>
<th>Name of sample ID</th>
<th>C</th>
<th>O</th>
<th>Al</th>
<th>Cl</th>
<th>Si</th>
<th>Ca</th>
<th>Fe</th>
<th>Mg</th>
<th>S</th>
<th>K</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>11.39</td>
<td>59.57</td>
<td>8.73</td>
<td>nd</td>
<td>nd</td>
<td>11.34</td>
<td>6.42</td>
<td>2.55</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>NAB</td>
<td>54.90</td>
<td>3535</td>
<td>0.69</td>
<td>0.42</td>
<td>3.97</td>
<td>1.78</td>
<td>0.34</td>
<td>nd</td>
<td>nd</td>
<td>1.07</td>
<td>1.49</td>
</tr>
<tr>
<td>CEL</td>
<td>24.55</td>
<td>50.85</td>
<td>1.1</td>
<td>nd</td>
<td>21</td>
<td>1.1</td>
<td>0.56</td>
<td>0.24</td>
<td>nd</td>
<td>0.21</td>
<td>0.3</td>
</tr>
<tr>
<td>RH</td>
<td>51.23</td>
<td>39.28</td>
<td>0.67</td>
<td>0.41</td>
<td>5.19</td>
<td>1.55</td>
<td>0.42</td>
<td>0.46</td>
<td>nd</td>
<td>0.24</td>
<td>0.55</td>
</tr>
</tbody>
</table>

nd: not detected.
issues, including bronchitis and asthma. Furthermore, prolonged contact with iron can cause skin and eye irritation. Remarkably, the analysis of sample ID CEL illustrates a prevailing presence of silicon and iron particles in the air, posing a significant risk to human health.

### 3.4 XRD Analysis

XRD analysis is a common method for determining the mineral composition of materials. Table 6 lists the minerals found in the studied atmospheric particle samples along with their corresponding diffraction angle, full width at half maximum (FWHM), interplanar spacings, and the average crystalline size. Moreover, Fig. 6 represents the XRD pattern of the gathered samples, highlighting their distinctive characteristics. FWHM is crucial for assessing the crystalline perfection of a material as it provides insights into the broadening of diffraction peaks, aiding in the characterization of crystal size and defects in the material under analysis. Including FWHM data in XRD analysis enhances the understanding of the structural properties and overall quality of the crystalline phases present. The average FWHM at CEC, NAB, CEL, and RH sampling site was found as 0.2232, 0.2586, 0.3722, and 0.667 respectively which indicated that the RH had the broader peak and small crystalline size (11.10 nm) than the other sampling locations as FWHM is inversely related to crystal size. The crystallinity of the studied samples was found in the range of 27.3% to 64.5% and the average crystalline size was 11.10 nm to 42.92 nm. Silicate minerals emerge as a subject of particular interest owing to their remarkable prevalence and substantial relevance in the context of our study. The presence of quartz, alpha quartz, kaolinite, and mullite sillimanite minerals were identified as silicate minerals. The most common form of crystalline silica, quartz was detected in samples of CEC, CEL, and NAB. The alpha or crystalline silica is carcinogens whereas the amorphous silica is not harmful for human health. This crystalline silica can cause silicosis which is a type of lung disease with shortness in breathing, lung cancer, asthma and chronic obstructive pulmonary diseases (COPD) etc. This crystalline silica can come to the atmospheric particles from the new and old construction works. The probable reasons for the presence of quartz can be due to the main road construction activities besides the new academic building (NAB), different
Table 6. Mineralogical analysis by XRD techniques.

<table>
<thead>
<tr>
<th>Assigned Minerals</th>
<th>Sample ID</th>
<th>Diffraction Angle, 2θ (°)</th>
<th>FWHM</th>
<th>Interplanar spacing, ( d_{hkl} ) (Å)</th>
<th>Average Crystalline Size, (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>CEC, CEL, NAB</td>
<td>21, 20.8, 20.5</td>
<td>0.16934</td>
<td>4.16, 3.26, 4.45, 4.27, 3.41</td>
<td>38.5</td>
</tr>
<tr>
<td>Orthoclase Feldspar</td>
<td>CEC, CEL, NAB, RH</td>
<td>26, 28, 26.70, 26.5,</td>
<td>0.37767</td>
<td>3.34, 3.14, 3.25, 3.44, 3.29, 3.45</td>
<td>24.6</td>
</tr>
<tr>
<td>Microcline Feldspar</td>
<td>CEC, CEL, NAB</td>
<td>36.50, 36.60</td>
<td>0.19022</td>
<td>2.4, 2.46</td>
<td>40.4</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>CEC, CEL, RH, NAB</td>
<td>50.20, 50.1, 50</td>
<td>0.24367</td>
<td>1.77, 1.82, 1.833, 1.78, 1.81</td>
<td>29.5</td>
</tr>
<tr>
<td>Hematite</td>
<td>CEL, RH, NAB</td>
<td>39.40</td>
<td>0.21867</td>
<td>2.22, 2.45, 2.32, 2.48, 2.29</td>
<td>42.0</td>
</tr>
<tr>
<td>Magnetite</td>
<td>NAB</td>
<td>42.66</td>
<td>0.24074</td>
<td>2.17</td>
<td>43.7</td>
</tr>
<tr>
<td>Mullite-Sillimanite</td>
<td>CEC, RH, NAB</td>
<td>60, 68.2, 68, 68.3</td>
<td>0.60879</td>
<td>1.58, 1.54, 1.53, 1.56, 1.58</td>
<td>38.9</td>
</tr>
</tbody>
</table>

Fig. 6. Typical XRD diffraction pattern of sample CEC, NAB, RH, CEL.

...laboratory activities related to soil and sand in the geotechnical engineering lab (CEL), and the main source of dust in civil engineering classroom (CEC) site is the transport of dust from the side road which contains silica. According to Meldrum and Howden (2002), the cytotoxicity associated with cristobalite and quartz surpasses that of other polymorphic forms of crystalline silica. In the XRD...
diffractogram of atmospheric samples, Lafuente et al. (2015) and Tazaki et al. (1989) discovered an abundance of mullite-sillimanite minerals with similar d-spacings but distinct compositions. Although the respiratory hazard of mullite or sillimanite remains uncertain, occupational exposure has been linked to chronic bronchitis, silico-tuberculosis, and pneumoconiosis, as reported by Alemán-Vázquez et al. (2005). Brown et al. (2011) also propose mullite as a potential respiratory hazard.

4 CONCLUSIONS

This study used various advanced techniques to accurately characterize the indoor particles collected by the deposition mechanism from various locations of KUET Campus. The results are summarized in the sentences below:

- The maximum indoor particles deposition rate was found as 3.96 µg cm⁻² day⁻¹.
- Indoor particles exhibited an array of organic groups, each with its distinct chemical identity. The aliphatic carbon (-CH₂) group which shows strong stretching vibration at 2919 cm⁻¹ was attributed to the C-H stretching and bending at 1419 cm⁻¹ was assigned to -CH₂ bending, indicating that these organic compounds may originate from microplastic like polypropylene (PP), polystyrene (PS) which is a matter of concern for human being. Besides the organic group some inorganic bonding, Si-O, C=O, and CO³ were the prominent linkages detected in the indoor particles, each contributing to the intricate composition of this captivating ensemble.
- The indoor particles size was less than 75 µm with very rough surface texture and the morphology of sample depicts mostly micro-flake, angular, spherical and irregular rod-shape with agglomeration.
- The elemental composition of indoor particles was found as C, O, Fe, Al, Na, Ca, Si from SEM-EDS, and Si was found as the dominant element from element mapping.
- The average crystallinity of studied atmospheric particles was found to be 27.3% to 64.5% and the crystalline size was in the range of 11.10 nm to 42.92 nm.
- The XRD analysis showed the presence of quartz, alpha-Quartz, Halite, Feldspar, Hematite, Magnetite, Bilinite etc. in which crystalline silica was carcinogen and able to cause serious health issues like Silicosis, lung cancer, asthma and chronic obstructive pulmonary disease (COPD) etc.
- Among the four location the air quality in CEC site is better than CEL, RH and NAB site as the classroom is cleaned everyday by the office staff on the other hand there was lack of cleaning activities on the other sites. The deposition rate in this site is moderate and the presence of suspicious microplastic can be waived by avoiding the use of skin care products and plastic bags.
- The indoor air quality of KUET campus can be improved by taking some steps like implementing green spaces which creates green areas to act as natural filters, reducing vehicle emissions and encouraging walking, installing efficient HVAC systems, minimizing the use of harmful chemicals in lab, and promoting awareness about air quality and personal contributions to pollution reduction.

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DISCLAIMER

The authors emphatically affirm that they harbor no discernible conflicts of financial interest or personal connections that might have given the appearance of exerting an influence on the findings presented in this manuscript.
REFERENCES


