METHODOLOGY Chapter 3

3.1 Study Area

The present study is conducted in educational institutions and households of Guwahati and Tezpur. The study area and the sampling sites are as follows:

3.1.1 Guwahati

Guwahati (26° 10′ N 91 ° 44′ E) is the largest city of Assam and the and the principal metropolis of Northeast India. The city is situated on the South bank of the river Brahmaputra. Guwahati presents a diverse urban landscape, encompassing areas adjacent to the Brahmaputra River, forested zones, and industrial regions. Geographically, it is nestled between the Brahmaputra River and the foothills of the Shillong Plateau [1]. Over the past decade, Guwahati has witnessed a marked rise in vehicular density, comprising both light and heavy vehicles. Additionally, the city is currently undergoing extensive infrastructural development such as the construction of the Guwahati Ring Road and multiple flyovers.

3.1.1.1 Educational Institution in Guwahati

In Guwahati, Cotton University (CU) (26.18741° N, 91.74671° E) was selected as the sampling site. Established in 1901, it is among the oldest higher education institutions in Northeast India. The university is located in the heart of Guwahati city and is surrounded by busy commercial areas and major traffic routes. Ongoing construction activities, including the development of a new auditorium and renovation of existing buildings, have increased the structural density of the campus. With high daily footfall and notable environmental pressures, the site provides a representative setting for the characterization of air pollutants and SD in an urban campus (UC).

Sites for Characterization of Air Pollutants

Four classroom microenvironments were selected at CU for the characterization of air pollutants: Classroom 1 (CR1_U), Classroom 2 (CR2_U), Classroom 3 (CR3_U), and Classroom 4 (CR4_U). Fig. 3.1 presents the spatial distribution of these sampling locations within the university campus.

Sites for Characterization of Settled Dust (SD)

SD samples were collected to assess elemental concentrations across various indoor environments at CU. Sampling locations included classrooms and laboratories within the School of Sciences, classrooms in the School of Humanities & Social Sciences, and the library. Based on these locations, the sampling sites were categorized as "Academic Classrooms and Labs" and "Library Complex". The detailed description is given below in Table 3.1. Fig. 3.2 shows the sampling locations for SD collection.

Table 3.1 Description of the sampling site in Cotton University for collection of indoor settled dust

Indoor Environment		**Sampling Sites**	**Purpose**
Academic classroom and Labs (5)	School of Sciences – Classrooms (2)	CR1_S, CR2_S	Elemental concentration in SD
	School of Humanities & Social Sciences-Classrooms (2)	CR3_HSS, CR4_HSS	
	School of Sciences – Laboratory (1)	LAB5_S	
Library complex (3)	Main Hall (1)	LIB_MH	
	Reference Room (1)	LIB_RR	
	Stock Room (1)	LIB_SR	

3.1.1.2 Households in Guwahati

Six households were selected from Guwahati to characterize air pollutants and SD in indoor environments. The selection included two households from commercial areas, two from industrial areas, and two from residential areas. This categorization aimed to capture the variability in indoor environmental quality across different urban settings. Fig. 3.3 showed the sampling locations of households. A detailed description of the surroundings along with the coordinates for each household is provided below in Table 3.2.

3.1.2 Tezpur

Tezpur city (26° 65′ N and 92° 79′ E) is located in the Sonitpur district of Assam situated on the northern bank of the Brahmaputra River, representing the regions around the river's middle stretch in India. Two major highways, NH 15 and NH 715, intersect and pass through Tezpur. The region predominantly consists of agricultural plains, forests, tea plantations, riverine, and marshy areas. Numerous enterprises operate in the area, including tea processing facilities, brick kilns, auto workstations, and other agriculture-based businesses, which primarily utilize coal and wood as energy sources [2]. Additionally, urban centers in the region have seen the development of malls and shopping complexes.

Table 3.2 Neighbourhood characteristics of surveyed household locations in Guwahati

Area Type	Household name	Description of neighbourhood	Latitude	Longitude
Commercial	CH1_G	Located in a densely developed commercial area of Guwahati, with retail outlets, heavy traffic, and constant pedestrian flow in the immediate vicinity.	26.178240° N	91.825600° E
Commercial	CH2_G	Characterized by ongoing commercial activity, with nearby shops, vendors, malls, and local markets contributing to high pedestrian density and heavy vehicular traffic.	26.180350° N	91.831440° E
Industrial	IH3_G	Located approximately 1.6 km (by road) from India Carbon Limited (ICL) and 2.0 km (by road) from the IOCL Guwahati Refinery. The surrounding area comprises a mix of industrial operations, residential settlements, and commercial establishments. The locality experiences moderate to high vehicular traffic.	26.178150° N	91.814640° E
Industrial	IH4_G	Located in the Noonmati industrial zone of Guwahati, this site lies approximately 1.1 km from the IOCL Guwahati Refinery and about 1.7 km (by road) from the Bamunimaidam Industrial Estate. The surrounding area comprises small-scale industrial units, including mechanical workshops and storage yards. The locality experiences moderate to heavy vehicular traffic.	26.183607° N	91.801449° E
Residential	RH5_G	Located in a low-density, uncongested residential neighbourhood, the site experiences minimal vehicular traffic and limited commercial activity.	26.148160° N	91.642600° E
Residential	RH6_G	Located in a residential area with moderate levels of human activity, the site is situated near arterial roads, leading to intermittent exposure to vehicular emissions.	26.166600° N	91.825220° E

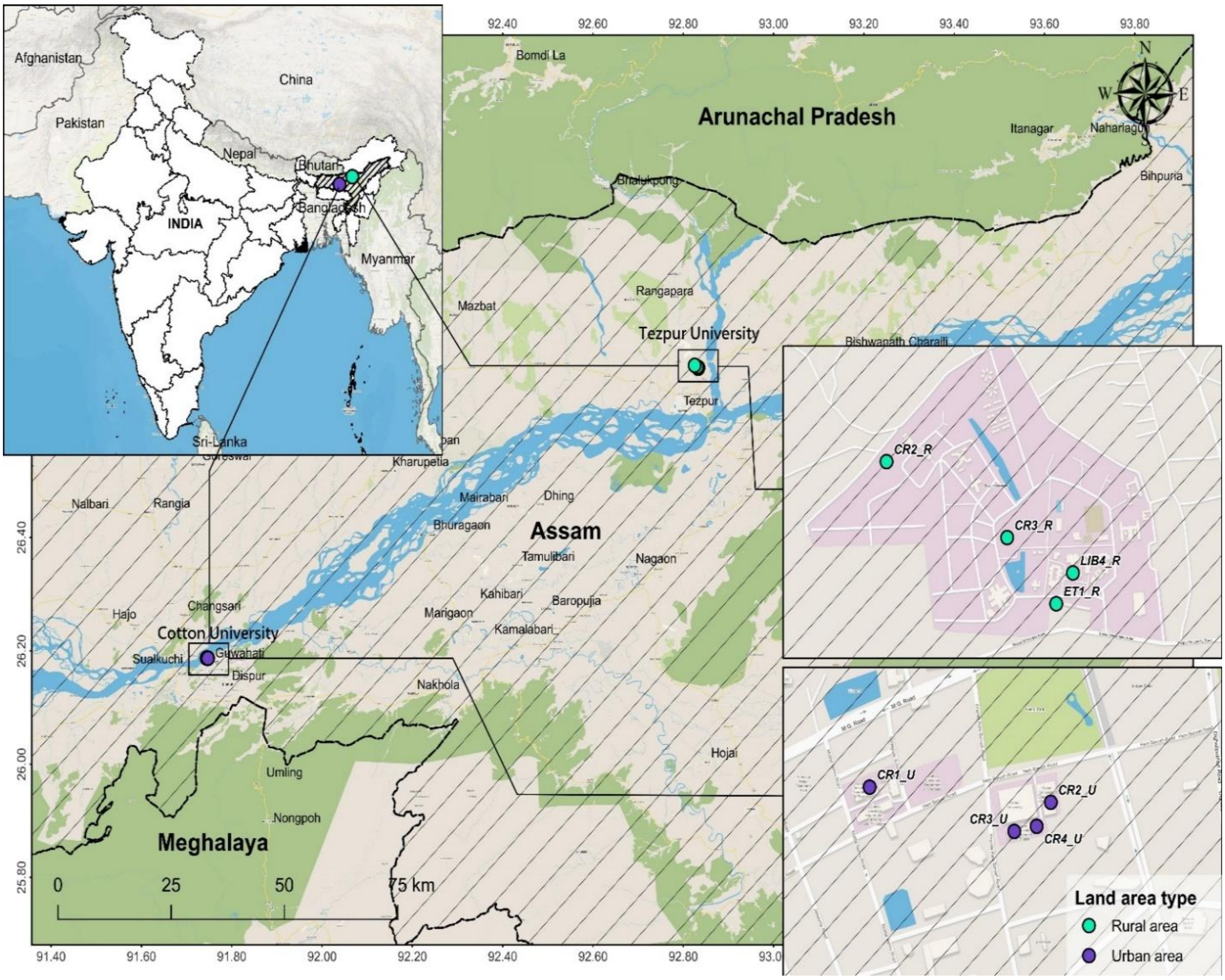

Fig. 3.1 Study area showing selected microenvironments for characterization of air pollutants across two university campuses: Cotton University in Guwahati and Tezpur University in Tezpur, Assam

3.1.2.1 Educational Institution in Tezpur

Tezpur University (TU) (26.70047° N, 92.83079° E), a central university established in 1994, is located in Napaam, approximately 13 km from Tezpur city in Sonitpur District. The residential campus is set within a green landscape, surrounded by agricultural land and low-density residential areas. It experiences minimal traffic and lower levels of ambient pollution compared to urban institutions. However, ongoing construction activities on campus may contribute to localized dust generation and emissions. This setting provides a useful comparison for studying IAQ and characterization of SD in a rural campus (RC)

Sites for Characterization of Air Pollutants

Four microenvironments were selected for TU for the characterisation of air pollutants: ET1_R (eatery), CR2_R, CR3_R (classrooms) and LIB4_R (library main hall). Fig. 3.1 showed the sampling sites at TU.

Sites for Characterization of Settled Dust

SD samples were collected to assess elemental concentrations across a range of indoor environments at the university. The selected sites included classrooms of the School of Humanities and Social Sciences, School of Law, School of Engineering, School of Sciences, and School of Management. One laboratory was also taken from School of Sciences. To examine variability in elemental composition, additional samples were collected from various utility and social spaces across the campus, including eateries, the auditorium hall, and the main hall of the library. The detailed description is given below in Table 3.3. Fig. 3.2 illustrates the sampling locations for SD collection.

Table 3.3 Description of the sampling sites in Tezpur University for collection of indoor settled dust

Categories	Building/School/Facility	Sampling Sites	Purpose
Academic Classrooms and Lab (9)	School of Humanities & Social Sciences (3)	CR1_HSS, CR2_HSS, CR3_HSS	Elemental concentration in SD
	School of Law (1)	CR4_L	
	School of Engineering (2)	CR5_E, CR6_E	
	School of Sciences (2)	CR7_S, LAB8_S	
	School of Management (1)	CR9_M	
Utility and Social Spaces (4)	Eateries (1)	ET1, ET2	
	Auditorium (1)	AH3	
	Library (1)	LIB4	

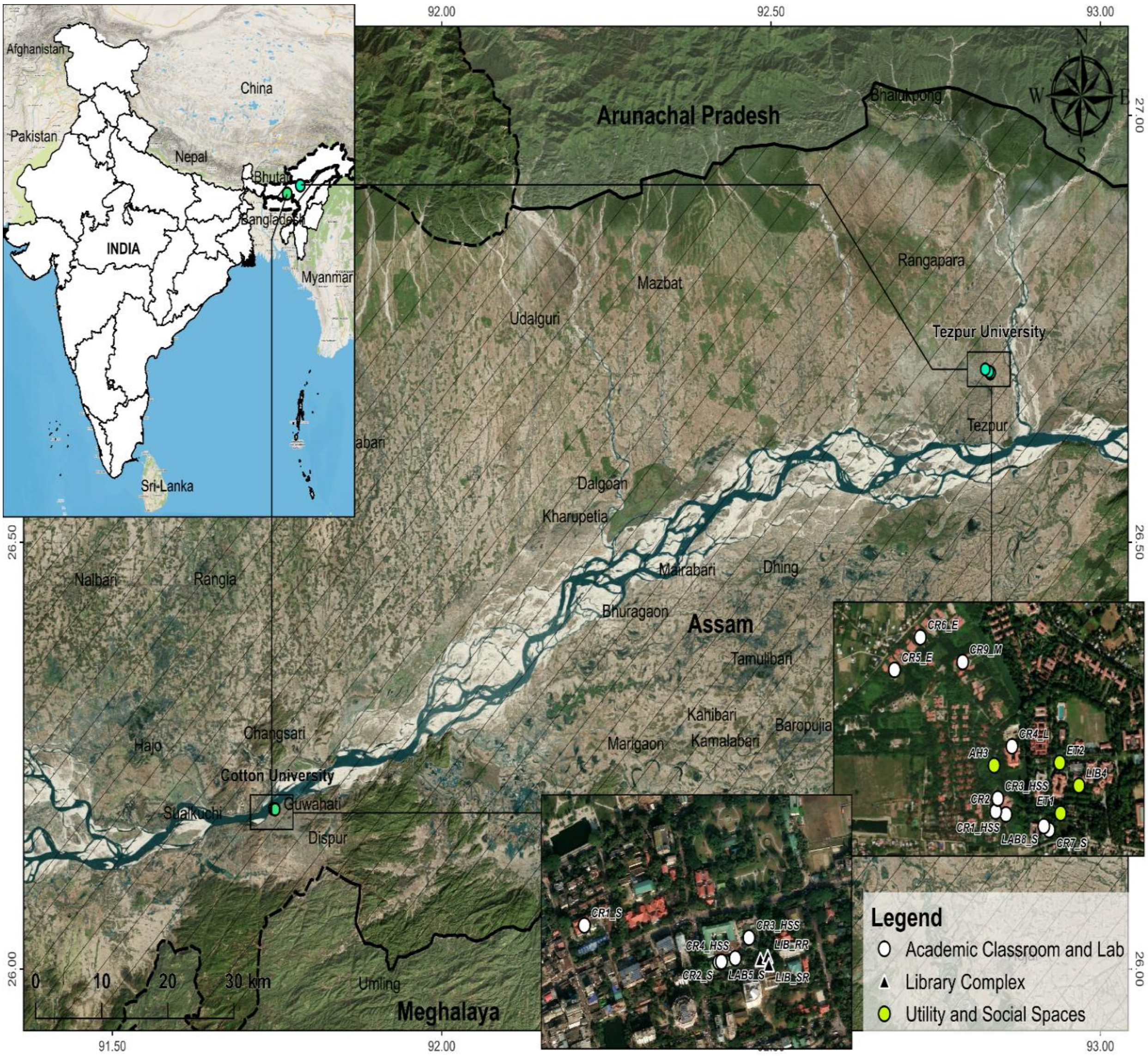

Fig. 3.2 Study area showing selected microenvironments for collection of settled dust across two university campuses- Cotton University in Guwahati and Tezpur University in Tezpur, Assam

3.1.2.2 Households in Tezpur

Eight households were selected from Tezpur to characterize air pollutants and SD in indoor household environments. The selection included three households from urban residential areas, three households from commercial areas, two from rural residential areas. This categorization aimed to capture the variability in indoor environmental quality across different settings of Tezpur. Fig. 3.3 showed the sampling locations of households. A detailed description of the neighbourhood along with the coordinates for each household is provided below in Table 3.4.

Table 3.4 Neighbourhood characteristics of surveyed household locations in Tezpur

Area Type	Household name	Site description	Latitude	Longitude
Urban Residential	RHu1_T	Located in a dense residential locality, the site experiences moderate levels of human activity with limited influence from nearby commercial activities.	26.64958° N	92.82191° E
Urban Residential	RHu2_T	The area has a planned residential layout with urban elements. Traffic is generally low, with occasional moderate flow	26.64955° N	92.82194° E
Urban Residential	RHu3_T	Situated in a denser residential setting within urban Tezpur. It is closer to internal roads and semi-commercial spaces	26.63564° N	92.78532° E
Commercial	CH4_T	Located in a commercial block with nearby retail stores, shops, and clinics. The area experiences high daytime human activity due to its mixed-use development	26.6576° N	92.7969° E
Commercial	CH5_T	Located adjacent to food outlets, office units, and apartments. It shows typical characteristics of small-town commercial saturation	26.65769° N	92.79676° E
Commercial	CH6_T	This site shares similar characteristics with CH3_T and CH4_T, featuring nearby medical shops, retail outlets, and proximity to a busy roadway	26.65763° N	92.79691° E
Rural Residential	RHr7_T	Located within the Tezpur University campus, this site lies in a peripheral and greener section of the campus. Ongoing construction in the vicinity contributes to dust and noise disturbances	26.69709° N	92.82848° E
Rural Residential	RHr8_T	Located within the Tezpur University campus, near the School of Engineering. Low vehicular movement and minimal commercial activity. Ongoing construction causes regular dust generation	26.70131° N	92.82737° E

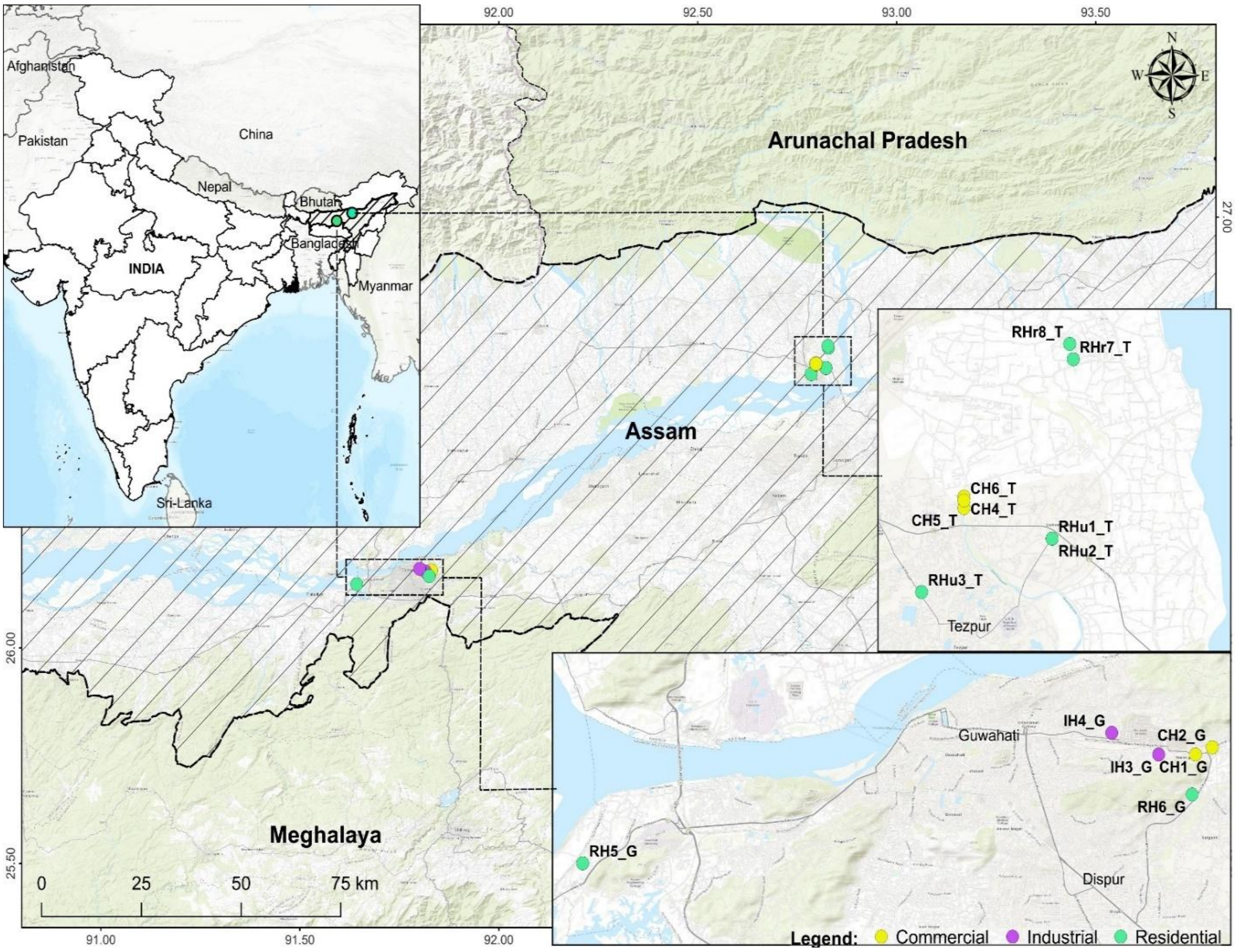

Fig. 3.3 Study area showing households selected for characterization of air pollutants and SD, located across different environmental settings in Guwahati and Tezpur, Assam

3.2 Measurements of Air Pollutants

3.2.1 Sampling Techniques

Table 3.5 presents the sampling sites and the corresponding measurement periods for both CU and TU. Due to the presence of multiple sampling sites and the use of a single set of instruments; it was not feasible to conduct measurements simultaneously at both locations. As a result, sampling at CU was carried out during November and December 2021, while measurements at TU were conducted from March to May 2022.

Similarly, Table 3.6 presents the sampling sites and the corresponding measurement periods for household surveys conducted in Guwahati and Tezpur. In Guwahati, the sampling was carried out from November 2021 to January 2022. For Tezpur, the measurement period extended from December 2022 to April 2023. All household measurements were conducted in the room where the highest level of activity occurred, typically the living room or dining room. In some households, the living and dining rooms were combined into a single space

Table 3.5. Measurement period and duration of sampling at different microenvironments of Cotton University and Tezpur University

Educational Institution	Location	Measurement Period	Duration	Parameters Measured
CU (Guwahati)	Classroom (CU)	Classroom hours	5 days	Temperature, Relative Humidity, CO_2, $PM_{2.5}$
TU (Tezpur)	Classroom (TU)	Classroom hours	5 days	
	Library (LIB4_R)	Library hours	5 days	
	Eatery (ET1_R)	Operational hours	4 days	
CU and TU	Outdoor	Comparable hours to that of indoor classroom measurement	1 day	

Table 3.6 Measurement period and duration of sampling at different households of Guwahati and Tezpur

City	Location	Measurement Period	Duration	Parameters Measured
Guwahati	Household (Indoor)	10 hours	3 consecutive days	Temperature, Relative Humidity, CO_2, $PM_{2.5}$
Guwahati	Household (Outdoor)	10 hours	1 day	Temperature, Relative Humidity, CO_2, $PM_{2.5}$
Tezpur	Household (Indoor)	10 hours	3 consecutive days	Temperature, Relative Humidity, CO_2
	Due to instrumental constraints	9-10 hours	1 day	$PM_{2.5}$
Tezpur	Household (Outdoor)	6 hours	1 day	$PM_{2.5}$

3.2.2 Temperature, Relative Humidity, and CO_2 Measurements

Temperature, relative humidity, and CO_2 levels were recorded with a logging interval of 1 min using Testo 400 devices. The temperature measurements were accurate to within ± 0.5 °C, with a range of 0 to 50 °C. The precision for relative humidity was ± 3%, with a range of 5–95%, whereas CO_2 levels were measured within a range of 0 to 10,000 ppm, with a precision of ± 50 ppm. At the beginning of each measurement session, the instruments were calibrated. To prevent potential disturbances from air streams, the indoor sampling instruments were positioned at a height of 0.75 m to 1.5 m above the floor corresponding to breathing zone, away from doors and windows. Similarly, the measurements were taken outside in the open.

3.2.3 $PM_{2.5}$ Measurement

A SidePak™ personal aerosol monitor (Model: AM520), a battery-operated laser photometer pre-calibrated by the manufacturer with ISO 12103-1 using A1 Arizona test dust, continuously measured the indoor $PM_{2.5}$ levels in classrooms. The device operated at a flow rate of 1.7 L/min, with detection limits ranging from 0.001 mg/m³ to 100 mg/m³. Adhering to the manufacturer's guidelines, the monitor prior to data collection was calibrated. The equipment was placed centrally in rooms, away from windows, doors, and corners, and set at a height corresponding to the occupant's breathing zone. Indoor measurements were taken with a logging interval of one minute. Similarly, the aerosol monitor was positioned outside in the open to measure outdoor $PM_{2.5}$ concentrations.

3.2.4 MPPD v3.04 Model

The MPPD model is developed by Applied Research Associates, Inc. for simulating the deposition of airborne particles within human and rat species. The model simulates both the overall and regional lung deposition as well as the deposition for each lung lobe. The MPPD model offers five models for human lung geometry which include the Yeh/Schum Symmetric, Yeh/Schum 5-Lobe, Stochastic Lung, Age-specific Symmetric, and Age-specific 5-lobe model of the human lung. In this study, deposition estimates were performed using human airway morphometry data for the age specific 5-lobe model with uniform expansion. This model was adopted as it simulates an anatomically and physiologically realistic conditions for people of different ages [3]. This model takes into account that the differences of airway dimensions of lungs and breathing rates in children from those of adults [4]. Using the MPPD, deposition of inhaled $PM_{2.5}$ was modelled in this study for different age groups. The model provides default input values such as functional residual capacity (FRC), and the upper respiratory tract (URT) for children aged 8 and 9 years, and adolescents aged 14 and 18 years. These age groups were incorporated into the present analysis, along with adult males and females (aged 21 years) and elderly males and females (aged 70 years). The model parameters for the adult age group (male, female) and elderly age group (male, female) were obtained from the Anshita et al. [5]. A summary of the specific input values used is provided in Table 3.7.

Table 3.7 Input values for age specific 5 lobe MPPD model and for daily dose calculation

Airway Morphology	**Options/Values**			
Age groups	Adult male	Adult female	Elderly male	Elderly female
Species		Human		
Model		Age-specific 5 lobe		
FRC (ml)**	3300	2680	3140	2340
URT (ml)**	50	40	50	40
Particle properties				
Density*		$1 g/cm^1$		
Aspect ratio*		1		
Diameter		CMD		
Particle distribution		Single		
Inhalability adjustment		$PM_{2.5}$		
GSD (diameter)*		1		
GSD (length)*		1		
Constant exposure		Yes		
Body orientation		Upright		
Breathing Frequency(breadth/min) **	20	21	20	21
TV (ml)**	1250	992	1000	650
Breathing scenario		Nasal		

FRC: functional residual capacity; URT: upper respiratory tract; GSD: geometric standard deviation; CMD: count median diameter; TV: tidal volume **Anshita et al. [5] *Default model values for all age groups

3.3 Elemental Analysis of Settled Dust

3.3.1 Sampling Techniques for Indoor SD Collection

The SD samples were collected by gently sweeping the indoor surface using a plastic dustpan and a soft paintbrush. Five samples from 1 m^2 areas were collected and mixed to form one representative composite sample for each indoor site (with samples taken from the four corners and the centre of the sampling site). The collected sample was placed into self-sealing plastic bags and labelled cleanly to transport to the laboratory and also to store for further analysis. After collection, the samples were screened using a stainless-steel sieve with a pore size of 53µm. The samples were then oven-dried at 105º C for 24 hours [6,7]. These samples were stored at 4º C for further analysis.

3.3.2 Settled Dust Collection and Sample Preparation for ICP-OES

0.5 grams of the oven-dried samples were weighed in a 4-digit microbalance (Radwag, Germany 4-digit microbalance). The digestion process involved a mixture of concentrated acids to ensure complete dissolution of the matrix and release of metal ions. The 0.5 grams aliquot was dissolved with 12 mL of aqua regia solution made with concentrated HNO_3 (69%) and concentrated HCl (37%) along with 3 mL HF (40%) [8]. The sample and acids were combined and put into Teflon containers for digestion utilizing a microwave digestion system (Anton Paar, Multiwave GO, Austria). Blank samples, prepared under identical conditions without the indoor SD, were included to control for potential contamination. Post-digestion, the samples were filtered with 47-mm diameter Whatman filter paper, followed by a secondary filtration using 0.2-µm syringe filters, to achieve ultrafine particulate clarity for analysis. After volume makeup, the samples were kept in Teflon wide-mouth Teflon bottles at 4 °C for elemental analysis.

3.3.3 Quality Control and Quality Assurance

To minimize contamination, all glassware was pre-treated by soaking overnight in a 10% HNO_3 solution, followed by thorough rinsing with deionized water before use. Analytical-grade acids and reagents were employed to maintain high purity standards, and ultrapure water was used throughout the experiment for preparing blanks and sample dilutions. The accuracy of the measurements obtained using ICP-OES was ensured by validating the instrument readings against metal standards with known concentrations. To enhance precision and reliability, each sample was analysed in triplicate, and calibration curves were accepted only when the coefficient of determination (R^2) ≥ 0.99. The relative standard deviation (RSD) for the repeated analyses of each element was less than 5%. The limit of detection (LOD) of the elements were Al (1 ppb), Cr (0.2 ppb), Mn (0.1 ppb), Ni (0.5 ppb), Co (0.2 ppb), Cu (0.4 ppb), Zn (0.2 ppb), Cd (0.1 ppb), Pb (1 ppb) and Mg (0.04 ppb). Limit of Quantification (LOQ) of the elements in sequence follows: Al (3.3 ppb), Cr (0.66 ppb), Mn (0.33 ppb), Ni (1.65 ppb), Co (0.66 ppb), Cu (1.32 ppb), Zn (0.66 ppb), Cd (0.33 ppb), Pb (3.3 ppb) and Mg (0.13).

3.3.4 Pollution Indices

3.3.4.1 Enrichment Factor

Enrichment factor (EF) is an index used to evaluate the extent of metal contamination in the environment. It is calculated by comparing the concentrations of elements in the samples to their natural abundance in the Earth's crust. It determines the degree of anthropogenic contamination in dust samples [6, 9]. Enrichment factor is calculated as-

$$EF = \frac{(X_i/X_r)_{sample}}{(X_i/X_r)_{background}} \quad (1)$$

The concentration of the reference element is denoted by X_r, while the concentration of the target metal in the indoor dust sample and the Earth's crust (background) is represented by X_i [10] Fe was chosen as the reference element due to its natural abundance in the Earth's crust and its minimal association with anthropogenic activities or metal pollution. Moreover, it exhibits high geochemical stability in soils, characterized by negligible vertical mobility and strong resistance to degradation processes [6, 11]. The reference values were taken from Taylor [12]. EF is categorized into five classes: minimum enrichment (EF < 2), moderate enrichment (2 ≤ EF < 5), considerable enrichment (5 ≤ EF < 20), very high enrichment (20 ≤ EF < 40), and extremely high enrichment (EF ≥ 40) [7, 9, 10, 13].

3.3.4.2 Contamination Factor and Pollution Load Index

Contamination factors and degree of contamination assess the extent of metal contamination in SD [14-16]. It is the ratio of elements present in the sample of SD to the continental crustal average, obtained from Taylor [12].

$$CF = \frac{Concentration\ of\ metals\ in\ road\ dust}{Concentration\ of\ metals\ in\ background} \quad (2)$$

The degree of contamination is determined by summing the contamination factors for each element in the sample, as expressed in the following equation:

$$C_{degree} = \sum CF \quad (3)$$

The classification of CF and C_{degree} into four categories is presented in Table 3.8 [17-20].

The pollution load index (PLI) is a metric used to evaluate the overall pollution burden caused by hazardous elements at a given site. It is calculated by taking into account the CF for each element present. A PLI value less than 1, 1, and greater than 1 indicates the absence of contamination, minimal contamination, and deterioration of the sampling site, respectively [19, 21]. The classification is provided in Table 3.8 [17, 20, 21].

PLI= (CF1×CF2×CF3×..........CFn)1/n (4)

where, n represents the number of metals assessed, and CF denoted the contamination factor of each element in the SD samples.

Table 3.8 Pollution indices (Contamination Factor and Pollution Load Index) and their description

Contamination Factor (CF) and Degree of Contamination (C_{degree})	Class I; Low CF; Low C_{degree} Class II; Moderate CF; Moderate C_{degree} Class III; Considerable CF; Considerable C_{degree} Class IV; Very high CF; Very high C_{degree}	CF <1; C_{degree} <8 CF=1-3; C_{degree} = 8-16 CF=3-6; C_{degree} =16-32 CF=>6; C_{degree} >32
Pollution load index (PLI)	No pollution Present that only baseline level of pollutants is present Deterioration of site quality	PLI < 1 PLI =1 PLI >1

3.3.4.3 Geo-accumulation Index (I_{geo})

The geo-accumulation index, developed by Muller [13], assesses the elemental concentrations in sediments/soil by evaluating the present levels with the background levels. It has been extensively employed to evaluate the elemental pollution [22-24].

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times C_b} \quad (5)$$

Here, C_n represents the elemental concentration (mg/kg) in SD sample and C_b represents the background concentration of crust given by Taylor [12]. 1.5 denotes element's potential to fluctuate in the background value as well as very little input or influence from humans [22]. The different classes for geo-accumulation index are given in Table 3.9 [17, 25, 26].

Table 3.9 Description of geo-accumulation index (Igeo) classes to evaluate the individual elemental pollution with respect to various sampling sites

Igeo Value	Igeo Class	Qualitative designation of SD
Igeo ≤ 0	0	Uncontaminated
0 < Igeo ≤ 1	1	Uncontaminated to moderately contaminated
1 < Igeo ≤ 2	2	Moderately contaminated
2 < Igeo ≤ 3	3	Moderately to heavily contaminated
3 < Igeo ≤ 4	4	Heavily contaminated
4 < Igeo ≤ 5	5	Heavily to extremely contaminated
Igeo > 5	6	Extremely contaminated

3.4 Mineralogy of Settled Dust

The settled dust samples were analyzed using X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) techniques. FTIR spectroscopy identified organic groups in indoor dust samples by detecting chemical bonds present in molecules through their infrared absorption spectra. To assess the molecular composition and structure of particles, the absorbance of infrared light energy in samples was measured at various wavelengths using FTIR (Perkin Elmer, Model Spectrum 100) in the range of 4000 to 400 cm^{-1}. Dry potassium bromide (KBr) was mixed with the sample in a 1:20 ratio using a mortar and pestle, and pellets were prepared to study the spectra.

The mineralogical composition of selected dust samples was determined by recording the qualitative mineralogy using the XRD (Bruker model, D8 focus) technique. The X-ray diffraction spectra were recorded with a scanning speed of 0.050/min at Bragg's angle 2θ, ranging from 10 to 80 degrees. A CuKα line with a wavelength of 1.54 Å was used as the X-ray source. Bragg's equation ($n\lambda = 2\ d_{hkl} \sin\theta$) was employed to calculate the interplanar spacing. The analysis of the XRD patterns was performed using X'Pert HighScore Plus software, in combination with the Crystallography Open Database (COD) [27, 28].

3.5. Health Risk Assessment

The objective of health risk assessment was to determine the likelihood that the elemental composition of indoor settled dust could pose a potential health risk to the occupants of the indoor environment. The method utilized to assess the health risks associated with metal exposure to settled dust was established by the US Environmental Protection Agency (USEPA) [29]. The three primary routes of dust exposure for children and adults are ingestion, inhalation, and dermal contact [6,7, 30, 31]. Using Equations (6), (7), and (8), the average daily dose (ADD) (mg/kg/day) of a pollutant via ingestion, inhalation, and dermal contact can be calculated:

$$ADD_{ing} = C_{dust} \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (6)$$

$$ADD_{inh} = C_{dust} \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \quad (7)$$

$$ADD_{der} = C_{dust} \times \frac{SA \times SAF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (8)$$

where ADD_{ing} is daily exposure amount of metals through ingestion (mg/kg/day); ADD_{inh} is daily exposure amount of metals through inhalation (mg/kg/day); ADD_{derm} is daily exposure amount of metals through skin/dermal contact (mg/kg/day). The exposure factors for these models are shown in Table 3.10.

The hazard quotient (HQ) was calculated by dividing the average daily dose value by a specific reference dose (RfD) based on non-cancer hazardous risk [7, 31, 32, 33, 35]. The specific reference dose (mg/kg/day) approximates the highest acceptable risk attributed to daily exposure to a given element throughout the person's lifetime. RfD values of individual elements are given in Table 3.11. The HQ values were then summed to determine the total non-carcinogenic risk across all pathways, using the hazard index (HI). $\Sigma HI \leq 1$ means no adverse health effects exist, whereas $\Sigma HI > 1$ implies potential undesirable health effects (USEPA).

Table 3.10 Exposure factors for dose models

Factor	Definition	Unit	Value Children	Value Adult	Reference
C_{dust}	The concentration of the contaminants in the dust	mg/kg			Present study
R_{ing}	Ingestion Rate	mg/day	200	100	[29-33]
EF	Exposure Frequency	days/year	350	350	
ED	Exposure Duration	years	6	24	
ABW	Average Body Weight	kg	15	60	
AT	Average Time	days			
		For carcinogenic risk	365×70	365×70	
		For non-carcinogenic risk	365×ED	365×ED	
CF	Conversion Factor	kg/mg	1×10^{-6}	1×10^{-6}	
R_{inh}	Inhalation Rate	m^3/kg	5	20	
PEF	Particle Emission Factor	m^3/day	1.36×10^{9}	1.36×10^{9}	
ABS_{dermal}	Dermal absorption factor		0.001	0.001	
SAF	Skin adherence factor for dust	m^3/cm^2/day	0.2	0.07	
SA	Surface area	cm^2	2800	5700	

$$HQ = \frac{ADD}{RfD} \quad (9)$$

$$HI = \sum HQ_{ing} + HQ_{inh} + HQ_{derm} \quad (10)$$

The Lifetime Average Daily Dose (LADD) was determined for the carcinogenic elements Cd, Ni, Co, Pb, and Cr in order to evaluate the potential cancer risks associated with exposure through inhalation.

$$LADD = \frac{C\times EF}{AT\times PEF} \times \left(\frac{InhR_{child}\times ED_{Child}}{BW_{child}} + \frac{InhR_{adult}\times ED_{adult}}{BW_{adult}}\right) \quad (11)$$

Table 3.11 RfD values for different elements

Elements	RfD_{ing} (mg/kg day)	RfD_{inh} (mg/kg day)	RfD_{derm} (mg/kg day)	*SF* (kg day/mg)	*References*
Cd	0.001	0.001	0.00001	6.3	[6, 7, 30, 31, 33, 34]
Ni	0.02	0.0206	0.0054	0.84	
Co	0.02	0.0000057	0.016	9.8	
Pb	0.0035	0.00352	0.000525	0.042	
Cr	0.005	0.000028	0.000075	42	
Mn	0.14	0.0000143	0.00184		
Fe	0.3	0.07	0.0022		
Zn	0.3	0.3	0.06		
Cu	0.04	0.0402	0.012		
Al	1		0.1		

The carcinogenic risk (CR) was defined as the product of the cancer slope factor (SF) and the mean daily intake during the lifespan. The cumulative risk (CR) that an individual will get cancer throughout their lifetime was calculated. Values falling from 10^{-6} to 10^{-4} are widely acknowledged to poss a carcinogenic influence on human health [21]. For instance, a CR of 10^{-5} indicates that 1 in 100,000 people may get cancer [35]. CR is calculated by the following formula.

$$CR = LADD \times SF \qquad (12)$$

3.6 Sick Building Syndrome

3.6.1 Sampling Approach

The study area purposively selected for this study was Guwahati, the largest metropolis of North east India with a population of 13,26,000 in Guwahati metropolitan (Population Census). Its status as the most urbanized and densely populated city in Northeast India, its rapid infrastructural growth, high indoor occupancy, and diverse built environments, all of which make it a suitable context for studying SBS, a topic largely underexplored in the region. The research design adopted for this study was a cross-sectional survey conducted in January and February, 2024. The ethical approval of the study was obtained from the Tezpur University Ethical Committee of Tezpur University, Assam, India. Informed consent was obtained from each participant. Sample size was estimated using the formula for infinite population developed by Cochran in 1963 given as:

$$N = \frac{[Z^2 \times pq]}{e^2} \qquad (13)$$

Where N is the minimum sample size, Z is the critical value, which is at 95% level of confidence, and in this study, it is 1.96; p is 0.5; q = 1-p, while e represents the desired level of precision in the statistical estimates, which in this research is 5%. In this study, however, we have taken 4.18% such that precision of estimate increases. Using this formula, approx. 550 participants were estimated as the sample size for the survey.

A purposive sampling approach was employed to ensure diverse representation from various urban public spaces across the city. Instead of conducting visits to each household directly, potential participants were approached at high-footfall locations such as schools, preschools (where parents visit during pickup times), and other public gathering sites across different areas of Guwahati. At these sites, individuals were informed about SBS and the purpose of the research. Interested participants were then either contacted later via personal texts or emails to arrange household visits for questionnaire completion, or they completed the questionnaire on the spot. Some participants also chose to respond through the online survey link provided to them. This multi-modal approach allowed for a broader reach and flexible participation, ultimately yielding a total of 550 responses—292 collected online and 258 through in-person, pen-and-paper methods. All participants were eighteen years of age or older, had resided in their current home for at least six months, and provided informed consent prior to participation.

The questionnaire covered sociodemographic information, neighbourhood/housing characteristics, description of indoor activities, perception of indoor air and SBS symptoms. The primary outcome variable in this study was the experience of at least one housing condition-related symptom within the past year. Participants were asked whether they had encountered any of the following symptom categories: nasal symptoms, throat symptoms, eye-related symptoms, dermatological symptoms, aches and pain, and general symptoms. Specific conditions included sinus issues, dry nose, sore throat, dry cough, eye irritation, skin irritation, headaches, and dizziness. To determine whether these symptoms were indicative of SBS, participants were further asked about the frequency of these symptoms specifically whether they occurred occasionally or frequently, such as once a week. If symptoms occurred at least once a week, participants were then asked whether they believed these symptoms were associated with their residential environment.

3.6.2 Statistical Analysis

Binomial logistic regression analysis was performed to investigate the associations between various residential and personal factors and the presence of a subcategory of SBS. The dependent variable was dichotomized as presence or absence of the symptom (e.g., headaches, migraines). All explanatory variables were entered simultaneously into the model using the forced entry method. The explanatory variables included: gender, age, age of residential building, type and structure of house, type of flooring and ceiling, cleaning frequency, use of incense and mosquito repellent, indoor smoking, pet present indoors, presence of cracks on the floor, cooking fuel, spray products, visible dust, wall conditions, presence of moulds, and medical history. Statistical significance was determined at a p-value < 0.05. Odds ratios (ORs) and 95% confidence intervals (CIs) were computed for each predictor.

Pilot Study

Initially, a pilot study was conducted across nineteen schools in Tezpur to assess IAQ and elemental exposure risks. The results showed that the $PM_{2.5}$ levels exceeded WHO guidelines in all schools, while CO_2 levels indicated adequate ventilation. For SD, EF value showed high enrichment for Pb, Cd, Ni, and Zn in all classrooms. Moreover, the average EF for the TREs was highest in urban schools, followed by suburban and rural schools. The C_{degree} values suggested a moderate level of contamination in all schools. The PLI values were below 1, indicating low to negligible pollution. FTIR and XRD analyses of classroom dust samples showed that quartz, calcite, and haematite were the most common minerals. Although non-carcinogenic and carcinogenic risks were within safe limits, the overall Total Lifetime Cancer Risk (TLCR) for rural (1.37E-04), suburban (1.09E-04), and urban (1.08E-04) areas were slightly above the acceptable limits. Insights from this pilot study has enabled further study on IAQ and settled dust along with the associated health risks in different indoor environments

3.7 References

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