RESULTS AND DISCUSSIONS Chapter 4

4.1 Characterization of Air Pollutants (Comfort Parameters, $PM_{2.5}$ and CO_2) in University

Temperature, relative humidity, carbon dioxide (CO_2), and fine particulate matter ($PM_{2.5}$) were monitored across four classroom microenvironments at Cotton University (CU), an urban campus, over five consecutive days during active classroom hours. Similarly, measurements were conducted at Tezpur University (TU), a rural campus, across four indoor microenvironments- namely, an eatery, two classrooms, and the library main hall- during their respective operational hours. The description of the building and the characteristics of the monitored sites are presented in Table 4.1.

4.1.1. Temperature and Relative Humidity

Indoor temperature and relative humidity are important parameters to assess the well-being and comfort level of the occupants. Table 4.2 show temperature and relative humidity in different microenvironments across CU and TU. The average indoor temperature at CU was 25.57 ± 1.24 °C, while at TU it was higher, averaging 28.78 ± 2.33 °C. This variation may be attributed to differences in the timing of sample collection between the two sites. The average relative humidity was comparable between the two campuses, recorded at 73.01 ± 4.09% for CU and 72.64 ± 6.85% for TU. Except for the average indoor temperature observed at CU, the temperature at TU and the relative humidity levels at both campuses exceeded the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 62.1-recommended comfort limits of 27 °C and 65%, respectively. In the present study, the relative humidity exceeded the recommended value by 94.87 % of the time. This is mainly due to the region's tropical climate. Similar observations were reported by Sugumar et al. [1] and Asif and Zeeshan [2] in Hyderabad, India and Islamabad, Pakistan, respectively. Furthermore, all the sampling sites relied on natural ventilation except the library which had mechanical ventilation.

4.1.2 Concentrations of $PM_{2.5}$

The concentrations of $PM_{2.5}$ across CU and TU is shown in Fig. 4.1. The average concentration of $PM_{2.5}$ at CU was 114.49 ± 28.58 µg/m³, whereas it was 71.61 ± 27.88µg/m³ ($p < 0.05$) at TU. Notably, all classroom microenvironments of CU recorded higher $PM_{2.5}$ concentrations than all the monitored sites of TU. Mohd Isa et al. [3], Nunes et al. [4], and Yoon et al. [5] reported similar findings, with urban $PM_{2.5}$ concentration being the highest. This may be attributed to increased automobile emissions and heavy traffic in urban areas [6].

Table 4.1 Building characteristics of different microenvironments of Cotton University and Tezpur University [Here CR=Classroom U=Urban R=Rural ET= Eatery Lib=Library]

	Codes	**Building characteristics**					**No of doors**	**No of Windows**	**No of windows open**	**No. of students in the classroom**	**Board type**	**Distance from the main road/ main gate**
		Floor material	**Ceiling material**	**Cracks on floor**	**Condition of wall painting**	**Molds on walls**						
Cotton University	CR1_U	Tiles	Concrete	No	Good	No	1	6	3	35	Blackboard	45 m
Cotton University	CR2_U	Concrete	Gypsum ceiling	Yes	Poor	Yes	1	2	2	17	Blackboard	30 m
CottonUniversity	CR3_U	Tiles	Gypsum ceiling	No	Moderate	No	1	6	3	21	Blackboard	80 m
Cotton University	CR4_U	Concrete	Concrete	Yes	Moderate	No	1	8	3	20	Blackboard	80 m
Tezpur University	ET1_R	PVC flooring	Gypsum ceiling	Yes	Moderate	No	2	5	4	12-15 (per hour) increase at peak hour (28-30)	NA	300 m
Tezpur University	CR2_R	Tiles	Gypsum ceiling	Yes	Good	No	2	11	4	57	Blackboard	1500 m
Tezpur University	CR3_R	Tiles	Gypsum ceiling	No	Good	No	1	3	3	15	Whiteboard	700 m
Tezpur University	LIB4_R	Tiles	Concrete	No	Good	No	1	10	0	12-15 per hour	NA	550 m

Table 4.2 Levels of temperature and relative humidity averaged over the entire day, across different microenvironments in Cotton University and Tezpur University [Here CR=Classroom U=Urban R=Rural ET= Eatery Lib=Library]

Cotton University	Days	Temperature [°C]	Relative Humidity [%]	Tezpur University	Days	Temperature [°C]	Relative Humidity [%]
CR1_U	**Day 1**	23.87	75.07	**ET1_R**	**Day 1**	25.92	74.05
	Day 2	23.99	77.9		**Day 2**	24.42	77.63
	Day 3	24.58	76.12		**Day 3**	26.02	79.75
	Day 4	25.67	76.58		**Day 4**	28.57	75.43
	Day 5	24.65	77.64				
	Average	**24.55 ± 0.71**	**76.66 ± 1.16**		**Average**	**26.23 ± 1.72**	**76.71 ± 2.50**
CR2_U	**Day 1**	27.66	65.14	**CR2_R**	**Day 1**	27.925	77.839
	Day 2	23.77	78.22		**Day 2**	28.905	70.814
	Day 3	24.57	72.5		**Day 3**	30.968	60.22
	Day 4	24.5	69.94		**Day 4**	32.853	60.381
	Day 5	25.83	64.56		**Day 5**	32.661	68.723
	Average	**25.27 ± 1.53**	**70.07 ± 5.64**		**Average**	**30.66 ± 2.21**	**67.60 ± 7.47**
CR3_U	**Day 1**	27.09	71.17	**CR3_R**	**Day 1**	29.04	67.28
	Day 2	27.35	69.95		**Day 2**	30.61	65.52
	Day 3	26.92	71.05		**Day 3**	30.16	69.69
	Day 4	26.33	72.65		**Day 4**	31.39	69.79
	Day 5	24.32	75.24		**Day 5**	30.5	66.42
	Average	**26.40 ± 1.22**	**72.01 ± 2.04**		**Average**	**30.34 ± 0.86**	**67.74 ± 1.93**
CR4_U	**Day 1**	26.26	72.71	**LIB4_R**	**Day 1**	27.75	82.27
	Day 2	26.08	79.31		**Day 2**	26.96	83.75
	Day 3	26.88	69.89		**Day 3**	27.27	77.2
	Day 4	25.33	73.61		**Day 4**	27.25	75.16
	Day 5	25.69	70.99		**Day 5**	27.63	78.21
	Average	**26.05 ± 0.59**	**73.30 ± 3.66**		**Average**	**27.37 ± 0.32**	**79.32 ± 3.58**

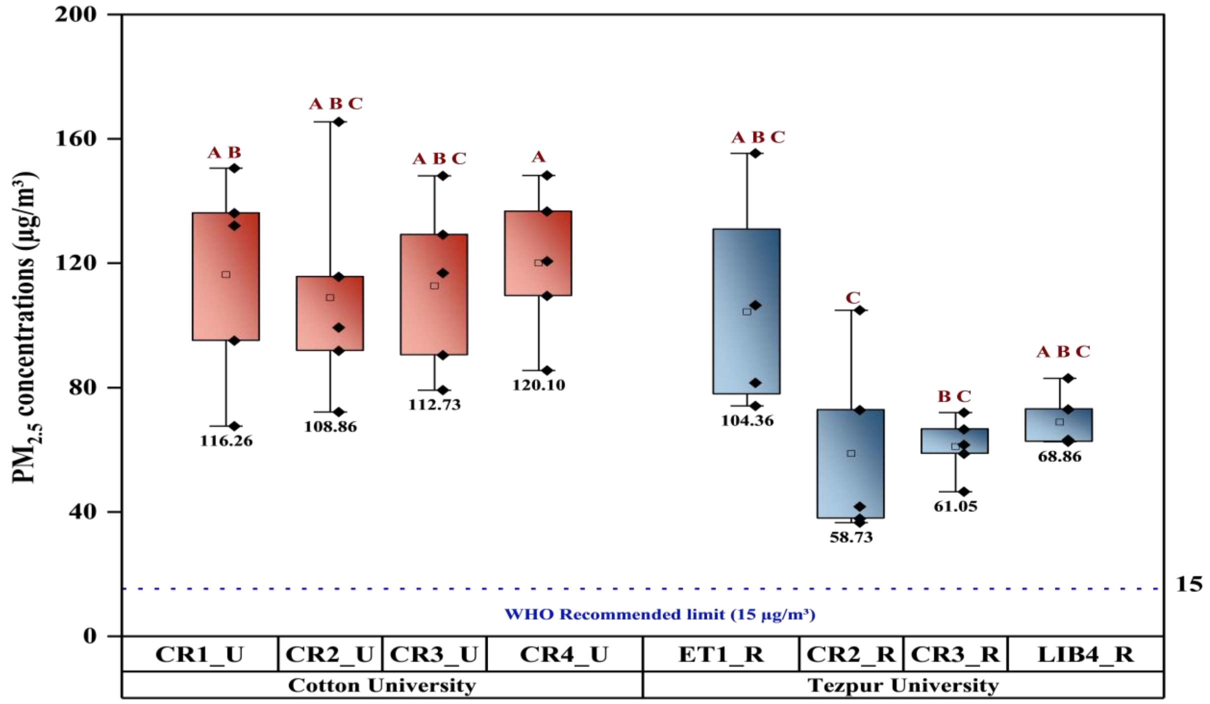


Fig. 4.1 $PM_{2.5}$ concentrations in different microenvironments of Cotton University and Tezpur University

Further; a one-way ANOVA was conducted to compare the mean $PM_{2.5}$ concentrations across the indoor microenvironments. The analysis revealed a statistically significant difference among groups at $p < 0.001$. Consequently, Tukey Post-hoc analysis was performed (Fig. 4.1). The test indicated that microenvironments not sharing a common alphabet differed significantly at $p < 0.05$. The concentrations of $PM_{2.5}$ in all the microenvironments were higher than the WHO's 24-hour recommended guideline value of 15 µg/m³. It was 4.5-11 times higher in CU and 2.4-10.4 times higher in TU than WHO guideline value. Because no standards were available for indoor air in India, all the findings were compared with available WHO standard. The classroom 2 (CR2_R) of TU recorded the lowest concentration (58.73µg/m³) among all the sampling sites of TU and CU. This can be attributed to its location, approximately 1.5 km from the main road, the farthest among all sampling sites (Table 4.1). The increased distance from the road, combined with the presence of surrounding vegetation, likely contributed to reduced $PM_{2.5}$ concentration in this site. This observation is further supported by correlation analysis, where $PM_{2.5}$ concentration was found to be significantly negatively correlated with distance from the main road, with a correlation coefficient of $R^2 = -0.87$ ($p < 0.05$), indicating that as distance increases, $PM_{2.5}$ levels decrease substantially [7].

Among all other microenvironments in TU, eatery (ETI_R) showed the highest $PM_{2.5}$. This could be attributed to cooking activities in the adjacent room, higher footfall, and poor exhaust ventilation, all of which contribute to increased indoor $PM_{2.5}$ concentration. Dede and Dede [8] also reported that higher foot fall at peak times along with insufficient ventilation may result in high $PM_{2.5}$ concentrations.

Indoor to outdoor ratio (I/O) was analyzed for both the universities as shown in Fig 4.2. If I/O ratio exceed 1, it indicates a strong influence of indoor sources. At CU, the I/O ratios of $PM_{2.5}$ for three classrooms were less than (CR2_U, and CR3_U) or equal to 1 (CR1_U), suggesting that outdoor sources were the primary contributors to indoor $PM_{2.5}$ concentrations. The short distance of these classrooms from a heavily trafficked main road, combined with natural ventilation, likely facilitated the infiltration of outdoor PM into the indoors. Thus, variations in outdoor $PM_{2.5}$ concentrations can have a substantial impact on indoor $PM_{2.5}$ concentrations. Comparable results were reported by Sahu and Gurjar [9]. However, CR4_U exhibited an I/O ratio slightly greater than 1, indicating potential contributions from indoor sources or poor dispersion. At TU, the I/O ratios indicated the presence of strong indoor sources of $PM_{2.5}$, as all monitored microenvironments exhibited I/O values ranging from 2.46 to 4.37.

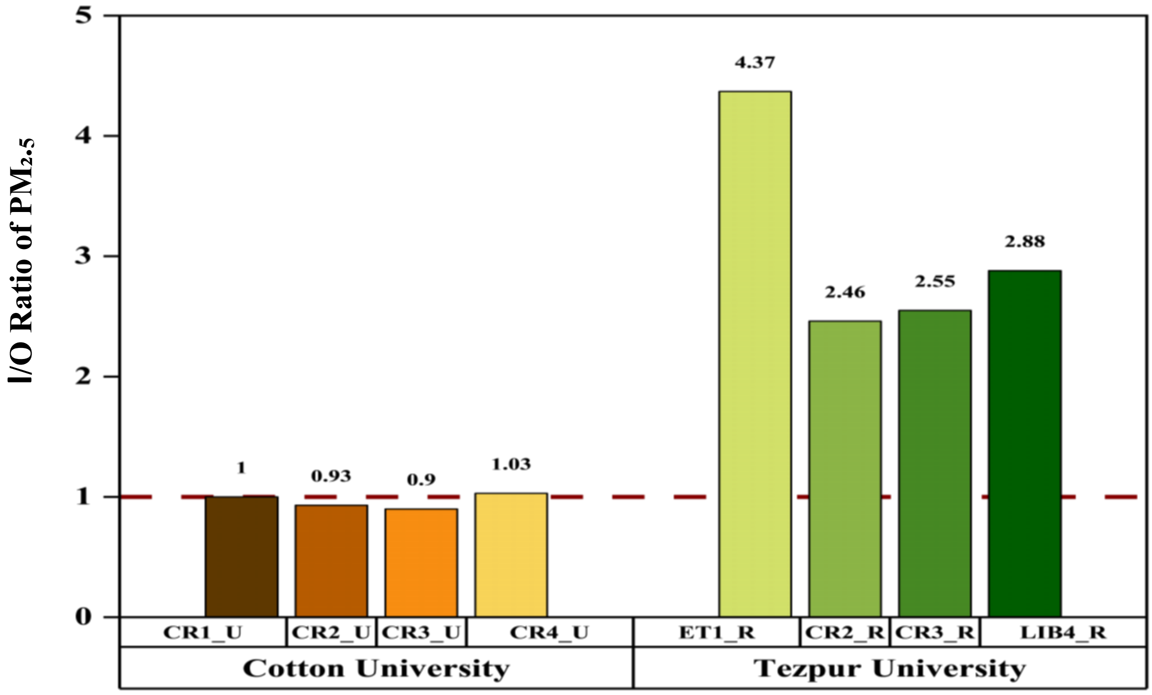


Fig. 4.2 Indoor-to-Outdoor (I/O) ratio of $PM_{2.5}$ in Cotton University and Tezpur University

Although the overall $PM_{2.5}$ concentrations at TU were lower compared to CU, the elevated I/O ratios suggest that the primary source of $PM_{2.5}$ was indoor rather than outdoor infiltration. The higher

I/O ratio observed in the eatery can be attributed to multiple indoor sources. In addition to poor exhaust ventilation and increased footfall during peak hours which contribute to the resuspension of settled dust, other significant sources include cooking emissions such as frying, serving and cleaning activities, and the transport of particulates into indoors via shoes and clothing, all of which further elevate indoor $PM_{2.5}$ concentrations [10-12]. The library main hall exhibited an I/O ratio of 2.88, primarily attributed to dust resuspension from chairs, tables, and bookshelves. Additionally, high occupancy during peak hours and inadequate air filtration in the centralized air-conditioning system could also contribute to elevated indoor $PM_{2.5}$ concentrations [13, 14]. Similarly, in classrooms, indoor sources of $PM_{2.5}$ could be attributed to inadequate cleaning practices. Additional contributing factors include high occupant density and the resuspension of dust through movement, footwear, and clothing [15, 16].

4.1.3 Concentrations of CO_2

The overall average indoor CO_2 concentrations at CU was 573.37 ± 82.75 ppm (Range: 436.53 - 737.42 ppm). At TU, the average CO_2 concentrations was 555.62 ± 81.43 ppm (range: 341.08 - 709.09 ppm). Fig. 4.3 illustrates the CO_2 concentrations across eight microenvironments at two universities. The findings suggest that CO_2 concentrations remained statistically uniform across both CU and TU. A one-way ANOVA conducted to assess differences in CO_2 concentrations across the eight sampling locations revealed no statistically significant difference among group means ($p = 0.51$). All measurements in the present study were within the acceptable limits established by ASHRAE Standard 62.1 (1000 ppm). Specifically for classrooms, the observed CO_2 concentrations also complied with the United Kingdom's Building Bulletin 101 guideline for educational spaces (1500 ppm). Furthermore, according to the classification by the Hong Kong Indoor Air Quality Management Group (IAQMG), all classrooms in this study fall under the 'Excellent' category, with average CO_2 concentrations remaining below 800 ppm [17-19]. These findings are consistent with those reported by Razali et al. [20], although several other studies have documented significantly higher CO_2 concentrations under similar settings like classrooms, canteens, cafeterias [21-23]

The I/O ratio for all sites at CU and TU, exceeded 1 (Fig 4.4), indicating that indoor sources, primarily human respiration and metabolism significantly contributed to CO_2 accumulation [20, 24]. Typically, in enclosed spaces with many occupants and limited ventilation, CO_2 concentrations often exceed outdoor concentrations due to the accumulation of exhaled CO_2 unless effective ventilation systems are in place [25].

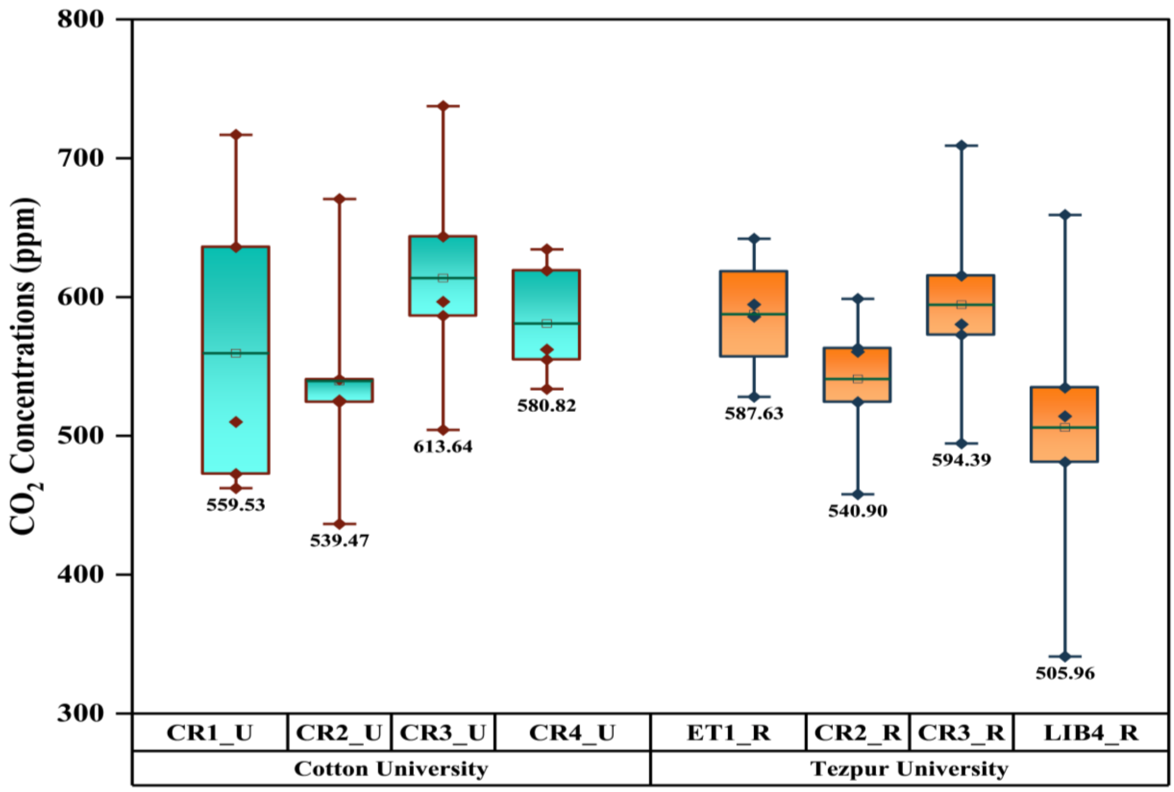


Fig. 4.3 CO_2 concentrations in different microenvironments of Cotton University and Tezpur University

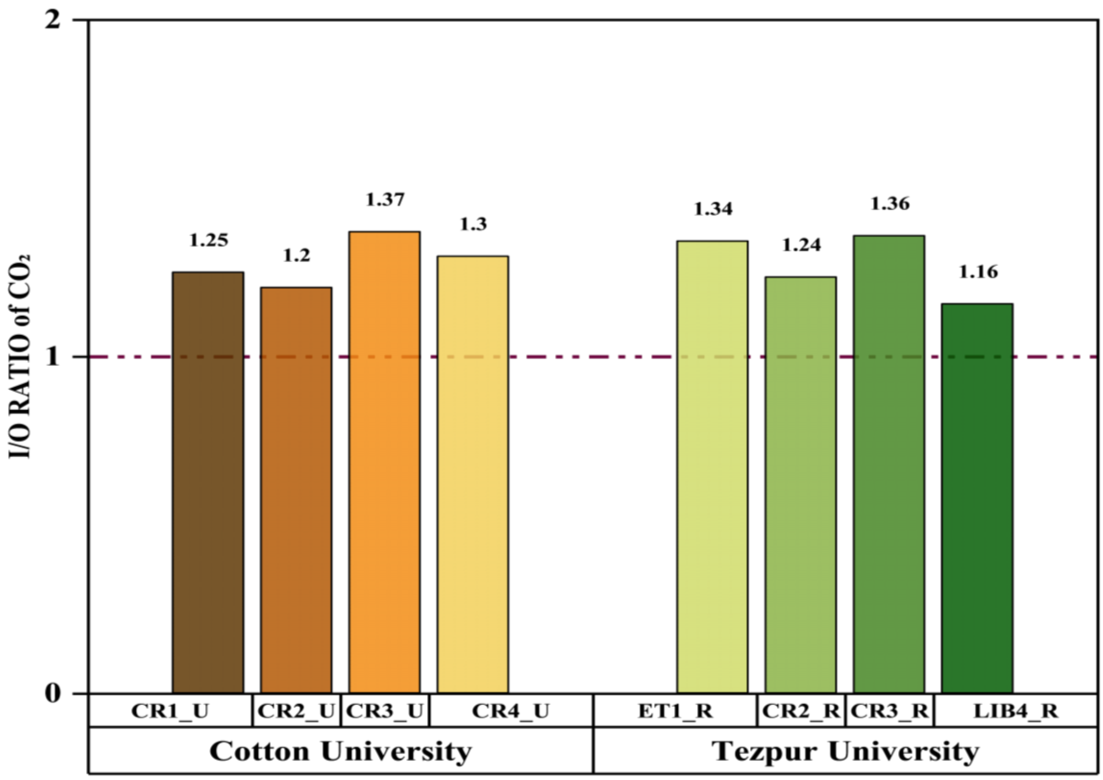


Fig. 4.4 Indoor-to-Outdoor ratio of CO_2 in Cotton University and Tezpur University

4.1.4 Application of Multiple-path Particle Dosimetry (MPPD) Model

The MPPD model was employed to evaluate the deposition of $PM_{2.5}$ in the respiratory tracts of university students, with the objective of assessing potential health risks associated with exposure across various university environments [26]. Since university going students are above the age of 18 years in India, we have taken 3 groups for universities viz., 18 year, 21-year-old (male) and 21-year-old (female). The deposition fractions of $PM_{2.5}$ across the selected age categories 18-year-olds (adolescent), 21-year-old male (adult), and 21-year-old female (adult) are presented in Table 4.3. The deposition fractions were found to be consistent across both university locations. Among the groups, total deposition was highest for 21-year-old male, followed by 21-year-old female, and lowest for 18-year-olds [27]. Across all the age and gender group the highest deposition was seen to have taken place in head (41.98%-74.8%) followed by pulmonary (27.91%-14.2%) followed by tracheobronchial (5.08%-3.49%) [28]. A significant portion of $PM_{2.5}$ deposition in the head region can be attributed to due to the combined effects of particles settling and impacting at the larynx and branching points of the airways [29].

Quantification of $PM_{2.5}$ deposition and its lobar distribution revealed that lobar deposition was highest in 18-year-olds, followed by 21-year-old females, and then 21-year-old males. Among the lobes, the highest deposition fractions were observed in the left lower lobe and right lower lobe, while the right middle lobe exhibited the lowest deposition. This is attributed to lobar volume differences. The lower lobes, having a larger volume, tend to accumulate more $PM_{2.5}$, whereas the middle lobe, with a smaller volume, receives comparatively less deposition, as shown in Fig. 4.5 [30]. The deposition fraction in the lower lobes was approximately 2.5 and 4.6 times higher than those in the upper and middle lobes, respectively. Our findings are consistent with previous studies reported by Junaidi et al. [28] and Khan et al. [31].

The deposited mass (µg) and deposited mass per unit area ($\mu g/m^2$) values, obtained from the MPPD model in different age and gender groups are shown in Fig. 4.6. The color scale indicates differences in deposition density. The total deposited mass of $PM_{2.5}$ followed the trend: 21-year-old adult males > 21-year-old adult females > 18-year-olds (Fig. 4.7). It was observed that $PM_{2.5}$ deposition increases with age and is higher in males compared to their female counterparts [31, 32].

Adults possess larger tidal volumes and a greater lung surface area, enabling them to inhale larger volumes of air [33, 34]. Deposition mass was calculated across the age and gender groups for both the universities (Fig. 4.7). A similar trend was observed for deposition density.

Furthermore, $PM_{2.5}$ deposition at CU both in terms of deposition mass and deposition density was approximately 1.54-1.55 times higher than that at TU across all age and gender groups as shown in the Fig. 4.7 and Fig. 4.8 respectively. This was due to higher $PM_{2.5}$ concentrations are associated with increased deposition in the respiratory tract.

Table 4.3 Total and regional deposition fractions (%) (Head, Tracheobronchial, Pulmonary, Total) of $PM_{2.5}$ in different age categories of university going student

Regions of deposition	Adolescent (18 Year)	Adult Male (21 Year)	Adult Female (21 Year)
Head	41.98	**74.8**	70.77
Tracheobronchial	**5.08**	3.49	3.9
Pulmonary	**27.91**	14.20	16.05
Total	74.97	**92.48**	90.73

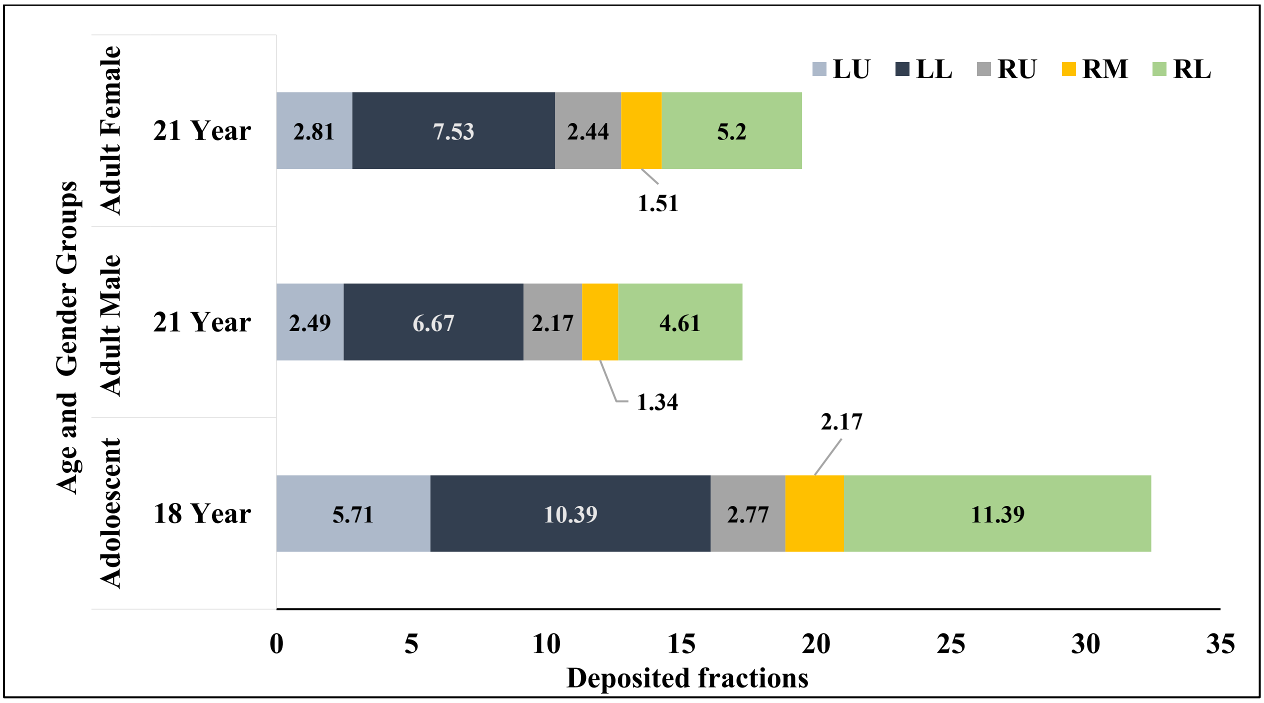


Fig. 4.5 Lobar deposition fractions of $PM_{2.5}$ in different age categories [Left Upper (LU), Left Lower (LL), Right Upper (RU), Right Middle (RM), Right Lower (RL)]

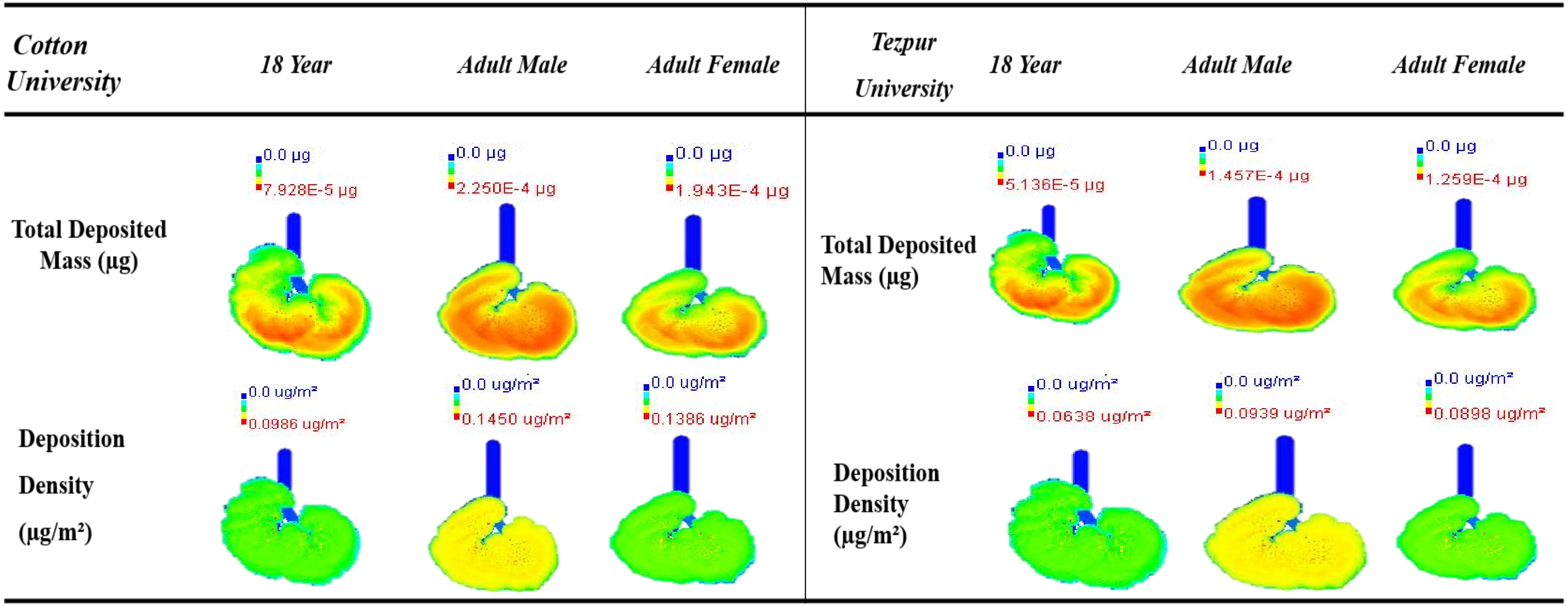


Fig. 4.6 Total deposited mass (µg) and deposition density (µg/m^3) of $PM_{2.5}$ in lungs across age and gender groups at Cotton University and Tezpur University (MPPD Model)

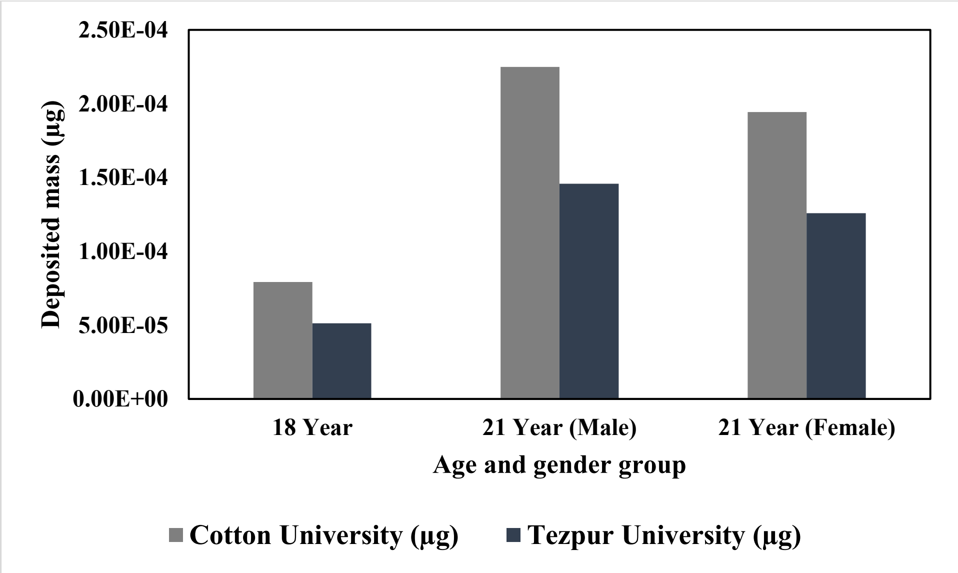


Fig. 4.7 Deposited mass (µg) of $PM_{2.5}$ across age groups and gender in Cotton University vs. Tezpur University

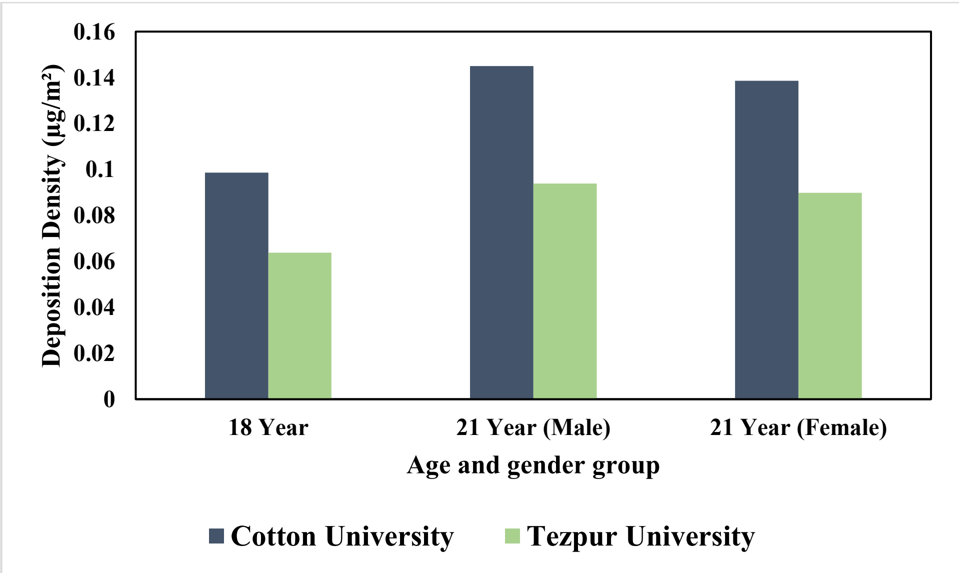


Fig. 4.8 Deposition Density (µg/m²) of $PM_{2.5}$ across age groups and gender in Cotton University vs. Tezpur University

4.2 Characterization of Air Pollutants (Comfort parameters, $PM_{2.5}$ and CO_2) in Households of Guwahati and Tezpur

To characterize air pollutants, six households in Guwahati and eight in Tezpur were selected. Measurements were conducted for both indoor and outdoor environments, focusing on $PM_{2.5}$, CO_2, temperature, and relative humidity. This facilitated a comparative analysis of air quality between the two cities, emphasizing the influence of urbanization and household practices on pollutant levels.

4.2.1 Building Characteristics

A detailed building characteristics and indoor household practices for six households of Guwahati and eight households of Tezpur are presented in Table 4.4a and 4.4b, respectively. The residential building age of the surveyed households ranged from 5 to 30 years in Guwahati and 3 to 30 years in Tezpur. Older buildings often experienced structural issues such as cracks in the walls, poorly sealed windows, and worn-out materials. These problems can make the building more permeable, allowing outdoor pollutants to enter more easily and reducing the ability to maintain good IAQ [35]. Majority of the households (78.6%) had tiled flooring, while 92.9% had concrete ceilings. All sampled households relied on natural ventilation systems except one household in Guwahati (CH2_G). Regarding cleanliness practices, sweeping and mopping were conducted daily in 11 out of 14 households (78.6%), while the remaining 3 households (21.4%) reported cleaning three times a week. Liquefied Petroleum Gas (LPG) was the exclusive cooking fuel used across all households. Smoking indoors was permitted in only 3 households (21.4%). Incense burning and the use of mosquito repellents (in the form of coils or similar products) were observed in all households. Additionally, spray-based household products were used in 10 households (71.4%). Plumbing issues and visible mould growth were reported in 6 households (42.9%).

As presented in Table 4.4a and 4.4b, visible mould growth was observed in approximately 42.9% of the surveyed households. Notably, all households that reported plumbing issues also exhibited visible mould growth, suggesting a possible association with moisture-related infrastructure problems. When assessed the mould growth in relation to residential age (i.e., building age), a weak positive correlation was observed (R^2= 0.29), though this association was not statistically significant. In Tezpur, all households in commercial area, despite having a

Table 4.4 Building characteristics and indoor activities of households in [Here, CH=Household in commercial area, IH=Households in industrial area, RH=Household in residential area, RHu=Household in urban residential area, RHr=Household in rural residential area, G=Guwahati and T=Tezpur]

a) Guwahati

Households	Residential Age	Resident Age	Floor type	Area (m²) of sampled room	Ceiling	No of Rooms	Doors leading to outdoors	Windows	No of Windows open	Distance from the main Road	Distance from the kitchen
CH1_G	30	29	Tiles	10.22	Concrete	5	2	3 pane window - 1	0	5 m	0.91
CH2_G	5	5	Tiles	22.25	Concrete	5	2	3 pane window - 1	0	10 m	1.22
IH3_G	15	13	Tiles	13.38	Concrete	5	1	3 pane window - 1	0	80 m	Adjacent
IH4_G	10	10	Tiles	11.15	Concrete	4	2	4 pane window- 1	1	300 m	Adjacent
RH5_G	23	2	Concrete	11.15	Gypsum	6	1	2 pane window - 2	1	500 m	Adjacent
RH6_G	13	12	Tiles	23.78	Concrete	5	3	3 pane window - 1	2	200 m	Adjacent
Households	**Ventilation**	**No of Occupants**	**Sweeping-Mopping Frequency**	**Fuel**	**Smoking inside home**	**Incense Burning**	**Mosquito Repellent (Burning)**	**Pets present**	**Spray product Used**	**Plumbing problem**	**Mould present**
CH1_G	Natural Ventilation	4	Everyday	LPG	✓	✓	✓	✗	✓	✓	✓
CH2_G	Artificial Ventilation	3	Everyday	LPG	✗	✓	✓	✗	✓	✗	✗
IH3_G	Natural Ventilation	3	Everyday	LPG	✗	✓	✓	✗	✓	✗	✗
IH4_G	Natural Ventilation	3	Everyday	LPG	✗	✓	✓	✗	✓	✗	✗
RH5_G	Natural Ventilation	3	Thrice a week	LPG	✓	✓	✓	✗	✓	✓	✓
RH6_G	Natural Ventilation	2	Everyday	LPG	✗	✓	✓	✗	✗	✗	✗

a) Tezpur

Households	Residential Age	Resident Age	Floor type	Area (m^2) of sampled room	Ceiling	No of Rooms	Doors leading to outdoors	Windows	No of Windows open	Distance from the main Road	Distance from the kitchen (m)
RHu1_T	12	12	Concrete	9.29	Concrete	5	1	4 pane window-1	2	30 m	0.61
RHu2_T	30	30	Concrete	12.08	Concrete	3	1	2 pane window-1	1	2200 m	2.44
RHu3_T	5	2	Tiles	11.15	Concrete	5	1	4 pane window-1	0	60 m	2.13
CH4_T	3	3	Tiles	15.72	Concrete	3	2	0	0	33.5 m	Adjacent
CH5_T	3	2	Tiles	15.72	Concrete	4	2	0	0	33.5 m	Adjacent
CH6_T	3	1	Tiles	15.72	Concrete	3	2	0	0	52 m	Adjacent
RHr7_T	11	11	Tiles	32.52	Concrete	4	2	3 pane window-1	2	800 m	Adjacent
RHr8_T	10	3	Tiles	32.52	Concrete	4	3	3 pane window-1	2	1100 m	Adjacent

Households	Ventilation	No of Occupants	Sweeping-Mopping Frequency	Fuel	Smoking inside home	Incense Burning	Mosquito Repellent (Burning)	Pets present	Spray product Used	Plumbing problem	Mould present
RHu1_T	Natural Ventilation	3	Everyday	LPG	✗	✓	✓	✗	✓	✗	✗
RHu2_T	Natural Ventilation	4	Everyday	LPG	✗	✓	✓	✗	✗	✓	✓
RHu3_T	Natural Ventilation	4	Everyday	LPG	✗	✓	✓	✗	✓	✗	✗
CH4_T	Natural Ventilation	2	Thrice a week	LPG	✓	✓	✓	✗	✓	✓	✓
CH5_T	Natural Ventilation	2	Everyday	LPG	✗	✓	✓	✗	✓	✓	✓
CH6_T	Natural Ventilation	3	Everyday	LPG	✗	✓	✓	✗	✓	✓	✓
RHr7_T	Natural Ventilation	4	Everyday	LPG	✗	✓	✓	✗	✗	✗	✗
RHr8_T	Natural Ventilation	4	Everyday	LPG	✗	✓	✓	✗	✗	✗	✗

relatively recent residential age of three years, reported plumbing problems. This may be attributed to substandard plumbing installations, even in newly constructed buildings. During field visits, occupants of these households reported issues such as damaged water pipes. Additionally, factors such as thermal bridging and surface temperatures falling below the dew point were identified as critical in contributing to indoor mould growth [36].

4.2.2 Temperature and Relative Humidity

Temperature and relative humidity of households in Guwahati and Tezpur are given in Table 4.5. The average indoor temperature recorded in Guwahati households was 23.55 ± 3.00 °C, with a relative humidity of 71.52 ± 3.46%. Similarly, the Tezpur households exhibited an average temperature of 22.85 ± 2.78 °C and a relative humidity of 69.59 ± 5.92%. The average temperature was below ASHRAE standard 62.1 recommended comfort limits of 27 °C. The lower temperature could primarily be attributed to the fact that measurements were conducted between November and April, prior to the onset of the peak summer season. However, the relative humidity levels exceeded the recommended standard threshold at all households. Elevated indoor humidity and damp conditions within buildings can create favorable conditions for microbial growth, which may pose health risks to occupants [37]. Indraganti [38] and Sudarsanam and Kannamma [39] reported lower mean relative humidity levels in indoor household environments in Hyderabad and Tamil Nadu, respectively, compared to those observed in the present study.

4.2.3 Concentrations of $PM_{2.5}$

$PM_{2.5}$ concentrations were assessed in all households of Guwahati and Tezpur. The overall average concentrations of $PM_{2.5}$ was 206.17 ± 106.85 µg/m³ in Guwahati households and 41.01 ± 21.95 µg/m³ for Tezpur households. $PM_{2.5}$ concentrations in Guwahati are significantly higher than Tezpur ($p < 0.001$). The mean difference is approximately 165 µg/m³ between the two locations, with concentrations in Guwahati being about five times higher than in Tezpur. A one-way Anova analysis revealed a statistically significant difference among households at $p < 0.001$. Consequently, Tukey Post-hoc analysis was done that indicated that households not sharing a common alphabet differed significantly at $p < 0.05$ (Fig. 4.9).

In Guwahati, the $PM_{2.5}$ concentrations in all households exceeded WHO's 24-hour guideline value of 15 µg/m³. These indicate a significant deviation from established air quality benchmarks and suggest a potential risk to occupant health. While in Tezpur, $PM_{2.5}$ concentrations

Table 4.5 Levels of temperature and relative humidity averaged over the entire day, in Guwahati and Tezpur Households

Tezpur Households				**Guwahati Households**			
Locations	**Days**	**Temperature [°C]**	**Relative Humidity [%]**	**Locations**	**Days**	**Temperature [°C]**	**Relative Humidity [%]**
RHu1_T	Day 1	23.12	64.07	**CH1_G**	Day 1	21.83	71.26
	Day 2	20.6	75.84		Day 2	21.41	74.44
	Day 3	28.21	60.02		Day 3	21.12	74.92
	Average	**23.98 ± 3.88**	**66.64± 8.22**		**Average**	**21.45 ± 0.36**	**73.54± 1.99**
RHu2_T	Day 1	23.95	68.83	**CH2_G**	Day 1	21.75	70.43
	Day 2	24.93	65.9		Day 2	21.15	70.72
	Day 3	24.94	67.54		Day 3	20.81	74.13
	Average	**24.61 ± 0.57**	**67.42± 1.47**		**Average**	**21.24 ± 0.48**	**71.76± 2.05**
RHu3_T	Day 1	20	69.07	**IH3_G**	Day 1	20.76	73.47
	Day 2	20.89	64.78		Day 2	20.8	73.05
	Day 3	26.26	63.44		Day 3	20.93	74.37
	Average	**22.39 ± 3.39**	**65.76± 2.94**		**Average**	**20.83 ± 0.09**	**73.63± 0.67**
CH4_T	Day 1	19.07	77.02	**IH4_G**	Day 1	22.7	75.36
	Day 2	19.17	76.36		Day 2	22.54	73.59
	Day 3	20.94	80.2		Day 3	22.81	75.33
	Average	**19.73 ± 1.05**	**77.86± 2.05**		**Average**	**22.68 ± 0.13**	**74.76± 1.01**
CH5_T	Day 1	23.87	57.15	**RH5_G**	Day 1	27.97	69.55
	Day 2	23.75	64.64		Day 2	27.71	69.23
	Day 3	23.68	77.91		Day 3	26.33	71.6
	Average	**23.77 ± 0.10**	**66.57± 10.51**		**Average**	**27.34 ± 0.88**	**70.13± 1.28**
CH6_T	Day 1	20.9	74.24	**RH6_G**	Day 1	28.38	65.12
	Day 2	20.27	77.06		Day 2	27.74	64.59
	Day 3	20.99	68.72		Day 3	27.17	66.15
	Average	**20.72 ± 0.39**	**73.34± 4.24**		**Average**	**27.76 ± 0.61**	**65.29± 0.79**
RHr7_T	Day 1	20.76	69.79				
	Day 2	20.74	69.59				
	Day 3	21.26	73.28				
	Average	**20.92 ± 0.30**	**70.89± 2.08**				
RHr8_T	Day 1	26.19	68.94				
	Day 2	28.64	69.52				
	Day 3	25.36	66.3				

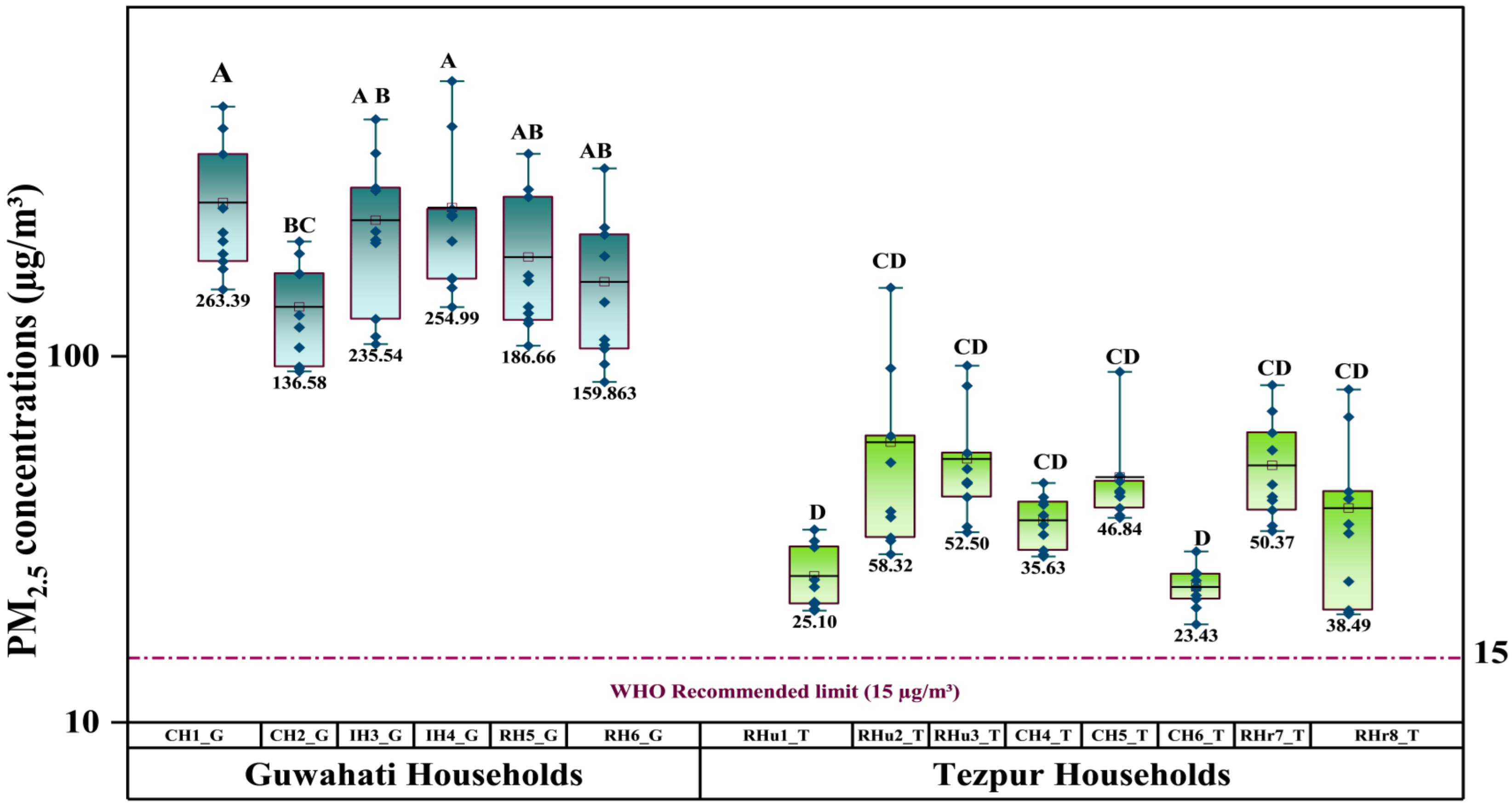


Fig. 4.9 $PM_{2.5}$ concentrations in different households located in Guwahati and Tezpur

in all households exceeded the WHO's 24-hour recommended limit. An overall significant positive correlation (R^2 = 0.99) at $p < 0.001$ was observed between indoor and outdoor $PM_{2.5}$ concentrations in households of Tezpur and Guwahati. These findings suggest that outdoor sources do have significant contribution to indoor $PM_{2.5}$ concentrations [7].

In Guwahati, the average concentrations of $PM_{2.5}$ exhibited variation across household categories, with households in industrial area recorded the highest average concentration (245.26 µg/m³), followed by households in commercial area (199 µg/m³) and households in residential area (173.26 µg/m³). Despite being located in a commercial area, household 2 (CH2_G) recorded the lowest $PM_{2.5}$ concentrations among all the households in Guwahati. This may be due to the use of air conditioning systems, which can reduce indoor $PM_{2.5}$ concentrations by trapping $PM_{2.5}$ in filters [40, 41]. In general, households situated near busy roads and areas of intense urban activity exhibited higher $PM_{2.5}$ concentrations especially in naturally ventilated homes [42]. These locations are characterized by elevated emissions from vehicular traffic and industrial operations, leading to the infiltration of $PM_{2.5}$ into indoor environments and, consequently increased exposure levels [7, 15]. As a result, industrial and commercial areas tend to exhibit higher indoor $PM_{2.5}$ concentrations compared to those observed in residential zones. While in Tezpur, the overall average $PM_{2.5}$ concentrations were found to be highest in urban residential households (45.56 µg/m³), followed by rural residential households (43.49 µg/m³), and lowest in commercial households (34.90 µg/m³). The elevated $PM_{2.5}$ concentrations in urban residential areas may be attributed to their proximity to densely populated urban environments, including busy roads, internal streets, and semi-commercial spaces, all of which are potential sources of particulate emissions. In the case of rural residential households, the relatively high $PM_{2.5}$ concentrations may be influenced by ongoing construction activities within the Tezpur University campus, which can contribute to increased $PM_{2.5}$ infiltration into indoor settings.

Table 4.6 shows the I/O ratio for both Tezpur and Guwahati households. An I/O ratio greater than 1 was observed in twelve households, suggesting the presence of potential indoor sources and human activities contributing to elevated indoor $PM_{2.5}$ concentrations. Conversely, I/O ratios below 1 were recorded for two households-RH6_G and CH4_T, with values 0.84 and 0.98, respectively. These ratios indicate that indoor $PM_{2.5}$ concentrations were lower than outdoor concentrations, implying minimal influence from indoor sources and a relatively higher impact from outdoor air. Indoor sources of $PM_{2.5}$ include cooking, smoking, and the burning of incense sticks or other smoke-generating materials.

Previous studies have identified cooking emissions as a major contributor to indoor particulate matter. Specifically, $PM_{2.5}$ emissions during oil heating have been associated with the release of heavy metals and organic compounds, thereby significantly contributing to IAP [43-45]. Studies have further demonstrated that cooking-related particles are not confined to the kitchen, but tend to spread throughout the indoor environment. This diffusion is often facilitated by the opening of kitchen and inner doors, which enables the movement of $PM_{2.5}$ into other parts of the house [46, 47]. The present study showed that 64.3% kitchens were adjacent to the

Table 4.6 The indoor-to-outdoor (I/O) ratios of $PM_{2.5}$ for households in both Guwahati and Tezpur

	Household	I/O RATIO		Household	I/O RATIO
Guwahati Households			Tezpur Households	RHu1_T	**1.9**
	CH1_G	**1.44**		RHu2_T	**1.03**
	CH2_G	**1.14**		RHu3_T	**1.83**
	IH3_G	**1.23**		CH4_T	**0.98**
	IH4_G	**1.47**		CH5_T	**1.61**
	RH5_G	**1.05**		CH6_T	**2.03**
	RH6_G	**0.84**		RHr7_T	**1.82**
				RHr8_T	**1.25**

sampling room. Incense burning is a traditional practice prevalent in many cultures, including in India. Additionally, research has shown that the combustion of incense sticks constitutes a significant source of $PM_{2.5}$, posing potential health risks, particularly to the respiratory system [48]. Additionally, the use of mosquito repellents, particularly in the form of coils or incense, has also been identified as an important indoor source of $PM_{2.5}$ [49]. In the present study, all surveyed households were observed to engage in incense burning and the use of mosquito repellents, both of which may have contributed to elevated indoor $PM_{2.5}$ concentrations.

The diurnal pattern of $PM_{2.5}$ are shown for both Guwahati households and Tezpur households in Fig. 4.10 and 4.11. In general, a noticeable rise in $PM_{2.5}$ concentrations was observed during the morning hours, particularly between 10:00 hours and 12:00 hours. This increase may be attributed to routine household activities such as cooking and cleaning, which are commonly performed during this time. Similarly, $PM_{2.5}$ concentrations were consistently higher during the evening hours, especially between 17:00 hours and 19:00 hours. This evening peak is likely associated with the return of all household members after their work or other activities, dinner preparation, reduced ventilation due to the closing of windows and doors after dark, and evening *puja* (prayer) rituals, which often involve the burning of incense sticks and Indian frankincense. Furthermore, field observations indicated that the use of mosquito coils and incense sticks was also prevalent during evening hours, further contributing to increased indoor $PM_{2.5}$ concentrations. These findings suggest that a combination of domestic routines and cultural practices play a significant role in shaping the diurnal variation of $PM_{2.5}$. Similar morning and evening peaks of $PM_{2.5}$ were reported by Saetae et al. [50], Both et al. [51] and Olszowski [52]. Notably, both indoor and outdoor $PM_{2.5}$ concentrations demonstrated similar diurnal trends, characterized by peaks in the morning and evening hours (Fig. 4.12 a and b). This observation aligns with findings by Singh et al. [53], who reported distinct diurnal patterns in outdoor $PM_{2.5}$ concentrations across five megacities in India, with elevated concentrations during the morning and evening and the lower concentrations in the late afternoon. In the case of Tezpur, outdoor $PM_{2.5}$ data were available for only an eight-hour interval due to equipment malfunction; therefore, the trend analysis was confined to this specific period, as illustrated in Fig. 4.13. The observed similarity between indoor and outdoor $PM_{2.5}$ concentrations is further validated by a strong and statistically significant correlation ($R^2 = 0.99$, $p < 0.001$).

4.2.4 Concentrations of CO_2

CO_2 concentrations were analyzed across households in both Guwahati and Tezpur. The overall average CO_2 concentrations were 575.52 ± 98.87 ppm in Guwahati and 556.76 ± 130.21 ppm in Tezpur. An independent sample t-test revealed no statistically significant difference between the mean CO_2 concentrations of the two locations ($p = 0.35$). However, a one-way ANOVA revealed significant differences among different household categories ($p < 0.001$). Subsequent Tukey post-hoc analysis showed that households not sharing a common grouping alphabet differed significantly at $p < 0.05$ (Fig. 4.13). In Guwahati, the highest CO_2 concentrations were observed in households located in industrial areas (640.88 ± 78.22 ppm), followed by those in commercial areas (606.75 ± 88.12 ppm), and the lowest concentrations in residential areas (478.93 ± 33.64 ppm). A similar trend was observed in Tezpur, where CO_2 concentrations were highest in households situated in commercial areas (625.97 ± 150.97 ppm), followed by urban residential households (534.23 ± 116.56 ppm), and rural residential households (486.75 ± 38.01 ppm). These elevated concentrations are likely influenced by the urban environment, where households in urban residential, commercial, and industrial areas are situated in densely populated settings with limited ventilation and close proximity to markets, highways, and heavy traffic [35, 54]. However, all measurements in the present study indicated that the CO_2 concentration concentrations fall within the established standards mentioned by ASHRAE standard 62.1 (1000 ppm).

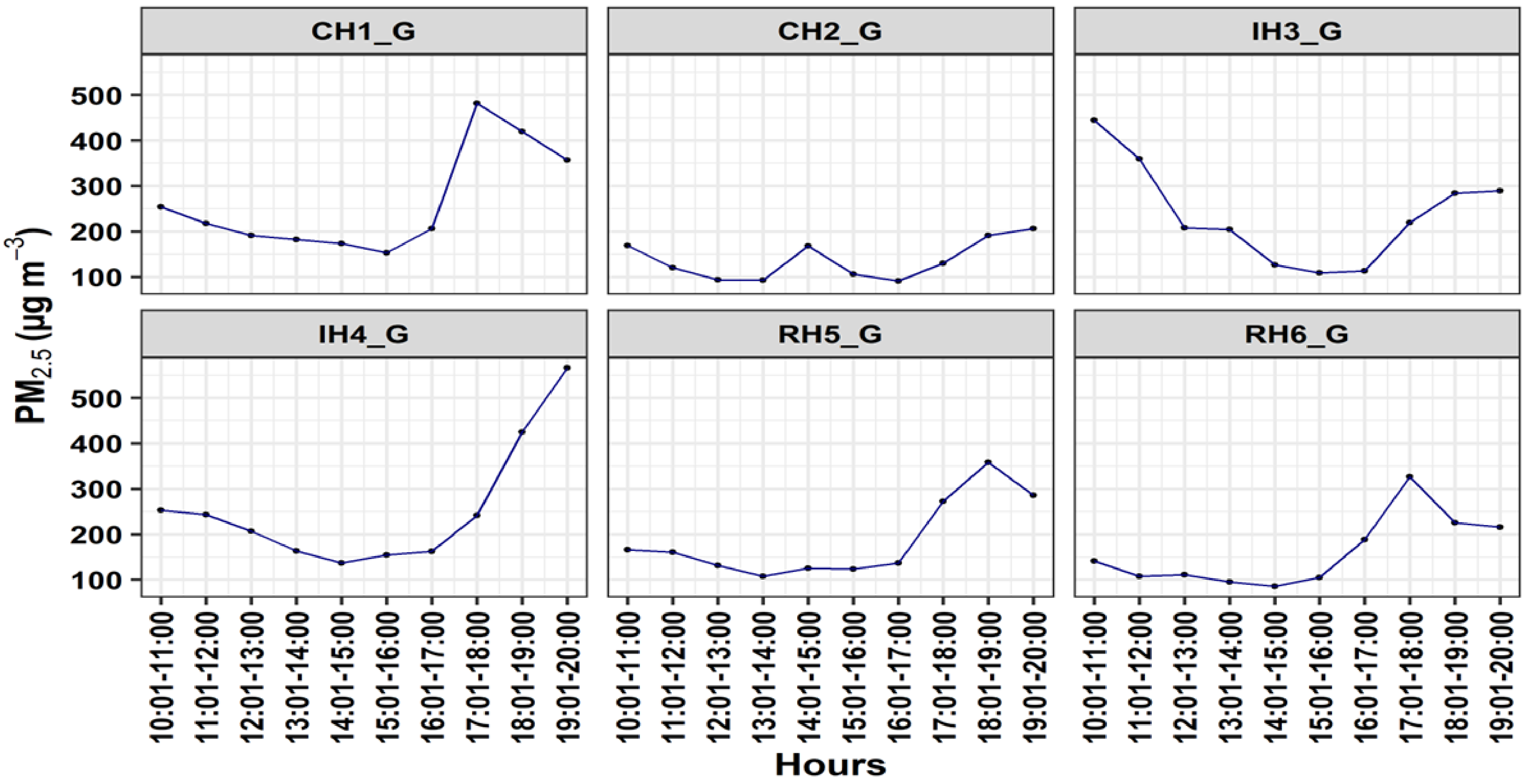


Fig. 4.10 Diurnal variation of $PM_{2.5}$ concentrations averaged over three days across six households in Guwahati, representing commercial, industrial, and residential areas

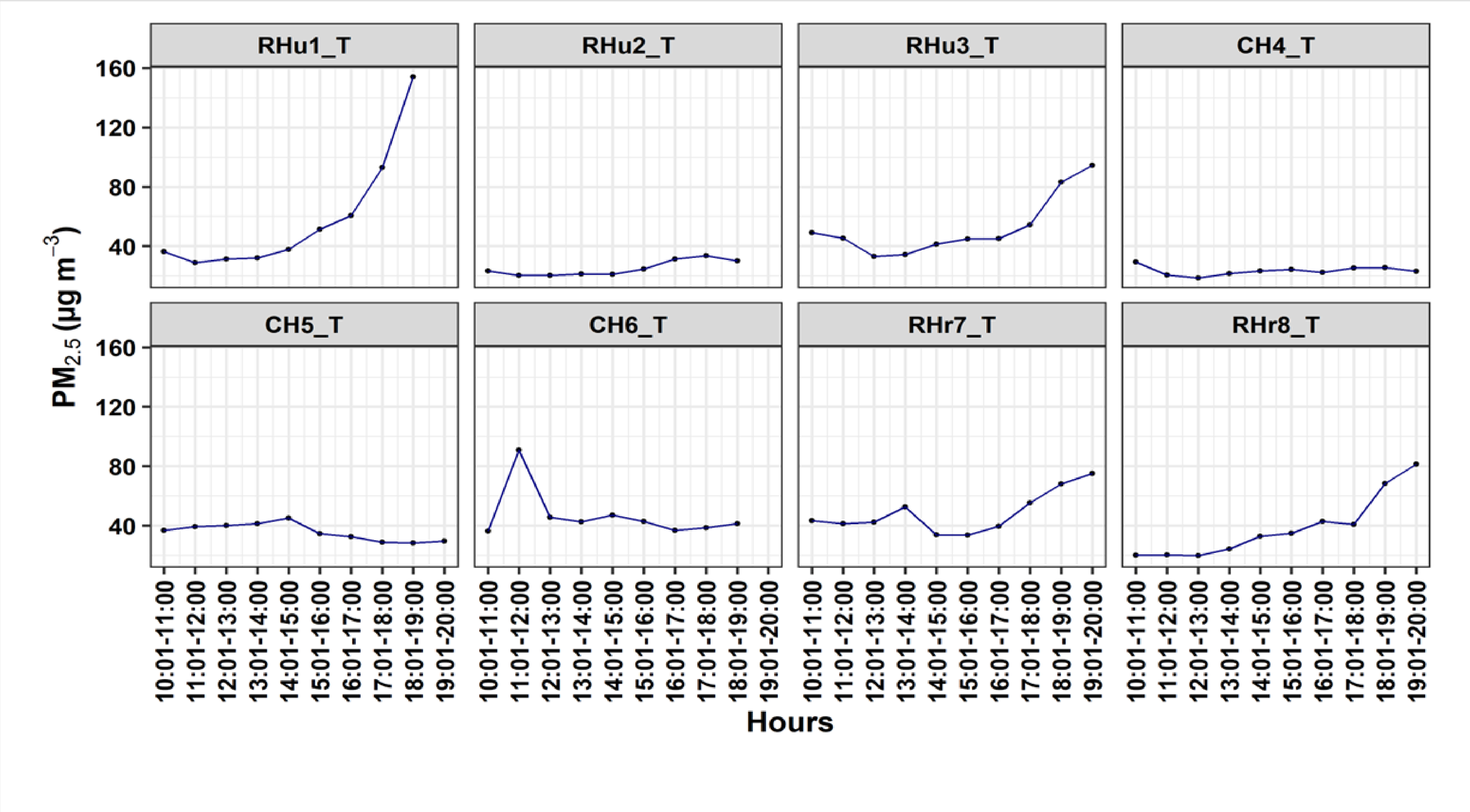
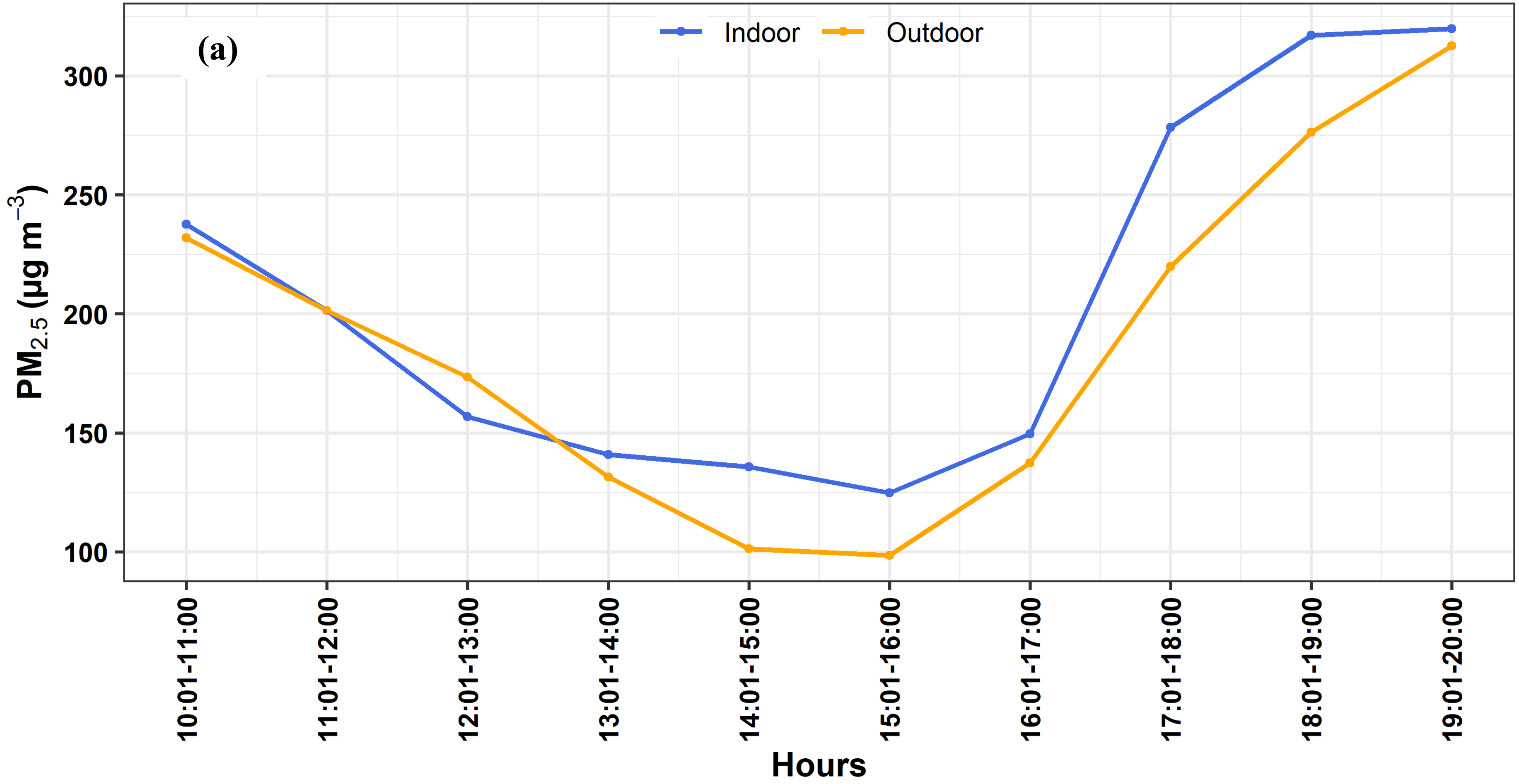


Fig. 4.11 Diurnal variation of $PM_{2.5}$ concentrations averaged over one day across eight households in Tezpur, representing urban residential, commercial, and rural residential areas.


(a)
Indoor
Outdoor
PM2.5 (μg m−3)
300
250
200
150
100
10:01-11:00
11:01-12:00
12:01-13:00
13:01-14:00
14:01-15:00
15:01-16:00
16:01-17:00
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18:01-19:00
19:01-20:00
Hours

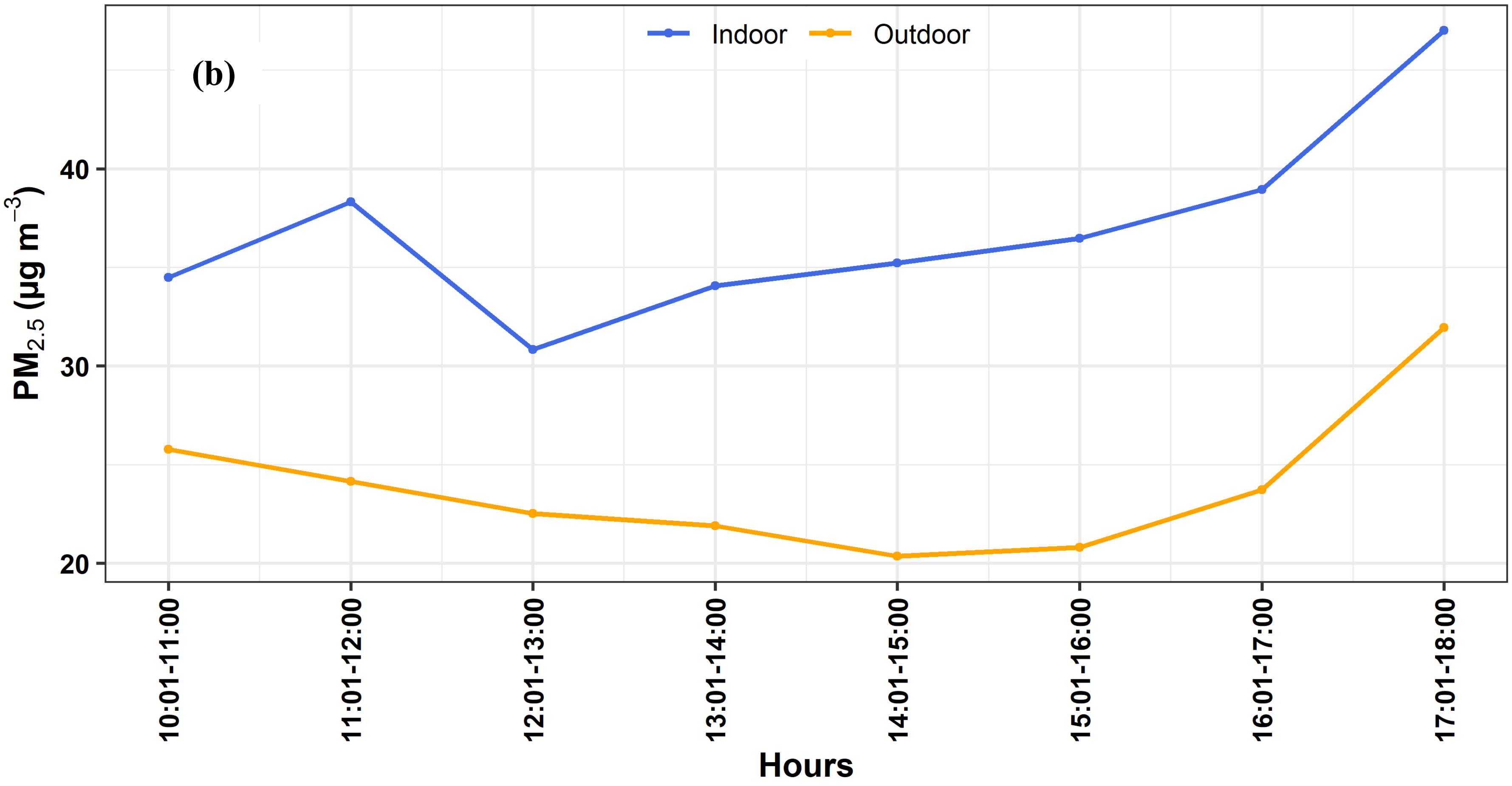


Fig. 4.12 Average hourly trend of $PM_{2.5}$ concentrations in households: **(a) Guwahati** (average of 6 households) and **(b) Tezpur** (average of 8 households) measured over the sampling period

The I/O ratio of CO_2 was greater than 1 for all households (Table 4.7), except for Household 2 in the commercial area of Guwahati (CH2_G). This household was the only one equipped with an air conditioning system, which may have facilitated better air circulation and ventilation, thereby maintaining an I/O ratio below 1 (0.98). However, despite this lower ratio, the indoor CO_2 concentration in CH2_G was still higher than those recorded in households located in both the residential areas of Guwahati and rural residential areas of Tezpur, which had I/O ratios greater than 1. This demonstrates that a lower I/O ratio does not necessarily indicate lower indoor CO_2 concentrations, as it also depends on the outdoor concentrations and other structural characteristics that influence indoor air accumulation. The I/O ratio greater than 1 suggest the presence of considerable indoor CO_2 sources and inadequate ventilation [55]. Several factors influence the I/O ratio of CO_2, including site type (residential, commercial, or industrial), the day of the week, and proximity to external pollution sources [56]. Moreover, a strong positive correlation was observed between indoor and outdoor CO_2 concentrations averaged across all households ($R^2 = 0.85$, $p < 0.001$), suggesting that outdoor CO_2 concentrations also play a significant role in shaping indoor air quality [57].

Diurnal variations of indoor CO_2 concentrations are presented in Fig. 4.14 and Fig. 4.15. Indoor CO_2 concentrations were consistently higher in households located in commercial and industrial areas of both Guwahati and Tezpur, particularly during the late afternoon to evening hours. This trend suggests inadequate ventilation and elevated indoor emissions, likely resulting from activities such as incense stick burning and the use of mosquito repellents. In contrast, households in the residential areas of Guwahati (RH5_G, RH6_G) and the rural residential areas of Tezpur (RHr7_T, RHr8_T) maintained lower and more stable CO_2 concentrations highlighting the benefits of natural ventilation, reduced human activity. These households consistently exhibited minimal fluctuations in indoor CO_2 concentrations throughout the day. However, a similar trend was not observed for $PM_{2.5}$ concentrations. This discrepancy may be attributed to localized sources of $PM_{2.5}$ such as proximity to cooking area, unpaved roads, or nearby construction activities. Unlike CO_2, which primarily reflects human respiration and indoor crowding, $PM_{2.5}$ levels are influenced by a broader range of indoor and outdoor activities and materials, making them more variable. Urban residential households in Tezpur (RHu1_T - RHu3_T) showed moderate increases through the day, with evening concentrations nearing 600-800 ppm, pointing to increasing indoor accumulation. Notably, significant variation was observed even within the same household category.

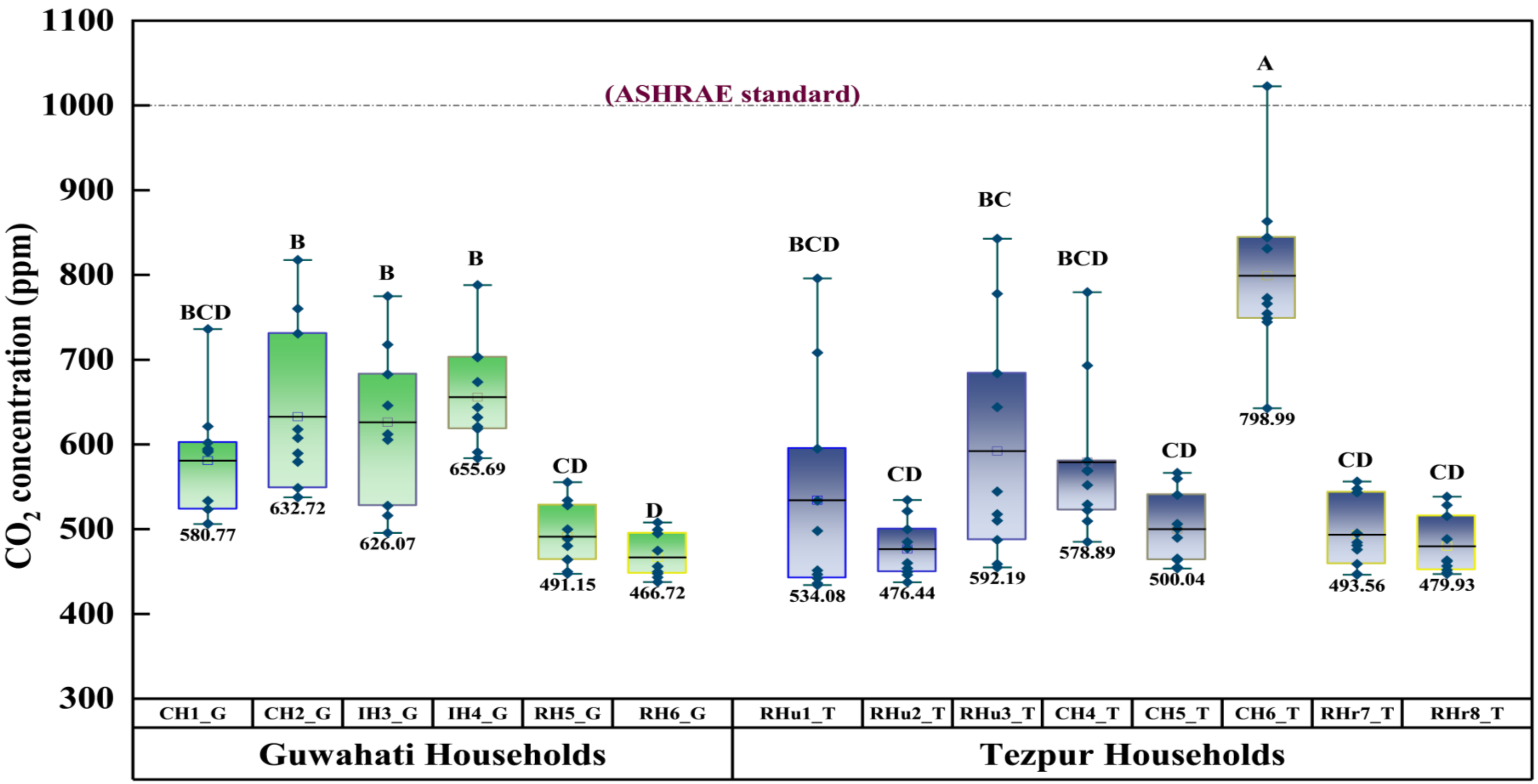


Fig. 4.13 CO_2 concentrations in different households located in commercial, industrial, and residential areas of Guwahati and urban residential, commercial and rural residential areas of Tezpur

For example, among the commercial households in Tezpur, CH6_T recorded the highest indoor CO_2 concentrations (1022.53 ppm) at around 11:00 hours, which remained elevated for the rest of the monitoring period, indicating continuous indoor emissions and insufficient ventilation. To address elevated indoor CO_2 concentrations, the implementation of proper ventilation systems and air conditioning is essential, as these measures promote air circulation and contribute to healthier IAQ [35].

Table 4.7 The indoor-to-outdoor (I/O) ratios of CO_2 for households in Guwahati and Tezpur

	Household	I/O RATIO		Household	I/O RATIO
Guwahati Households			Tezpur Households	RHu1_T	**1.18**
	CH1_G	**1.30**		RHu2_T	**1.02**
	CH2_G	**0.90**		RHu3_T	**1.25**
	IH3_G	**1.36**		CH4_T	**1.31**
	IH4_G	**1.26**		CH5_T	**1.05**
	RH5_G	**1.07**		CH6_T	**1.82**
	RH6_G	**1.02**		RHr7_T	**1.07**
				RHr8_T	**1.10**

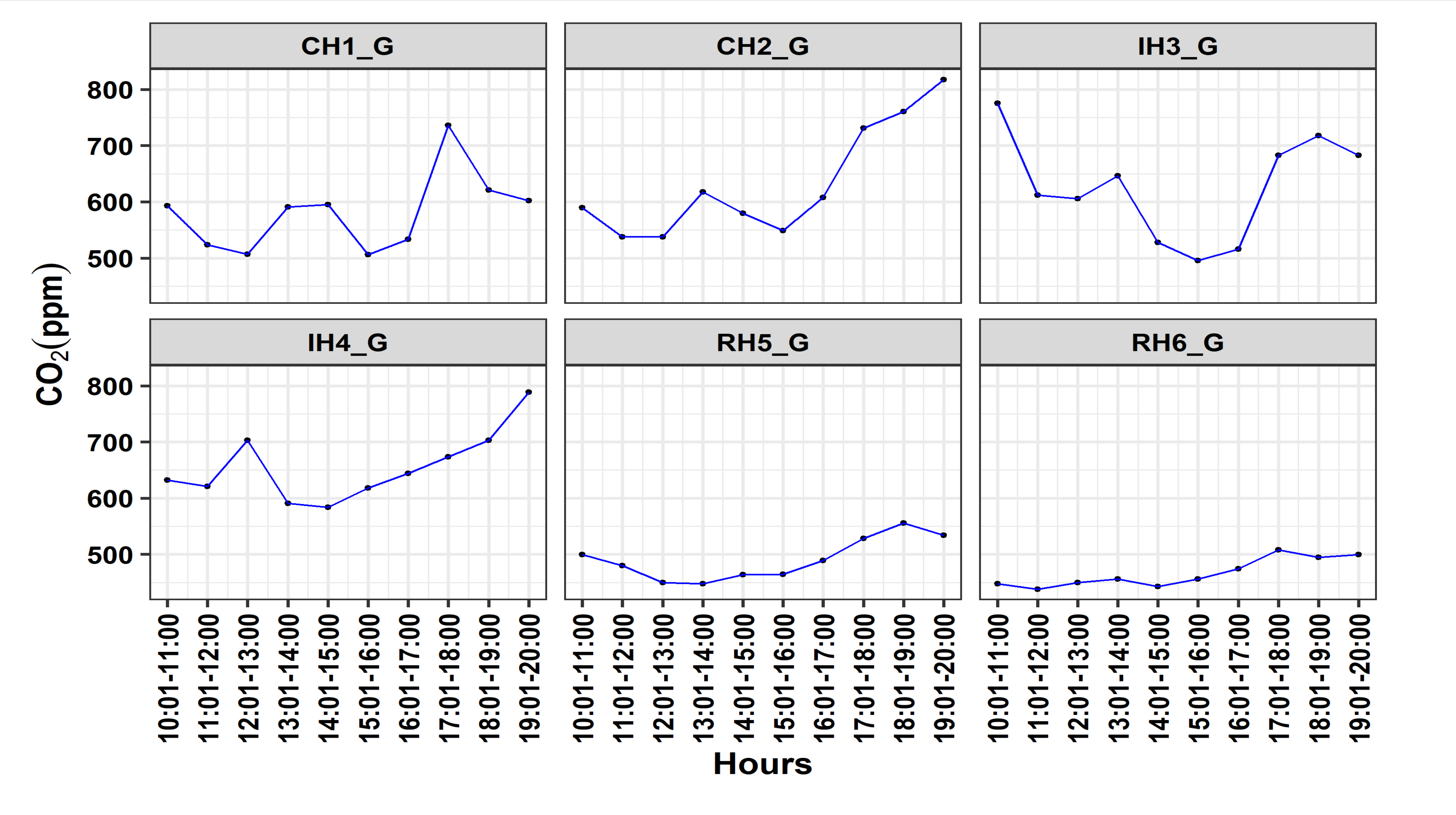


Fig. 4.14 Diurnal variation of CO_2 concentrations averaged over three days across six households in Guwahati, representing commercial, industrial, and residential areas

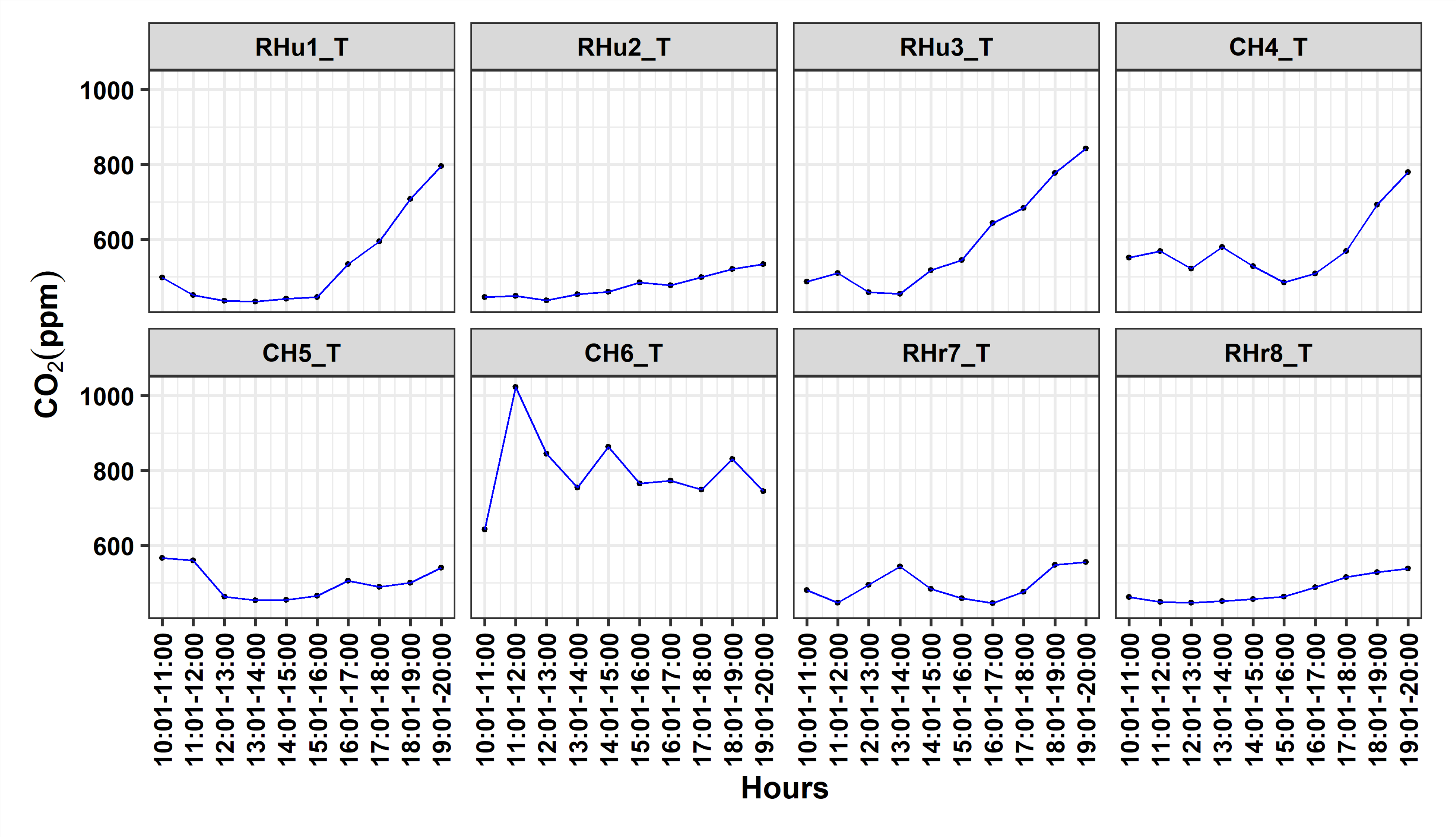


Fig. 4.15 Diurnal variation of CO_2 concentrations averaged over three days across six households in Tezpur, representing urban residential, commercial, and rural residential areas

4.2.5 Application of MPPD Model

The MPPD model was applied to evaluate $PM_{2.5}$ deposition in the respiratory tracts of occupants in households of Tezpur and Guwahati. Deposition fractions were analyzed across different age groups, including children (8–9 years), adolescents (14 and 18 years), adults (21-year-old males and females), and the elderly (70-year-old males and females), as presented in Fig. 4.16.

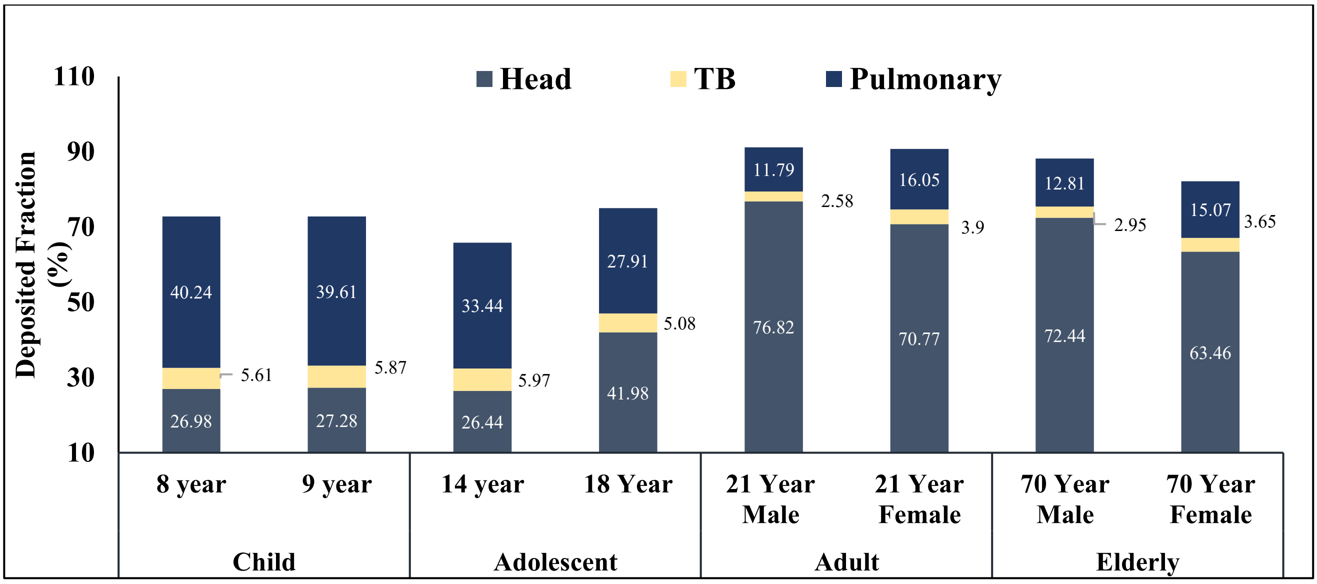


Fig. 4.16 Regional Deposition of $PM_{2.5}$ in the human respiratory tract [Head Region, TB Region (Tracheobronchial), Pulmonary Region] simulated using the MPPD model for Households of Guwahati and Tezpur across different age groups and gender

The total deposition of inhaled $PM_{2.5}$ ranged from 65.85 - 91.19% with higher deposition in adults and elderly compared to children and adolescents. At a given age, deposition may vary based on several factors, including gender, the structure of the lungs, the breathing cycle, breathing scenario, and body posture [58]. In this study, the highest pulmonary deposition of $PM_{2.5}$ particles was observed in 8-year-old group (40.24%), followed by 9-year-old group (39.61%). These values exceeded the deposition rates recorded in all other age and gender categories, indicating greater vulnerability among younger children to deeper respiratory tract exposure [27, 31]. Higher deposition in children is attributed to their faster breathing rates, smaller alveolar structures, along with relatively larger lung surface area promoting diffusion of finer particles in lower respiratory tract [34, 59]. Adults, in contrast, show lower deposition in pulmonary region, likely because of their larger airways and slower breathing rates, which limit particle retention [60, 61].

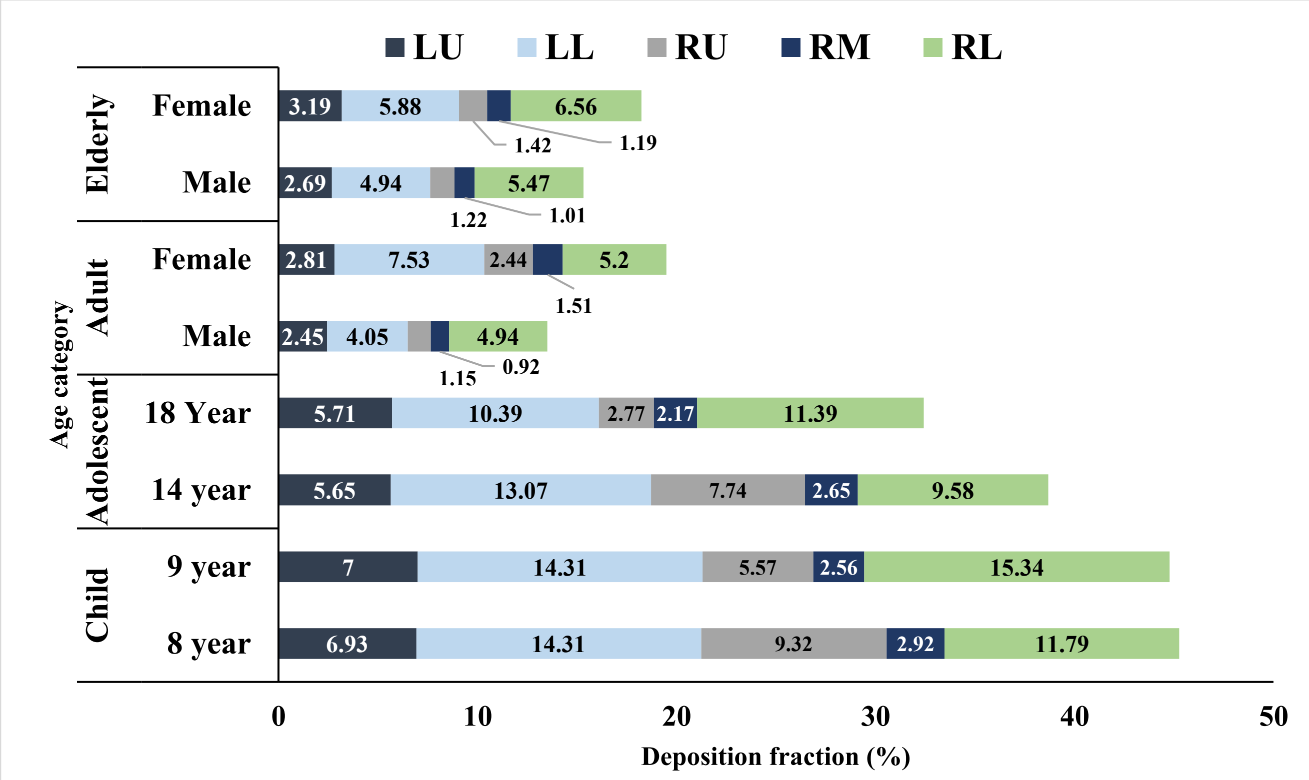


Fig. 4.17 $PM_{2.5}$ Deposition Across Lung Lobes [Left Upper (LU), Left Lower (LL), Right Upper (RU), Right Middle (RM), Right Lower (RL)] predicted by MPPD model for households of Guwahati and Tezpur across different age groups and gender

Fig. 4.17 illustrates the lobar distribution of $PM_{2.5}$, which indicated that children were the most affected group, exhibiting the highest deposition levels. This finding suggests an elevated risk of chronic obstructive pulmonary disease (COPD) and increased respiratory morbidity in children [27, 62, 63]. Among the lung lobes, the right and left lower lobes exhibited the highest $PM_{2.5}$ deposition, primarily due to gravitational settling and their greater volume compared to the upper and middle lobes, which facilitates more particle accumulation in these regions [30, 64]. Further, deposition mass and deposition density per unit area was obtained from the MPPD model for occupants in households of Guwahati and Tezpur as shown in Fig. 4.18 and Fig. 4.19. $PM_{2.5}$ deposition tends to increase with age due to larger tidal volumes and an expanded lung surface area, which enable greater air intake. However, in elderly individuals around 70 years of age, this trend reverses, as tidal volumes begin to decline, leading to reduced $PM_{2.5}$ deposition [31, 33, 34, 65].

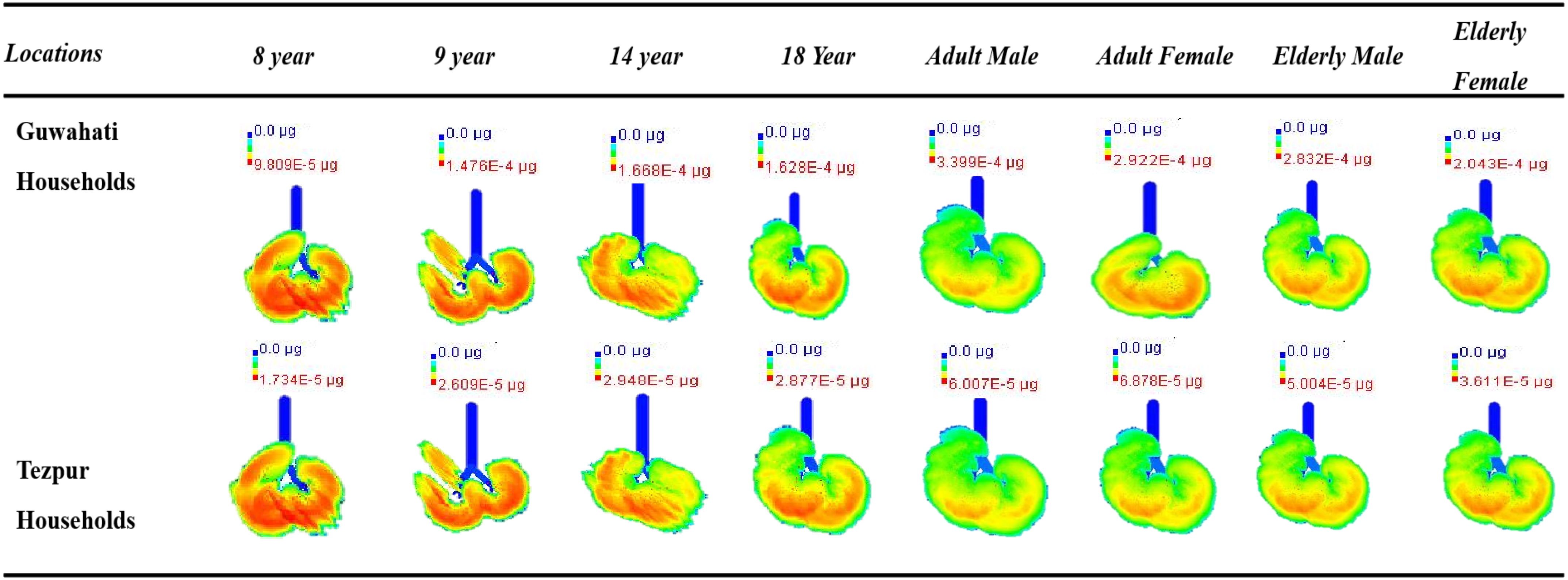


Fig. 4.18 Deposition of $PM_{2.5}$ mass (µg) deposition in human lungs for different age and gender across occupants of Guwahati and Tezpur households

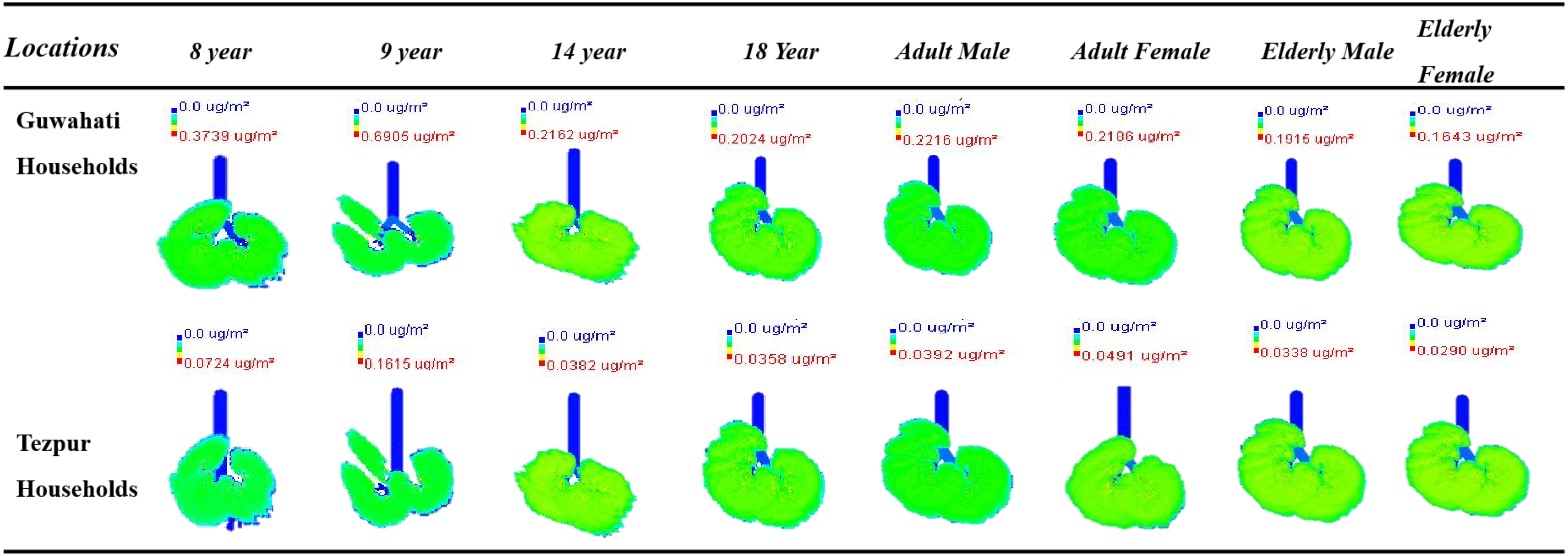


Fig. 4. 19 Deposition of $PM_{2.5}$ per unit surface area (µg/m²) in human lungs for different age and gender across occupants of Guwahati and Tezpur households

Deposited mass per unit area was found to be highest for children (specifically for 9-year-old) and lowest in adults. It is attributed to the large surface area to volume ratio of children compared to adults. Similar results were obtained by Khan et al. [32] and Manojkumar et al. [65]. Fig. 4.20 and Fig. 4.21 demonstrate that occupants of households in Guwahati were exposed to 4.25 to 5.66 times higher total deposited mass and deposited mass per unit area than those in Tezpur. This suggests that residents in Guwahati are subjected to significantly greater indoor exposure to $PM_{2.5}$.

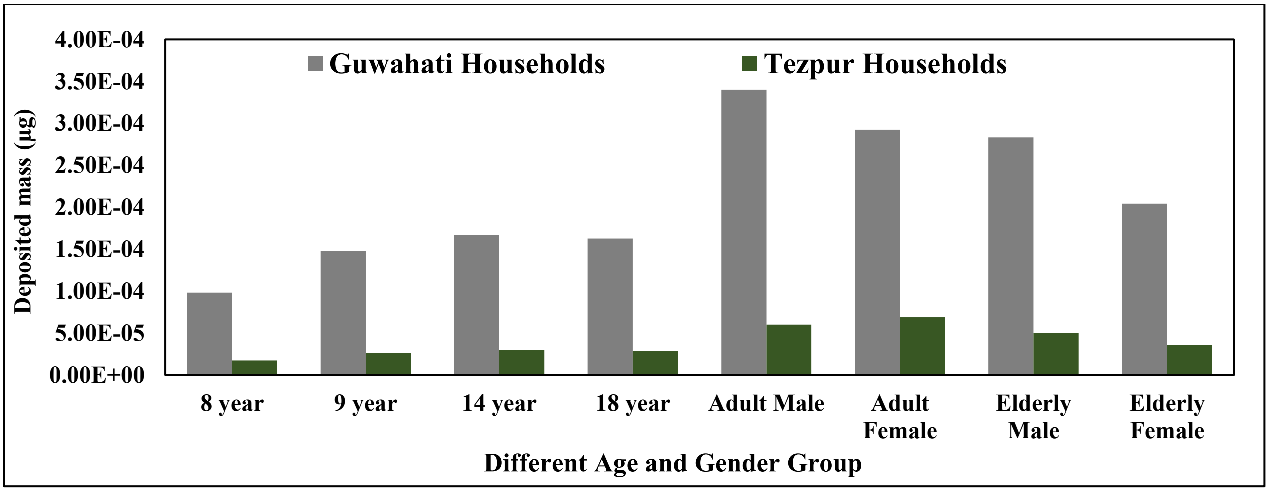


Fig. 4.20 Deposited mass of $PM_{2.5}$ (µg) across age groups and gender in occupants of Guwahati vs. Tezpur households

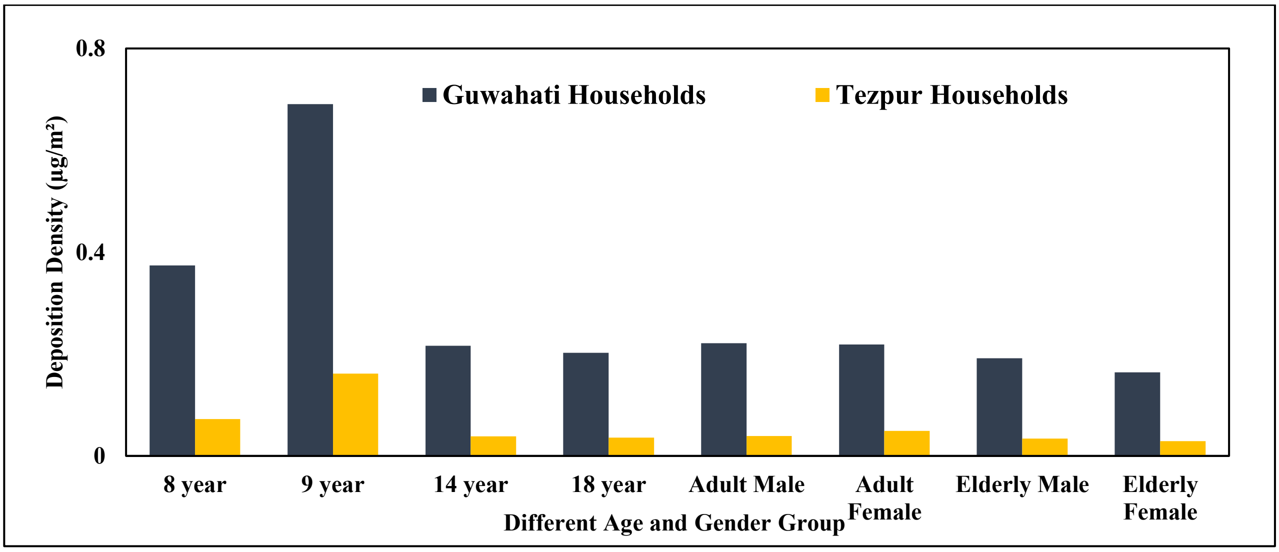


Fig. 4.21 Deposited mass per unit surface area (µg/m²) of $PM_{2.5}$ across age groups and gender in occupants of Guwahati vs. Tezpur households

4.3 Characterization of Settled Dust (SD) in University

Elemental concentrations in SD from various microenvironments across both universities were analyzed. The dust composition reflects contributions from both indoor and outdoor sources, serving as a valuable indicator of pollution origins. Given that students spend a significant amount of time in classrooms, libraries, and common areas, prolonged exposure to contaminated dust may pose significant health risks.

4.3.1 Elemental Concentrations

The elemental characterization of SD (mg/kg) was conducted across various microenvironments at CU and TU and are presented in Table 4.8 and Table 4.9 respectively. The overall average concentration at CU was higher (3610.50 ± 7744.05 mg/kg) than TU (3387.13 ± 8830 mg/kg); however, this difference was not statistically significant ($p = 0.7$). The average decreasing order of elements were Fe>Al>Cr>Mn>Ni>Mg>Pb>Cu>Zn>Co>Cd (CU) and Fe>Al>Mn>Cr>Cu>Mg>Pb>Ni>Zn>Co>Cd (TU). At CU, the microenvironments were classified as academic classrooms and labs, and the library complex, while at TU, they were categorized as academic classrooms and labs, and utility and social spaces.

In India, there is no prescribed limit for elemental concentrations in indoor dust. A few studies have reported the permissible limit of elements in Indian soil. Table 4.10 shows the background value of the soil for the elements, the concentration of elements in Indian soil, and previous published studies on deposited dust in educational institutions in India and abroad. Among all analyzed elements, Fe exhibited the highest concentrations both in CU (24,226.50 ± 4239.20 mg/kg) and TU (19,431.23 ± 3305.86 mg/kg), followed by Al with concentrations of 12,857.25 ± 5362.14 mg/kg in CU and 16,338.18 ± 18,693.98 mg/kg in TU. The Fe concentration exceeded concentrations reported by Nath et al. [15], Olujimi et al. [66], Ugwu and Ofomatah [67], Oyebanji et al. [68], Gohain and Deka [69], and Dubey et al. [70] and was comparable to that found by Famuyiwa and Entwistle [71] (Table 4.10). Al concentration, meanwhile, were lower than those reported by Dubey et al. [70], but comparable to concentrations found by Olujimi et al. [66]. However, the concentrations of both Fe and Al were considerably lower than their respective background soil values. These elements are primarily introduced into indoor settings through soil or road dust, which can be transported by wind and human activities [72-74]. Additionally, the presence of Al and Fe in indoor settled dust may also be attributed to vehicular sources, particularly from brake pad wear and exhaust emissions [75].

The present study also recorded the highest concentrations of Ni in SD at both CU and TU, exceeding concentrations reported by Nath et al. [15] in schools of Tezpur and Gohain and Deka [69] at Tezpur University. At CU, Ni concentrations were notably elevated in the library complex, particularly in the reference (LIB_RR) and stock (LIB_SR) rooms, which are infrequently cleaned and remain closed to regular student access, allowing dust to accumulate over time. The infiltration of outdoor air and lack of maintenance likely contributed to Ni buildup. Lin et al. [76] reported that regular cleaning significantly reduces heavy metal concentrations in indoor dust. At TU, Deka and Hoque [77] previously reported elevated Ni concentrations in PM_{10}, which were attributed to emissions from brick kilns located in nearby rural areas. Ismail et al. [78] also reported that brick kilns gradually release Ni into the atmosphere. Over time, as airborne particulate matter settles onto indoor surfaces, it may contribute to the accumulation of Ni in indoor SD. These findings suggest that the rural setting of Tezpur may be a contributing factor to the elevated Ni concentrations observed in indoor settled dust of Tezpur. The average concentration of Zn was 150.37 ± 45.11 mg/kg at CU and 61.32 ± 44.81 mg/kg at TU. The presence of Zn and Ni in indoor environments is likely influenced by the infiltration of outdoor polluted dust, particularly from traffic emissions and the abrasion of vehicle tires and components [15]. The relatively elevated Zn concentrations observed at CU may be due to its location in a densely populated urban center. Additionally, Zn's presence can also be attributed to sources such as white pigments in paints and electrode materials used in batteries [79].

Pb concentrations in the present study exceeded those reported in most previous studies (Table 4.10). However, they were comparable to findings by Moghtaderi et al. [73] in Shiraz, Iran, and by Al-Rawi et al. [80] at the University of Anbar, Iraq. The accumulation of Pb in classrooms and other university microenvironments may be attributed to paint usage and vehicular emissions [66, 67, 81]. Additionally, Tong and Lam [82] observed that wall paint color significantly influences heavy metal concentrations in indoor dust, with yellow paint associated with higher Cd, Cu, Pb, and Zn concentrations. The presence of Pb may also relate to building age, deteriorated wall surfaces, and floor fissures [83].

Cr concentrations in the present study were the highest among all studies included in Table 4.10. Between CU and TU, average Cr concentrations were notably higher at CU, primarily due to elevated concentrations in the SD collected from the reference and stock rooms of the library complex. Apart from these locations, Cr concentrations were lower or relatively similar across

Table 4.8 Elemental concentrations (mg/kg) in indoor settled dust of Cotton University [Here, CR= Classroom S=Science HSS=Humanities and Social Science LAB= Laboratory LIB=Library MH=Main Hall RR= Reference room SR= Stock room]

	Microenvironments	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe
Academic Classrooms and Lab	**CR1_S**	16626.00	121.92	826.20	65.64	28.81	133.14	243.24	8.36	234.66	267.00	22560.00
	CR2_S	24102.00	140.22	897.00	64.92	33.26	103.38	129.72	7.22	175.92	277.50	25122.00
	CR3_HSS	8268.00	127.50	736.20	65.28	27.02	109.80	163.14	7.18	180.00	233.88	20190.00
	CR4_HSS	10878.00	113.64	615.60	57.41	29.86	71.46	94.02	6.95	132.42	225.96	18918.00
	LAB5_S	14316.00	151.02	890.40	88.62	35.91	172.14	111.78	7.23	179.16	384.54	32256.00
	Average	14838.00 ± 6085.59	130.86 ± 14.85	793.08 ± 118.43	68.37 ± 11.82	30.97 ± 3.58	117.98 ± 37.44	148.38 ± 58.86	7.39 ± 0.56	180.43 ± 36.29	277.78 ± 63.50	23809.20 ± 5283.34
Library Complex	**LIB_MH**	9300.00	130.20	838.80	90.12	29.24	210.72	165.48	7.45	312.06	344.34	23826.00
	LIB_RR	9084.00	2738.40	760.80	1570.80	57.61	278.94	139.86	7.09	262.86	229.86	23232.00
	LIB_SR	10284.00	1409.40	840.00	925.80	50.05	200.04	155.70	7.22	363.48	151.26	27708.00
	Average	9556.00 ± 639.65	1426.00 ± 1304.18	813.20 ± 45.38	862.24 ± 742.38	45.63 ± 14.69	229.90 ± 42.80	153.68 ± 12.93	7.25 ± 0.18	312.80 ± 50.31	241.82 ± 97.09	24922.00 ± 2430.95
	Overall average	**12857.25 ± 5362.14**	**616.54 ± 967.16**	**800.63 ± 93.34**	**366.07 ± 571.28**	**36.47 ± 11.25**	**159.95 ± 68.41**	**150.37± 45.11**	**7.34 ± 0.44**	**230.07± 78.54**	**264.29 ± 73.10**	**24226.50 ± 4239.20**

Table 4.9 Elemental concentrations (mg/kg) in indoor settled dust of Tezpur University [CR=Classroom S=Science HSS=Humanities and Social Science L=Law E= Engineering M= Management LAB= Laboratory LIB=Library ET=Eatery AH=Auditorium Hall

	Microenvironments	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe
Academic Classrooms and Lab	**CR1_HSS**	7938.00	93.96	483.18	65.10	12.91	79.86	54.19	7.39	85.32	34.44	16248.00
	CR2_HSS	3471.60	101.58	537.90	50.17	17.24	58.99	39.50	4.54	84.12	153.78	19884.00
	CR3_HSS	34644.00	96.48	594.66	39.70	19.10	47.41	30.96	6.07	102.66	495.00	18504.00
	CR4_L	3559.20	128.88	897.00	73.50	24.91	323.34	63.72	5.74	392.22	139.20	20928.00
	CR5_E	4019.40	71.58	349.62	36.97	10.83	57.15	31.26	5.26	93.42	90.42	10560.00
	CR6_E	30654.00	101.40	603.00	43.23	19.31	59.73	33.95	6.39	118.98	204.12	18960.00
	CR7_S	5833.20	166.44	519.78	84.18	14.47	129.90	30.96	5.03	87.72	43.67	21330.00
	LAB8_S	67968.00	1144.20	715.80	418.56	29.50	421.08	193.32	30.28	363.36	475.92	23256.00
	CR9_M	3708.00	113.58	618.60	62.94	22.71	76.50	66.90	6.53	118.32	204.30	17322.00
	Average	17977.27 ± 22367.80	224.23 ± 346.00	591.06 ± 153.26	97.15 ± 121.59	19.00 ± 5.98	139.33 ± 136.39	60.53 ± 51.81	8.58 ± 8.18	160.68 ± 123.98	204.54 ± 170.55	18554.67± 3676.39
Utility and Social Spaces	**ET1**	19584.00	224.58	753.60	63.78	27.02	187.74	39.76	6.55	119.28	11.81	21732.00
	ET2	12684.00	187.92	739.80	51.40	24.52	83.70	40.94	5.78	104.10	27.36	21480.00
	AH3	13644.00	92.34	668.40	75.72	21.26	471.66	102.06	7.15	262.08	52.24	21618.00
	LIB4	4689.00	129.84	632.40	61.80	25.49	142.68	69.66	6.49	135.90	154.14	20784.00
	Average	12650.25 ± 6122.28	158.67 ± 58.96	698.55 ± 57.78	63.17 ± 9.97	24.57 ± 2.43	221.45 ± 172.16	63.10 ± 29.42	6.49 ± 0.56	155.34 ± 72.34	61.39 ± 64.04	21403.50 ± 425.66
	Overall Average	**16338.18 ± 18693.98**	**204.06± 285.78**	**624.13 ± 138.42**	**86.70± 100.73**	**20.71 ± 5.70**	**164.59 ± 146.17**	**61.32± 44.81**	**7.94 ± 6.76**	**159.04 ± 107.53**	**160.4± 158.57**	**19431.23 ± 3305.86**

Table 4.10 A comparison of elemental concentrations of the present study with other reported studies on settled dust in indoor classrooms in India and abroad

Location	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	Reference
Classrooms, Lab, Library Complex (Cotton University) (n=9)	12857.25	616.54	800.63	366.07	36.47	159.95	150.37	7.34	230.07	264.29	24226.5	Present study
Classrooms, Lab, Utility and Social Spaces (Tezpur University) (n=13)	16338.18	204.06	624.13	86.70	20.71	164.59	61.32	7.94	159.04	160.49	19431.23	Present study
Classrooms (Schools, Tezpur)	6069.20	20.07	223.93	85.51	3.58	13.74	164.93	0.27	18.37	2606.69	8991.05	[15]
Classrooms (Tezpur University)				71.67	3.41		277.14	0.75	54.15		1353.51	[69]
Classrooms (Nigeria)	12400	41.8	254	12.7	21.9	40.9	121	855	27.6	2200	13700	[66]
Classrooms (Ryerson University, Toronto)	-	39	223	47	-	188	890	2.5	41	-	-	[79]
Classrooms (Schools, Shiraz; Islamic Republic of Iran)	-	172.8	288.9	50.1	6.4	40.0	258.8	1	258.8	-	-	[73]
Classrooms (Schools, Sri Serdang, Malaysia)	-	-	-	-	-	53.27	-	1.89	89.05	-	-	[81]
Classrooms (Schools, Southeast, Nigeria)	-	74.47	-	34.17	-	48.01	103.19	-	27.74	-	5826.83	[67]
Classrooms (Schools, Lagos, Nigeria)	32000	130	368	20.9	-	28.1	208	0.5	47.4	-	24500	[71]

Location	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	Reference
Classrooms (Nursery and Kindergarten Schools, Ogun State, Nigeria)	-	43.45	160.38	37.53	70.62	10.77	33.83	-	-	-	2,018.77	[68]
Lecture rooms, Labs, Offices (University of Anbar, Iraq)	-	141.37	-	-	-	38.88	276.59	1.3	147.42	-	-	[80]
Classrooms (Schools, Agra, India)	6700.13	43.40	252.35	18.38	3.5	51.97	34.29	0.84	36.64	9485.95	16679.17	[70]
Indian natural soil		114		27.7		56.5	22.1	0.9	13.1			[84] [85]
Background value	82300	100	950	75	25	55	70	0.2	12.5	23300	56300	[86]

academic classrooms and laboratories of both CU and TU, as well as in utility and social spaces at TU. The average concentrations recorded were 130.86 ± 14.85 mg/kg in academic classrooms and labs at CU, 224.23 ± 346.00 mg/kg at TU, and 204.06 ± 285.78 mg/kg in TU's utility and social spaces. Furthermore, at TU, a significant exception was observed in a Science laboratory of TU (LAB8_S), which exhibited a markedly elevated Cr concentration of 1144.20 mg/kg. This finding is consistent with Al Hejami et al. (2020), who reported that laboratory dusts often exhibit the highest concentrations of metals such as Cr, likely due to the materials and instruments used in these environments. The average concentration of Cd was 7.34 ± 0.44 mg/kg at CU and 7.94 ± 6.76 at TU. Cheng et al. [87] noted that anthropogenic activities are a major source of Cd in indoor dust. The present study had the highest concentrations of Cd than all other reported studies except Olujimi et al. (2015). Concentrations of Cu were 159.95 ± 68.41 mg/kg at CU and 164.59 ± 146.17 mg/kg at TU. Copper have numerous sources including vehicle emissions, lubricant use, collisions between car components, tire wear and tear, and so on [88, 89].

Cobalt concentrations in the present study were higher than those reported in all referenced studies except Oyebanji et al. [68]. A likely source of Co is mobile device batteries, where it is commonly used as a core component. Additionally, Co is utilized in certain pigments and paints due to its vivid coloration. Over time, the degradation of painted surfaces may contribute to the accumulation of Co in indoor dust [73, 90]. In contrast, Mg concentrations were lower than all values reported in the studies listed in Table 15. The average Mg concentrations was 264.29 ± 73.10 mg/kg at CU and 160.40 ± 158.57 mg/kg at TU. On the other hand, Mn concentrations were among the highest, measured at 800.63 ± 93.34 mg/kg for CU and 624.13 ± 138.42 mg/kg for TU. Mg is known to be a minor component of chalk, which may contribute to indoor settled dust in educational settings [91]. Furthermore, natural sources such as soil and construction materials from nearby outdoor areas may introduce Mg- and Mn-containing particles into classrooms via footwear or clothing [92].

4.3.2 Pollution Indices

4.3.2.1 Enrichment Factor (EF)

The EF values for CU and TU are presented in Table 4.11 a and b respectively. At CU, Mg and Al consistently exhibited low enrichment (EF < 2) across all sites, suggesting a natural origin. Mn showed “low” to “moderate enrichment”, while Co exhibited “moderate enrichment”. Cu and Zn demonstrated “moderate” to “high enrichment” levels. Ni and Cr showed a broad EF range, varying from "low" to "extremely high" depending on the microenvironment. Pb ranged from "high" to "extremely high enrichment", and Cd consistently showed "extremely high" enrichment across all sites. EF values greater than 10 generally indicate anthropogenic influence, including vehicular emissions, paint residues, and construction-related activities [79, 93]

Similarly, TU showed a comparable pattern in EF values. Mg and Al exhibited the lowest EF value, in contrast, Cd showed "extremely high" enrichment across all TU microenvironments, indicating strong anthropogenic contribution.

4.3.2.2 Contamination Factor (CF), Degree of Contamination (C_{degree}) and Pollution Load Index (PLI)

Tables 4.12 a and b present the average values of CF, C_{degree}, and PLI for all elements in settled dust at CU and TU. Notably, very high CF values were observed for Cd and Pb across all sites at both universities, with CF values exceeding 6. Among all sites, LAB8_S at TU recorded the highest CF values for Cd reaching 151.38. Al Hejami et al. [79] also reported elevated Cd concentrations in laboratory environments. The exceptionally high CF values observed in the present study may be attributed to laboratory-related activities, particularly the intensive use of diverse instruments and materials that likely contribute to increased Cd contamination levels. At both universities, all other elements showed CF values ranging from "low" to "considerable" contamination (Al, Mn, Co, Zn, Mg, Fe), except for Cr, Ni, and Cu, which exhibited a wider range from "low" CF to "very high" CF. Higher CF values are generally indicative of anthropogenic sources [94-96]. The overall C_{degree} was found to be very high at both institutions, with values exceeding 32.

PLI values indicate that CU experienced a higher pollution load compared to TU. Most sites at CU showed deterioration of the site quality with PLI values (>1), except CR3_HSS and CR4_HSS, which showed baseline levels of pollution and no pollution levels, respectively. In contrast, all sites at TU exhibited low PLI values below 1, except for LAB8_S, which showed a PLI of 2.60, indicating a considerable pollution load. The differences in pollution levels between the universities may be attributed to their respective locations and surrounding environmental conditions.

Table 4.11 Enrichment factors of elements in different microenvironments of

(a) Cotton University

Academic Classrooms and Lab	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg
CR1_S	0.50	3.04	2.17	2.18	2.88	6.04	8.67	104.29	46.85	0.03
CR2_S	0.66	3.14	2.12	1.94	2.98	4.21	4.15	80.88	31.54	0.03
CR3_HSS	0.28	3.56	2.16	2.43	3.01	5.57	6.50	100.05	40.15	0.03
CR4_HSS	0.39	3.38	1.93	2.28	3.55	3.87	4.00	103.39	31.53	0.03
LAB5_E	0.30	2.64	1.64	2.06	2.51	5.46	2.79	63.10	25.02	0.03
Library Complex	**Al**	**Cr**	**Mn**	**Ni**	**Co**	**Cu**	**Zn**	**Cd**	**Pb**	**Mg**
LIB_MH	0.27	3.43	2.09	2.84	2.76	9.05	5.59	102.08	58.99	0.03
LIB_RR	0.27	66.36	1.94	50.76	5.58	12.29	4.84	85.93	50.96	0.02
LIB_SR	0.25	28.64	1.80	25.08	4.07	7.39	4.52	73.39	59.08	0.01

Reference value
EF ≤ 2 Low EF
2 < EF ≤ 5 Moderate EF
5 < EF ≤ 20 High EF
20 < EF ≤ 40 Very High EF
EF > 40 Extremely High EF

(b) Tezpur University

Academic Classrooms and Lab	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg
CR1_HSS	0.33	3.26	1.76	3.01	1.79	5.03	2.68	127.96	23.65	0.01
CR2_HSS	0.12	2.88	1.60	1.89	1.95	3.04	1.60	64.34	19.05	0.02
CR3_HSS	1.28	2.94	1.90	1.61	2.32	2.62	1.35	92.37	24.99	0.06
CR4_L	0.12	3.47	2.54	2.64	2.68	15.82	2.45	77.17	84.41	0.02
CR5_E	0.26	3.82	1.96	2.63	2.31	5.54	2.38	140.24	39.85	0.02
CR6_E	1.11	3.01	1.88	1.71	2.29	3.22	1.44	94.87	28.26	0.03
CR7_S	0.19	4.39	1.44	2.96	1.53	6.23	1.17	66.44	18.52	0.00
LAB8_S	2.00	27.70	1.82	13.51	2.86	18.53	6.69	366.47	70.37	0.05
CR9_M	0.15	3.69	2.12	2.73	2.95	4.52	3.11	106.18	30.77	0.03
Utility and Social Spaces	**Al**	**Cr**	**Mn**	**Ni**	**Co**	**Cu**	**Zn**	**Cd**	**Pb**	**Mg**
ET1	0.62	5.82	2.06	2.20	2.80	8.84	1.47	84.79	24.72	0.00
ET2	0.40	4.93	2.04	1.80	2.57	3.99	1.53	75.78	21.83	0.00
AH3	0.43	2.40	1.83	2.63	2.22	22.33	3.80	93.13	54.60	0.01
LIB4	0.15	3.52	1.80	2.23	2.76	7.03	2.70	87.85	29.45	0.02

Reference value
EF ≤ 2 Low EF
2 < EF ≤ 5 Moderate EF
5 < EF ≤ 20 High EF
20 < EF ≤ 40 Very High EF
EF > 40 Extremely High EF

Table 4.12 Contamination Factor (CF), Degree of Contamination (Cd), and Pollution Load Index (PLI) across different microenvironments of

(a) Cotton University

Location	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	C_{degree}	PLI
CR1_S	0.20	1.22	0.87	0.88	1.15	2.42	3.47	41.79	18.77	0.01	0.40	*71.19*	*1.2*
CR2_S	0.29	1.40	0.94	0.87	1.33	1.88	1.85	36.09	14.07	0.01	0.45	*59.19*	*1.1*
CR3_HSS	0.10	1.28	0.77	0.87	1.08	2.00	2.33	35.88	14.40	0.01	0.36	*59.08*	*1.0*
CR4_HSS	0.13	1.14	0.65	0.77	1.19	1.30	1.34	34.74	10.59	0.01	0.34	*52.20*	*0.9*
LAB5_E	0.17	1.51	0.94	1.18	1.44	3.13	1.60	36.15	14.33	0.02	0.57	*61.04*	*1.2*
LIB_MH	0.11	1.45	0.88	1.20	1.17	3.83	2.36	43.20	24.96	0.01	0.42	*79.62*	*1.3*
LIB_RR	0.11	27.38	0.80	20.94	2.30	5.07	2.00	35.46	21.03	0.01	0.41	*115.52*	*2.1*
LIB_SR	0.12	14.09	0.88	12.34	2.00	3.64	2.22	36.12	29.08	0.01	0.49	*101.01*	*1.9*

Contamination Factor	
Low CF	CF < 1
Moderate CF	1 < CF < 3
Considerable CF	3 < CF <6
Very high CF	CF > 6

Degree of Contamination	
Low Cdegree	< 8
Moderate Cdegree	8-16
Considerable Cdegree	16-32
Very high Cdegree	> 32

Pollution Load Index	
No pollution	< 1
Only baseline levels of pollutants are present	1
Deterioration of site quality	>1

(b) Tezpur University

Location	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	C_{degree}	PLI
CR1_HSS	0.10	0.94	0.51	0.87	0.52	1.45	0.77	36.93	6.83	0.00	0.29	*49.20*	*0.58*
CR2_HSS	0.04	1.02	0.57	0.67	0.69	1.07	0.56	22.72	6.73	0.01	0.35	*34.43*	*0.58*
CR3_HSS	0.42	0.96	0.63	0.53	0.76	0.86	0.44	30.36	8.21	0.02	0.33	*43.53*	*0.78*
CR4_L	0.04	1.29	0.94	0.98	1.00	5.88	0.91	28.69	31.38	0.01	0.37	*71.48*	*0.95*
CR5_E	0.05	0.72	0.37	0.49	0.43	1.04	0.45	26.30	7.47	0.00	0.19	*37.51*	*0.46*
CR6_E	0.37	1.01	0.63	0.58	0.77	1.09	0.49	31.95	9.52	0.01	0.34	*46.75*	*0.76*
CR7_S	0.07	1.66	0.55	1.12	0.58	2.36	0.44	25.17	7.02	0.00	0.38	*39.36*	*0.62*
LAB8_S	0.83	11.44	0.75	5.58	1.18	7.66	2.76	151.38	29.07	0.02	0.41	*211.08*	*2.60*
CR9_M	0.05	1.14	0.65	0.84	0.91	1.39	0.96	32.67	9.47	0.01	0.31	*48.38*	*0.72*
ET1	0.24	2.25	0.79	0.85	1.08	3.41	0.57	32.73	9.54	0.00	0.39	*51.85*	*0.76*
ET2	0.15	1.88	0.78	0.69	0.98	1.52	0.58	28.91	8.33	0.00	0.38	*44.21*	*0.68*
AH3	0.17	0.92	0.70	1.01	0.85	8.58	1.46	35.76	20.97	0.00	0.38	*70.80*	*0.97*
LIB4	0.06	1.30	0.67	0.82	1.02	2.59	1.00	32.43	10.87	0.01	0.37	*51.13*	*0.80*

Contamination Factor	
Low CF	CF < 1
Moderate CF	1 < CF < 3
Considerable CF	3 < CF <6
Very high CF	CF > 6

Degree of Contamination	
Low Cdegree	< 8
Moderate Cdegree	8-16
Considerable Cdegree	16-32
Very high Cdegree	> 32

Pollution Load Index	
No pollution	< 1
Only baseline levels of pollutants are present	1
Deterioration of site quality	>1

4.3.2.3 Geo-accumulation Index (I_{geo} index)

The I_{geo} values for both universities are presented in Table 4.13 a and b for CU and TU, respectively. At CU, the I_{geo} values for Pb range from 2.13 (I_{geo} Class 2) to 5.84 (I_{geo} Class 6). Cd was classified as "extremely contaminated" i.e., I_{geo} Class 6, at all sites. The reference room (LIB_RR) and the stock room (LIB_SR) of the library complex were found to be "heavily to extremely contaminated" and "moderately to heavily contaminated" with Ni, respectively. For Cr, levels ranged from "moderately to heavily contaminated" to "extremely contaminated". LIB_RR was also "moderated contaminated" by Cu. Besides this, all other elements showed "uncontaminated to moderately contaminated" levels i.e., they belong to I_{geo} Class 1.

At TU, the majority of elements, except Pb and Cd, were classified under I_{geo} Class 1 (uncontaminated to moderately contaminated) across nearly all sites (n=17). In contrast, Pb levels ranged from I_{geo} Class 2 (moderately contaminated) to Class 6 (extremely contaminated) at all locations. Similarly, Cd showed I_{geo} values ranging from Class 5 (heavily to extremely contaminated) to Class 6. Notably, in LAB8_S, in addition to high I_{geo} values for Pb and Cd both Cu and Cr exceeded Class 1 I_{geo} category. Cu was categorized under I_{geo} Class 2 (moderately contaminated), while Cr fell into I_{geo} Class 3 (moderately to highly contaminated).

The contamination levels due to Pb could be because it is a highly persistent metal, and its accumulation in soil from historical sources cannot be overlooked, despite eliminating Pb from fuel in 2000 [97]. The source of Cd, Cr, Ni, Cu could be traffic density, vehicular emissions, burning of fossil fuels etc. [98, 99].

Table 4.13 Geo-accumulation Index (I_{geo}) in microenvironments of **(a) Cotton University**

Microenvironments	CR1_S	CR2_S	CR3_HSS	CR4_HSS	LAB5_E	LIB_MH	LIB_RR	LIB_SR
Al	0.04	0.06	0.02	0.03	0.06	0.02	0.02	0.03
Cr	0.24	0.28	0.26	0.23	0.28	0.29	5.50	2.83
Mn	0.17	0.19	0.16	0.13	0.19	0.18	0.16	0.18
Ni	0.18	0.17	0.17	0.15	0.17	0.24	4.20	2.48
Co	0.23	0.27	0.22	0.24	0.27	0.23	0.46	0.40
Cu	0.49	0.38	0.40	0.26	0.38	0.77	1.02	0.73
Zn	0.70	0.37	0.47	0.27	0.37	0.47	0.40	0.45
Cd	**8.39**	**7.24**	**7.20**	**6.97**	**7.24**	**8.67**	**7.12**	**7.25**
Pb	**3.77**	**2.82**	**2.89**	**2.13**	**2.82**	**5.01**	**4.22**	**5.84**
Mg	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.001
Fe	0.08	0.09	0.07	0.07	0.09	0.08	0.08	0.10

(b) Tezpur University

Microenvironments	CR1_HSS	CR2_HSS	CR3_HSS	CR4_L	CR5_E	CR6_E	CR7_S	LAB8_S	CR9_M	ET1	ET2	AH3	LIB4
Al	0.02	0.01	0.08	0.01	0.01	0.07	0.01	0.17	0.01	0.05	0.03	0.03	0.01
Cr	0.19	0.20	0.19	0.26	0.14	0.20	0.33	2.30	0.23	0.45	0.38	0.19	0.26
Mn	0.10	0.11	0.13	0.19	0.07	0.13	0.11	0.15	0.13	0.16	0.16	0.14	0.13
Ni	0.17	0.13	0.11	0.20	0.10	0.12	0.23	1.12	0.17	0.17	0.14	0.20	0.17
Co	0.10	0.14	0.15	0.20	0.09	0.15	0.12	0.24	0.18	0.22	0.20	0.17	0.20
Cu	0.29	0.22	0.17	1.18	0.21	0.22	0.47	1.54	0.28	0.68	0.31	1.72	0.52
Zn	0.16	0.11	0.09	0.18	0.09	0.10	0.09	0.55	0.19	0.11	0.12	0.29	0.20
Cd	**7.41**	**4.56**	**6.09**	**5.76**	**5.28**	**6.41**	**5.05**	**30.38**	**6.56**	**6.57**	**5.80**	**7.18**	**6.51**
Pb	**1.37**	**1.35**	**1.65**	**6.30**	**1.50**	**1.91**	**1.41**	**5.83**	**1.90**	**1.91**	**1.67**	**4.21**	**2.18**
Mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe	0.06	0.07	0.07	0.07	0.04	0.07	0.08	0.08	0.06	0.08	0.08	0.08	0.07

4.4. Characterization of Settled Dust in Households

Settled dust in households comprises a complex mixture of particles originating from both indoor and outdoor sources. Understanding the composition of household dust provides critical insights to understand the indoor air quality and human exposure pathways.

4.4.1 Elemental Concentrations

The concentrations of various elements in household samples from six residences in Guwahati and eight in Tezpur are presented in Table 4.14 and Table 4.15, respectively. The average elemental concentrations, arranged in decreasing order, was found to be Al > Fe > Mn > Mg > Cu > Pb > Cr > Zn > Ni > Co > Cd for Guwahati, and Al > Fe > Mg > Cr > Mn > Ni > Cu > Zn > Pb > Co > Cd for Tezpur. Based on the standard deviation values, a wide variation in elemental concentrations was observed among households in both cities, indicating heterogeneous pollution sources.

In Guwahati, households in commercial areas recorded the highest concentrations for elements such as Al (37,440 ± 25,472.81 mg/kg), Mn (872.85 ± 448.91 mg/kg), Co (21.77 ± 10.34 mg/kg), Cu (199.23 ± 60.03 mg/kg), Zn (71.65 ± 0.41 mg/kg), Cd (11.69 ± 7.61 mg/kg), and Pb (211.35 ± 89.56 mg/kg). Conversely, Cr (130.92 ± 34.62 mg/kg), Ni (99.32 ± 68.11 mg/kg), and Mg (544.68 ± 13.41 mg/kg) concentrations were highest in households of industrial area. Households in residential areas showed consistently lower concentrations of all analyzed elements. In Tezpur, households in urban residential area showed the highest concentrations of Al (34118.00 ± 2752.06 mg/kg), Cd (6.80 ± 0.56 mg/kg), and Pb (116.33 ± 10.84 mg/kg). The commercial area households recorded the highest concentrations of Cr (2405.96 ± 2339.32 mg/kg), Mn (705.80 ± 88.04 mg/kg), Ni (1432.65 ± 1474.65 mg/kg), Co (50.54 ± 33.68 mg/kg), Cu (173.42 ± 78.54 mg/kg), and Fe (23678.00 ± 8007.92 mg/kg). In contrast, rural residential households exhibited the highest concentrations for Zn (188.43 ± 165.00 mg/kg) and Mg (8767.50 ± 11368.16 mg/kg).

Table 4.16 presents a comparative analysis of elemental concentrations observed in the present study and the reported studies from India and abroad. The table also includes reference values for natural Indian soil and background soil levels. Among the elements analyzed, Fe and Al consistently exhibited the highest concentrations across all studies. These elements primarily originate from crustal sources and are commonly introduced into indoor environments via tracked soil or wind-blown dust. Additional anthropogenic contributors to indoor Fe and Al concentrations include construction activities, packaging materials, and vehicular emissions [100, 73].

Elements such as Zn, Cd, Ni, Cu, and Pb are commonly classified as traffic-related elements (TREs) [101]. Their presence is predominantly attributed to traffic-associated processes, including emissions from the combustion of fossil fuels, friction between vehicle components or between vehicles and road surfaces, and the mechanical abrasion of roadways due to continuous vehicular activity [101-103]. These elements can thereby infiltrate indoor environments, especially in urban areas with high traffic density. The mean concentrations of these TREs were highest in households located in commercial area (114.71 mg/kg), followed by those in industrial area (74.77 mg/kg), and then residential area (56.44 mg/kg). However, statistical analysis revealed no significant difference in TRE concentrations among the three areas ($p = 0.27$). Though not significant, the concentration of TREs in SD of commercial areas are 2.03 and 1.53 times higher in residential and industrial areas, respectively. In Tezpur, the highest average concentration of TREs was recorded in households from the commercial area (362.11 mg/kg), followed by rural residential households (105.84 mg/kg), and urban residential households (56.83 mg/kg). Households in commercial areas exhibited 6.37 times higher TRE concentrations than urban residential and 1.86 times higher than rural residential households. However, no significant difference among the sites were found ($p=0.23$). The elevated TRE concentrations in rural residential households could not be clearly explained; however, it is inferred that ongoing construction activities within the premises and other indoor sources may have contributed to the increase in the above elements. Commercial households showed highest concentrations of TREs in both Tezpur and Guwahati. This elevated concentrations in households of commercial area suggest a strong influence of urban traffic dynamics and associated activities.

Cu and Zn, recognized as key tracers of non-exhaust vehicular emissions, particularly from brake and tire wear, indicate significant contamination of roadside environments. The presence of these elements suggests the infiltration of traffic-related particles into indoor settings [104]. Additionally, the elevated Zn concentrations may also be linked to the use of rubber materials and zinc-based paints. Indoor sources also contribute notably to Pb concentrations, particularly in older buildings where deteriorating lead-based paint, carpets could release Pb into SD [105]. In addition, traffic activities and vehicular emissions further exacerbate Pb accumulation in indoors [106].

Table 4.14 Elemental concentrations (mg/kg) in indoor settled dust from households in commercial, industrial, and residential areas of Guwahati

	Locations	**Al**	**Cr**	**Mn**	**Ni**	**Co**	**Cu**	**Zn**	**Cd**	**Pb**	**Mg**	**Fe**
Households in Commercial Areas	**CH1_G**	19428	73.38	555.42	60.78	14.46	156.78	71.94	6.31	148.02	388.02	22908
	CH2_G	55452	136.32	1190.28	98.45	29.09	241.68	71.36	17.08	274.68	484.92	22932
	Average	37440 ± 25472.81	104.85 ± 44.51	872.85 ± 448.91	79.61 ± 26.64	21.77 ± 10.34	199.23 ± 60.03	71.65 ± 0.41	11.69 ± 7.61	211.35 ± 89.56	436.47 ± 68.52	22920.00 ± 16.97
Households in Industrial Areas	**IH3_G**	8118	106.44	529.74	51.16	17.35	66.06	44.02	5.57	103.26	554.16	15258
	IH4_G	24510	155.4	682.8	147.48	22.8	120	73.98	6.26	129.9	535.2	18996
	Average	16314 ± 11590.89	130.92 ± 34.62	606.27 ± 108.23	99.32 ± 68.11	20.08 ±3.85	93.03 ± 38.14	59.00 ± 21.19	5.92 ± 0.49	116.58 ± 18.84	544.68 ± 13.41	17127.00 ± 2643.17
Households in Residential Areas	**RH5_G**	5578.2	48.77	408.12	69.18	11.32	74.22	45.62	bdl	25.5	336.72	13212
	RH6_G	39132	102.08	772.08	41.08	22.91	164.4	37.48	4.73	102.64	556.44	21972
	Average	22355.10 ± 23726.12	75.43 ± 37.70	590.10 ± 257.36	55.13 ± 19.87	17.12 ±8.19	119.31 ±63.77	41.55 ± 5.76	2.15 ± 3.64	64.07 ± 54.54	446.58 ± 155.37	17592.00 ± 6194.26
	Overall Average	**25369.7 ± 19077.28**	**103.73 ± 39.20**	**689.74 ± 275.80**	**78.02 ± 39.25**	**19.66 ± 6.50**	**137.19 ± 65.36**	**57.40 ± 16.71**	**7.99 ± 5.12**	**130.67 ± 82.02**	**475.91 ± 93.06**	**19213 ± 4166.47**

Table 4.15 Elemental concentrations (mg/kg) in indoor settled dust from households in urban residential, commercial, and rural residential areas of Tezpur

	Locations	**Al**	**Cr**	**Mn**	**Ni**	**Co**	**Cu**	**Zn**	**Cd**	**Pb**	**Mg**	**Fe**
Households in Residential Areas (Urban)	RHu1_T	32298	88.38	632.4	54.41	19.19	79.56	46.67	7.41	125.7	464.04	18354
	RHu2_T	32772	72.24	588.66	38.27	16.51	38.26	70.62	6.68	104.46	391.02	14172
	RHu3_T	37284	106.3	784.2	47.51	25.12	60.47	47.32	6.3	118.84	456.84	23568
	Average	34118.00 ± 2752.06	88.97 ± 17.04	668.42 ± 102.63	46.73 ± 8.1	20.27 ± 4.4	59.43 ± 20.67	54.87 ± 13.65	6.80 ± 0.56	116.33 ± 10.84	437.30 ± 40.24	18698.00 ± 4707.44
Households in Commercial Areas	CH4_T	19476	101.88	646.8	44.55	17.53	112.14	38.41	6.41	96.84	209.58	15450
	CH5_T	2094	2337	663.6	1272.6	49.27	146.16	219.96	4.47	85.38	3846.6	31446
	CH6_T	13476	4779	807	2980.8	84.84	261.96	53.75	4.59	103.56	136.26	24138
	Average	11682.00 ± 8828.78	2405.96 ± 2339.32	705.80 ± 88.04	1432.65 ± 1474.65	50.54 ± 33.68	173.42 ± 78.54	104.04 ± 100.68	5.16 ±1.09	95.26 ±9.19	1397.48 ± 2121.32	23678.00 ± 8007.92
Households in Residential Area (Rural)	RHr7_T	26856	113.4	455.1	190.14	11.27	99.72	71.76	5.86	119.28	729	13368
	RHr8_T	3522.6	78.42	383.16	108.72	8.42	63.36	305.1	4.23	90.18	16806	17994
	Average	15189.30 ±16499.21	95.91 ± 24.73	419.13 ± 50.87	149.43 ± 57.57	9.84 ±2.02	81.54 ± 25.71	188.43 ± 165.00	5.05 ±1.15	104.73 ± 20.58	8767.50 ± 11368.16	15681.00 ± 3271.08
	Overall Average	**20972.33 ±13562.08**	**959.58 ± 1731.55**	**620.12 ± 145.88**	**592.13 ± 1052.64**	**29.02 ± 25.82**	**107.70 ± 70.88**	**106.70 ± 99.51**	**5.74 ± 1.18**	**105.53 ± 14.62**	**2879.92 ± 5757.70**	**19811.25 ± 6164.00**

Table 4.16 A comparison of elemental concentrations of the present study with other reported studies on settled dust in households in India and abroad

Locations		Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	Reference
Households, Guwahati, Assam	Commercial	37440	104.85	872.85	79.61	21.77	199.23	71.65	11.69	211.35	436.47	22920	This study
	Industrial	16314	130.92	606.27	99.32	20.08	93.03	59	5.92	116.58	544.68	17127	
	Residential	22355.1	75.43	590.1	55.13	17.12	119.31	41.55	2.15	64.07	446.58	17592	
Households, Tezpur, Assam	Residential (Urban)	34118	88.97	668.42	46.73	20.27	59.43	54.87	6.8	116.33	437.3	18698	
	Commercial	11682	2405.96	705.8	1432.65	50.54	173.42	104.04	5.16	95.26	1397.48	23678	
	Residential (Rural)	15189.3	95.91	419.13	149.43	9.85	81.54	188.43	5.05	104.73	8767.5	15681	
Households, Penang State, Malaysia	Seberang Jaya City (Urban)	-	-	-	15.07	-	6.84	17.6	-	33.27	-	-	[107]
Households, Jharia, Jharkhand India India	Jharia Commercial	7500	42.3	700	25.9	14.9	56.1	-	0.37	70.5	4000	23900	[108]
	Jharia Residential	7500	53.6	600	45.3	17.6	44.7	-	0.41	49.8	3600	22600	
Households, Nairobi, Kenya	Nairobi City (Urban)	-	82.65	-	-	-	-	321.77	27.40	129.12	-	-	[109]
Households, Chengdu, China	Urban area	-	82.7	-	52.6	-	161	675	2.37	123	-	-	[87]

Locations		Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg	Fe	Reference
Households, Bushehr, Iran	Bushehr (Urban)	-	117.95	-	46.33	-	164.12	496.45	3.34	151.84	-	-	[110]
Households, Athens, Greece	Athens (Urban)	4217	65.2	128	29.9	-	339	401	0.5	46.1	-	4913	[111]
Households, Turkey, Ankara	Ankara (Urban)	-	23.8	65.9	32.3	-	65.7	263	-	27.5	-	-	[112]
Households, Kuangshan, Huize Country, Yunnan province, China	Mining town (Pb/Zn ore mining area)	-	124	1010.3	-	-	174	3029	25.2	927	-	-	[113]
Households, Ramadi, Iraq	Ramadi City (Urban)	-	0.51	-	1.49	-	1.25	1.9	0.007	0.92	-	-	[114]
Indian natural soil			114		27.7		56.5	22.1	0.9	13.1			[84] [85]
Background value		82300	100	950	75	25	55	70	0.2	12.5	23300	56300	[86]

Furthermore, Cd, commonly used in motor vehicle accumulators, can be released into the environment during combustion and subsequently infiltrate indoor environments. Likewise, Ni primarily originates from engine oil and fuel additives, with oil combustion and waste incineration contributing up to 70% of its atmospheric emissions. In addition to these outdoor sources, tobacco smoke serves as a significant indoor contributor of Cd, Ni, and Pb, further intensifying heavy metal exposure within indoor settings [115-117].

From the table, it is evident that average TRE concentrations were higher in studies conducted by Cheng et al. [87], Ogilo et al. [109], Hashemi et al. [110], and Stamatelopoulou et al. [111] than the present study. Exceptionally high TRE concentrations were reported in households from Kuangshan, China, an area characterized by intensive Pb/Zn ore mining activity (Cao et al. 113].

Manganese concentrations in Tezpur and Guwahati are comparable to Jharia in Jharkhand, a study by Rout et al. [108]. Higher concentrations of Mn were found by Cao et al. [113]. Additionally, lower concentrations were reported by Stamatelopoulou et al. [11] in Athenes, Greece, and Gul et al. [112] in Ankara, Turkey than the present study. The presence of Mn in indoor environments can be attributed to both automotive emissions and its natural abundance in soil, which may be introduced through resuspended dust or soil tracking [118, 119].

Cr concentrations exhibited considerable variability, particularly in Tezpur. Notably, two households-CH5_T and CH6_T recorded exceptionally high Cr concentrations of 2337 mg/kg and 4779 mg/kg, respectively. Despite being located in the same neighbourhood as CH4_T (commercial area), these two households demonstrated a stark difference in Cr concentrations. The mean Cr concentration was 103.73 mg/kg in Guwahati and significantly higher (Tezpur at 863.61 mg/kg). The average Cr level in Guwahati households aligns with those reported by Cao et al. [113], Hashemi et al. [110], Ogilo et al. [109] and Cheng et al. [87] which recorded concentrations of 124 mg/kg, 117.95 mg/kg, 82.65 mg/kg and 82.7 mg/kg, respectively. However, the average Cr concentration in Tezpur far exceeds those in previously reported studies, largely due to the unusually high values in the two aforementioned households. Cr in indoor environments may originate from both anthropogenic and indoor sources. These include metal-rich slag used in tile production, indoor smoking, Cr-Ni plated household items, and automotive components such as plating and alloys, as well as road markings that use yellow paint [120-122]. However, this exceptional increase of Cr at these two sites could not be known.

The concentrations of Mg observed in the present study is comparable to the values reported by Rout et al. [108]. Natural sources, such as soil and construction materials from nearby outdoor sites, may contribute to indoor Mg concentrations as Mg-containing dust can be tracked indoors via footwear or clothing [92].

4.4.2 Pollution Indices

4.4.2.1 Enrichment Factor

The enrichment factor (EF) is a useful indicator for determining whether an element originates from natural sources or is influenced by anthropogenic activities. An EF value less than 2 suggests minimal or low enrichment, typically pointing to a predominantly natural origin. In the present study, EF values for Al and Mg were consistently below 2 across all households in both Guwahati and Tezpur, indicating their primary origin from natural sources such as crustal material or soil [73; 123]. Conversely, an EF greater than 10 suggests significant enrichment and strong association with anthropological activities [123].

Varying levels of elemental enrichment were observed in both Guwahati and Tezpur, as presented in Tables 4.17 and 4.18. In Guwahati, the highest EF values for TREs were found in households from the commercial area (39.83), followed by the industrial area (28.15) and the residential area (12.58). These values indicate "very high enrichment" in the commercial and industrial area, and "high enrichment" in the residential area. Khajooee et al. [124], that reported that indoor elemental levels are often exacerbated by urban environmental conditions, such as traffic congestion and densely populated built environments. Additionally, Nath et al. [15] emphasized that location significantly influences the elemental composition of SD. Similarly, in Tezpur, the average EF values for TREs across all three household types were classified as "very high": 27.34 for urban residential households, 28.54 for commercial households, and 29.68 for rural residential households. Despite Tezpur being an urban agglomeration, consistently high EF for TREs were observed across all sites.

Cadmium showed "extremely high" EF across all locations except RH5_G. Lead also ranged from "high" EF to "extremely high" EF for both Guwahati and Tezpur. These findings suggest that elemental concentrations may also be influenced by broader infrastructural and sanitation-related factors [67]. Additionally, location-specific variables such as household practices, building materials, and adjacent land use pattern may further shape the elemental composition of indoor dust.

Table 4.17 Enrichment Factors of elements in indoor settled dust from households in commercial, industrial, and residential areas of Guwahati

Elements	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg
Households in Commercial Area										
CH1_G	0.58	1.80	1.44	1.99	1.42	7.01	2.53	77.56	29.10	0.04
CH2_G	1.65	3.35	3.08	3.22	2.86	10.79	2.50	209.62	53.95	0.05
Households in Industrial Area										
IH3_G	0.36	3.93	2.06	2.52	2.56	4.43	2.32	102.70	30.48	0.09
IH4_G	0.88	4.61	2.13	5.83	2.70	6.47	3.13	92.83	30.80	0.07
Households in Residential Area										
RH5_G	0.29	2.08	1.83	3.93	1.93	5.75	2.78	bdl	8.69	0.06
RH6_G	1.22	2.62	2.08	1.40	2.35	7.66	1.37	60.57	21.04	0.06

Table 4.18 Enrichment Factors of elements in indoor settled dust from households in urban residential, commercial, and rural residential areas of Tezpur

Elements	Al	Cr	Mn	Ni	Co	Cu	Zn	Cd	Pb	Mg
Households in Urban Residential Area										
RHu1_T	1.2	2.71	2.04	2.23	2.35	4.44	2.05	113.65	30.85	0.06
RHu2_T	1.20	2.71	2.04	2.23	2.35	4.44	2.05	113.65	30.85	0.06
RHu3_T	1.08	2.54	1.97	1.51	2.40	2.63	1.61	75.25	22.71	0.05
Households in Commercial Area										
CH4_T	0.86	3.71	2.48	2.16	2.55	7.43	2.00	116.75	28.23	0.03
CH5_T	0.05	41.84	1.25	30.38	3.53	4.76	5.63	40.03	12.23	0.30
CH6_T	0.38	111.47	1.98	92.7	7.92	11.11	1.79	53.54	19.32	0.01
Households in Rural Residential Area										
RHr7_T	1.37	4.78	2.02	10.68	1.90	7.64	4.32	123.43	40.19	0.13
RHr8_T	0.13	2.45	1.26	4.54	1.05	3.60	13.64	66.22	22.57	2.26

4.4.2.2 Contamination Factor, Degree of Contamination (C_{degree}) and Pollution Load Index (PLI)

Table 4.19 showed the average CF factor for households at different sites in Guwahati and Tezpur. Aluminum, Mn, Mg, and Fe exhibited low contamination levels, with CF values < 1, indicating their likely origin from resuspended dust and natural soil sources [15]. Cobalt and Zn showed "low" to "moderate" CF across all households, while Cu demonstrated "moderate" to "considerable" contamination. Furthermore, CF values for Cr and Ni ranged from "low" to "very high" CF. In contrast Cd, and Pb consistently displayed "very high" CF values, reflecting their strong association with anthropogenic activities [94-96]. Households in commercial areas of both Guwahati and Tezpur exhibited the highest CF values for maximum elements. The C_{degree} values also suggested a "very high" level of contamination overall. PLI values less than 1 were found for households in industrial and residential areas of Guwahati and households in urban residential areas of Tezpur. PLI value less than 1 indicate negligible pollution and an acceptable household environmental quality. PLI values more than 1 were found for households of commercial areas of both Guwahati and Tezpur and rural residential areas of Tezpur reflecting site deterioration.

Table 4.19 Contamination Factor (CF), Degree of Contamination (C_{degree}), and Pollution Load Index (PLI) Across households of different areas in Guwahati and Tezpur

	Guwahati Households			**Tezpur Households**		
Elements	Households in Commercial Area	Households in Industrial Area	Households in Residential Area	Households in Urban Residential Area	Households in Commercial Area	Households in Rural Residential Area
Al	**0.45**	0.20	0.27	0.41	0.14	0.18
Cr	1.05	1.31	0.75	0.89	**24.06**	0.96
Mn	**0.92**	0.64	0.62	0.70	0.74	0.44
Ni	1.06	1.32	0.74	0.62	**19.10**	1.99
Co	0.87	0.80	0.68	0.81	**2.02**	0.39
Cu	**3.62**	1.69	2.17	1.08	3.15	1.48
Zn	1.02	0.84	0.59	0.78	1.49	**2.69**
Cd	**58.47**	29.58	10.76	33.99	25.78	25.24
Pb	**16.91**	9.33	5.13	9.31	7.62	8.38
Mg	0.02	0.02	0.02	0.02	0.06	**0.38**
Fe	0.41	0.30	0.31	0.33	**0.42**	0.28
C_{degree}	**84.80**	**46.04**	**22.04**	**48.95**	**84.59**	**42.41**
PLI	**1.25**	0.94	0.72	0.87	**2.02**	**1.17**

4.4.2.3 Geo-accumulation Index (I_{geo} index)

The I_{geo} index values presented in Table 4.20 indicate that, when averaged by household at each locality, all assessed elements except Cr, Ni, Cd and Pb fall under Class 1 contamination levels, corresponding to "uncontaminated to moderately contaminated" conditions. This reflects relatively low overall pollution levels for most elements. However, Cd was classified as “extremely contaminated” in all localities of Guwahati and Tezpur, except in the residential areas of Guwahati, where Cd levels were categorized as “moderately to heavily polluted.” Similarly, Pb levels were deemed “moderately contaminated” in all localities of Guwahati and Tezpur, with the exception of the commercial area in Guwahati, where Pb reached the “heavily contaminated” category. These findings suggest significant anthropogenic contributions as the primary sources of Cd and Pb contamination.

Table 4.20 Geo-accumulation Index (I_{geo}) in different households of Guwahati and Tezpur

Guwahati Households				**Tezpur Households**		
Elements	Households in Commercial Area	Households in Industrial Area	Households in Residential Area	Households in Urban Residential Area	Households in Commercial Area	Households in Rural Residential Area
Al	0.09	0.04	0.05	0.08	0.03	0.04
Cr	0.21	0.26	0.15	0.18	4.83	0.19
Mn	0.18	0.13	0.12	0.14	0.15	0.09
Ni	0.21	0.27	0.15	0.13	3.83	0.40
Co	0.17	0.16	0.14	0.16	0.41	0.08
Cu	0.73	0.34	0.44	0.22	0.63	0.30
Zn	0.21	0.17	0.12	0.16	0.30	0.54
Cd	**11.73**	**5.94**	**2.16**	**6.82**	**5.17**	**5.06**
Pb	**3.39**	**1.87**	**1.03**	**1.87**	**1.53**	**1.68**
Mg	0.00	0.00	0.00	0.00	0.01	0.08
Fe	0.08	0.06	0.06	0.07	0.08	0.06

4.5 Mineralogy of Elements

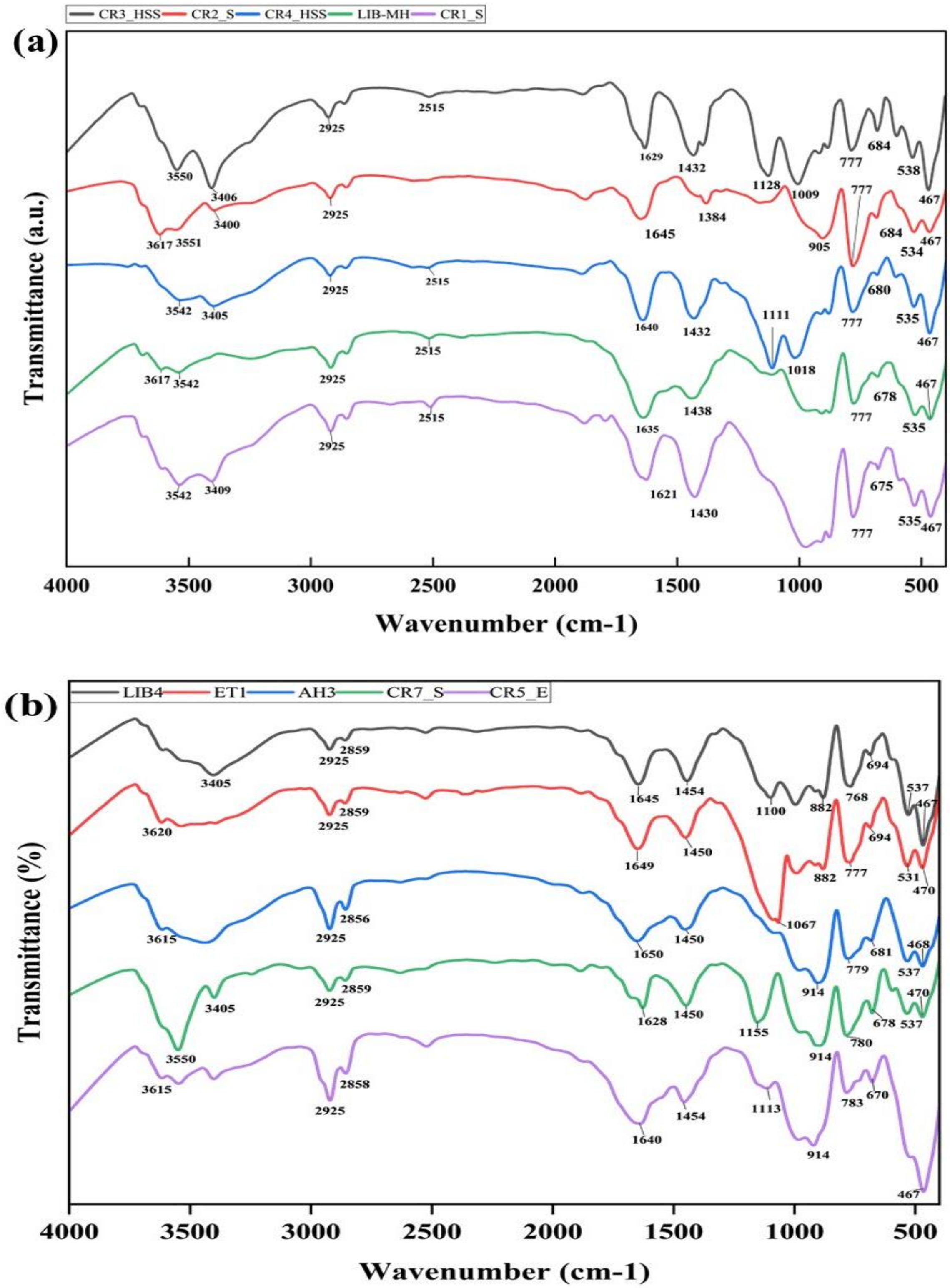
To assess the mineralogical composition and functional group characteristics of the indoor SD samples, FTIR and XRD were employed. These analytical tools help identify the chemical bonding, organic and inorganic constituents, and crystalline mineral phases, providing a comprehensive understanding of the dust's composition.

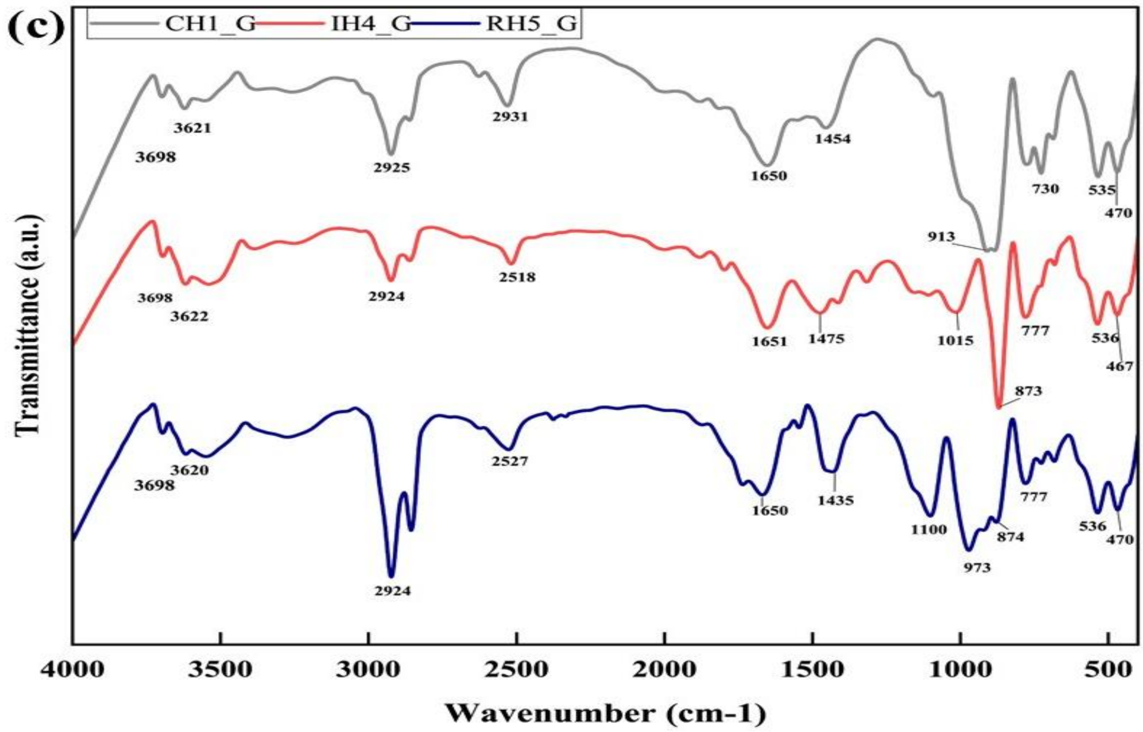
4.5.1 FTIR Spectroscopy

The FTIR spectrum of the indoor dust from different microenvironments of CU, TU, households of Guwahati, and households of Tezpur are shown in Fig. 4.21 (a-d) respectively. FTIR spectral analysis of indoor dust samples from CU (4.21a), TU (4.21b), and households in Guwahati (4. 21 c) and Tezpur (4.21 d) revealed a composite mixture of silicate, carbonate, clay, metal oxide, and organic components, reflecting a combination of crustal origin, construction materials, and anthropogenic pollution.

Quartz was the dominant mineral identified across all sites. Strong Si–O–Si stretching and bending vibrations were observed at 465 cm^{-1}, 467 cm^{-1}, 468 cm^{-1}, 470 cm^{-1}, 538 cm^{-1}, 694 cm^{-1}, 777 cm^{-1}, 779 cm^{-1}, 780 cm^{-1}, 783 cm^{-1}, 1067 cm^{-1}, 1100 cm^{-1}, confirming its widespread presence [125-131]. Quartz, derived mainly from crustal and soil sources, get resuspended in indoor environments through human activity, open windows, and dust infiltration. Its presence is of health concern due to the carcinogenicity of inhalable crystalline silica, which is linked to silicosis, pulmonary fibrosis, and lung cancer [132, 133]. Clay minerals were identified by O–H stretching bands between 3617- 3698–cm^{-1}, Al–OH bending around 907-914 cm^{-1}, and overlapping Si–O stretching near 1100 cm^{-1}. These minerals, including kaolinite, illite, and montmorillonite, originate from weathered soils, construction dust, and degraded plaster [134, 135]. They not only contribute to indoor particulate matter but also act as adsorbents of heavy metals and organic pollutants, potentially increasing dust toxicity [136]. FTIR bands at 1432-1450 cm^{-1}, 873-882 cm^{-1}, 2518- 2527 cm^{-1}, and occasionally 876- 905–cm^{-1} signify the presence of carbonates, primarily calcite and occasionally dolomite. These are likely derived from building materials such as cement, gypsum, and chalkboards, which degrade over time [92, 125]. Iron and Al oxides were identified through low-frequency bands between 531 cm^{-1}, 534 cm^{-1}, 535 cm^{-1},536 cm^{-1}, 537 cm^{-1}, 538 cm^{-1},1113 cm^{-1}, attributed to metal–oxygen stretching in minerals like hematite (Fe_2O_3) and gibbsite ($Al(OH)_3$) [125, 129, 136,137]. These oxides may enter indoor dust via road dust, combustion residues, or corroded building materials. Inhalation of iron-rich particulates is associated with oxidative stress, pulmonary inflammation, and other respiratory issues [133, 136].

C–H stretching bands observed at 2926–2859 cm^{-1} across all sites indicate the presence of aliphatic hydrocarbons, which may arise from synthetic textiles, cleaning agents, or vehicular emissions entering indoor spaces [138]. Additionally, peaks at 873 cm^{-1} , 874 cm^{-1} , 1650 cm^{-1} , 2515 cm^{-1} , and 1430 cm^{-1} reflect carbonyl (C=O) functional groups, pointing to indoor contamination by aldehydes, ketones, and possibly volatile organic compounds (VOCs), which are associated with endocrine disruption and carcinogenic risks in long-term exposure [138]. In a study by Mahmud


(a)
CR3_HSS
CR2_S
CR4_HSS
LIB-MH
CR1_S
Transmittance (a.u.)
Wavenumber (cm-1)
4000
3500
3000
2500
2000
1500
1000
500
(b)
LIB4
ET1
AH3
CR7_S
CR5_E
Transmittance (%)
Wavenumber (cm-1)
4000
3500
3000
2500
2000
1500
1000
500



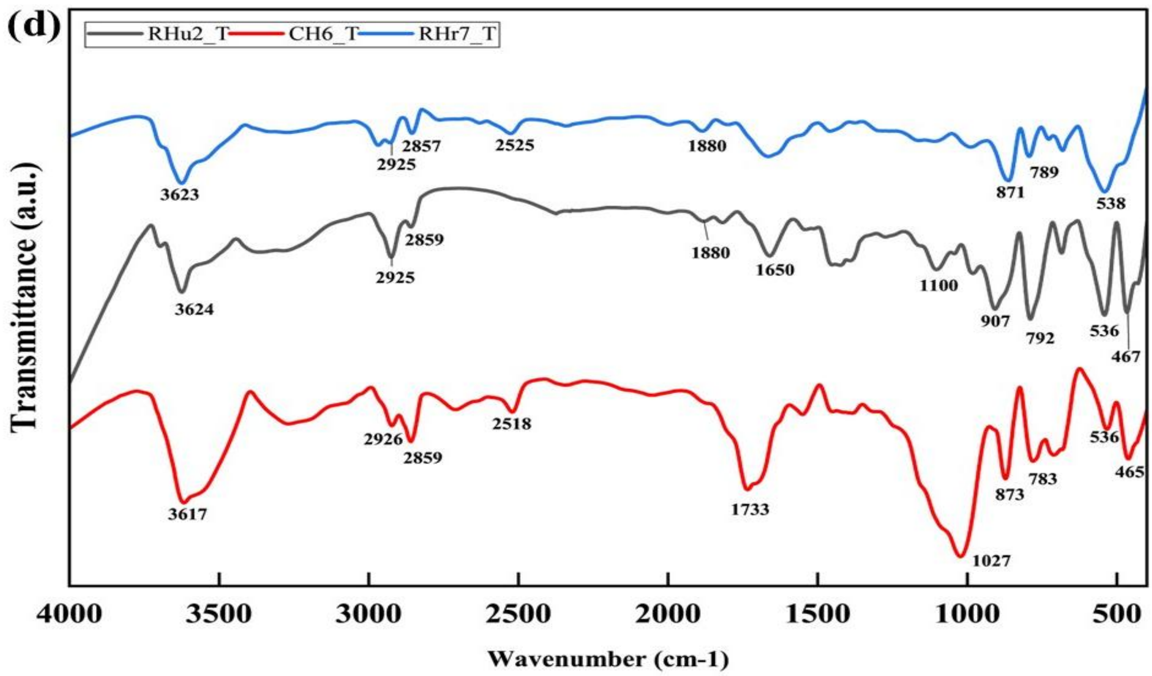


Fig 4.22 FTIR spectrum of the indoor dust from different microenvironments of (**a) Cotton university, (b) Tezpur University, (c) Households of Guwahati, and (d) Households of Tezpur**

Table 4.21 FTIR peaks and their functional Groups and Minerals present in indoor dust of

(a) Cotton University

Minerals/ Tentative assignment	Observed wavelength	References
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**467**	[125]; [126]
Feldspar, Si-O asymmetrical bending vibration	**534**	[137]
Haematite, Fe-O	**535**	[125]
Si-O structure, Si-O-Al structure	**538**	[127], 2007
Out of plane bending of the aromatic ring C-H bonds	**675** **678**	[128]
Proto, Si-O bending	**680**	[125]
Out of plane bending of the aromatic ring C-H bonds	**684**	[128]
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**777**	[125]; [128]
Nacrite, Si-O stretching, Al-Al-OH deformation, O-H stretching	**905**	[125]
Kaolinite	**1009**	[130]
Feldspar, Al-O coordination, Si-O stretching, O-H bending, O-H stretching, O-H deformation	**1111**	[125]
O–Si–O stretching of silica, sulfates Si–OH of alumino-silicate lattice, kaolinite, illite, smectite	**1128**	[139]
Cerussite, C-O bending	**1384**	[125]
Calcite, doubly degenerate asymmetric Stretching, CO_3 stretching, C=O stretching, combinational mode, O-H stretching	**1430, 1432**	[125]
Vibrations of $CO_3{}^{2-}$ in calcite, dolomite groups. C-H bending vibrations of CH_3 and CH_2 groups	**1438**	[128]
Kaolinite, Si-O deformation, O-H deformation, O-H stretching	**1621**	[125]
O-H bending of water	**1629**	[139]
Calcite, double degenerate asymmetric Stretching, CO_3 stretching, C=O stretching, combinational mode, O-H stretching	**1635**	[125]
Illite	**1640**	[130]
Palygorskite, Si-O deformation, Si-O stretching, O-H deformation	**1645**	[125]
Calcite, doubly degenerate asymmetric stretching, CO_3 stretching, C=O stretching, combinational mode, O-H stretching	**2515**	[125]
Organic carbon (2922- 2925)	**2925**	[130]
Stretching of O-H bond in water, carboxyl and hydroxyl group	**3400, 3405, 3406, 3409, 3542, 3550 3551**	[128]
Oxides	**3617**	[139]

(b) Tezpur University

Minerals and their tentative assignment	Observed wavelength	References
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**467, 468**	[125], [126]
Quartz, Si-O asymmetric stretching vibrations	**470**	[129]
Fe-o stretching of Haematite	**531**	[136]
Haematite, Fe-O	**537**	[125]
Vermiculite, Si-O symmetrical bending, O-H out of plane bending	**670**	[125]
Out of plane bending of the aromatic ring C-H bonds,	**678**	[128]
Proto, Si-O bending	**681**	[125]
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**694**	[125], [137], [130]
Carbonate, Kaolinite	**768**	[139]
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**777**	[125], [128]
Symmetric stretching of Si-O in quartz (795-800)	**779, 780**	[128],[140]
Carbonate, Kaolinite	**783**	[139]
Vibration of CO_3^{-2} in calcite and minerals of the calcite and dolomite group	**882**	[128]
Fundamental vibration in illite	**914**	[128], [130]
, Quartz, Si-O stretching	**1067**	[125]
Quartz, Si-O asymmetric stretching vibrations	**1100**	[129]
Feldspar, Al-O coordination, Si-O stretching, O-H bending, O-H stretching, O-H deformation	**1113**	[125]
	1155	
Carbonates	**1450**	[139], [136]
O-H bending of water	**1628**	[139]
Illite	**1640**	[130]
C=O, stretching vibrations in amides	**1650**	[128]
Palygorskite, Si-O deformation, Si-O stretching, O-H deformation	**1645** **1649**	[125]
Organic carbon	**2925**	[130]
Symmetric and asymmetric C-H stretching of CH_3 and CH_2 group	**2859** **2856**	[128]
O-H stretching, N-H, Carboxyl, alcohols and phenols/ amine & amide, hydroxyl group	**3405**	[128]
Stretching of O-H bond in water, carboxyl and hydroxyl group	**3550**	[128]
Oxides	**3615**	[139]
Kaolinite	**3620**	[130], [141]

(c) Household of Guwahati

Minerals and their tentative assignment	Observed wavelength	References
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**467**	[125], [126]
Quartz, Si-O asymmetric stretching vibrations	**470**	[129]
Haematite, Fe-O	**535**	[125]
Feldspar (535) Si-O asymmetrical bending vibration	**536**	[137]
Out of plane bending of the aromatic ring C-H bond	**730**	[128]
Quartz, Si-O symmetric bending, Si-O symmetric stretching,	**777**	[125], [130]
Out of plane bending of the aromatic ring C-H bond	**873**	[128]
Calcite, doubly degenerate asymmetric Stretching, CO3 stretching, C=O stretching, combinational mode, O-H stretching	**874**	[125], [137], [130]
Fundamental vibration in illite	**913**	[128]
Stretching Si-O	**973**	[142]
Smectite	**1015**	[139]
Quartz, Si-O asymmetric stretching vibrations	**1100**	[129]
Vibrations of CO_3^{-2} in calcite minerals and dolomite groups, C-H bending vibrations of CH_3 and CH_2 groups	**1435**	[128]
C-H aliphatic carbon	**1454**	[143]
Carbonates	**1475**	[139]
C=O, stretching vibrations in amides	**1650** **1651**	[128]
Calcite, doubly degenerate asymmetric Stretching, CO3 stretching, C=O stretching, combinational mode, O-H stretching	**2518**	[125]
Vibrations of CO_3^{-1} in calcite and minerals of the calcite and dolomite groups	**2527**	[128]
Symmetric and asymmetric C-H stretching of CH_3 and CH_2 groups	**2931**	[128]
Organic carbon, C-H stretching	**2924**	[125]
Organic carbon	**2925**	[130]
Kaolinite	**3620** **3621**	[130]
Kaolinite, Si-O deformation, O-H deformation, O-H stretching	**3622**	[125]
(OH) assigned to surface hydroxyl groups of kaolinite clay mineral	**3698**	[126], [139]

(d) Household of Tezpur

Minerals and their tentative assignment	Observed wavelength	References
Quartz, Si-O symmetric bending, Si-O symmetric stretching	**465, 467**	[131] [125]
Haematite, Fe-O	**536**	[125]
Feldspar, Si-O asymmetrical bending vibration	**538**	[129]
Quartz, Si-O asymmetric stretching vibrations	**783**	[129]
Aliettile , O-H stretching	**789**	[125]
Out of plane bending of the aromatic ring C-H bond	**792** **871**	[128]
Calcite, doubly degenerate asymmetric stretching, CO_3 stretching, C=O stretching, combinational mode, O-H stretching	**873**	[125]
Nacrite, Si-O stretching, Al-Al-OH deformation, O-H stretching	**907**	[125]
Kaolinite, Si-o stretching	**1027**	[137]
Quartz, Si-O asymmetric stretching vibrations	**1100**	[129]
C=O, stretching vibrations in amides	**1650** **1733**	[128]
Overtones and combination bands for quartz and silicates	**1880**	[128], [130]
Calcite, doubly degenerate asymmetric Stretching, CO_3 stretching, C=O stretching, combinational mode, O-H stretching	**2518**	[125]
Vibrations of $CO_3{}^{2-}$ in calcite and minerals of the calcite and dolomite groups	**2525**	[128]
Organic carbon stretching vibration	**2857**	[140]
Carbonate (calcite or aragonite) (overtone/combination band)	**2527**	[139]
Symmetric and asymmetric CH stretching of CH_3 and CH_2 groups	**2859,2926**	[128]
Organic carbon	**2925**	[130]
Oxides	**3617**	[139]
Kaolinite, Si-O deformation, O-H deformation, O-H stretching	**3623**	[125]
Kaolinite, stretching O-H bond	**3624**	[130]

and Mohiuddin [144], conducted in a university campus in Bangladesh, the FTIR analysis of indoor deposited particles found the presence of hydroxyl (-OH), aliphatic carbon ($-CH_2$), carbonyl (-CO) and amino ($-NH_2$) groups.

4.5.2 XRD

The XRD peaks of the samples are shown in Fig. 4.23 (a) CU, (b) TU (c) Households of Guwahati, (d) Households of Tezpur. From the XRD study, six minerals can be identified viz. Quartz (Q), Dolomite (D), Calcite (C), Illite (I), Haematite (H), and Bornite (B), (Table 4.22). The XRD analysis of SD samples revealed a varied group of minerals, reflecting a combination of both natural (geogenic) and human-induced (anthropogenic) sources. The analysis of SD confirmed quartz as the dominant mineral phase across all sites. A study conducted by Kumar & Jain [145] in Dhanbad, India found that calcite, dolomite, haematite, vaterite, and quartz were found in the household dust. Another study of indoor deposited particles in a university campus at Bangladesh found that Quartz was found predominantly in all samples [144]. Carbonate minerals, specifically calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), were also identified. These minerals are common in limestone-derived construction materials, road aggregates, and soil dust, often resuspended by vehicular movement or wind turbulence in urban settings [92, 134]. Calcite was found in all the sites whereas dolomite was found in CR3_HSS and CR4_HSS of Cotton University. Illite, a potassium-rich phyllosilicate, is found in all the sites except in the households of Guwahati. Hematite (Fe_2O_3) was observed in the samples of CR3_HSS of Coton University and Households of Guwahati and Tezpur. Bornite (Cu_5FeS_4) was found only in CR4_HSS of Cotton University.

The XRD results were supported by FTIR analysis, with both techniques revealing complementary and consistent mineralogical signatures. This cross-validation enhances the reliability and robustness of the mineralogical characterization of the settled dust samples.

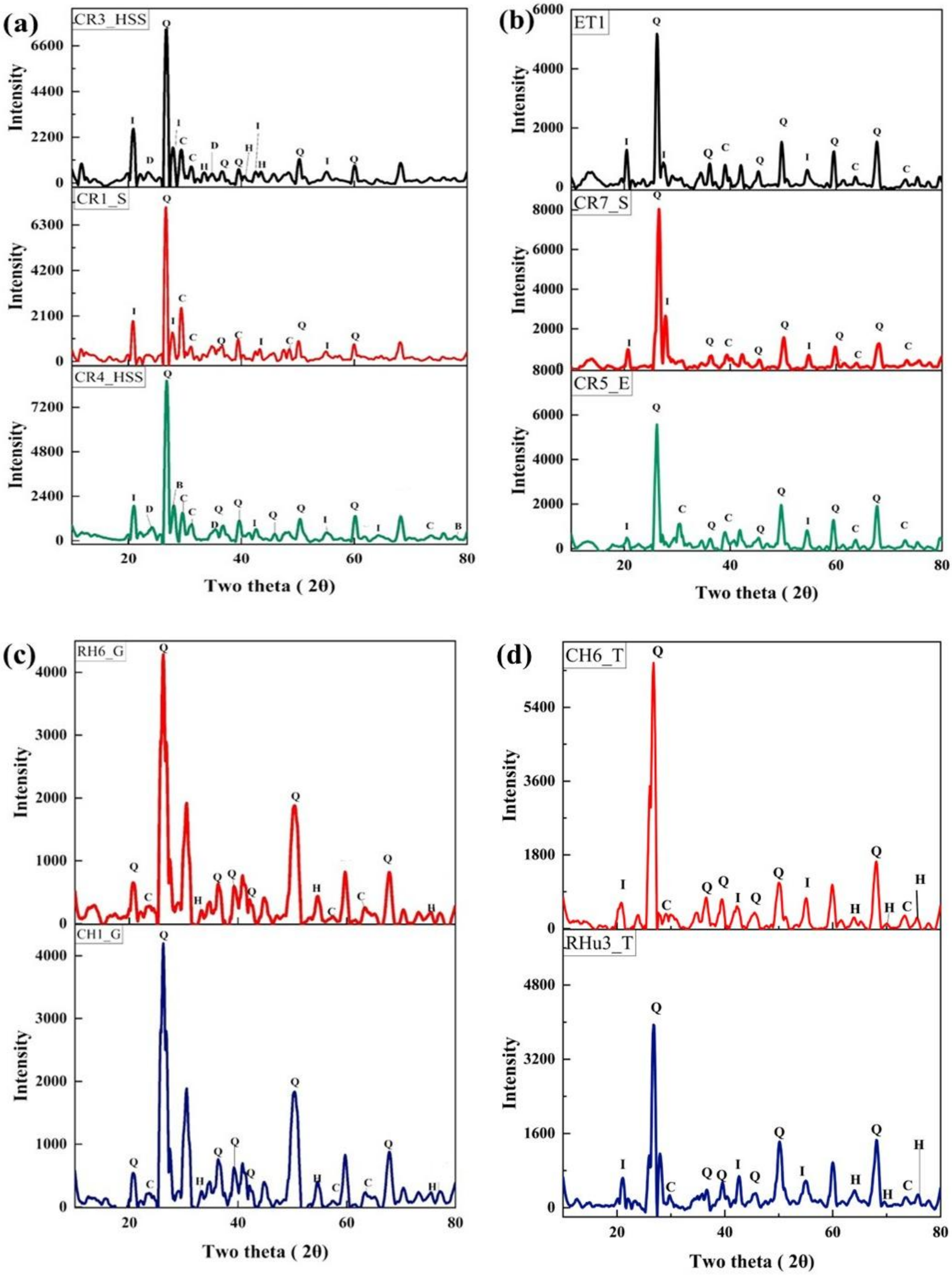


Fig 4.23 XRD peaks of the indoor dust of **(a) Cotton University, (b) Tezpur University, (c) Households of Guwahati, and (d) Households of Tezpur**

Table 4.22 Minerals and corresponding XRD peak positions (2θ) and calculated interplanar spacing and plane (d_{hkl})

Mineral	2θ (degrees)	d (Å)	hkl Plane
Quartz	26.64, 36.55, 39.47, 45.80, 68.15, 50.14, 68.13, 39.46, 59.96, 50.14, 20.85, 42.47, 67.75	3.34, 2.46, 2.28, 1.98, 1.37, 1.82, 1.38, 2.28, 1.54, 1.82, 4.26, 2.13, 1.38	[101], [110], [102], [201], [203], [112], [203], [102], [211], [112], [100], [200], [212]
Dolomite	24.14, 35.44, 50.72, 60.04, 35.44, 68.20, 61.35, 41.69, 70.36	3.68, 2.53, 1.80, 1.54, 2.53, 1.37, 1.51, 2.17, 1.34	[012], [015], [018], [21-2], [015], [300], [018], [006], [125]
Calcite	29.41, 31.42, 73.73, 39.42, 48.51, 29.80, 63.69, 57.40, 63.06	3.04, 2.85, 1.28, 2.28, 1.87, 3.00, 1.46, 1.60, 1.47	[104], [006], [306], [113], [116], [025], [316], [122], [125]
Ilite	20.91, 42.55, 55.25, 64.33, 43.46, 27.72	4.25, 2.12, 1.66, 1.45, 2.08, 3.22	[112], [224], [242], [-335], [223], [114]
Haematite	43.52, 33.15, 40.86, 63.97, 69.50, 54.09	2.08, 2.70, 2.21, 1.45, 1.35, 1.69	[202], [104], [113], [300], [208], [116]
Bornite	28.24, 78.07	3.16, 1.22	[111], [024]

4.6 Health Risk Assessment

The non-carcinogenic and carcinogenic health risk assessments of elements are presented in Tables 4.23 (a-d) for CU, TU, households of Guwahati and households of Tezpur, respectively. In CU and TU, adult exposure via ingestion accounted for 73.17% and 71.54% of the total hazard index (HI), followed by dermal contact (23.21% and 24.44%) and then inhalation (4.03% and 4.47%). Similarly, in households of Guwahati ingestion contributed 78.67% to HI for children and 71.71% for adults. In Tezpur, ingestion comprised 78.73% for children and 73.60% for adults followed by dermal and inhalation pathways. These findings underscore ingestion as the primary route of exposure. Fig. 4.24 a and b showed the contribution of HQ_{ing}, HQ_{inh}, and HQ_{dermal} to HI for each element in children and adults, respectively. With the exception of Co and Mn, where the route of exposure was in the order $HQ_{ing} > HQ_{inh} > HQ_{derm}$, all other elements had the order $HQ_{ing} > HQ_{derm} > HQ_{inh}$. Notably, Mn exposure was highest through inhalation in adults. Previous studies had also reported oral ingestion as the major pathway for exposure of dust in humans [15, 146-148].

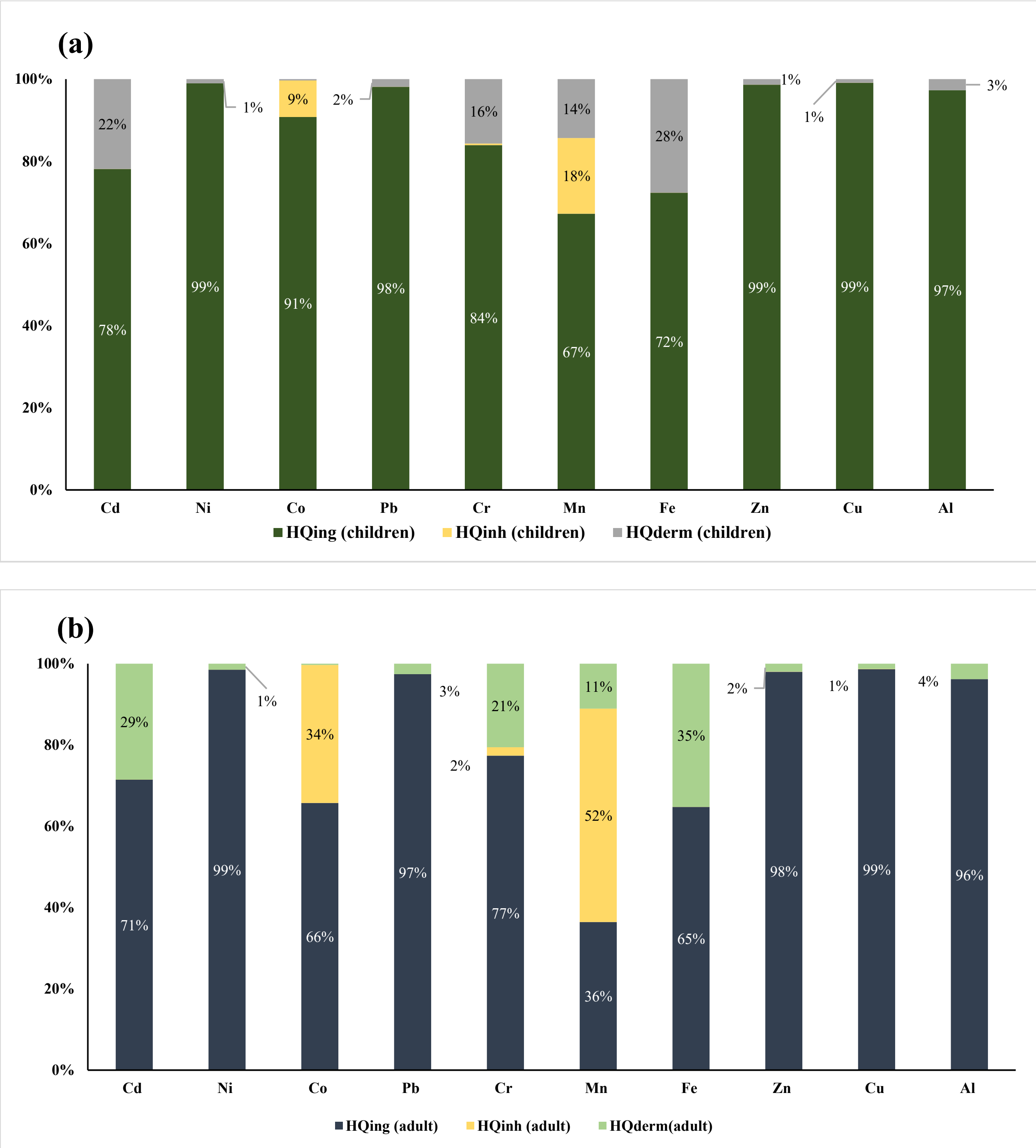


Fig. 4.24 Contribution of HQ_{ing}, HQ_{inh}, and HQ_{dermal} to the HI for each element in **(a) children (b) adults**

The overall hazard index (HI) values for adults remained below 1 across all study sites, including both universities and households in Tezpur and Guwahati. This indicates that elemental concentrations in SD of the sampled area were within acceptable limits and are unlikely to pose significant non-carcinogenic health risks to adults. In contrast, HI values for children exceeded 1 in all household samples, suggesting a potential non-carcinogenic health risk, primarily through the ingestion pathway. In children the HI value has gone up to 2.5. This elevated risk in children may be attributed to their frequent hand-to-mouth behavior, increased likelihood of playing on the ground, and a higher rate of metal absorption in their developing bodies [147, 149, 150] . Although the HI values for adults remained below the threshold limit, it is important to recognize that prolonged exposure and increased concentrations of elements could elevate health risks over time. Specifically, the accumulation of these elements in body tissues may contribute to adverse neurological and developmental effects [94,151, 152]. Consequently, regular monitoring and comprehensive assessments of both university microenvironments and residential settings are essential for early risk detection and management.

In order to assess the lifetime cancer risks linked to heavy metal exposure through SD inhalation, the cancer risk values for Cd, Ni, Co, Pb, and Cr were calculated. In most settings, including university spaces and households, the LCR values consistently followed the descending order: Cr > Co > Ni > Cd > Pb. Notably, a deviation from this trend was observed in the Library Complex of CU as well as in households situated in the commercial and rural residential areas of Tezpur, where the sequence shifted to Cr > Ni > Co > Cd > Pb. Cancer risk values for these elements showed that Cr posed the highest risk while Pb exhibited the lowest risk. Our findings are consistent with Nath et al. [146] and Somsunun et al. [148]. The individual carcinogenic effects of these elements were not significant in the present study, as the carcinogenic risk for all elements was within the acceptable limits of 10^{-6} to 10^{-4} given by HHRA [153]. Similar findings are reported by Bhandari et al. [154] and Tan et al. [155]. The assessment reveals no significant LCR via inhalation exposure to indoor dust in the sampled locations of both Guwahati and Tezpur. However, in Guwahati, ongoing infrastructure development and widespread construction activities may contribute to a gradual decline in indoor environment, potentially increasing health risks over time. In Tezpur, although current LCR levels appear within safe limits, the urban expansion observed in both residential and commercial zones could similarly alter indoor environmental conditions. These findings highlight the need for continued surveillance and effective mitigation strategies to safeguard indoor environmental health in both urban centers.

Table 4.23 Hazard Quotients (HQ), Hazard Index (HI), and Carcinogenic Risk (CR) for adults exposed to elements in indoor dust in **(a) Cotton University**

Microenvironments	Elements	HQ_{ing} (adult)	HQ_{inh} (adult)	Hq_{derm} (adult)	HI	ΣHI	CR
Academic Classrooms and Labs	**Cd**	4.05E-03	5.95E-07	1.62E-03	5.66E-03	**0.31**	5.18E-09
	Ni	1.87E-03	2.67E-07	2.77E-05	1.90E-03		6.39E-09
	Co	8.49E-04	4.38E-04	4.23E-06	1.29E-03		3.38E-08
	Pb	2.82E-02	4.13E-06	7.51E-04	2.90E-02		8.43E-10
	Cr	1.43E-02	3.77E-04	3.81E-03	1.85E-02		6.11E-07
	Mn	9.05E-03	1.30E-02	2.75E-03	2.48E-02		
	Fe	1.27E-01	7.99E-05	6.90E-02	1.96E-01		
	Zn	7.90E-04	1.16E-07	1.58E-05	8.06E-04		
	Cu	4.71E-03	6.90E-07	6.27E-05	4.78E-03		
	Al	2.37E-02		9.46E-04	2.47E-02		
Library Complex	**Cd**	3.94E-03	5.79E-07	1.57E-03	5.51E-03	**0.61**	5.03E-09
	Ni	3.07E-02	4.38E-06	4.53E-04	3.11E-02		1.05E-07
	Co	1.40E-03	7.22E-04	6.98E-06	2.13E-03		5.57E-08
	Pb	4.90E-02	7.17E-06	1.30E-03	5.03E-02		1.46E-09
	Cr	2.04E-01	5.35E-03	5.42E-02	2.63E-01		8.68E-06
	Mn	9.19E-03	1.32E-02	2.79E-03	2.52E-02		
	Fe	1.35E-01	8.49E-05	7.33E-02	2.08E-01		
	Zn	7.98E-04	1.17E-07	1.59E-05	8.14E-04		
	Cu	9.44E-03	1.38E-06	1.26E-04	9.57E-03		
	Al	1.54E-02		6.15E-04	1.60E-02		

(b) Tezpur University

Microenvironments	Elements	HQ_{ing} (adult)	HQ_{inh} (adult)	Hq_{derm} (adult)	HI	ΣHI	CR
Academic Classrooms and Labs	**Cd**	3.22E-03	4.73E-07	1.28E-03	4.50E-03	**0.23**	4.11E-09
	Ni	1.56E-03	2.23E-07	2.31E-05	1.58E-03		5.32E-09
	Co	4.85E-04	2.50E-04	2.42E-06	7.37E-04		1.93E-08
	Pb	2.12E-02	3.10E-06	5.64E-04	2.18E-02		6.32E-10
	Cr	1.20E-02	3.14E-04	3.18E-03	1.55E-02		5.10E-07
	Mn	6.57E-03	9.46E-03	1.99E-03	1.80E-02		
	Fe	9.57E-02	6.03E-05	5.21E-02	1.48E-01		
	Zn	2.34E-04	3.44E-08	4.67E-06	2.39E-04		
	Cu	4.16E-03	6.09E-07	5.53E-05	4.22E-03		
	Al	1.87E-02		7.48E-04	1.95E-02		
Social and Utility spaces	**Cd**	5.67E-03	8.34E-07	2.26E-03	7.94E-03	**0.33**	7.25E-09
	Ni	3.33E-03	4.75E-07	4.91E-05	3.37E-03		1.13E-08
	Co	6.64E-04	3.43E-04	3.31E-06	1.01E-03		2.64E-08
	Pb	2.92E-02	4.27E-06	7.77E-04	3.00E-02		8.72E-10
	Cr	3.45E-02	9.06E-04	9.17E-03	4.46E-02		1.47E-06
	Mn	7.77E-03	1.12E-02	2.36E-03	2.13E-02		
	Fe	1.13E-01	7.10E-05	6.13E-02	1.74E-01		
	Zn	4.35E-04	6.39E-08	8.67E-06	4.43E-04		
	Cu	9.40E-03	1.37E-06	1.25E-04	9.52E-03		
	Al	3.47E-02		1.38E-03	3.61E-02		

(c) Households of Guwahati

	Elements	HQ_{ing} (children)	HQ_{inh} (children)	HQ_{derm} (children)	HI	ΣHI	HQ_{ing} (adult)	HQ_{inh} (adult)	HQ_{derm} (adult)	HI	ΣHI	CR
Households in Industrial Area	Cd	6.48E-03	1.81E-07	1.82E-03	8.30E-03	**1.4**	3.24E-03	4.77E-07	1.29E-03	4.54E-03	**0.2**	4.14E-09
	Ni	5.44E-03	1.48E-07	5.64E-05	5.50E-03		2.72E-03	3.88E-07	4.02E-05	2.76E-03		9.28E-09
	Co	1.10E-03	1.08E-04	3.85E-06	1.21E-03		5.50E-04	2.84E-04	2.74E-06	8.37E-04		2.19E-08
	Pb	3.65E-02	1.01E-06	6.81E-04	3.72E-02		1.83E-02	2.67E-06	4.85E-04	1.87E-02		5.44E-10
	Cr	2.87E-02	1.43E-04	5.36E-03	3.42E-02		1.43E-02	3.77E-04	3.82E-03	1.85E-02		6.11E-07
	Mn	5.54E-02	1.51E-02	1.18E-02	8.23E-02		6.92E-03	9.96E-03	2.10E-03	1.90E-02		
	Fe	7.30E-01	8.74E-05	2.79E-01	1.01E+00		9.12E-02	5.75E-05	4.96E-02	1.41E-01		
	Zn	2.51E-03	7.03E-08	3.52E-05	2.55E-03		3.14E-04	4.62E-08	6.27E-06	3.21E-04		
	Cu	2.97E-02	8.27E-07	2.78E-04	3.00E-02		3.72E-03	5.44E-07	4.94E-05	3.77E-03		
	Al	2.09E-01		5.84E-03	2.14E-01		2.61E-02		1.04E-03	2.71E-02		
Households in Commercial Area	Cd	1.28E-02	3.58E-07	3.59E-03	1.64E-02	**2.1**	6.41E-03	9.42E-07	2.56E-03	8.97E-03	**0.3**	8.19E-09
	Ni	4.36E-03	1.18E-07	4.52E-05	4.41E-03		2.18E-03	3.11E-07	3.22E-05	2.21E-03		7.44E-09
	Co	1.19E-03	1.17E-04	4.18E-06	1.31E-03		5.97E-04	3.08E-04	2.98E-06	9.07E-04		2.37E-08
	Pb	6.62E-02	1.84E-06	1.24E-03	6.74E-02		3.31E-02	4.84E-06	8.80E-04	3.40E-02		9.87E-10
	Cr	2.30E-02	1.15E-04	4.29E-03	2.74E-02		1.15E-02	3.02E-04	3.06E-03	1.48E-02		4.90E-07
	Mn	7.97E-02	2.18E-02	1.70E-02	1.18E-01		9.96E-03	1.43E-02	3.02E-03	2.73E-02		
	Fe	9.77E-01	1.17E-04	3.73E-01	1.35E+00		1.22E-01	7.70E-05	6.64E-02	1.89E-01		
	Zn	3.05E-03	8.53E-08	4.28E-05	3.10E-03		3.82E-04	5.61E-08	7.62E-06	3.89E-04		
	Cu	6.37E-02	1.77E-06	5.94E-04	6.43E-02		7.96E-03	1.16E-06	1.06E-04	8.07E-03		
	Al	4.79E-01		1.34E-02	4.92E-01		5.98E-02		2.39E-03	6.22E-02		
Households in Residential Area	Cd	2.36E-03	6.59E-08	6.60E-04	3.02E-03	**1.5**	1.18E-03	1.73E-07	4.70E-04	1.65E-03	**0.2**	1.51E-09
	Ni	3.02E-03	8.19E-08	3.13E-05	3.05E-03		1.51E-03	2.16E-07	2.23E-05	1.53E-03		5.15E-09
	Co	9.38E-04	9.19E-05	3.28E-06	1.03E-03		4.69E-04	2.42E-04	2.34E-06	7.13E-04		1.87E-08
	Pb	2.01E-02	5.57E-07	3.74E-04	2.04E-02		1.00E-02	1.47E-06	2.67E-04	1.03E-02		2.99E-10
	Cr	1.65E-02	8.25E-05	3.09E-03	1.97E-02		8.27E-03	2.17E-04	2.20E-03	1.07E-02		3.52E-07
	Mn	5.39E-02	1.47E-02	1.15E-02	8.01E-02		6.74E-03	9.70E-03	2.05E-03	1.85E-02		
	Fe	7.50E-01	8.98E-05	2.86E-01	1.04E+00		9.37E-02	5.91E-05	5.10E-02	1.45E-01		
	Zn	1.77E-03	4.95E-08	2.48E-05	1.80E-03		2.21E-04	3.26E-08	4.42E-06	2.26E-04		
	Cu	3.81E-02	1.06E-06	3.56E-04	3.85E-02		4.77E-03	6.98E-07	6.34E-05	4.83E-03		
	Al	2.86E-01		8.00E-03	2.94E-01		3.57E-02		1.43E-03	3.72E-02		

(d) Households of Tezpur

	Elements	HQ_{ing} (children)	HQ_{inh} (children)	HQ_{derm} (children)	HI	ΣHI	HQ_{ing} (adult)	HQ_{inh} (adult)	HQ_{derm} (adult)	HI	ΣHI	CR
Households in Residential Area (Urban)	**Cd**	7.45E-03	2.08E-07	2.09E-03	9.54E-03	**1.7**	3.72E-03	5.48E-07	1.49E-03	5.21E-03	**0.3**	4.76E-09
	Ni	2.56E-03	6.95E-08	2.66E-05	2.59E-03		1.28E-03	1.83E-07	1.89E-05	1.30E-03		4.36E-09
	Co	1.11E-03	1.09E-04	3.89E-06	1.22E-03		5.55E-04	2.87E-04	2.77E-06	8.45E-04		2.21E-08
	Pb	3.64E-02	1.01E-06	6.80E-04	3.71E-02		1.82E-02	2.66E-06	4.84E-04	1.87E-02		5.43E-10
	Cr	1.95E-02	9.73E-05	3.64E-03	2.32E-02		9.75E-03	2.56E-04	2.59E-03	1.26E-02		4.16E-07
	Mn	6.10E-02	1.67E-02	1.30E-02	9.07E-02		7.63E-03	1.10E-02	2.32E-03	2.09E-02		
	Fe	7.97E-01	9.54E-05	3.04E-01	1.10E+00		9.96E-02	6.28E-05	5.42E-02	1.54E-01		
	Zn	2.34E-03	6.53E-08	3.27E-05	2.37E-03		2.92E-04	4.30E-08	5.83E-06	2.98E-04		
	Cu	1.90E-02	5.28E-07	1.77E-04	1.92E-02		2.37E-03	3.47E-07	3.16E-05	2.41E-03		
	Al	4.36E-01		1.22E-02	4.48E-01		5.45E-02		2.18E-03	5.67E-02		
Households in Commercial Area	**Cd**	5.65E-03	1.58E-07	1.58E-03	7.23E-03	**2.5**	2.83E-03	4.16E-07	1.13E-03	3.95E-03	**0.6**	3.61E-09
	Ni	7.85E-02	2.13E-06	8.14E-04	7.93E-02		3.93E-02	5.60E-06	5.80E-04	3.98E-02		1.34E-07
	Co	2.77E-03	2.72E-04	9.69E-06	3.05E-03		1.38E-03	7.15E-04	6.91E-06	2.11E-03		5.51E-08
	Pb	2.98E-02	8.29E-07	5.57E-04	3.04E-02		1.49E-02	2.18E-06	3.97E-04	1.53E-02		4.45E-10
	Cr	5.27E-01	2.63E-03	9.84E-02	6.28E-01		2.64E-01	6.92E-03	7.01E-02	3.41E-01		1.12E-05
	Mn	6.45E-02	1.76E-02	1.37E-02	9.58E-02		8.06E-03	1.16E-02	2.45E-03	2.21E-02		
	Fe	1.01E+00	1.21E-04	3.85E-01	1.39E+00		1.26E-01	7.95E-05	6.86E-02	1.95E-01		
	Zn	4.43E-03	1.24E-07	6.21E-05	4.50E-03		5.54E-04	8.15E-08	1.11E-05	5.65E-04		
	Cu	5.54E-02	1.54E-06	5.17E-04	5.59E-02		6.93E-03	1.01E-06	9.22E-05	7.02E-03		
	Al	1.49E-01		4.18E-03	1.54E-01		1.87E-02		7.45E-04	1.94E-02		
Households in Residential Area (Rural)	**Cd**	5.53E-03	1.55E-07	1.55E-03	7.08E-03	**1.3**	2.77E-03	4.07E-07	1.10E-03	3.87E-03	**0.2**	3.54E-09
	Ni	8.19E-03	2.22E-07	8.49E-05	8.27E-03		4.09E-03	5.85E-07	6.05E-05	4.16E-03		1.40E-08
	Co	5.39E-04	5.29E-05	1.89E-06	5.94E-04		2.70E-04	1.39E-04	1.34E-06	4.10E-04		1.07E-08
	Pb	3.28E-02	9.11E-07	6.12E-04	3.34E-02		1.64E-02	2.40E-06	4.36E-04	1.68E-02		4.89E-10
	Cr	2.10E-02	1.05E-04	3.92E-03	2.51E-02		1.05E-02	2.76E-04	2.80E-03	1.36E-02		4.48E-07
	Mn	3.83E-02	1.05E-02	8.15E-03	5.69E-02		4.78E-03	6.89E-03	1.45E-03	1.31E-02		
	Fe	6.68E-01	8.00E-05	2.55E-01	9.24E-01		8.35E-02	5.26E-05	4.55E-02	1.29E-01		
	Zn	8.03E-03	2.24E-07	1.12E-04	8.14E-03		1.00E-03	1.48E-07	2.00E-05	1.02E-03		
	Cu	2.61E-02	7.25E-07	2.43E-04	2.63E-02		3.26E-03	4.77E-07	4.33E-05	3.30E-03		
	Al	1.94E-01		5.44E-03	2.00E-01		2.43E-02		9.69E-04	2.52E-02		

4.7 Sick Building Syndrome

This study is an attempt to assess the prevalence of Sick Building Syndrome (SBS) and its associated risk factors in 550 households of Guwahati, aiming to provide insights into indoor environmental quality (IEQ) (which encompasses not only indoor air quality (IAQ) but also factors such as access to daylight, thermal and acoustic comfort, and lighting conditions) and its impact on residents' health.

4.7.1 Personal Details, Neighborhood, Description of Indoor Activities and Perception of IAQ by Occupants

The demographic characteristics of the participants, along with information on building and neighborhood features, lifestyle factors including indoor activities, and perceptions of indoor air quality, are summarized in Table 4.24. Among the respondents, 44.4% were men and 55.6% were women. The age distribution was as follows: 20–29 years (53.6%), 30–39 years (18.5%), 40–49 years (14.7%), 50–59 years (6.2%), and 60–69 years (6.9%). A medical history was reported by 37.5% of participants, with allergic rhinitis being the most common condition (12.9%). Children were being raised in 31.6% of the households. Regarding the age of residential buildings, 6.4% were <1 year old, 6.9% were 1-<3 years, 10.2% were 3-<5 years, 10% were 5-<10 years, 31.5% were 10-<20 years, and 35.1% were over 20 years old. Within 50 meters of most residences, neighboring structures included other houses (74.9%) and stores (26.9%). A total of 31.3% of participants lived in apartments, while 68.7% resided in detached houses. Regarding flooring materials, 54.2% of homes had tile or marble flooring, followed by concrete and other materials. A daily cleaning frequency was reported by 82.5% of participants, while 17.5% reported cleaning less frequently. Indoor smoking was permitted in 22.7% of households. Spray products were used in 59.1% of homes, and incense burning was reported by 84.6% of households. Mosquito repellents (coils or vaporizers) were used in 75.6% of homes. Pets were kept indoors in 32.5% of households. 72.5% of the homes had walls in good condition, showing no signs of cracks or peeling paint. However, mould growth on walls was observed in 14% of the households. 77.8% of occupants perceived that air pollution is present indoors, while 7.3% of households experienced poor ventilation.

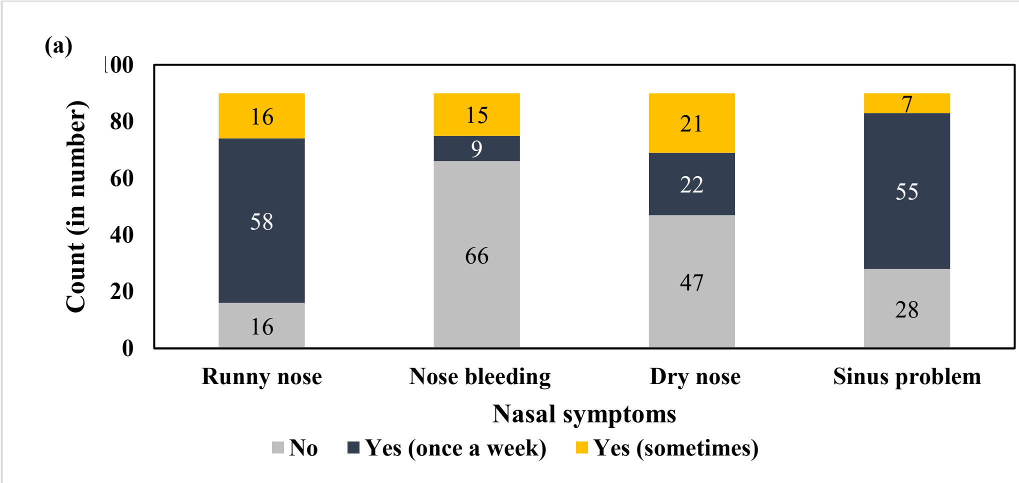
4.7.2 Basic Details about Occurrence of SBS (Nasal Problem, Throat Problem, Eye Related Problem, Aches and Pain, Dermal Problem and General Complaints)

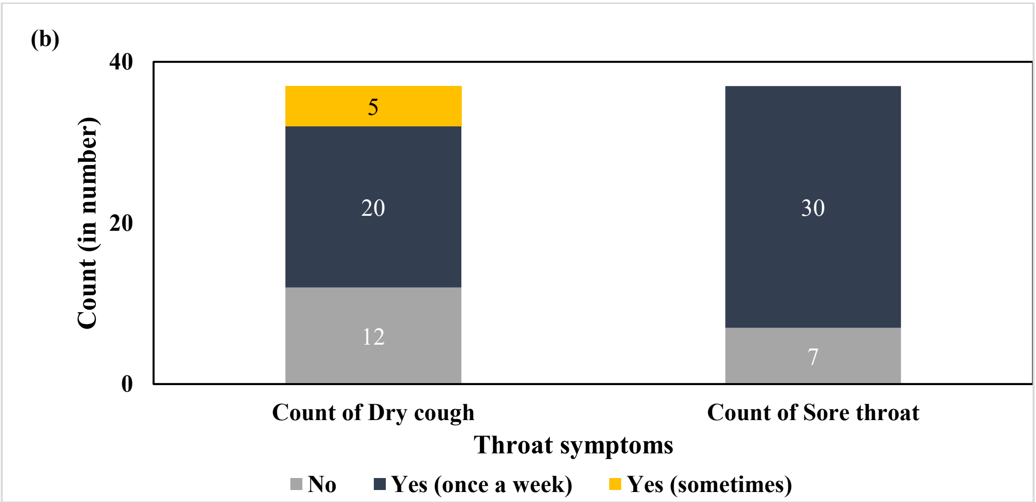
The symptoms experienced by the occupants and their frequency of occurrence (once a week or sometimes) are presented in Fig. 4. 25 (a-f). The onset of any one: nasal symptoms (sinus/runny nose/ nose bleeding/dry nose) were reported by 90 participants (16.36%), throat symptoms (sore throat/dry cough) by 37 (6.72%), eye problems (redness/burning/watery/dryness/irritation of eyes/ blurred vision) by 40 participants (7.27%) dermal problems (skin irritation, dryness, flakiness and dandruff) by 84 (15.27%), aches and pains (Headaches/migraines/joint pains/muscle pains) by 92 (16.72%) and general complaints (drowsiness/dizziness/faintness/breathing problem/digestion problem) by 119 (21.6%) participants. Among these, 64.4% experienced a runny nose once a week, while 61.1% reported sinus problems. Among respondents with throat issues, 54.05% experienced a dry cough and 81.08% reported a sore throat. Eye-related symptoms were also common, with eye irritation (40%), watery or dry eyes (52.5%), redness (42.5%), blurred vision (17.5%), and a burning sensation (32.5%) reported to occour once a week. Among those reported dermal symptoms, flakiness and dryness were the most frequently experienced, occurring at least once a week. Headaches and migraines were highly prevalent, affecting 96.7% of those complaining of aches and pains. Similarly, 68.9% of those with general complaints reported digestive problems.

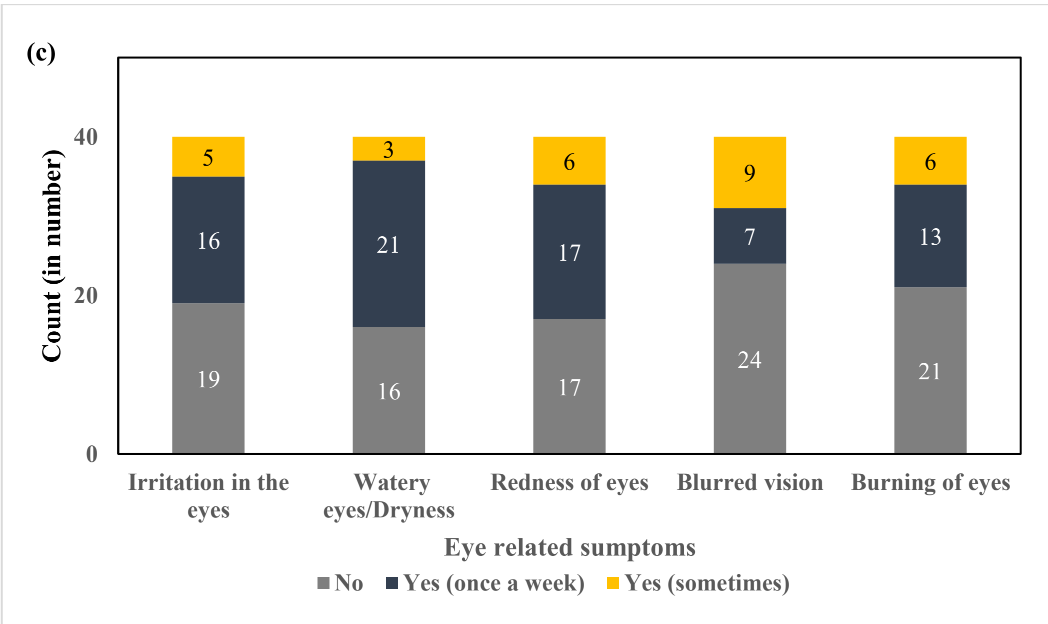
Table 4.24 The demographic characteristics of the participants, neighborhood features, lifestyle factors, indoor activities, and perceptions of indoor air quality among occupants

Personal Details			**Neighbourhood/Housing**		
Gender	**N**	**%**	**Age of residential building (years)**	**N**	**%**
Male	244	44.4	<1	35	6.4
Female	306	55.6	1 to <3	38	6.9
Age (years)	**N**	**%**	3 to <5	56	10.2
20-29	295	53.6	5 to <10	55	10
30-39	102	18.5	10 to <20	173	31.5
40-49	81	14.7	>20	193	35.1
50-59	34	6.2	**Residence history (years)**	**N**	**%**
60 and above	38	6.9	<1	85	15.5
Medical History	**N**	**%**	1 to <3	78	14.2
None	344	62.5	3 to <5	67	12.2
Allergic conjunctivitis	14	2.5	5 to <10	50	9.1
Allergic rhinitis	71	12.9	10 to <20	127	23.1
Mental illness	35	6.4	**Neighbourhood environments within 50 m**	**N**	**%**
Asthma	17	3.1	Housing	412	74.9
Atopic dermatitis	19	3.5	Strores	148	26.9
Food allergy	14	2.5	Factory	19	3.5
More than one	36	6.5	Mainroad	93	16.9
Raising Children at home	**N**	**%**	Playground	28	5.1
Yes	174	31.6	**Type of House**	**N**	**%**
No	326	59.3	Apartment/Flats	172	31.3
			Detached house	378	68.7

Structure of House	**N**	**%**	**Cracks on Floor**	**N**	**%**
Assam type (Ikra house)	120	21.8	Yes	96	17.5
Reinforced Cement Concrete house (RCC house)	430	78.2	No	454	82.5
Flooring material			**Count of Condition of wall painting**	**N**	**%**
Others	15	2.7	Average	132	24
Concrete	237	43.1	Bad	19	3.5
Tiles/Marble	298	54.2	Good	399	72.5
Ceiling material	**N**	**%**	**Moulds on walls**	**N**	**%**
Asbestos	90	16.4	No	473	86
Concrete	429	78	Yes	77	14
Other	31	5.6	**Visible dust in the house**	**N**	**%**
C. **Description of Indoor activities**			No	181	32.9
Cleaning frequency	**N**	**%**	Yes	369	67.1
Everyday	454	82.5	**D. Perception of Indoor air**		
Not Everyday	96	17.5	**Indoor air pollution present**	**N**	**%**
Indoor cigarette smoking	**N**	**%**	Yes	428	77.8
Yes	125	22.7	No	122	22.2
No	425	77.3	**Ventilation inside the household**	**N**	**%**
Spray products used	**N**	**%**	Well Ventilated	510	92.7
Yes	325	59.1	Poorly Ventilated	40	7.3
No	225	40.9	**Pollution comes from outside**	**N**	**%**
Incense burning	**N**	**%**	Yes	398	72.4
Yes	475	86.4	No	152	27.6
No	75	13.6	**If yes, it remains inside for a longer period of time**	**N**	**%**
Mosquito repelling	N	%	Yes	106	19.3
Yes	416	75.6	No	292	53.1
No	134	24.4			
Pet present	**N**	**%**			
Yes	179	32.5			
No	371	67.5			
Cooking fuel	**N**	**%**			
Non-LPG	7	1.3			
LPG	543	98.7			


(a)
Count (in number)
100
80
60
40
20
0
16
58
16
15
9
66
21
22
47
7
55
28
Runny nose
Nose bleeding
Dry nose
Sinus problem
Nasal symptoms
No
Yes (once a week)
Yes (sometimes)


(b)
Count (in number)
40
20
0
5
20
12
30
7
Count of Dry cough
Count of Sore throat
Throat symptoms
No
Yes (once a week)
Yes (sometimes)


(c)
Count (in number)
40
20
0
5
16
19
3
21
16
6
17
17
9
7
24
6
13
21
Irritation in the eyes
Watery eyes/Dryness
Redness of eyes
Blurred vision
Burning of eyes
Eye related sumptoms
No
Yes (once a week)
Yes (sometimes)

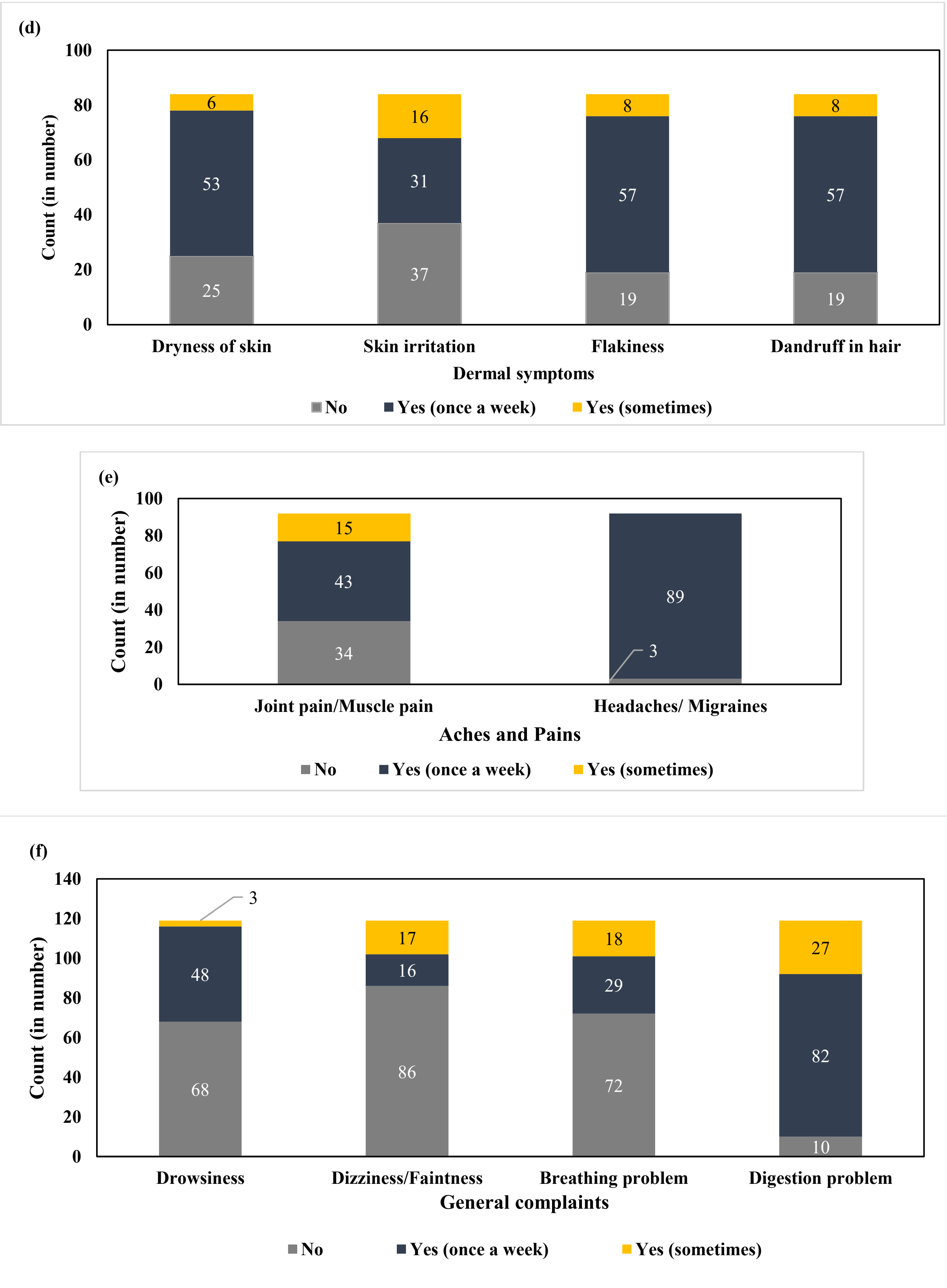


Fig. 4.25 Frequency and occurrence of SBS symptoms **a) Nasal b) Throat c) Eye d) Dermal d) Aches and Pain f) General complaints**

Binomial logistic regression analysis for SBS (nasal problems, throat problems, dermatology problems, eye related problems, general problems and aches and pain) is shown in Table 4.25. According to previous studies, it has been reported that multiple SBS are more common in women [156, 157]. In the present study as well lower odds were shown for throat, dermatological, and general symptoms among male participants compared to females, though these differences were not statistically significant. Notably, for the present study male participants showed significantly higher odds of experiencing nasal problems compared to females (AOR = 1.77; 95% CI: 1.03–3.05).

Residents in buildings aged 5–<10 years showed elevated odds of nasal symptoms (AOR = 2.97; 95% CI: 0.55–15.99), although not statistically significant. General health symptoms demonstrated a trend of decreasing odds with older buildings, with marginal significance observed for structures aged over 20 years ($p = 0.07$). Meanwhile, the high and unstable odds for eye and throat problems suggest potential data irregularities or sample limitations.

Several studies have identified age as a relevant factor in the prevalence of SBS, with individuals over 30 years reported to be more vulnerable to its symptoms [158, 159]. The present findings support this, revealing a clear age gradient in risk: participants aged 40–49 (AOR = 2.77, 95% CI: 1.37–5.58), 50–59 (AOR = 8.97, 95% CI: 3.60–22.33), and 60 and above (AOR = 5.77, 95% CI: 2.43–13.68) exhibited significantly elevated odds of general complaints linked to SBS, compared to those aged 20–29.

Smoking was associated with elevated adjusted odds across almost all symptom, with the strongest and statistically significant association observed for aches and pain (AOR = 1.78, 95% CI: 1.00–3.16). Previous evidence also implicates both smoking history and exposure to secondhand smoke as important risk factors in the development of SBS-related symptoms [156, 160].

Mould/dampness in the wall is yet another factor that played a major role in SBS symptoms. Individuals exposed to mould reported higher odds of aches and pains (AOR = 2.27, 95% CI: 1.18–4.37), suggesting a borderline strong association at $p=0.06$. Lu et al. [161] found that the presence of mould or dampness on floors and ceilings has been linked to symptoms such as fatigue and headaches [161]. Moreover, high levels of mould exposure may trigger cold-like symptoms, skin rashes, and worsen asthma conditions [162]. Cracks on the floor were linked to increased odds across multiple symptoms, with a statistically significant association observed for dermatological symptoms (AOR = 2.02; 95% CI: 1.05–3.85; $p = 0.03$) and a marginally significant for nasal symptoms ($p = 0.06$). Supporting this, Igwe et al. [163] identified active bacterial and fungal growth in wall cracks and on wooden surfaces, indicating a strong link between microbial contamination and the onset of SBS. In addition, the presence of visible dust has been significantly associated with various SBS-related symptoms such as drowsiness, dizziness, and respiratory and digestive issues (AOR = 2.03; 95% CI: 1.08–3.81; $p = 0.03$). Similarly, Yussuf et al. [157] reported that the prevalence of SBS was five times higher in households with significant dust accumulation.

Regarding medical history, individuals with previous health conditions showed elevated odds across four categories (nasal, throat, aches and pain, general complaints) of SBS symptoms. Notably, those with a history of allergic rhinitis or mental illness demonstrated a greater susceptibility to developing SBS. It suggests that pre-existing health conditions may amplify sensitivity to SBS. Suzuki et al. [156] reported similar findings in Japan.

The findings from the binomial logistic regression analysis underscore the interrelated nature of factors contributing to SBS, wherein demographic characteristics, building age and condition, environmental exposures such as dust and mould, lifestyle factors like smoking, and underlying medical histories collectively influence the risk and manifestation of SBS-related symptoms. These insights emphasize the need for integrated indoor environmental management strategies and targeted interventions for vulnerable populations.

Table 4.25 Binomial logistic regression analysis for SBS, nasal problems, throat problems, dermatology problems, eye related problems, general problems and aches and pain

Factors	Nasal problem (AOR, 95% Cl)	Throat Problem (AOR, 95% Cl)	Dermatology Problem (AOR 95% Cl)	Eye Problem (AOR, 95% Cl)	General Problem (AOR, 95% Cl)	Aches and Pain (AOR, 95% Cl)
Gender						
Female	1	1	1	1	1	1
Male	**1.77 (1.03, 3.05)**	0.97 (0.43, 2.19)	0.70 (0.41, 1.2)	1.51(0.82, 2.78)	0.91(0.54, 1.53)	1.03 (0.61, 1.72)
Residential Building Age						
<1	1	1	1	1	1	1
1-<3	1.26 (1.19,8.27)	AOR >10,000 (non-significant p value)	**4.57 (1.02, 20.48**)	AOR >10,000 (non-significant p value)	0.78 (0.21, 2.82)	0.88 (0.23, 3.40)
3-<5	3.67 (6.69,19.62)	-	1.91 (0.43, 8.42)	-	0.53 (0.16, 1.79)	0.72 (0.2, 2.54)
5-<10	2.97 (5.55, 15.99)	-	2.13 (0.50, 9.18)	-	0.4 (0.11, 1.42)	0.85 (0.25, 2.86)
10-<20	1.81 (3.37,8.91)	-	1.44 (0.37, 5.59)	-	0.38 (0.13, 1.12)	0.60 (0.20, 1.77)
>20	3.23 (6.66,15.92)	-	1.44 (0.37, 5.73)	-	0.35 (0.11, 1.07)	0.68 (0.22, 2.05)
Floor type						
Marbles/Title	1	1	1	1	1	1
Concrete	1.28 (0.73,2.26)	1.05 (0.45, 2.45)	0.75 (0.42, 1.33)	0.95 (0.5, 1.8)	0.82 (0.48, 1.4)	0.75 (0.43, 1.31)
Others	2.76 (0.50,15.16)	2.32(0.15, 35.45)	2.86 (0.56, 14.67)	0.89 (0.12, 6.46)	1.06 (0.18, 6.28)	1.5 (0.25, 9.15)
Ceiling Type						
Concrete	1	1	1	1	1	1
Asbestos	1.08 (0.47,2.49)	1.14 (0.32, 4.03)	0.85 (0.36, 1.98)	**0.34 (0.11, 1.02)**	1.3 (0.59, 2.87)	0.85 (0.37, 1.94)
Others	0.34 (0.07,1.61)	0.63(0.10, 3.92)	0.34 (0.08, 1.37)	0.94 (0.24, 3.65)	0.3(0.06, 1.34)	0.39 (0.09, 1.69)
Type of House						
Detached House	1	1	1	1	1	1
Apartments	**0.86(0.44,1.67)**	1.57(0.59, 4.18)	0.76 (0.39, 1.48)	1.36 (0.64, 2.88)	**0.49 (0.25, 0.93)**	0.92 (0.49, 1.74)
Structure of House						
Assam Type	1	1	1	1	1	1
RCC House	1.02 (0.45,2.32)	0.67(0.19, 2.29)	0.54 (0.24, 1.21)	0.51 (0.2, 1.28)	1.05 (0.48, 2.29)	0.59 (0.26, 1.31)

Factors	Nasal problem (AOR, 95% Cl)	Throat Problem (AOR, 95% Cl)	Dermatology Problem (AOR 95% Cl)	Eye Problem (AOR, 95% Cl)	General Problem (AOR, 95%Cl)	Aches and Pain (AOR, 95% Cl)
Age						
20-29	1	1	1	1	1	1
30-39	1.16 (0.58,2.30)	0.91 (0.33, 2.5)	0.72 (0.33, 1.54)	1.04 (0.47, 2.32)	1.26 (0.62, 2.54)	0.84 (0.40, 1.75)
40-49	0.94 (0.42,2.10)	1.31 (0.45, 3.81)	0.88 (0.39, 1.98)	1.18 (0.51, 2.75)	**2.77 (1.37, 5.58)**	1.62 (0.78, 3.39)
50-59	1.74 (0.64,4.74)	Non-significant p value	2.17 (0.84, 5.65)	0.96 (0.28, 3.29)	**8.97 (3.60, 22.33)**	1.85 (0.72, 4.73)
60 and above	1.97 (0.75,5.14)	0.56 (0.10, 3.16)	2.08 (0.79, 5.50)	1.03 (0.29, 3.61)	**5.77 (2.43, 13.68)**	2.18 (0.87, 5.46)
Frequency of cleaning						
Not Everyday	1	1	1	1	1	1
Everyday	1.25 (0.60,2.61)	1.36 (0.45, 4.14)	0.43 (0.22, 0.83)	1.40 (0.59, 3.33)	0.86(0.44, 1.68)	1.01(0.5, 2.02)
Smoking						
Non smoking	1	1	1	1	1	1
Smoking	1.06 (0.58,1.95)	1.45 (0.59, 3.60)	1.10 (0.59, 2.03)	0.77 (0.37, 1.60)	1.52 (0.85, 2.70)	**1.78 (1, 3.16)**
Incense burning						
Not Burning	1	1	1	1	1	1
Burning	0.83 (0.36,1.91)	2.98 (0.60, 14.77)	1.01 (0.45, 2.23)	0.56 (0.23, 1.33)	0.70 (0.31, 1.55)	1.12 (0.5, 2.56)
Mosquito repellent						
Not burned	1	1	1	1	1	1
Burned	1.37 (0.71,2.66)	0.61 (0.25, 1.53)	**1.33(0.69, 2.56)**	1.21 (0.59, 2.49)	0.97(0.53, 1.79)	1.11 (0.59, 2.08)
Pets						
No pets present	1	1	1	1	1	1
Pets present	0.89 (0.51,1.54)	0.48(0.19, 1.22)	0.99 (0.57, 1.72)	1.59(0.86, 2.96)	1.32 (0.80, 2.2)	0.76 (0.44, 1.31)
Cooking fuel						
Not LPG	1	1	1	1	1	1
LPG	0.38 (0.05,2.67)	0.31 (0.02, 4.86)	1.00(0.13, 7.36)	1.05 (0.08, 13.87)	0.37 (0.07, 1.96)	**0.19 (0.04, 1.02)**
Spray products						
Not Used	1	1	1	1	1	1
Used	0.84 (0.50,1.44)	1.09 (0.49, 2.42)	0.90 (0.52, 1.54)	0.69 (0.37, 1.29)	0.97 (0.59, 1.61)	1.17 (0.69, 1.97)

Factors	Nasal problem (AOR, 95% Cl)	Throat Problem (AOR, 95% Cl)	Dermatology Problem (AOR 95% Cl)	Eye Problem (AOR, 95% Cl)	General Problem (AOR, 95%Cl)	Aches and Pain (AOR, 95% Cl)
Cracks On Floor						
Not Present	1	1	1	1	1	1
Present	1.56 (0.82, 2.97)	1.80 (0.70, 4.59)	**2.02 (1.05, 3.85)**	1.43 (0.68, 3.02)	1.85 (0.98, 3.47)	1.16 (0.60, 2.25)
Condition of wall						
Good	1	1	1	1	1	1
Average	0.12 (0.60,2.06)	1.31 (0.54, 3.19)	1.00 (0.53, 1.87)	1.71 (0.86, 3.39)	0.97 (0.53, 1.78)	1.1 (0.6, 2.04)
Bad	0.49 (0.12,1.94)	1.47 (0.3, 7.20)	1.08 (0.30, 3.9)	0.47 (0.09, 2.6)	0.80 (0.22, 2.89)	0.21 (0.04, 1.12)
Moulds present						
Not Present	1	1	1	1	1	1
Present	**2.27 (1.18,4.37)**	2.15(0.82, 5.68)	1.66 (0.84, 3.28)	1.75 (0.84, 3.67)	1.54 (0.81, 2.94)	1.86 (0.97, 3.55)
Visible Dust Present						
Not Present	1	1	1	1	1	1
Present	1.57 (0.84,2.92)	0.57 (0.23, 1.37)	0.87 (0.48, 1.57)	1.56 (0.77, 3.16)	**2.03 (1.08, 3.81)**	0.92 (0.52, 1.66)
Medical History						
None	1	1	1	1	1	1
Allergic conjunctivitis	0.78 (0.16,3.90)	2.56 (0.26, 25.61)	2.55 (0.72, 8.94)	1.46 (0.34, 6.37)	2.45 (0.71, 8.44)	1.76 (0.48, 6.36)
Allergic rhinitis	**3.10 (1.61,5.97)**	**5.73 (2.29, 14.33)**	0.69 (0.31, 1.57)	0.95 (0.39, 2.31)	**2.04 (1.03, 4.04)**	1.21 (0.59, 2.49)
Mental illness	0.79 (0.25,2.55)	0.41 (0.05, 3.51)	1.38 (0.51, 3.72)	1.84 (0.66, 5.18)	2.13 (0.82, 5.50)	**3.05 (1.32, 7.08)**
Asthma	8.13 (2.56,25.76)	**5.45(1.13, 26.29)**	2.74 (0.84, 8.94)	2.42 (0.66, 8.85)	2.10 (0.59, 7.54)	0.87 (0.18, 4.16)
Atopic dermatitis	1.10 (0.27,4.50)	1.21(0.13, 11.09)	1.27 (0.32, 5.09)	0.43 (0.05, 3.59)	0.83 (0.19, 3.58)	0.36 (0.04, 2.97)
Food allergy	0.58 (0.07,5.03)	0(0, 0)	1.09 (0.22, 5.46)	>10000 (very high p value)	2.29 (0.52, 10.03)	1.09 (0.21, 5.49)
Any one	**2.53 (1.00,6.43)**	3.28(0.79, 13.57)	1.79 (0.70, 4.59)	1.07 (0.31, 3.70)	**4.18 (1.73, 10.11)**	**3.05 (1.26, 7.37)**

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