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Assessment of indoor air quality and their inter-association in hospitals of northern India—a cross-sectional study

Anam Taushiba[1,2] · Samridhi Dwivedi[1] · Farheen Zehra[1] · Pashupati Nath Shukla[3] · Alfred J. Lawrence[1]

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Abstract

This study was commenced to evaluate the indoor and outdoor air quality concentrations of $PM_{2.5}$, sub-micron particles ($PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.50}$, and $PM_{<0.25}$), heavy metals, and microbial contaminants along with their identification in three different hospitals of Lucknow City. The study was conducted from February 2022 to April 2022 in hospitals situated in the commercial, residential, and industrial belts of the city. The indoor concentration trend of particulate matter as observed during the study suggested that most of the highest concentrations belonged to the hospital situated in an industrial area. The highest obtained indoor and outdoor concentrations for $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.50}$, and $PM_{<0.25}$ are 40.44 μg/m^3, 56.08 μg/m^3, 67.20 μg/m^3, 74.50 μg/m^3, 61.9 μg/m^3, 79.3 μg/m^3, 82.0 μg/m^3, and 93.9 μg/m^3, respectively, which belonged to hospital C situated in the industrial belt. However, for $PM_{>2.5}$, the highest indoor concentration obtained belonged to hospital B, i.e., 30.7 μg/m^3, which is situated in the residential belt of the city. Regarding $PM_{2.5}$, the highest indoor and outdoor concentrations obtained are 149.41 μg/m^3 and 227.45 μg/m^3, which were recorded at hospital A and hospital C, respectively. The present study also observed that a high bacterial load of 1389.21 CFU/m^3 is recorded in hospital B, and the fungi load was highest in hospital C with 786.34 CFU/m^3. Henceforth, the present study offers thorough information on the various air pollutants in a crucial indoor setting, which will further aid the researchers in the field to identify and mitigate the same more precisely.

Keywords Indoor air quality · Nosocomial infection · Exposure · Mold · Bacteria · Indoor pollution

Introduction

Globally air pollution has been proven to be a major health risk responsible for 3.7 million premature deaths and fourth-ranked in terms of risk factors in premature mortality in 2019 according to the most recent Global Burden of Diseases Study (Jin et al. 2022) and affecting human health at multiple levels (Ding et al. 2019). Just like ambient air quality, indoor air quality is equally important; however, it is often neglected. The indoor air quality relies not only on outdoor sources but also on indoor activities like fossil fuel burning, e.g., wood, coal, etc., and waste burning such as animal dung, waste crop, etc. According to estimates from the World Health Organization (WHO), 2.6 billion people utilize these sources for heating and various types of cooking (Lee et al. 2020). Air pollution rose to the position of second-most significant health risk in 2022 (September 15, 2022) (https://www.republicworld.com/india-news/general-news/23-03-2022). Furthermore, indoor air pollution is one of the leading hazard issues associated with India's national burden of disease (Lim et al. 2012). A greater body of work on indoor air quality assessment is based on households, whereas indoor air quality assessment in vulnerable settings like hospitals needs attention and is crucial at the same time. Microbial contaminants and their assessment and identification are essential in hospitals to avoid any hospital-acquired infections [HAI] (Weiss et al. 2017). Molds and dust can cause acquaintance with pathogenic bacteria, viruses, and fungi leading to aspergillosis and pneumocystosis (Gangneux et al. 2016). People working together in offices, schools, buildings, hospitals, etc., can also cause

✉ Alfred J. Lawrence
alfred_lawrence@yahoo.com

[1] Department of Chemistry, Isabella Thoburn College, Lucknow, India

[2] Department of Environmental Science, Integral University, Lucknow, India

[3] Department of Pharmacology & Microbial Technology, National Botanical Research Institute, Lucknow, India

serious infections by sneezing, coughing, and direct as well as indirect contact (Verde et al. 2015). Air quality maintenance is even more important in hospitals as the population present in the setting has comparatively lower immunity and, hence, is more prone to infections. Also, patients have a lower metabolic rate and need a higher operative temperature, which affects their metabolism. Because of this, the indoor environment in hospitals is complex and unique from that in household settings. Because patients are sensitive to chemical and biological contaminants, hospitals and healthcare facilities should be closely scrutinized for contamination. The continuous outside airflow also degrades the air quality inside hospitals, which is crucial for patients and also has a negative effect on hospital staff. Furthermore, particles in confined settings transport pathogenic bacteria and microbial metabolites, both of which are common in hospitals (Slezakova et al. 2014), posing health dangers such as airborne infectious disease transmission (Hogrefe et al. 2011). The inhalable microorganisms, i.e., *Cladosporium*, *Penicillium*, and *Aspergillus* spores, and *Staphylococcus* species in closed environments may lead to a number of health issues (Fekadu and Getachewu 2015), particularly in hospital setups. Although this microenvironment is particularly important as there are a number of potential sources such as disinfectants, sterilizers, and limonene-based products that lead to the emission of noxious pollutants like ethylene oxide, formaldehyde, alcohols, etc. (Bessonneau et al. 2013), yet very scarce literature is available on the quantification of chemical and physical pollutants along with microbial assessments in hospitals and clinics. Various deadly diseases in association with HAI are common and need imperative attention (Singh et al. 2020). The commutation of visitors, workers, staff members, and patients also contribute to HAI (hospital-acquired infections). To protect the health and well-being of patients, workers, physicians, and others from such infectious illnesses, it is necessary to use different air quality standards (Andualem et al. 2019). CO, carbon dioxide (CO_2), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), airborne bacteria, fungi, and TVOCs (total volatile organic compounds) are some of the common air pollutants spotted so far. Particles can also be carriers of pathogens increasing the risk of respiratory infections (Gralton et al. 2011). Apart from the above, microorganisms can be transferred through improper functioning of HVAC (heating, ventilation, and air conditioning) systems (Mousavi et al. 2019). Studies conducted in countries like Pakistan, Iran, and Turkey have shown that bioaerosols can enter the body through ingestion and consumption, influencing human well-being (Nasir et al. 2012). Another study to evaluate indoor air quality issues that was carried out in hospitals of Finland found that employees are particularly impacted by poor indoor air quality although it did not mention the specific pollutants responsible for the symptoms experienced by the same (Kumar et al 2021a, b, c; Dey et al. 2019). Bioaerosols may exacerbate infectious disorders (Bolookat et al. 2018; Faridi et al. 2017; Montazer et al. 2021; Mbareche et al. 2019) including asthma, allergies, and neurological conditions, according to research conducted in a hematology unit (Brilhante et al. 2010). According to Sri Lankan research, the Kandy General Hospital is one of the sites in Kandy City with the highest degree of indoor air pollution (Sivagnanasundaram et al. 2019). *Penicillium, Mucor, Aspergillus*, and *Fusarium* were among the fungal isolates found in the hospital's interior air in a different investigation carried out in Benin City, Nigeria (Ekhaise and Ogboghodo 2011). According to another study, *Aspergillus sp.*, *Candida sp.*, *Fusarium sp.*, and *Mucorales sp.* are the most common pathogens in Sari, Iran's hospitals (Sorkheh et al. 2022). According to studies from the World Health Organization (WHO), the overall microbial load in living and working spaces should not be more than 1000 CFU/m^3 (Ikhtiar et al. 2017). The level of particulate contamination may be influenced by human movement in indoor spaces (Meng et al. 2010). Numerous studies have also shown the negative impact of high ambient PM concentrations on hospital admission, especially for cardiac and respirational conditions (Atkinson et al. 2014). Furthermore, conferring to the World Health Organization (WHO), 92% of the world's population resides in regions with annual mean $PM_{2.5}$ levels greater than 10 g/m3, which is above their air quality recommendation for $PM_{2.5}$ exposure. Recent research has looked into the impacts of PM on health from a wider range of sources, such as biomass burning, and in other geographical locations. Consistent evidence of respiratory morbidity was found in a valuation of the health impacts of wildfire smoke, while the effects on cardiovascular health were less obvious (Reid et al. 2016). According to many researchers, exposure to HCHO (formaldehyde) and TVOC (total volatile organic compounds) may potentially raise the chance of developing allergy disorders or cancer (Smith et al. 2012; DeLeon-Rodriguez et al. 2013). Metal compounds and particulate matter in the ambient air especially allied with sub-micron constituent parts have lately been a major factor harmfully affecting human well-being because of their smaller size and higher number. Metals such as lead, arsenic, mercury, chromium, cadmium, aluminum, copper, iron, manganese, lead, nickel, mercury, and zinc are abundantly present and associated with fine particulate matter ($PM_{2.5}$) in the air (Lin et al. 2020). They may cause a lot of adverse effects like asthma, cough, brain/kidney damage, etc. Many metals produce reactive oxygen species (ROS) in biological tissues and may lead to the generation of free radicals (Kermani et al. 2021; Domingo et al. 2017). Also, Ni, Cr, As, and Pb were found profusely in fine particles [PM2.5] than in the course [PM10] fraction (Slezakova et al. 2012). Moreover, the COVID-19 outbreak has placed unprecedented challenges on hospital

environmental hygiene and indoor air quality. The second wave of the SARS-CoV-2 (COVID-19) infection has hit India with full force and affected the whole country. Uttar Pradesh stands in the second position with a high viral load. Air pollution has emerged as a potent factor related to the transmission of the coronavirus. Long-lived microorganisms in the hospital environment are directly connected to the incidence of associated illnesses (Beggs et al. 2015). Thus, it is very crucial to assess the hospital's indoor air quality. It is also pertinent to monitor the thermal comfort, humidity, chemical contamination, ventilation, and air distribution in hospitals as the detrimental effects of indoor air quality would not just reduce comfort levels of the occupants but also lead to increased occurrence of symptoms including, headache, dry throat, fatigue, anxiety, etc. (Zuo et al. 2019).

The present study was conducted in hospitals situated in three belts, i.e., commercial, residential, and industrial belts of Lucknow City. Lucknow is the second-largest city in northern and central India and the capital of Uttar Pradesh, which is the most polluted and populated state in the world. The study deals with major air pollutants, comprising fine and sub-micron particulate matter, i.e., $PM_{2.5}$, $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.50}$, and $PM_{<0.25}$, together with associated heavy metals and biological contaminants. Apart from biological contaminants, all the other pollutants were assessed in both indoor and outdoor environments for appropriate evaluation of the analogy between the two. The study illustrates the mass concentrations of the pollutants in consort with indoor/outdoor [I/O] ratios. This study was conducted in the city hospitals, and the study projects an overview of the air quality of the hospitals and healthcare facilities of the region to regulate and govern the standards, particularly for sensitive environments. The findings may help policymakers with the implementation of guidelines for confined spaces guided by substantial data.

Materials and methods

Area of study

The present study was conducted in three hospitals in Lucknow City from February to April 2022 (shown in Fig. 1). Lucknow is the second-largest city in northern and central India and the capital of Uttar Pradesh. Additionally, it serves as the administrative center for the division and district with the same name. The city is located at a height of around 123 m (404 feet) above sea level. Lucknow is located on the Gomti River's western coast. There were 110 wards in the city as of 2008 (Khan et al. 2022). The city's population is expected to surpass 7 million in 2021, representing an increase of over 90% in 10 years (Dwivedi et al. 2022). The study was conducted in three different hospitals, one each situated in (a) commercial, (b) residential, and (c) industrial microenvironments. The microenvironments were selected on the basis of population and traffic density (depicted in Fig. 2). Written consent was sought from the management of the hospitals for the study period. During the study period, $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.50}$, and $PM_{<0.25}$ were monitored in the indoor air. Microbial contaminants were also monitored in the indoor air of different wards. Since the identification of the hospitals is kept confidential, therefore, the hospitals located in the commercial, residential, and industrial area have been marked as A, B, and C, respectively. The general characteristics of the selected hospitals are given in Table 1. Hospital A, located in the commercial area, had a capacity of 60 beds with an occupancy of 350 people, including paramedic staff and attendants. According to the presiding authority, approximately 50 patients were either admitted or availed of the

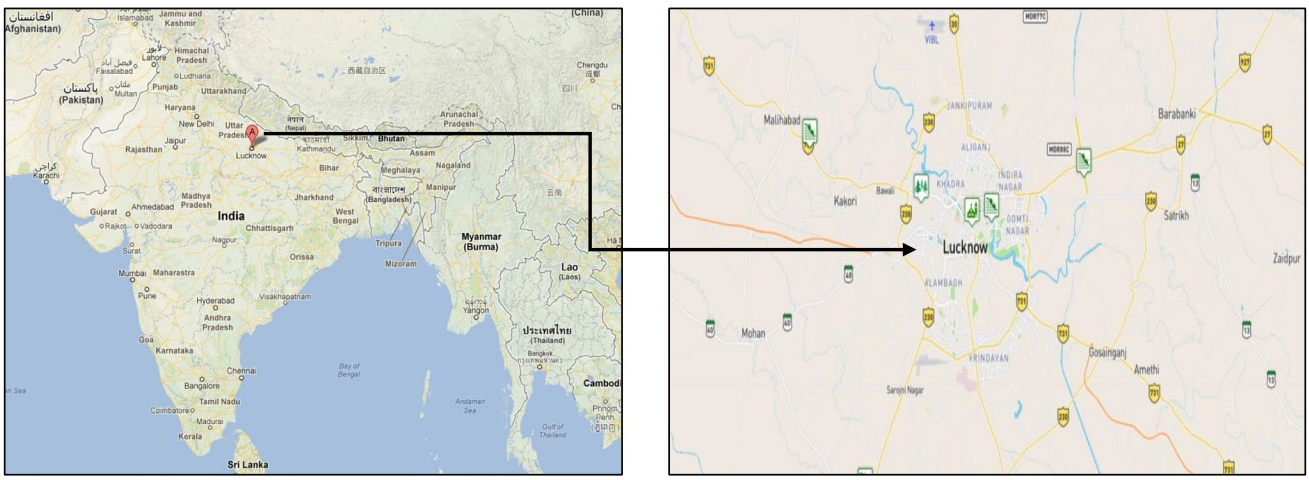

Fig. 1 Geographical description and study location in the city of Lucknow

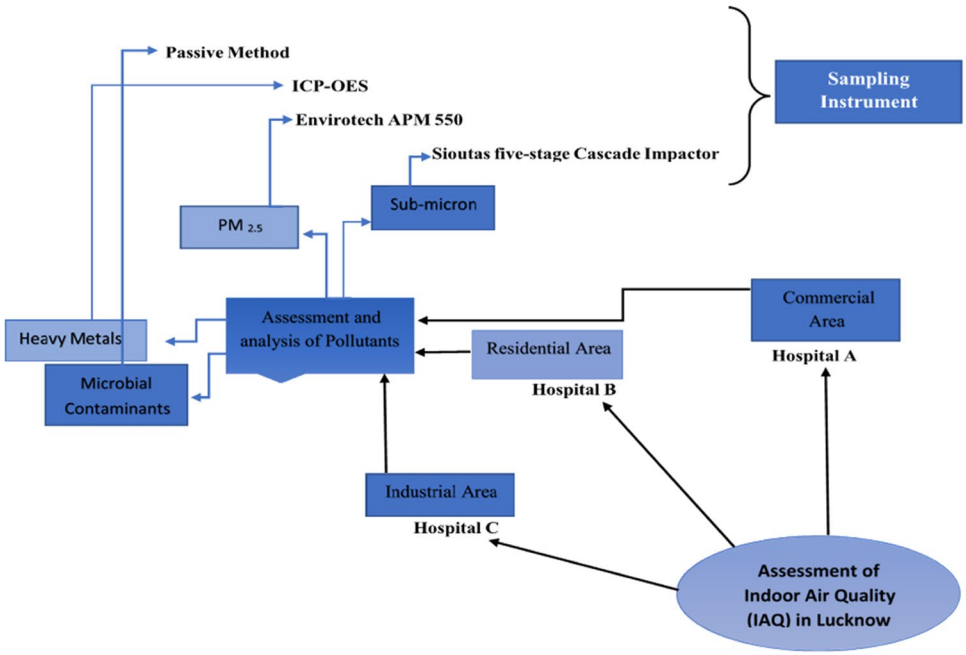

Fig. 2 Selection of microenvironment and its analysis by various methods

Table 1 Characteristics of hospital environment

S no	Area	Indoor environment				Outdoor environment			
		Presence of greenery	Number of beds	Patients' entry per day	Outpatients' entry yearly	Construction ageof hospital	Dwelling types	Road dust	Presence Of dampness
1	Commercial [commercial area, urban downtown, densely populated]	Less greenery, high- vehicular exhaust	60	50–55	9000	25 years	Planned	Highly contaminated	Visible
2	Residential [residential area, semi, urban, moderately populated]	Moderate greenery, low vehicular exhaust	35	15–20	5000	15 years	Planned	Lower contaminated	Visible
3	Industrial [rural areas, less populated]	Less greenery, low vehicular exhaust	15	10–12	2000	5 years	Unplanned	Less contaminated	Highly visible

outpatient facility daily, on an average of 950 patients per month. Hospital B, located in the residential colony, had a capacity of 35 beds, including an operation theater, a general ward, and an outpatient facility with an intake of 15–20 patients daily and 450 patients per month. Hospital C, located in an industrial area, had a capacity of 15 beds with a footfall of 10–12 patients daily and on an average 300 patients monthly. The description of the respective hospital is displayed in Table 2.

Sampling and analyses of microbiological contaminants

The Petri plate gravitational settling (passive) method of sampling was chosen due to its straightforward approach and practical viability, which makes use of existing resources. The technique is based on the media's ability to adhere, which traps airborne particles onto their surface when plates containing the media are exposed face up to the atmosphere to gather

Table 2 Site description of sampling location of different hospitals

Site	Sampling area	Area	Ventilation system	People indoors during sampling hour	Attendants allowed per patient
Hospital A	General ward	400 sq. ft	Centralized HVAC system and cross ventilation	35	2–3
	Minor O. T	80 sq. ft	Mechanized HVAC with no cross ventilation	5	1
Hospital B	O. T	90 sq. ft	Mechanized HVAC with no cross ventilation	5	1
	General ward	250 sq. ft	Natural and cross ventilation	15	3
Hospital C	General ward	300 sq. ft	Mechanized HVAC and cross ventilation	25	2–3
	O. T	120 sq. ft	Artificial HVAC with no cross ventilation	3	1

particles falling by gravity. This method has been used by various researchers around the world in past decades (Sudharsanam et al. 2008; Verdier et al. 2014; Kumar et al 2021a, b, c; Kumar et al. 2022). The Petri plates were exposed (9-cm diameter) in general wards and OT of the hospitals for 60 min at a breathing height of approximately 70 cm with media of MacConkey agar (MCA) nutrient agar (NA), (Salmonella Shigella) SS agar, and (*E. coli*-Coliform Selective Agar Chromo Select) ECC agar for bacteria and Sabouraud dextrose agar (SDA) and RBA (rose Bengal agar) for fungal sampling (shown in Fig. 3). After exposure, all the agar plates were sealed and transferred to the laboratory for incubation; the bacterial plates were incubated for 24–48 h at 37 °C and for fungi at room temperature (25–27 °C) for 5 to 6 days. The sample was processed and identified for various bacteria, gram-positive and gram-negative. After being heat fixed on the slide, the microbial culture was stained for 1 min with a crystal violet staining solution. Slides were cleaned with water before being flooded with the mordant (3% water/iodine gram's mixture). Slides were then treated with a decolorizing chemical (95% ethanol) after being cleaned with water. Slides were counter stained with safranin for 30 s to 1 min after decolorization. Slides were afterward rinsed with water until no more colored effluent was visible, and then they were blotted dry with absorbent paper. Slides were then examined using a brightfield microscope (100X) while submerged in oil, and pictures were taken with a Nikon Optiphot microscope fitted with an Amscope MU1000 Camera. And, for the determination of morphological structures of fungi, the lactophenol cotton blue staining process was used. Direct counting is used for quantitative measurement of microbial communities (bacteria and fungi load) on samples. Bergey's manual of systematic microbiology was also used to identify and categorize all bacteria into groupings like gram-negative and gram-positive (Kumar et al 2021a, b, c). A fungal colony's appearance, color, and other characteristics were initially used to categorize it. To get the right surface density for counting and to figure out the load in proportion to the exposure period, the sample intervals were set at 60 min during the day. After the incubation period, the number of bacteria and fungi was counted as colony-forming units (CFU), and the formula for CFU/m^3 was used to calculate it (Omeliansky 1940; Fleischer et al. 2006; Toivola et al. 2002).

$$N = 5a^{*}10^{4}(bt)^{-1}, where$$

N microbial CFU/m^3 of indoor air

Fig. 3 Monitoring of microbial contaminants in hospital environment

A number of colonies per Petri dish

B dish surface (cm^2)

t exposure time (minutes)

Sampling of particulate matter

The Leland Legacy sample pump (SKC Cat. No. 100-3002; Inc. Eighty-Four, PA, USA) with a five-stage Sioutas cascade impactor was used to collect PM in the size range of $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.50}$, $PM_{<0.25}$ on 25-mm Millipore filter paper and 37-mm GF/A filter paper (for $PM_{<0.25}$). The instrument was adjusted to 9 l min−1 airflow rate. $PM_{2.5}$ was measured using GF/A 47-mm filter paper (pore size, 0.5 µm) through Envirotech APM 550 sampler, which was set at a flow rate of 17.57 l pm for 8 h. All of the filter papers were conditioned by being placed in a desiccator for 24 h at a temperature of 20 to 30 °C, and then being weighed three times on a SHIMADZU ATX 224 weighing scale with a sensitivity of ± 0.2 mg and a capacity of 230 g. The instruments were placed in the general wards of the three selected hospitals at approximately 2 m away from the doors and walls of the room as depicted in Fig. 4. For outdoor monitoring, the instruments were placed in the hospital yard. The instruments were placed 1 m away from any potential source of pollution and 1.5 m above the ground. The monitoring was done during the daytime (9:00 am to 4:00 pm). In each of the selected hospitals, monitoring was done for 14 consecutive days. In total, monitoring was done for 42 days. Also, seven common heavy metals viz. Pb, Mn, Cr, Fe, Ni, Cu, and Zn were estimated using inductively coupled plasma optical emission spectroscopy (ICP-OES).

Quality check and quality assurance

The quality of the instruments was examined each and every time before and after the relocation of the instruments from one place to another. All the instruments were calibrated at least once a month.

Metrological parameters

Metrological parameters such as relative humidity, temperature, wind speed, and wind direction were recorded during the monitoring period. The average temperature was found to be 30.83 °C, average relative humidity was found to be 38.38 [%], and the wind speed was 11.79 km/h, respectively. The prominent wind direction was west to the northwest, and no rainfall was observed during monitoring days.

Results and discussion

Concentration of particulate matter

Particulate exposure has been associated with adverse health outcomes. The exposure is particularly risky for those with compromised immunity and people with pre-existing health conditions (Mohammadyan et al. 2017a; b). The indoor-to-outdoor (I/O) ratio of $PM_{2.5}$ concentrations has been explored, and they can differ, owing to a number of features like the location of a building, its design, or human activities (López-Villarrubia et al. 2021). For the hospital situated in commercial microenvironment, the I/O (indoor/outdoor) ratio for average values of $PM_{2.5}$ was found to be 0.69 (130.9 μgm^{-3}/189.9 μgm^{-3}), whereas I/O ratios for $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.5}$, and $PM_{<0.25}$ were found to be 0.72 (22.4 μgm^{-3}/31.5 μgm^{-3}), 0.82 (28.7 μgm^{-3}/34.6 μgm^{-3}), 0.75 (36.4 μgm^{-3}/48.8 μgm^{-3}, 0.72 (55.1 μgm^{-3}/75.3 μgm^{-3}), and 0.79 (59.0 μgm^{-3}/74.5 μgm^{-3}). For hospital situated in residential microenvironment, the I/O ratio of $PM_{2.5}$, $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.5}$, and $PM_{<0.25}$ was found to be 0.47 (74.5 μgm^{-3}/158.4 μgm^{-3}), 0.56 (20.1 μgm^{-3}/36.1 μgm^{-3}), 0.80 (25.6 μgm^{-3}/32.8 μgm^{-3}), 0.68 (33.8 μgm^{-3}/49.0 μgm^{-3}), 0.66 (37.7 μgm^{-3}/55.2 μgm^{-3}), and 0.56 (27.2 μgm^{-3}/49.3 μgm^{-3}), respectively. For hospital situated in industrial microenvironment, the I/O ratio of $PM_{2.5}$, $PM_{>2.5}$, $PM_{1.0–2.5}$, $PM_{0.50–1.0}$, $PM_{0.25–0.5}$, and $PM_{<0.25}$ was found to be 0.53 (117.8 μgm^{-3}/220.8 μgm^{-3}), 0.59 (26.8 μgm^{-3}/44.9 μgm^{-3}), 0.63 (37.1 μgm^{-3}/58.4 μgm^{-3}), 0.72 (52.9 μgm^{-3}/73.3 μgm^{-3}), 0.77 (61.9 μgm^{-3}/79.8 μgm^{-3}), and

Fig. 4 Monitoring of particulate matter and submicron in different microenvironments

0.70 (59.4 μgm^{-3}/84.2 μgm^{-3}), respectively. The concentration and composition of these particles depend upon different parameters and factors like temperature, humidity, ventilation mechanism, and rate of exchange of air (Faridi S et al. 2018). Their health effects are also dependent on their composition like black carbon, toxic minerals (metals), and carbon-based components (Krajewska-Kułak et al. 2007). Indoor air studies of fungal contamination at the Neonatal Department and Intensive Care Unit have shown that health care workers are more likely to get cancer as a result of exposure of more than 8 h based on the I/O ratio, which is quite alarming (Gillum et al. 2011). Since the hospitals were nonsmoking environments, with no unvented combustion sources, hence, the indoor concentration of ultrafine particulate may be attributed to indoor activities like the use of vacuum cleaners, electrical equipment, centrifuge machines, automated blood pressure monitors, etc. (Riesenfeld et al. 2000). Indoor $PM_{2.5}$ concentrations at each hospital were positively related to the outdoor $PM_{2.5}$. Variables such as the number of occupants, ambient temperature, areas of the room, windows, and doors may have an effect on the concentrations as well. Wind speed may also have a role to play in the indoor and outdoor concentrations of particulate contamination. The $PM_{2.5}$ concentrations were compared with the USEPA standards (35 $\mu g/m^3$) (Esworthy and Bearden 2015). In the conducted study, the indoor fractions were found to be lower than the outdoor fractions. Resuspension of particulate matter due to cleaning and human movement may have also contributed to the concentrations of $PM_{2.5}$ (Mohammadyan et al. 2017a, b). Indoor PM concentrations have also been evaluated in hospital settings of cities like Lahore (Pakistan), Istanbul (Turkey), and Guangzhou (China), which have climatic and economic similarities to the selected city for the study. All these cities reported higher PM levels, exceeding the 24-h, $PM_{2.5}$ standards recommended by USEPA and WHO (Yurtseven et al. 2012). Additional studies conducted in the People Hospital of Shijing, People Hospital of Liwan, Phthisic Hospital, and Pediatric Hospital in Guangzhou, China (Wang et al. 2020) have shown high $PM_{2.5}$ concentrations indoors as these hospitals were situated next to busy roads in heavily populated regions. The elevated concentrations may be attributed to outdoor sources as well.

Sudden rises in the concentrations were also observed on particular days. From the hospital located in a commercial area, a sudden rise with respect to $PM_{2.5}$ (149.41 $\mu g/m^3$) given in Fig. 5 and $PM_{0.25–0.50}$ (67.12 $\mu g/m^3$) was obtained, whereas from the hospital in an industrial area, a sudden raise in the concentration of $PM_{<0.25}$ fraction (86.32 $\mu g/m^3$) was obtained on the second day of monitoring. Episodic increases in the concentrations may be due to the increase in the number of inhabitants on a particular day.

The average concentration of sub-micron particles has been for hospital A, hospital B, and hospital C as depicted in Figs. 6, 7, and 8, respectively.

Chronic daily intake [CDI] and total cancer risk [TCR] associated with heavy metals

A study conducted by Qin et al. 2022. reported that the order of concentration of metals in the total suspended particulate matter was Cu > Pb > Cr > Ni > Cd and claimed that usage of plastics in electronic gadgets has the highest and lowest proportion of Cu and Cd, respectively. A study conducted by Bisht et al. 2022 on the concentration of heavy metals in road dust, reported a high concentration in commercial whereas, a considerable level in residential areas. Also, the PCA analysis done during the study suggested the source of Fe contamination as building construction activities, rolling and sliding of tires, etc. Zn sources as suggested were brakes and tires of vehicles followed by Cu as metallic materials, corrosion of alloys, etc. (Pant and Harrison 2013; Roy et al. 2019; Bhattacharya et al. 2013; Bisht, L. et al. 2022). Heavy metals in indoor dust require extensive research due to their non-biodegradability, high toxicity, and negative effects on humans (Darus et al. 2012). Metals considered during the present study have been reported to be vital content of cigarette

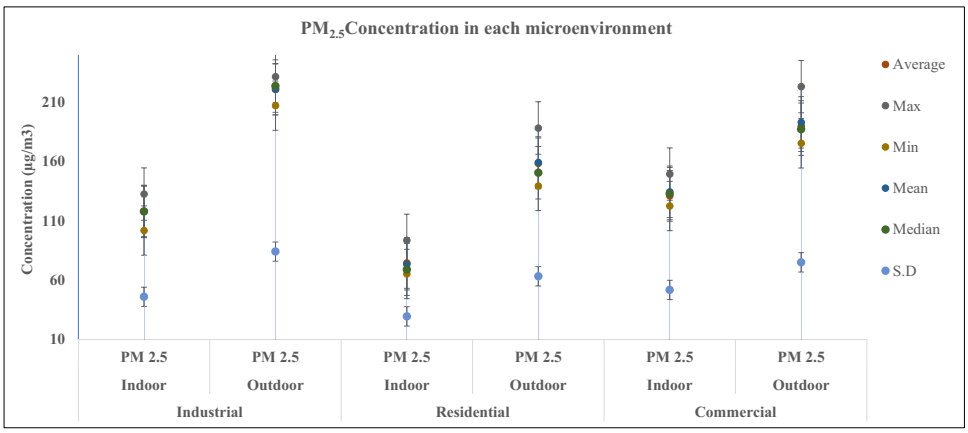

Fig. 5 Comparison graph of $PM_{2.5}$ concentration in each microenvironment

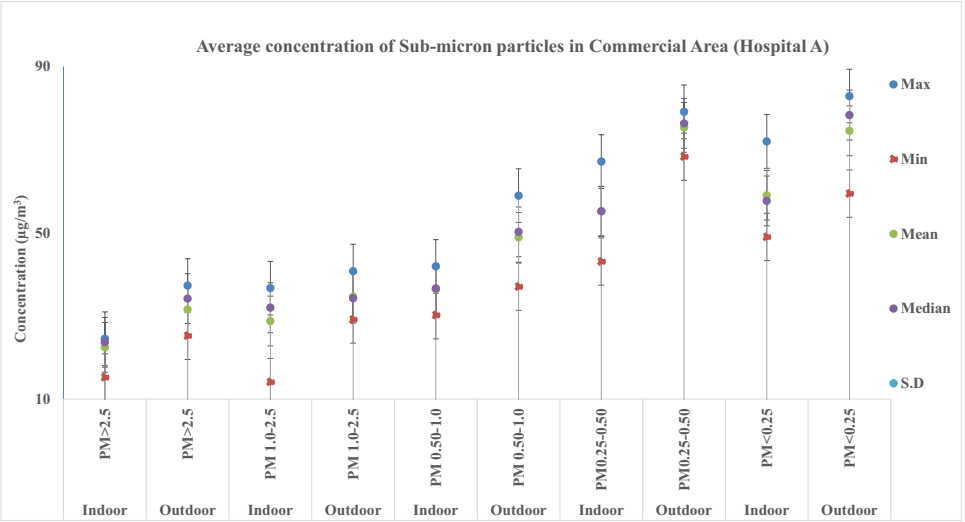

Fig. 6 Average concentration of sub-micron particles in hospital A

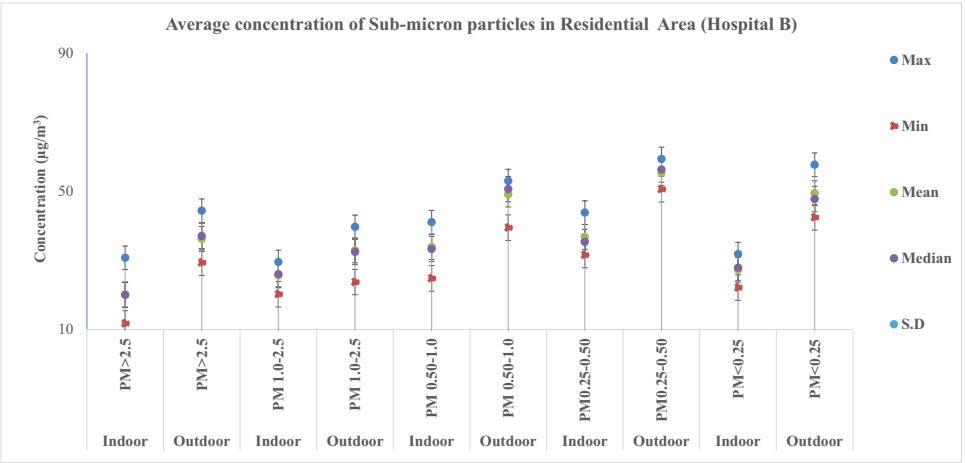

Fig. 7 Average concentration of sub-micron particles in hospital B

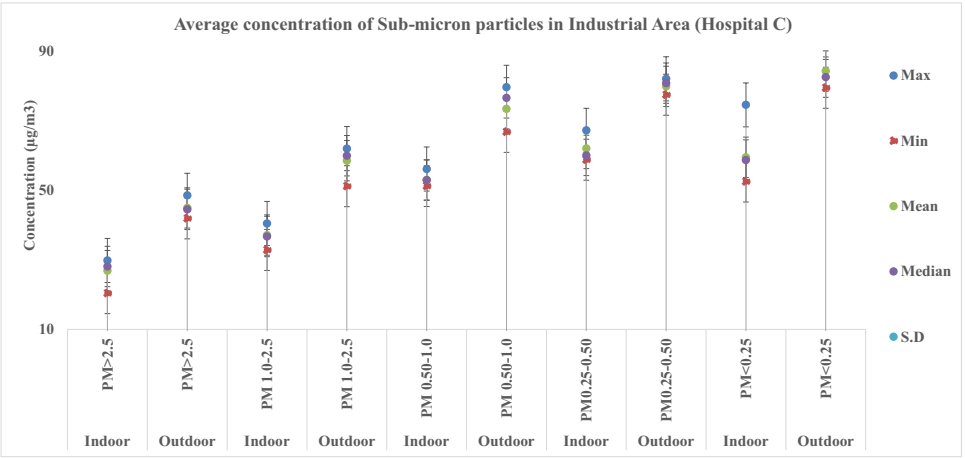

Fig. 8 Average concentration of sub-micron particles in hospital C

and tobacco smoke (Ghoma et al. 2022). These metals are reported to be carcinogenic, causing urinary, prostate, breast, pancreas, and endometrium cancers (Adams et al. 2012). Heavy metals in dust can also enter the human body via ingestion, inhalation, and absorption through the skin (Latif et al. 2014).

During the current study, seven heavy metals, namely chromium (Cr), iron (Fe), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), were estimated. Chronic daily intake [CDI] and total cancer risk [TCR] associated with heavy metals were calculated.

The total cancer risk (TCR) of all the heavy metals was in the range of 7.21×10^{-13} 1.25×10^{-10}. The TCR range was 1×10^{-6} to 1×10^{-4}, while TNCR (total noncancer risk) for heavy metals was below 1; the values established by US EPA.

$$\text{Chronic Daily Intake (Carcinogens) CDI} = \frac{CS\times IR\times EF\times ED\times CF}{BW\times AT}$$

where *CS* depicts exposure point concentration: mg/kg, *IR* is ingestion rate: 100 mg/day,

EF is exposure frequency: 350 days/year,

ED is exposure duration: 30 years (EPA/540/1-89/002 1989; US EPA 1996) *BW* is body weight: 65 kg,

AT that is averaging time for carcinogens is 365×70 days, *CF* is units conversion factor (10^{-6} kg $mg^{-}.^{1}$) (USEPA 2002)

$$\textit{Cancer risk} = \textit{CDI}\times \textit{SF slope factor}\ (\textit{SF}) = 1/6\ (\textit{ED})$$

The indoor and outdoor concentrations of the metals in respective hospitals have been given individually in Tables 3, 4, and 5.

Microbial contamination

Bacterial concentration in an indoor environment

In case of bacterial load, the highest concentration [1389 CFU/m^3] is recorded in hospital B, situated in the commercial area in a general ward at NA [nutrient agar] during daytime (2:00 p.m.) at 60-min exposure, while in the same context, the concentration of bacteria in all general wards was high at nutrient agar. On the other hand, the lower concentration is in SSA agar media in the same microenvironment (microbial loads and their levels of contamination are depicted in Fig. 9). Table 6 shows the concentration of bacteria in all the selected microenvironments at different agar media.

In addition to this, the high bacterial load is mostly due to problems in temperature, humidity, insufficient ventilation, etc. (Hayleeyesus and Manaye 2014). Biological contaminants may find their way indoors through both natural and artificial sources. Also, there are several factors responsible for presence and transmission of microbial contaminants (depicted in Fig. 10). Meteorological parameters such as air pollutants ($PM_{2.5}$), temperature, moisture content, air currency fluctuations, etc., have a significant correlation with microbiological concentrations (Kumar et al 2021a, b, c).

Table 3 Indoor and outdoor concentrations of heavy metals in hospital A [commercial area]

S. no	Metals	Indoor concentrations (μg/m^3)	Outdoor concentrations (μg/m^3)	Cancer risk for indoor (CDI × SF)	Cancer risk for outdoor (CDI × SF)
1	Cr	0.10	0.3168	0.316×10^{-12}	1.00×10^{-12}
2	Fe	0.07	0.03168	0.221×10^{-12}	0.100×10^{-12}
3	Mn	0.06	0.2376	0.189×10^{-12}	0.751×10^{-12}
4	Ni	0.22	0.5456	0.695×10^{-12}	1.724×10^{-12}
5	Cu	0.28	0.5016	0.885×10^{-12}	1.585×10^{-12}
6	Zn	3.81	0.616	12.044×10^{-12}	1.947×10^{-12}
7	Pb	0.23	1.32	0.727×10^{-12}	4.172×10^{-12}

Table 4 Indoor and outdoor concentrations of heavy metals in hospital B [residential area]

S. no	Metals	Indoor concentrations (μg/m^3)	Outdoor concentrations (μg/m^3)	Cancer risk for indoor (CDI × SF)	Cancer risk for outdoor (CDI × SF)
1	Cr	0.22	0.3526	0.695×10^{-12}	1.114×10^{-12}
2	Fe	0.12	0.3612	0.379×10^{-12}	1.141×10^{-12}
3	Mn	0.07	0.2494	0.221×10^{-12}	0.788×10^{-12}
4	Ni	0.19	0.4558	0.600×10^{-12}	1.438×10^{-12}
5	Cu	0.31	0.516	0.979×10^{-12}	1.631×10^{-12}
6	Zn	4.33	0.1462	13.688×10^{-12}	0.462×10^{-12}
7	Pb	0.87	1.548	2.750×10^{-12}	4.893×10^{-12}

Table 5 Indoor and outdoor concentrations of heavy metals in hospital C [industrial area]

S. no	Metals	Indoor concentrations (μg/m^3)	Outdoor concentrations (μg/m^3)	Cancer risk for indoor (CDI × SF)	Cancer risk for outdoor (CDI × SF)
1	Cr	0.22	0.2988	0.695×10^{-12}	0.944×10^{-12}
2	Fe	0.081	0.2988	0.256×10^{-12}	0.944×10^{-12}
3	Mn	0.07	0.2241	0.221×10^{-12}	0.708×10^{-12}
4	Ni	0.255	0.5146	0.806×10^{-12}	1.626×10^{-12}
5	Cu	0.32	0.4731	1.01×10^{-12}	1.495×10^{-12}
6	Zn	2.20	0.581	6.954×10^{-12}	1.836×10^{-12}
7	Pb	0.26	1.245	0.821×10^{-12}	3.935×10^{-12}

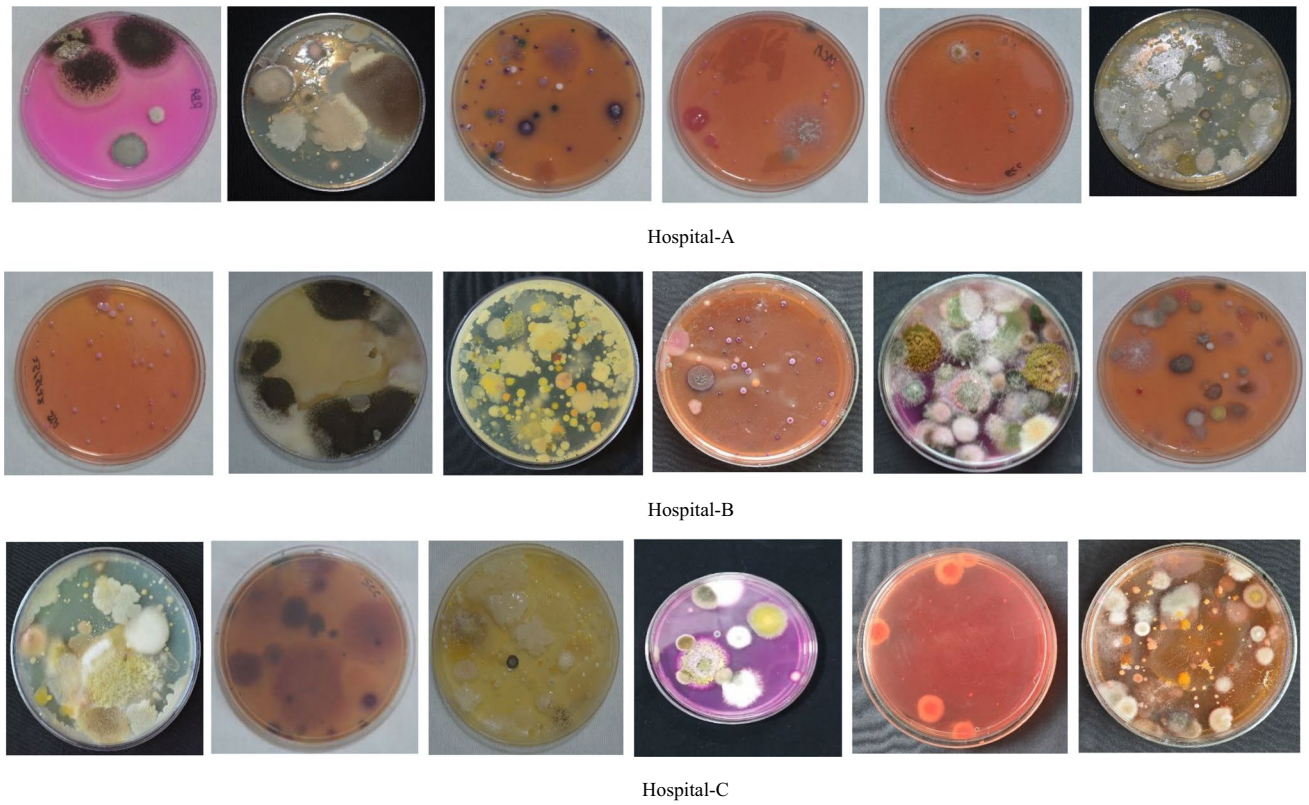

Fig. 9 Representative Petri plates of bacterial and fungal (highly contaminated) colonies were obtained from air samples of different locations

Fungal concentration (load) in an indoor environment

The result revealed that the fungal concentration on SDA (Sabouraud dextrose agar) media is highest in hospital C (786.34 CFU/m^3) during the daytime, at 60 min exposure, and the lowest concentration (131.05 CFU/m^3) on RBA (rose Bengal agar) was recorded at hospital A in OT (operation theater). Table 7 shows the fungal load in each hospital and details of microbiological profile through the passive method (gram-positive and gram-negative) bacteria and fungi are enumerated in Table 8

Limitations of the study

Several communicable ailments, such as whooping cough, tuberculosis, and other fungal infections, human and avian influenza, chickenpox, and some of the emerging viruses, such as Middle East respiratory syndrome coronavirus (MERS-CoV), can possibly escalate via aerosol transmission. However, deep-sequencing technologies can be applied to environmental air samples to characterize the presence and variety of airborne pathogens in the air we breathe in different environments such as hospitals,

Table 6 The concentration of bacteria in each microenvironment

S.No	Hospitals	Sites/Wards	Media used for monitoring	Colonies observed on plate	CFU/m^3
1	H- A	General ward	MCA	55	720.81
			ECC	90	117.95
			SSA	45	589.76
			NA	105	1376.11
		OT	MCA	45	589.76
			ECC	40	524.23
			SSA	30	393.17
			NA	14	183.48
2	H- B	General ward	MCA	30	393.17
			ECC	60	786.34
			SSA	10	131.05
			NA	106	1389.21
		OT	MCA	30	393.17
			ECC	40	524.23
			SSA	20	262.11
			NA	35	458.70
3	H- C	General ward	MCA	68	891.19
			ECC	55	720.81
			SSA	20	262.11
			NA	90	1179.52
		OT	MCA	32	419.38
			ECC	22	288.32
			SSA	24	314.53
			NA	75	982.93

MCA, Mac Conkey agar; *ECC*, *E. coli*-Coliform selective agar chromo select; *SSA*, Salmonella Shigella agar; *NA*, nutrient agar.

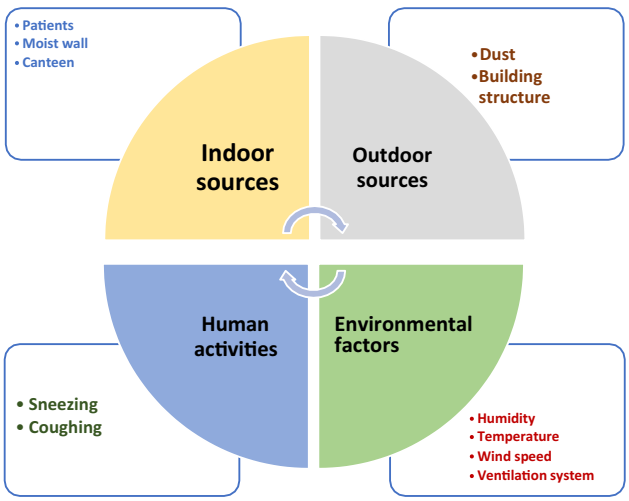

Fig. 10 Sources of biological contaminants

clinics, offices, entertainment venues, public transport, etc. The present study investigated air-borne particulate concentration in indoors for 24 h. However, time-bound study with proper bifurcation of particulate size is required. Future study based on size-segregated PM-targeting specific indoor sources will be prolific for policy makers and researchers in the field. Moreover, simultaneous evaluation of pollutants at multiple places over longer period of time is essential to provide a thorough understanding of the airborne microbiome and the various factors that influence its ecology. Our future study will employ active methods for microbial sampling to give a better insight of the variation in the species of bacteria and fungi targeting a larger surface area.

Table 7 The concentration of fungi in each microenvironment

S. no	Hospitals	Sites/wards	Used media	Colonies per plate	CFU/m^3
1	H- A	General ward	RBA	22	288.32
			SDA	52	681.50
		OT	RBA	10	131.05
			SDA	40	524.23
2	H- B	General ward	RBA	30	393.17
			SDA	45	589.76
		OT	RBA	20	262.11
			SDA	40	524.23
3	H- C	General ward	RBA	40	524.23
			SDA	60	786.34
		OT	RBA	25	327.64
			SDA	14	183.48

RBA, rose Bengal agar; *SDA*, Sabouraud dextrose agar

Table 8 Microbiological profile of general ward and OT in each microenvironment

Bacteria obtained from the different microenvironments	Filamentous fungi
Escherichia coli	*Aspergillus niger*
Staphylococcus aureus	*Aspergillus flavus*
Shigella sonnel	*Aspergillus fumigatus*
Salmonella enterica	*Candida asbicans*
Proteus mirabilis	*Cunninghamella bertholletiae*

Conclusion

This study is the first to analyze particles, heavy metals, and microbiological pollutants in three sample locations in an integrated manner. Hospitals are microenvironments with people who can be more sensitive to air pollution. It might be difficult to achieve adequate indoor air quality in

hospitals. Among the numerous air contaminants within due to their fatal effects on people, particulate matter of various sizes, and the heavy metals linked with it, along with microbiological contaminants are some of the key pollutants researched throughout the work. Three hospitals were selected based on their locations and areas nearby. It was observed that the outdoor vehicular load, greenery, industries, etc., played a crucial role in the maintenance of indoor air quality. It was found during the study that the general ward of hospital B, situated in a semi-urban, moderately polluted area, was highly contaminated with high bacterial load, i.e., 1389.21 CFU/m^3, whereas fungi concentrations were high in hospital C (786.34 CFU/m^3) in the general ward. A low bacterial (183.48 CFU/m^3) and fungal load (131.05 CFU/m^3) was found in hospital A, which is situated at a commercial belt out of three hospitals. At the end, it is worth mentioning that the variation in the concentration of pollutants in the different hospitals directs toward the fact that outdoor situations play a vital role in upkeeping indoor air quality; therefore, to uphold sustainable air quality inside the hospital, proper nearby location of the same should be managed along with apposite greenery inside as well as outside to tackle air pollution.

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Data availability The datasets generated during and/or analyzed during this study are not publicly available as they were monitored, analyzed, and calculated but are not publicly available as they were monitored, analyzed, and calculated but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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