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Indoor air quality monitoring in metropolitan city Lahore: Using handheld devices

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ABSTRACT

Introduction: Outdoor air pollution has been considered the primary issue by scientists and environmentalists for decades. With the advancement of technology, the activities of human are shifting from outdoor to indoor, urging researchers to investigate the indoor environment. Theerefore, the focus of this study is to examine indoor air quality in the metropolitan of Lahore.

Materials and methods: The Temtop M2000C and Temtop H3 Laser monitors were used to collect data on Particulate Matter (PM), Carbon dioxide (CO_2) concentration, Total Volatile Organic Compounds (TVOC), and formaldehyde (HCHO). The concentration of air pollutants in nine indoor areas was measured for a specified time interval. The values of particulate matter are measured to find the impact of the outdoor environment on the indoor environment.

Results: The maximum average values of the particulate matter $PM_{2.5}$ and PM_{10} were 488.6 µg/m³ and 737.2 6 µg/m³, respectively, which reduced drastically after the rain to 219 µg/m³ and 340 µg/m³, respectively. The maximum values of $PM_{2.5}$ and PM_{10} during coal burning outside the room were 997.6 µg/m³ and 999.9 µg/m³, respectively, far higher than the values during normal conditions. TVOC and HCHO were found within the prescribed limits.

Conclusion: The outcomes of this study established a deep impact of the outdoor environment on the indoor environment and recommend air purifiers to reduce the level of pollutants in the indoor environment.

Introduction

Harmful air pollutants in the indoor environment affect humans as most people spend almost 90% time in indoor areas [1]. Resultantly people are more at risk due to extensive exposure time [2]. The emissions from industries, vehicles, and fossil burning are the major contributors to the spread of pollutants worldwide [3]. Exposure to air pollutants risks human health, causing several diseases. Only in 2019, poor air quality resulted in the premature death of 7 million people, a drop in biodiversity and crop production, and climate change [4]. Investigation of the indoor environment has now overlapped with the

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research conducted in outdoor spaces due to more exposure time in the indoor environment [5]. Air pollutants are categorized as Particulate Matter (PM) and gases which mainly include nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Carbon monoxide (CO), Carbon dioxide (CO_2), ozone (O_3), volatile organic compounds (VOC) [6]. Many cities in the developed and developing countries monitor air pollutants as they face the extra burden of ill-health. Epidemiological studies have shown that long exposure to air contaminants increases the chances of lung cancer, cardiovascular and respiratory diseases [7]. Data from 2007 to 2011 in Pakistan depict that annual monitoring values of particulate matter ranged between 100% to 500% of the allowed limit defined by the World Health Organization (WHO) [8]. A study in Nigeria has also shown that vehicular activities near the park have a key impact on the ambiance [9]. In the same way, house location, size, renovation, and outdoor air contribute a lot to indoor air pollution [10].

The Air Quality Index (AQI) was developed to determine the magnitude of air quality deterioration as the human body is very sensitive to air quality due to its direct effect [11]. Besides the health effects, the productivity of people also declines in poor indoor environmental conditions, which can be improved by removing the sources of pollution [12]. COVID-19 has made us realize the importance of a good ambiance and urged us to effectively control the quality of indoor environment [13]. Recent studies highlighted that the level of indoor air pollution could be more than outdoor [14].

Activities like cooking, smoking, cleaning, building materials, and decorating contribute to air pollutants [15]. The chances of mortality and illness are directly linked to air pollutants, and most of the developing countries are deeply concerned about it [16]. American Studies of Allergies showed that polluted air contributes to 50% of illnesses. Moreover, indoor air pollution is potentially a risk due to building-related disease and sick building syndrome [17]. Air pollution also affects the building infrastructure due to gas emissions contributing to global warming and material deterioration, affecting integrity of the building infrastructure [18].

In a study, researchers revealed that particulate matter is considered a great problem and causes psychological stress [19]. In other study, researchers analyzed sleep satisfaction in the different age groups of girls by monitoring CO_2 concentration and found dissatisfaction in one group of girls exposed to high CO_2, caused due to less air circulation [20]. In a study, it was observed that the occupants of high-rise buildings were dissatisfied and suggested improving the indoor environment [21]. In the other research, it was studied the impact of biomass burning on people's health and suggested efficient fuels [22]. Other researchers suggested improving the stoves, using environment friendly energy sources, and improving housing infrastructure to improve the indoor atmosphere after analyzing the health impacts of using poor energy sources [23]. It was monitored in the other study, TVOC, HCHO, $PM_{2.5}$, CO_2, humidity, temperature, ventilation airflow, and weather conditions in energy-efficient buildings and found high levels of TVOC and HCHO [24]. In a study , it was observed that using solid fuel instead of cleaner energy leads to increased medical expenses [25]. In the other study, it was discussed the time series trend of CO_2, CO, O_3, HCHO, TVOC, $PM_{2.5}$, and PM_{10} in an underground metro system in winter and summer [26]. In a study, researchers monitored PM_{10}, CO_2, temperature, and humidity for three days, which shows that air quality can be improved by increasing the air flow rate [27].

Researchers highlighted the dependency of CO, CO_2, NO_2, O_3, SO_2, and $PM_{2.5}$ on indoor and outdoor activities [28]. In a study, it was compared indoor and outdoor environments and found a higher level of $PM_{2.5}$ in winter [29]. In the other research, it was studied VOCs from different sources and concluded that they could be diffused to areas very far from the source, resulting in an increased risk of exposure [30].

Many researchers determined the dependency of VOC and PM on the smoke concentrations in the kitchen due to cooking, which also affects the living room [31]. Researchers of a study analyzed TVOC, SO_2, CO_2, O_3, NO_x, PM_{10}, and $PM_{2.5}$ in different scenarios like open windows, closed windows, cleaning, air conditioner turned on, air conditioner turned off, and smoking, and found excess concentrations of VOC and CO_2 in the residential area. In contrast, particulate matter concentration was prominent in offices [32].

In a research, it was monitored the concentration of PM, VOC, and formaldehyde in different outdoor areas and found a direct relationship between the crowd and the air pollutants [33]. In the other study, it was monitored VOC and O_3 at photocopying centers and found high concentrations during the daytime which go down gradually at night [34]. Researchers in atudy, recently assessed the impact of COVID-19 on $PM_{2.5}$ and showed a drastic change in the concentration [35]. Many researchers mentioned that indoor air quality in Lahore was poor due to cleaning and smoking inside the houses [36]. Other researchers monitored PM and CO in air-conditioned vehicles and roadside and found that commuters are badly exposed to higher concentrations of pollutants [37]. In the other study, it was determined the relationship of temperature with bacteria and particulate matter as these pollutants pose more health risks [38]. Many researchers reported an innovative development of photo-paint to degrade nitrogen oxide and toluene to improve the IAQ [39]. Other researchers tested an advanced cooking stove to completely burn biomass fuels to decrease gas emisemissionssuring better health and indoor ambiance [40].

According to the World Air Quality Report of 2018, major cities of Pakistan were among the top 10 polluted cities of the world. In 2020, Lahore moved to the second position. This situation urged us to monitor the air quality regularly to cope with the overall bad situation [41]. Moreover, it is noticed that Lahore has the worst condition of air pollution in the year 2021, as reported by Dawn newspaper [42]. Therefore, it is imperative to reinitiate the detailed monitoring of different air pollutants in houses to re-evaluate the exposure level.

Previous studies mainly focused on the outdoor environment. The studies investigating the indoor environment primarily focused on monitoring particulate matter in Pakistan. The studies conducted on indoor environments in Lahore include comparing the rural and urban sites regarding the usage of fuels [36], correlating the particulate matter with the kitchen, living room, and outside surroundings [43], and volatile organic compounds along with ozone in the photocopying centers in Lahore only for day time [33]. Based on above-mentioned discussion, this study aims to monitor carbon dioxide, total volatile organic compounds, formaldehyde, and particulate matter in the indoor environment of Lahore to investigate the record-high levels of AQI in 2021. This study is the first to analyze the indoor environment of Lahore after being ranked the world's second most polluted city. The outcomes of this study will help develop counteractions to control indoor air quality.

Materials and methods

Handheld devices (Temtop 2000c and Temtop H3) were used for continuous real-time and extensive temporal and spatial monitoring of pollutants in indoor environments. These devices are similar to Laser Egg, and Life Basis DM 106 A used by Zuo, Ji [29] and Aslam, Javed [33]. Temtop 2000c (Fig. 1) measures $PM_{2.5}$, PM_{10}, CO_2, Temperature, and humidity, while Temtop H3 (Fig. 2) monitors TVOC and formaldehyde. The devices were placed on the table at approximately 1 m from the ground, and 12 readings were noted every hour for three consecutive days. The working principle of these types of equipment is based on laser technology to detect the particles, a nondispersive infrared sensor to monitor CO_2, and an electrochemical sensor to measure the concentrations of TVOC and formaldehyde.

Fig. 1. Temtop M2000c Air Quality Monitor

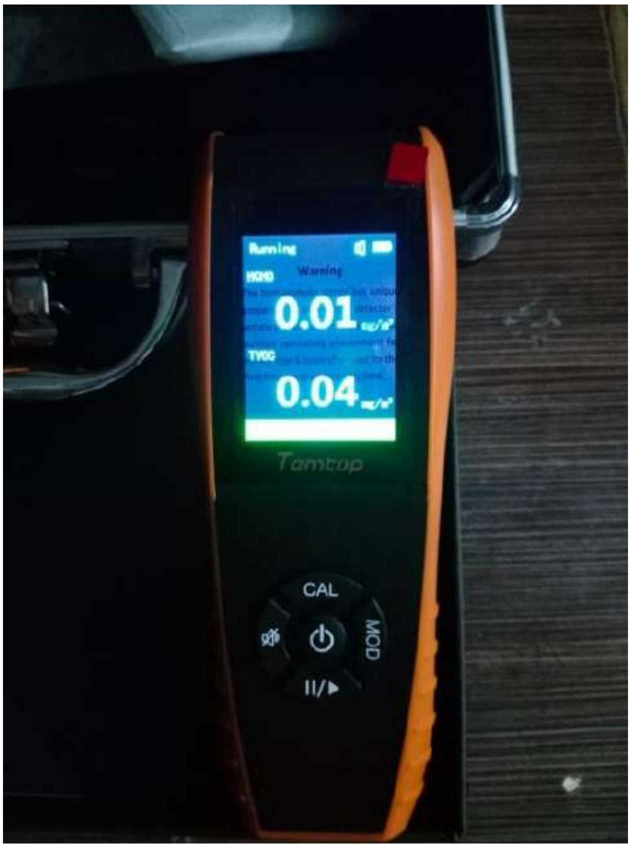


Fig. 2. Temtop H3 Air Quality Detector

Area of study

The recent developments in Lahore, one of the world's megacities and the second largest in the country after Karachi, have converted the city of gardens into a concrete city. Urban expansion, economic development, industrial expansion, vehicular emissions, and biomass burning are the causes that have deteriorated the city. Lahore is northeast of Punjab, surrounded by Amritsar (India), Sheikhupura, and Kasur districts. On the map, it is situated between 31 15’ and 31 45’ North latitude and 74 01’ and 74 39’ East longitude.

Lahore has a semi-arid climate and different seasons with sharp climate changes. May, June, and July are the warmest months, with minimum temperature between 39 °C and 26 °C, followed by the monsoon season, which spans around three months (July to September). Heavy rainfall is the major attribute of monsoon. Temperature falls tremendously in the winter, having foggy nights from December to February [44, 45].

Sample points

Various sites were selected to monitor the indoor air quality of Lahore based on the access and willingness of residents for three days. Data is categorized into different time zones like morning (5 AM to 12 PM), afternoon (12 PM to 5 PM), evening (5 PM to 9 PM), and night (9 PM to 5 AM) to analyze the trend of different pollutants. The location and characteristics of sample points are briefly mentioned in Table 1.

Table 1. Location, occupants, and infrastructure details of the sample points

Sample points	Location	Surroundings	Occupiers	Building characteristics
SP 1	Mehmood Booti	Iron bar mills	5	Windows and doors mostly remained open
SP 2	Kamboh colony	Residential houses and small road	6	Doors and windows mostly remained close
SP 3	Samnabad	Main Road	6	Doors and windows mostly remained close
SP 4	Chowk Baba Azam	Residential houses	6	Doors mostly remain closed and covered with curtains
SP 5	Ichra Bazaar	Fast Food and clothing shops	5	Windows mostly remained close
SP 6	Baghbanpura	Residential houses and Main Road	2	Small rooms with windows remained close and covered with curtains
SP 7	Sultanpura	Hide market and small road	5	Windows mostly remained close
SP 8	Kahna Kacha	Wood-cutting factory and small road	2	Doors and Windows mostly remained close
SP 9	Niaz Baig	Construction activity and urban site	2	The room door remained open all the time

Results and discussions

The average, minimum, and maximum values of the air pollutants at selected indoor locations of Lahore are presented in Table 2.

$PM_{2.5}$ and PM_{10} level

Continuous monitoring for 3-days revealed that commutes of Mehmood Booti are highly exposed to $PM_{2.5}$, while residents of Sultan Pura are less exposed. The concentration of PM_{10} was highest in Mehmood Booti and lowest in Sultan Pura. As values of the particulate matter significantly reduced after the rain, the concentrations of $PM_{2.5}$ and PM_{10} before and after the rain are presented in Figs. 3 and 4, respectively.

The highest $PM_{2.5}$ is recorded in Mehmood Booti with an average value of 488.6 µg/m³ followed by a house in Ichra Bazaar with an average value of 483.3 µg/m³. The lowest value is recorded at Sultan Pura, with an average value of 335.7 µg/m³. These values are 20, 19, and 13 times more than the WHO guidelines (presented in last row of Table 2).

Table 2. Descriptive analysis of the pollutants at selected indoor locations and standards

SP		$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	CO_2 (ppm)	HCHO (mg/m³)	TVOC (mg/m³)	T (ºC)	RH (%)
SP1	Average	488.6	710.5	722	0.013	0.061	22.9	48.7
	Min	102.7	157.3	442	0.01	0.04	19	40
	Max	992.3	999.9	1343	0.1	0.52	25	64
SP2	Average	370.4	581.5	681	0.019	0.089	22.7	41.3
	Min	119.7	185	497	0.01	0.04	19	32
	Max	997.3	999.9	998	0.06	0.29	24	47
SP3	Average	411.9	666.8	810	0.025	0.112	21.9	51.3
	Min	231	381.6	609	0.01	0.04	18	50
	Max	724.5	999.9	1965	0.09	0.49	23	60
SP4	Average	293.5	461.7	638	0.011	0.056	22.0	40.5
	Min	155.4	236.2	407	0.01	0.04	20	36
	Max	847.5	999.9	868	0.12	0.56	23	52
SP5	Average	483.3	737.2	516	0.024	0.104	18.9	48.6
	Min	130.2	200.3	398	0.01	0.04	16	40
	Max	994.1	999.9	876	1.27	3.91	21	53
SP6	Average	435.2	664.7	855	0.012	0.062	21.9	51.8
	Min	145.5	225.2	400	0.01	0.04	20	44
	Max	992.9	999.9	2371	0.29	0.93	23	59
SP7	Average	335.7	521.5	630	0.015	0.074	22.3	49.5
	Min	78.5	121.5	400	0.01	0.04	18	42
	Max	951.9	999.9	1275	0.06	0.24	24	58
SP8	Average	360.9	574.6	986	0.010	0.049	21.1	49.4
	Min	82.8	128.7	400	0.01	0.04	18	40
	Max	789.7	999.9	1890	0.02	0.11	22	56
SP9	Average	392.1	607.3	805	0.026	0.120	17.8	59.4
	Min	130.7	197.5	400	0.01	0.04	15	50
	Max	966.1	999.9	2188	0.15	0.63	20	65
WHO Standard		25	50	1000	0.081	0.6	--	--

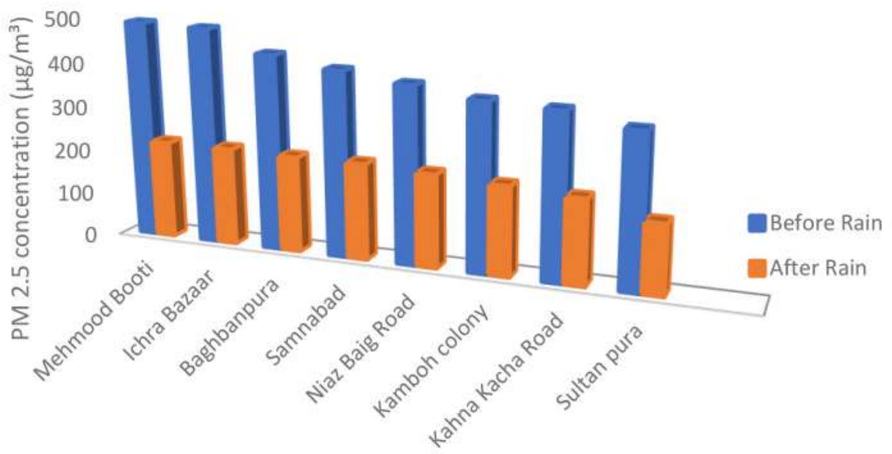


Fig. 3. Comparison of $PM_{2.5}$ concentration before and after the rain

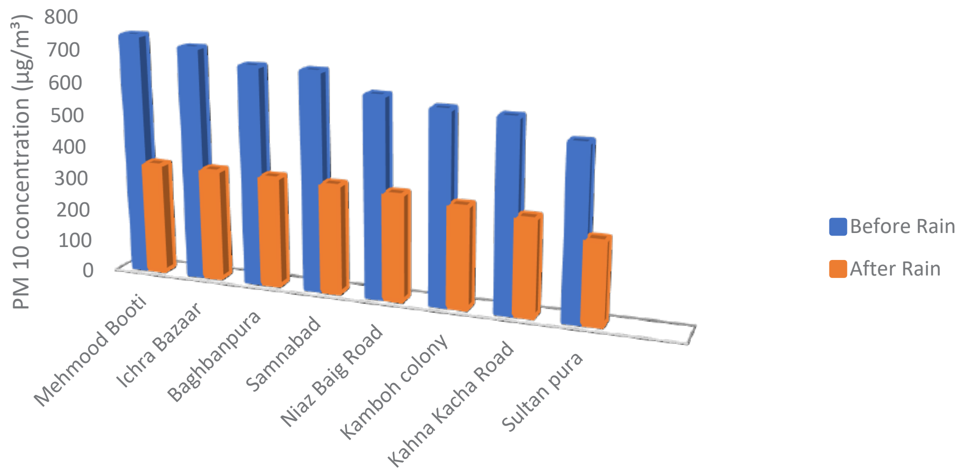


Fig. 4. Comparison of PM_{10} before and after the rain

The values of PM_{10} concentrations before and after the rain are shown in Fig. 4. Mehmood Booti has the highest value of PM_{10}, which is 737.2 µg/m³, 15 times greater than the WHO standard, followed by 710.5 µg/m³ at Ichra Bazaar, 14 times greater than the standard limits. The lowest value is at Sultan Pura, with a concentration of 518.4 µg/m³, which is ten times greater than the WHO standard.

It was experienced that environmental conditions such as rain directly relate to the decrease in concentrations of $PM_{2.5}$ and PM_{10}. The minimum values of $PM_{2.5}$ and PM_{10} were 153 µg/m³ and 248 µg/m³, respectively, while the maximum values were 219 µg/m³ and 340 µg/m³, respectively. These values are lower than the foggy days; however, they are still 5 to 8 times more than WHO standard.

The lowest values of $PM_{2.5}$ and PM_{10} were 72.9 µg/m³ and 109.5 µg/m³, respectively. The noticeable decrease in the concentration is due to washing away the air pollutants from the outdoor ambient air through a rain shower. In contrast, the highest value of $PM_{2.5}$ observed in the Kamboh colony was 997.3 µg/m³.

The change in concentrations of $PM_{2.5}$ during 24 h starting from midnight 00:00 to 24:00 is shown in Fig. 5.

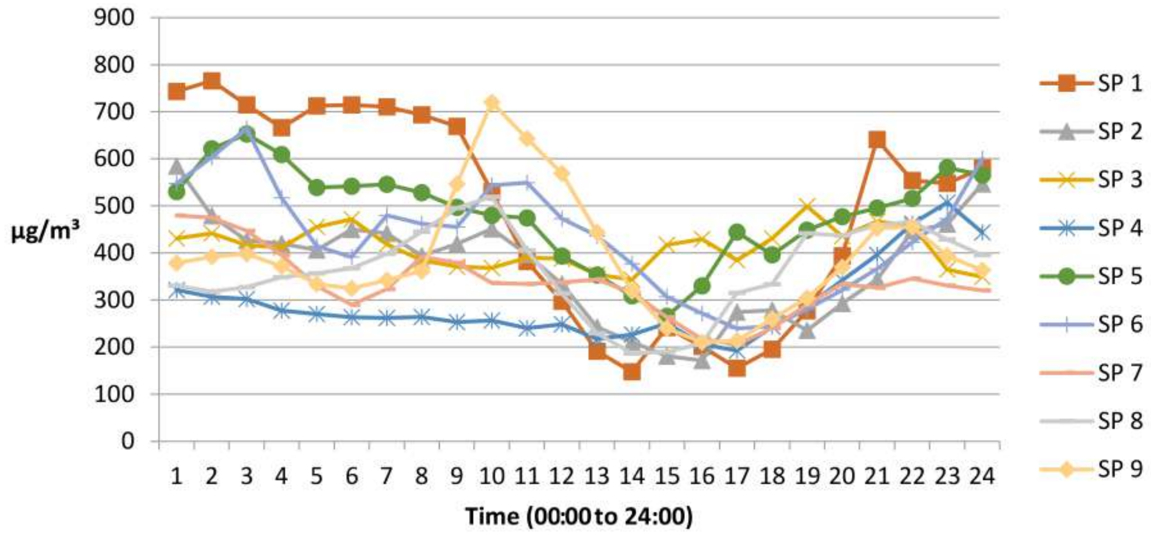


Fig. 5. Hourly trend of change in $PM_{2.5}$ concentration from midnight 00:00 to 24:00

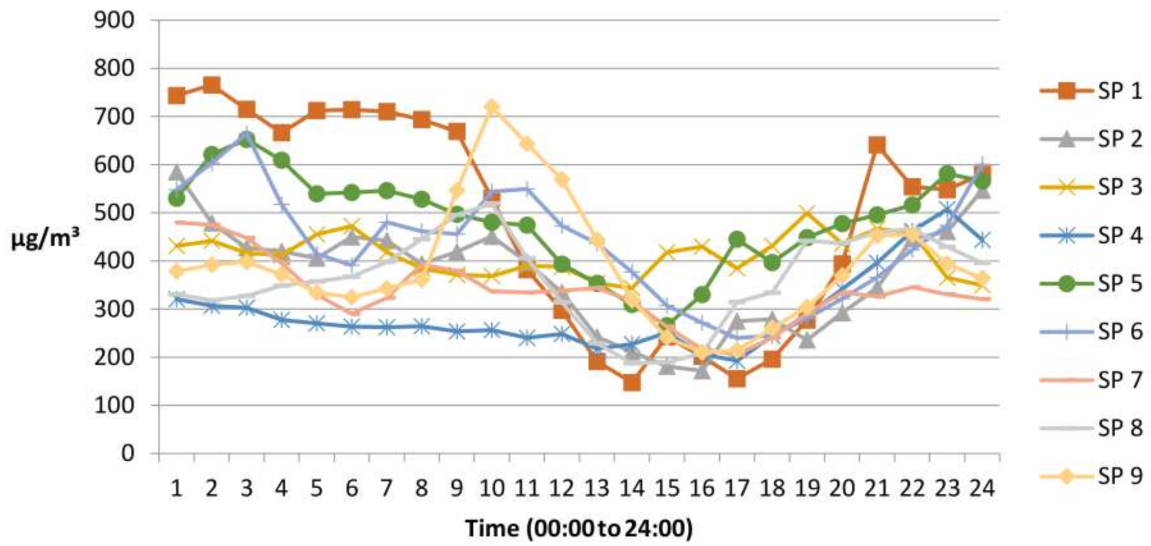


Fig. 6. Hourly trend of change in PM_{10} concentration from midnight 00:00 to 24:00

Similarly, the change in concentrations of PM_{10} during 24 h starting from midnight 00:00 to 24:00 is shown in Fig. 6.

The trends of $PM_{2.5}$ and PM_{10} during different time zones of a day are shown in Figs. 7 and 8, respectively. The presented data is the average of the values measured at all locations. It represents that during morning values were high and became less during day time and then again escalated to the maximum at night.

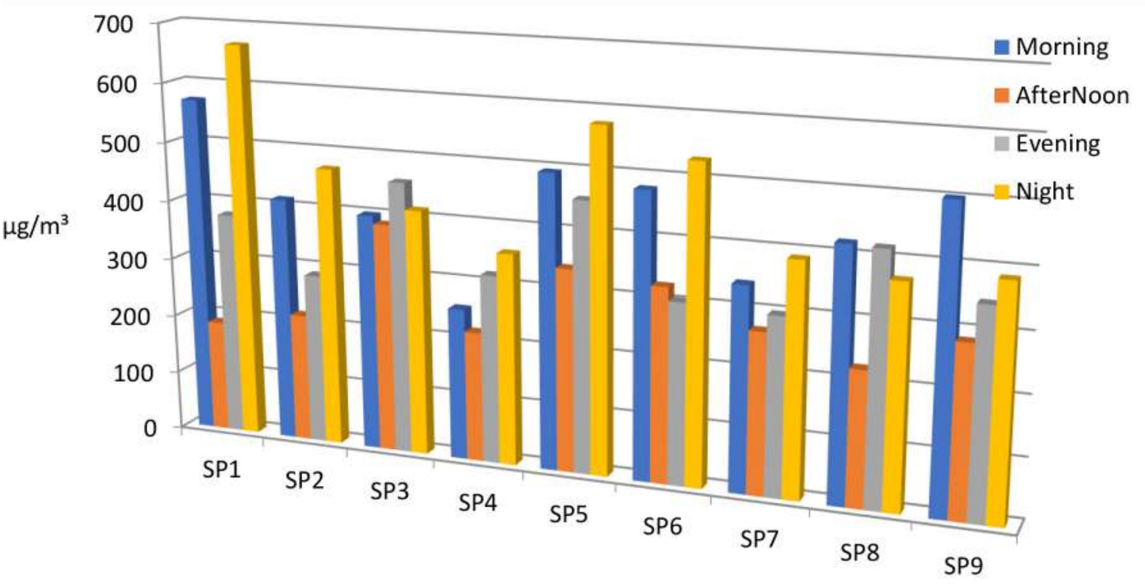


Fig.7. Concentration level of $PM_{2.5}$ at morning, afternoon, evening and night

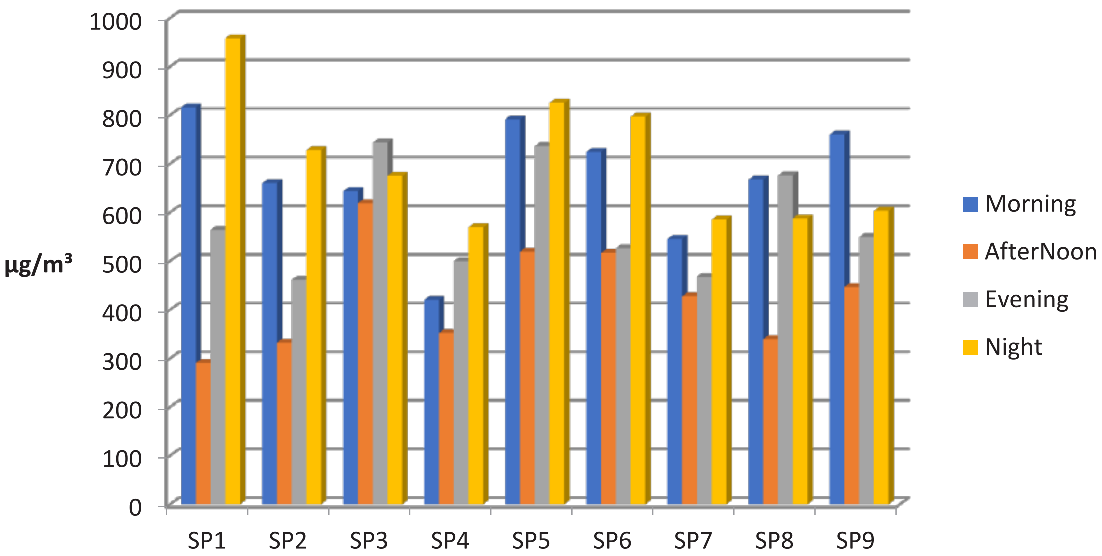


Fig. 8. Concentration level of PM_{10} at morning, afternoon, evening and night

CO_2 level

The highest concentration of CO_2 was observed at Kahna Kacha (986.5 ppm), while the lowest at Ichra Bazaar (516 ppm). The concentrations level of CO_2 at selected locations are presented in Fig. 9.

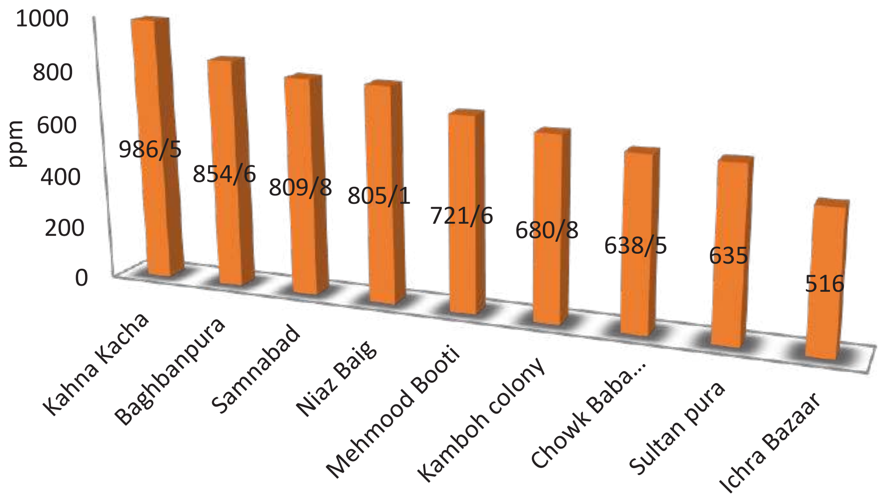


Fig. 9. Concentration level of CO_2 at selected locations

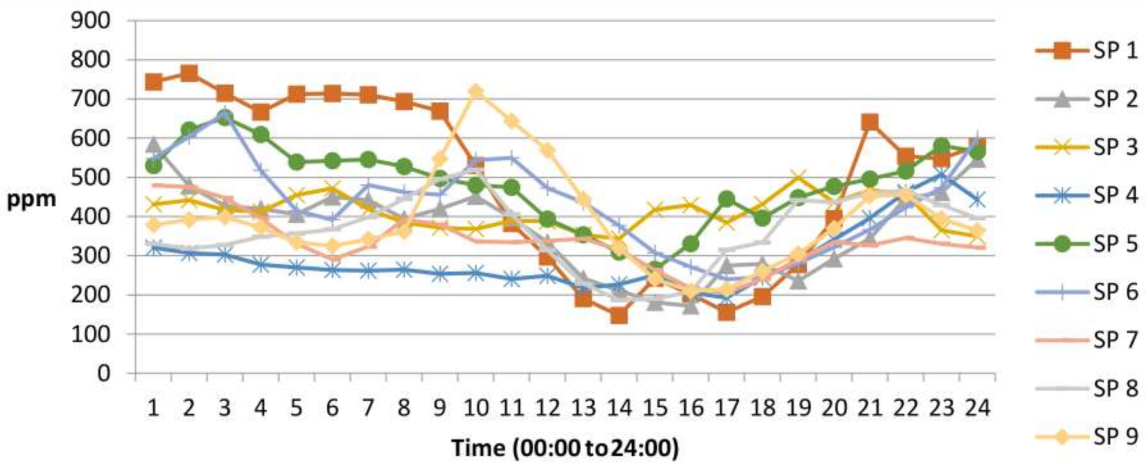


Fig. 10. Hourly trend of CO_2 concentration from midnight 00:00 to 24:00

From Table 2, the individual minimum value of CO_2 was 398 ppm, monitored at Ichra Bazaar, and the highest value was 2371 ppm, recorded at Baghbanpura. The reason for this high value is less number of occupants in the house which is directly related to the opening and closing of the door. If the doors remain closed for a very long period, the value goes to a higher level. In other words, if ventilation is poor, the concentration of pollutants will increase. This trend is similar to the results discussed by a researchers [46]

Fig. 10 shows the hourly trend of CO_2 levels during 24 h starting from midnight 00:00 to 24:00. In most places, there are no sharp changes with little higher values during the night than in the morning. Abnormal peaks can be observed due to burning low-quality fuel, closed doors for a very long time in the morning, and the winter season.

From Fig. 11, the concentration level of CO_2 is least in the morning, escalating gradually and becoming high at night. It can be analyzed that the highest level is due to the exhalation of CO_2 by humans, which remain in the room due to less air exchange as the doors remain closed at night, and a major role is played by plants which also pass out CO_2 at night.

Formaldehyde (HCHO) and total volatile organic compounds levels

Primarily, the concentrations of formaldehyde and total volatile organic compounds depends on indoor activities such as cooking, smoking, ironing clothes, using the polish remover, and construction activities. Moreover, the values of both pollutants remained low in the morning, which gradually increased as the day passed and became high during the night because doors remained closed. The organic compounds emitted through cooking activities also stays in the rooms due to the closure of the doors. The values of HCHO and TVOC at different times are shown in Figs. 12 and 13, respectively.

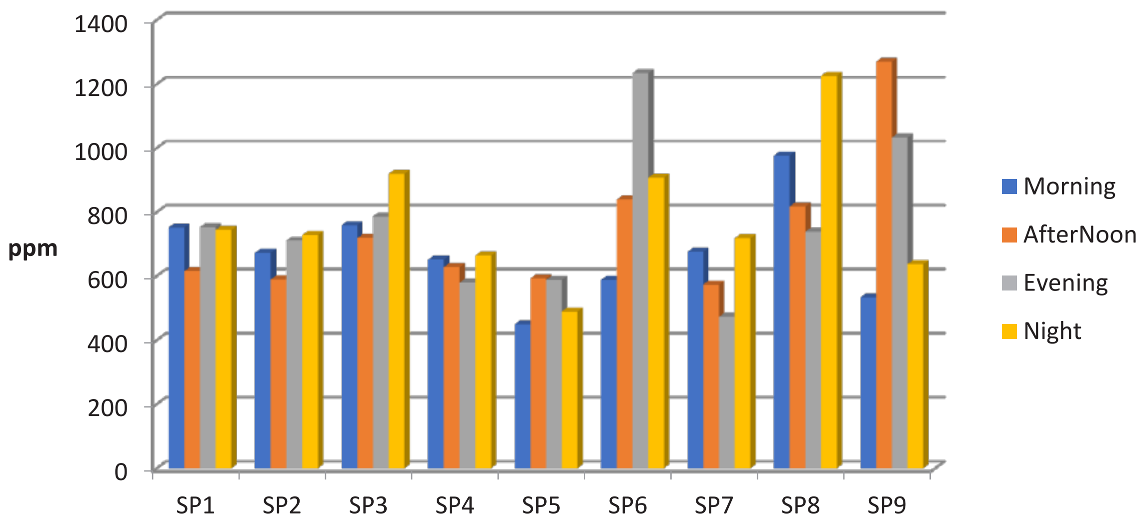


Fig. 11. Concentration level of CO_2 at morning, afternoon, evening and night

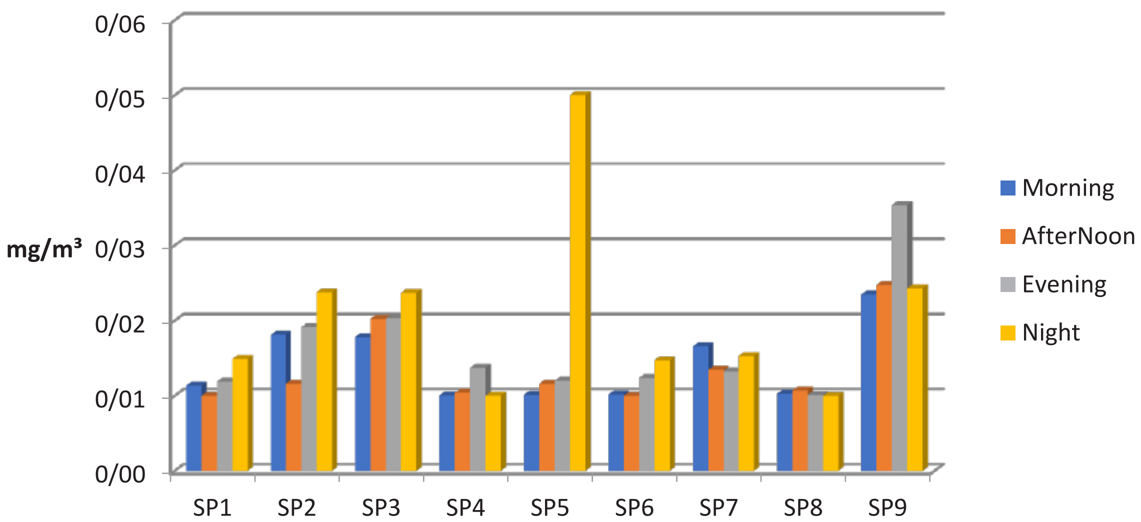


Fig. 12. Concentration level of HCHO at morning, afternoon, evening and night

The highest values of TVOC (3.91 mg/m³) and HCHO (1.27 mg/m³) were observed at Ichra Bazaar when the pickle bottle was opened, while the values of TVOC (0.04 mg/m³) and HCHO (0.01 mg/m³) were within the prescribed limit at all other places.

From Table 2, the maximum average value of formaldehyde was noticed at Niaz Baig (0.026 mg/m³), followed by Samnabad (0.025 mg/m³), and the lowest at Kahna Kacha (0.01 mg/m³, before the rainy days. Regarding TVOC, the highest value was observed at Niaz Baig (0.12 mg/m³), followed by Samnabad (0.11 mg/m³), and the lowest average value of 0.04 mg/m³ at multiple places. The values of formaldehyde and TVOC values are within the acceptable limits.

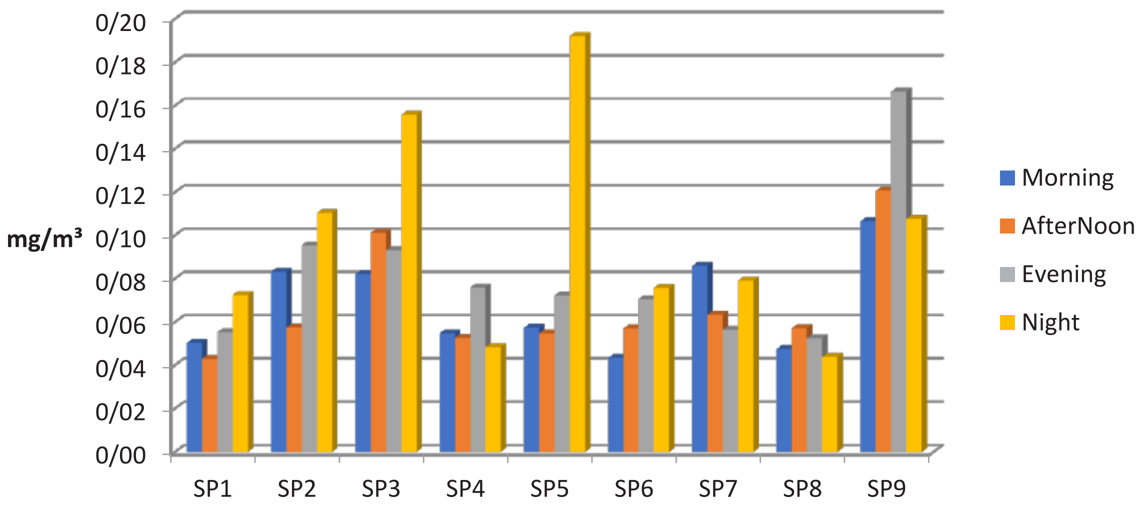
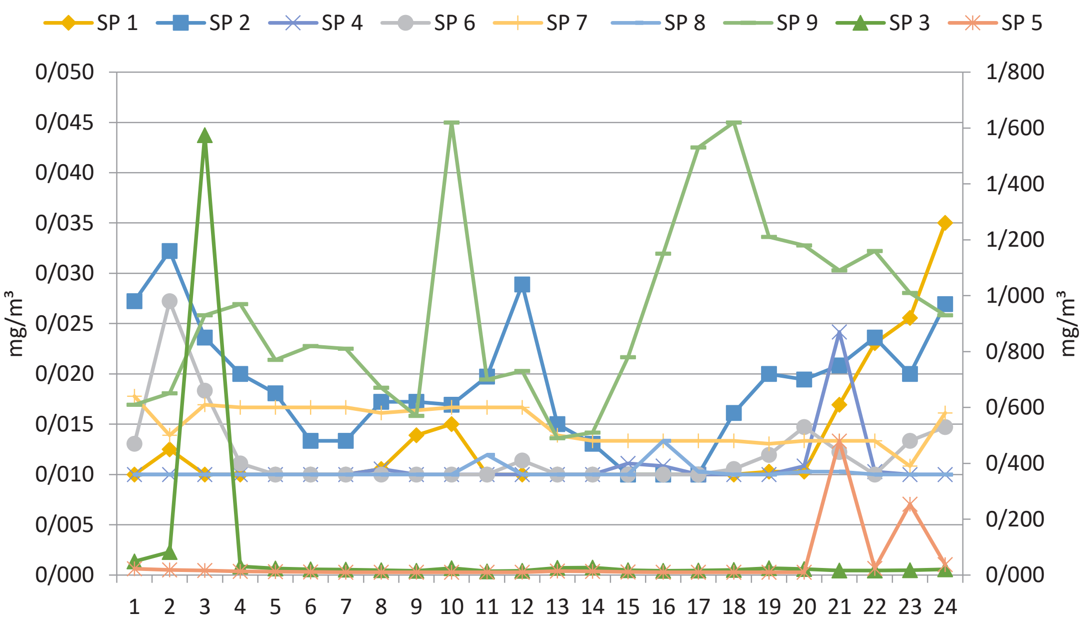


Fig. 13. Concentration level of TVOC at morning, afternoon, evening and night



Note: Secondary verticle axis is used for SP 3 and SP 5, while primary verticle axis is used for all other points (SPs)

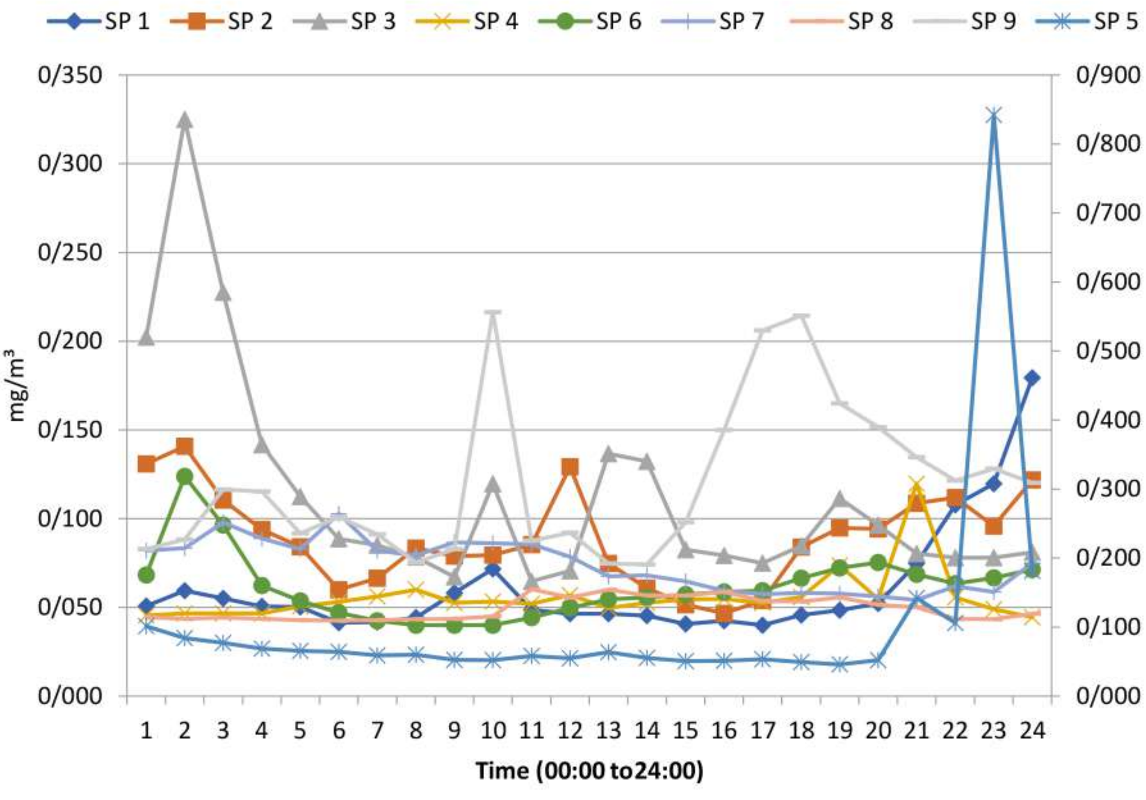
Fig. 14. Hourly trend of HCHO concentration from midnight 00:00 to 24:00

Figs. 14 and 15 show the hourly trend of HCHO and TVOC values during 24 h starting from midnight 00:00 to 24:00, respectively. The peak in the graph shows occurance of the activities which are the sources of the respective pollutant. These activities include construction, cooking, smoking, cleaning, and using perfumes. There is also no decrease in values after the rainy days because they predominantly originate from indoor sources. The minimum values of both pollutants TVOC and HCHO were 0.087 and 0.019 mg/m³, while the maximum values were 0.117 and 0.025 mg/m³, respectively.

Values measured in the second phase for HCHO and TVOC seem to be high at all locations because sunny days or high temperatures after rainy days also cause the substances to emit from different things placed in the rooms.

Controlling and sources of air pollutants

Knowing the sources of indoor air pollutants is also imperative to improve and control their concentration. Table 3 summarizes air pollution particulate matter, volatile organic compounds, carbon monoxide, nitrogen dioxide, Sulphur dioxide, and ozone sources and their associated health impacts on human life [47, 48].



Note: Secondary verticle axis is used for SP 5, while primary verticle axis is used for all other points (SPs)

Fig. 15. Hourly trend of TVOC concentration from midnight 00:00 to 24:00

Table 3. Sources and health impacts of air pollutants

Pollutants	Sources	Health Impacts
PM	Outdoor air, cooking, cleaning, and combustion activities	Heart and lung diseases
VOC's	Building materials, paints, solvents, air fresheners, perfumes, dry-cleaned clothes, tobacco products, etc.	Eyes, nose, and throat irritation, nausea, headache, damage to kidney, liver, and central nervous system, and cancer
Cox	Outdoor air, cooking activities, smoking, and fireplaces	Fatigue, impaired vision, reduced brain function, and higher concentration of CO (700 ppm) lead to death.
NO2	Outdoor air, cooking activities, and fireplaces	Respiratory problems, lung irritation
SO2	Outdoor air, cooking activities, and fireplaces	Weakens the respiratory function
O3	Outdoor air, photocopying machines, disinfecting devices	Lung damage, asthma, and DNA damage disturb the respiratory function

Based on the observed values, measures need to be taken to control the levels of air pollutants. These measures need to be specific and target oriented. The main concern is particulate matter and CO_2, which can be controlled by reducing outdoor emissions. The drastic decrease in pollutants such as $PM_{2.5}$, PM_{10}, and CO_2 was observed due to the change in the environmental condition, which implies that outdoor air pollution level is directly proportional to indoor pollutant levels.

There is a need for stronger legislation on environmental conservation to improve outdoor and indoor air quality. Air purifiers and indoor plants are recommended to enhance indoor air quality. Genus ficus plant is reported to help decrease the VOC levels, and Nephrolepis Obliterata reduces formaldehyde by up to 100% [49]. In addition, the building infrastructure should be designed to improve ventilation and fresh air circulation. In short, a detailed road map is needed in Pakistan to reduce air pollution by analyzing the recent developments and impacts of strategies implemented by other countries. The use of artificial ventilation and air-conditioning can also be helpful in improving indoor air quality [50].

Conclusion

Indoor air quality is critical improving the indoor environment. Spatial and temporal trends of different pollutants revealed that all the monitored pollutants remained higher during the night except particulate matter, which was high during the morning. The outdoor areas' surroundings deeply affect the indoor levels, which can obstruct the normal trend of the pollutants. Particulate matter was high in the areas where sources, such as iron mills, low-quality burning fuel, fast food shops, and other eatable stuff, were prepared. The lowest levels were recorded in areas where least/ no sources of PM were present. Therefore, using such poor-quality fuel to save costs should be banned at the industrial level, and alternative energy sources should be adopted.

Carbon dioxide was noticed to be higher at night, and the peak values were recorded where the door remained closed for a long time. Moreover, the number of occupants is also interconnected with concentration of CO_2 due to the air exchange rate. So, the replenishment of bad quality air with a fresh air through ventilation is the key in controlling the concentration of CO_2.

The levels of TVOC and HCHO are not so alarming, and their levels only surge during specific activities that are the sources of such pollutants like burning, cleaning, and construction. The highest values were noted in Ichra Bazaar (3.91 mg/m3 and 1.27 mg/m3) for both pollutants during cooking and eating time. Moreover, the highest average values of TVOC (0.12 mg/m3) and HCHO (0.12 mg/m3) were recorded in the houses near the construction sites. The inhalation of a small amount regularly can lead to the deterioration of health.

This research is limited to investigating indoor pollutants using handheld monitors from Temtop with a maximum measurable value (for $PM_{2.5}$ and PM_{10}) of 999.9 μg/m³. This work can be extended to a simultaneous measurement of indoor and outdoor pollutants using fixed monitors for a longer period.

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Competing interests

The authors declare that there is no competing interest.

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Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

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