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# Indoor Air Quality Detection inside Several Healthcare Units of Medical City in Baghdad

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**Abstract**

Indoor air quality (IAQ) in healthcare facilities has become a critical area of research due to its significant influence on patient health, staff safety, and operational efficiency. This study examines the levels of various indoor air pollutants, including formaldehyde (HCHO), volatile organic compounds (VOCs), carbon dioxide ($CO_2$), nitrogen dioxide ($NO_2$), humidity, and temperature, in multiple healthcare units within the Medical City of Baghdad from September to the end of December of 2024 from different units, such as consulting units, waiting halls, corridors, and emergency rooms. Different IAQ monitoring systems that provide real-time measurements of these parameters were used in this study. The findings show that $CO_2$ levels tend to be elevated, with a significant difference detected in Baghdad Teaching Hospital. $NO_2$ concentrations were also monitored, which suggested a possible connection with specific activity within the healthcare settings. Formaldehyde and VOC levels were examined in order to understand their effects on respiratory health among patients and workers and showed that HCHO concentrations were consistently elevated in Sep.-Oct., while the Medical City Dialysis Center documented the highest VOC levels during these months. Humidity and temperature measurements were crucial in evaluating the effectiveness of ventilation systems and their impact on maintaining a healing environment. In conclusion, the Medical City Center was characterized by consistently elevated levels of temperature, formaldehyde, VOCs, and $NO_2$, particularly during September and October, whereas the Children's Welfare Teaching Hospital exhibited the lowest pollutant concentrations alongside higher humidity. Ghazi Al-Hariri Hospital, in contrast, maintained relatively stable air quality indicators throughout the study period. This research demonstrates the importance of a regular IAQ assessment in healthcare settings to reduce health risks resulting from poor air quality. By identifying and addressing air quality issues proactively, healthcare providers can enhance patient safety, comply with established health standards, and improve staff working conditions.

**Keywords:** Indoor air quality (IAQ), $CO_2$, $NO_2$, VOC, Temperature, Humidity .

## 1. Introduction

According to the World Health Organization, air pollution is the most significant environmental health threat worldwide and poses a substantial negative impact on human health[1,2]. Concern over indoor air quality (IAQ) has grown significantly as a result of the air pollutants' detrimental influence on human health, including elevated risks of cancer and respiratory and cardiovascular disorders [3-6].

Maintaining optimal indoor air quality (IAQ) in intricate hospital environments is essential to protect patients and healthcare workers from nosocomial infections and occupational diseases [7]. IAQ is a complicated and dynamic issue that is influenced by multiple factors, including indoor activities, outdoor air quality, indoor occupant density, the widespread use of alcohol-based cleaning products indoor intrinsic emissions, the presence of anesthetic gases, the chemicals employed in laboratory settings, and ventilation methods (e.g., equipment/furniture/coatings) [8].

The necessity of effectively regulating indoor air quality in healthcare facilities is highlighted by the existence of susceptible persons and the features of ongoing operations. Healthcare workers often complain of headaches, fatigue, dryness, and irritation of the eyes and skin, all of which have been linked to low IAQ [9-11]. Furthermore, hospitals are open twenty-four hours a day, seven days a week, with no downtime to recuperate from emissions from operations and the resulting influence on indoor air quality [12,13].

The most prominent measured pollutants impacting indoor air quality in hospitals include chemical pollutants like carbon dioxide ($CO_2$), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and particulate matter (PM), alongside biological contaminants like bacteria, fungi, viruses, and pollen [14,15].

Carbon dioxide levels serve as an indicator of ventilation adequacy, with elevated concentrations implying insufficient air exchange, which can increase the risk of airborne disease transmission [16]. High-resolution $CO_2$ monitoring in enclosed environments serves as a particular alert system to prevent airborne viral transmission by optimizing human occupancy, especially in sensitive settings such as hospitals during the SARS-CoV-2 pandemic [17].

A research studied $CO_2$ levels in a wide range of settings in an acute care hospital to assess ventilation and has shown that $CO_2$ concentrations often exceed 800 parts per million (ppm) during periods of high occupancy (like small conference room (31 $m^3$) with 8 people, office (38.5 $m^3$) with 3 people, and bathroom in patient care area with 2 people) or when ventilation is compromised[18]. $NO_2$ exposure poses potential health problems, especially for susceptible populations such as children and individuals with respiratory conditions [19]. Thus, understanding the dynamics of air pollutants like $NO_2$ and $CO_2$ within hospitals is essential for establishing effective strategies to improve indoor air quality, minimize the risk of infection transmission, and enhance overall healthcare outcomes.

This study seeks to comprehensively evaluate indoor air quality in multiple healthcare facilities within Baghdad Medical City by measuring key air pollutants, including carbon dioxide, nitrogen dioxide, formaldehyde, and volatile organic compounds, as well as humidity and temperature during both summer and winter seasons.

## 2. Materials and Methods

### 2.1 Air quality measurement

Levels of air quality parameters, including nitrogen dioxide (NO2), carbon dioxide (CO2), Volatile organic compounds (VOCs), and formaldehyde (HCHO) were measured in this study at various locations inside three hospitals and one center (Baghdad Teaching Hospital, Children Welfare Teaching Hospital, Ghazi Al-Hariri Hospital for Surgical Specialties, and Medical City Dialysis Center). Measurements were taken from different units, such as consulting units, waiting halls, corridors, and emergency rooms. High-risk zones such as operating rooms and intensive care units were excluded due to logistical and infection control considerations requiring special protocol, from the period between September and the end of December 2024, as shown in **Figure 1**.

During the peak hours in the morning between 9-12 AM, the temperatures ($^oC$) and percent relative humidity (%RH) were recorded simultaneously with the measurement of air pollutants using an SL-4112 (AUTO RANGE, SOUND METER + TYPE K TEMP, OPTIONAL % RH, ANEMOMETER, LIGHT). Levels of all gaseous air pollutants were measured directly by RAE Systems MultiRAE Plus PGM-50-5P multi-gas monitor detector and Extech CO250. Levels of VOCs and HCHO were assessed by an air quality monitor. At each measuring point, three replicate readings were taken for each pollutant at each site. All monitoring instruments were placed at a height between 1.0 and 1.5 meters above floor level, corresponding to the typical

human breathing zone, in accordance with international indoor air quality monitoring recommendations for healthcare environments. This ensured that it reflected actual occupant exposure.
The readings were taken from September to the end of December of 2024 using a short measurement technique (30 min/ reading). It must be mentioned that all instruments were calibrated before measurements according to standard operating procedures recommended by the manufactures.

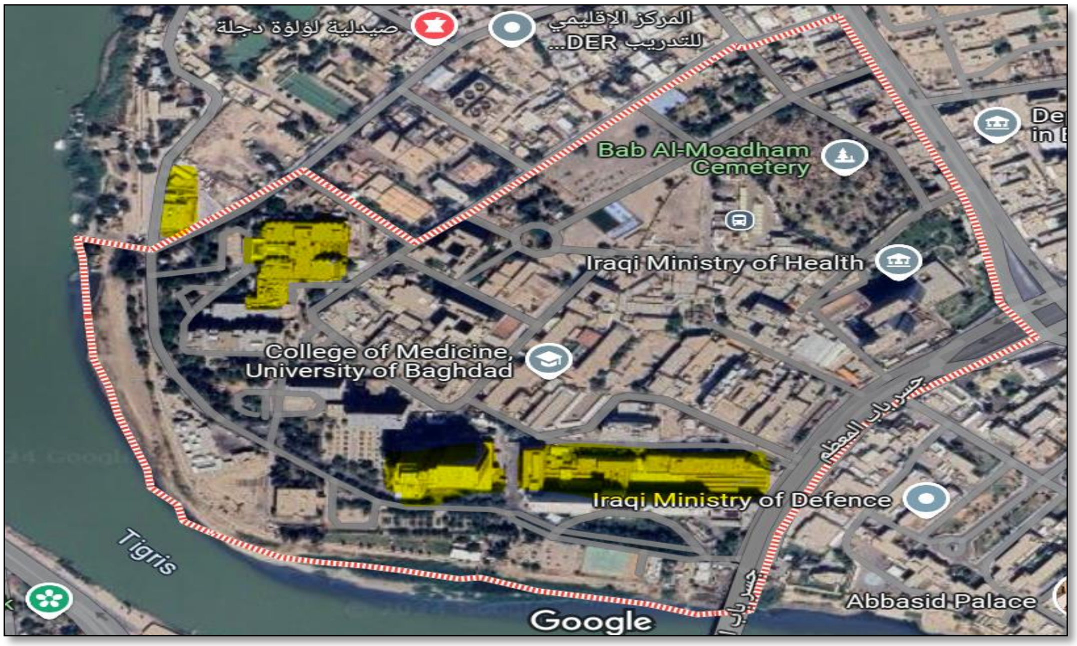


**Figure 1.** Map of the study area showing the hospitals in which indoor air pollutants were measured (yellow buildings).

## 2.2 Statistical analysis

The collected raw results were analyzed using the SPSS program (V.20, IBM) by using an independent T-test and One-Way ANOVA and obtaining Least Significant Difference (LSD) as appropriate. The outcomes were expressed as mean ± S.E., and a significant difference was considered at $p \leq 0.05$.

# 3. Results

From the results shown in **Tables 1, 2, 3**, and **4**, six variables were studied from September to the end of December of 2024 in three different hospitals and one center inside Medical City, which is located in the same area in Baghdad City. The data collected highlights the mean values of air quality parameters across these facilities. Air sample were taken from different working areas (waiting halls, lobbies, corridors, emergency rooms, and consulting units):

## 3.1 Temperature and Humidity

The Medical City Dialysis Center exhibited the highest mean temperature (30.5 °C) in September and October, whereas the Children Welfare Teaching Hospital recorded the lowest temperatures during the study period (Sep.-Oct.: 26.88 °C; Nov.-Dec.: 26.25 °C) and the highest humidity in Sep.-Oct. (44.38%). The lowest humidity value was recorded during Nov.-Dec. at the Medical City Dialysis Center (27.0%). These findings highlight substantial inter-hospital variability in environmental conditions, with both temperature and humidity suggesting seasonal variations.

## 3.2 HCHO and VOC

Formaldehyde (HCHO) and volatile organic compound (VOC) levels were measured across four hospitals in Medical City in Baghdad during the four months. Notably, HCHO concentrations were consistently elevated in Sep.-Oct. compared to Nov.-Dec., with the most pronounced seasonal decline at the Medical City Dialysis Center (from 159 ± 41 to 139± 14 μg/$m^3$), whilst the lowest was recorded at the Children Welfare Teaching Hospital in Nov.-Dec. (98.25 ± 5.53 μg/$m^3$). Regarding VOCs, the Medical City Dialysis Center documented the highest Sep.-Oct. value (0.124 ± 0.007 ppm), whereas the lowest detectable VOC concentration was found at the Children Welfare Teaching Hospital during Nov.-Dec. (0.001 ± 0.001 ppm); at Ghazi AL-Hariri Hospital for Surgical Specialties, both HCHO and VOC levels remained relatively stable throughout the four months, with only slight declines observed in Nov.-Dec.

### 3.3 $NO_2$ and $CO_2$

Nitrogen dioxide ($NO_2$) is a strongly reactive gas that is emitted into the atmosphere mainly through the oxidation of nitric oxide (NO). During this study, the peak Sep.-Oct. $NO_2$ levels were observed at the Medical City Dialysis Center, with a concentration of 1.9 ± 0.3 ppm, whereas the lowest Sep.-Oct. concentration was noted at the Children Welfare Teaching Hospital at 1.275 ± 0.048 ppm. Baghdad Teaching Hospital recorded the lowest level at 1.021 ± 0.066 ppm during Nov.-Dec. The Ghazi Al-Hariri Hospital reported intermediate values in both periods, with Sep.-Oct. levels at 1.45 ± 0.078 ppm and 1.275 ± 0.111 ppm in Nov.-Dec. These results highlight that the Dialysis Center consistently recorded the highest $NO_2$ concentration across the four months, whereas the Baghdad Teaching Hospital had the lowest levels in Nov.-Dec., and the Children Welfare Teaching Hospital had the lowest in Sep.-Oct.

For $CO_2$ concentrations, Baghdad Teaching Hospital exhibited the highest Sep.-Oct. concentration at 1304.5 ± 63.82 ppm, significantly greater than its Nov.-Dec. value of 1008.75 ± 17.99 ppm. In contrast, the Medical City Dialysis Center documented the lowest Sep.-Oct. $CO_2$ concentration at 836 ± 415 ppm and Nov.-Dec. level of 789 ± 207 ppm.

**Table 1.** Mean of air pollutants inside Baghdad Teaching hospital during the study period

| Parameter | Study period | Mean±S.E. | P value | WHO levels [22, 29, 32] |
|---|---|---|---|---|
| Temperature (°C) | Sep.-Oct. | 29.5±2.598 | 0.8 NS | 20-24 |
| | Nov.-Dec. | 29±1.080 | | |
| Humidity (%) | Sep.-Oct. | 36.1751.658 | 0.27 NS | 30-60 |
| | Nov.-Dec. | 32.75±2.323 | | |
| HCHO (μg/$m^3$) | Sep.-Oct. | 125±28.662 | 0.6 NS | 100 |
| | Nov.-Dec. | 110.5±19.985 | | |
| VOC (ppm) | Sep.-Oct. | 0.029±0.024 | 0.86 NS | Below 0.1222 |
| | Nov.-Dec. | 0.037±0.035 | | |
| $NO_2$ (ppm) | Sep.-Oct. | 1.378±0.141 | 0.06 NS | 0.1(short term exposure 1hr) |
| | Nov.-Dec. | 1.021±0.066 | | |
| $CO_2$ (ppm) | Sep.-Oct. | 1304.5±63.819 | 0.015* | Less than 1000ppm |
| | Nov.-Dec. | 1008.75±17.992 | | |

* significant differences, NS= Non-significant

**Table 2**. Mean of air pollutant inside Medical city dialysis center during the study period.

| Parameter | Study period | Mean±S.E. | P value | WHO levels [22, 29, 32] |
|---|---|---|---|---|
| Temperature (°C) | Sep.-Oct. | 30.5±5.5 | 0.76 NS | 20-24 |
| | Nov.-Dec. | 28.5±1.5 | | |
| Humidity (%) | Sep.-Oct. | 29.6±0.026 | 0.048* | 30-60 |
| | Nov.-Dec. | 27±2 | | |
| HCHO (μg/$m^3$) | Sep.-Oct. | 159±41 | 0.7 NS | 100 |
| | Nov.-Dec. | 139±14 | | |
| VOC (ppm) | Sep.-Oct. | 0.124±0.007 | 0.1 NS | Below 0.1222 |
| | Nov.-Dec. | 0.064±0.014 | | |
| $NO_2$ (ppm) | Sep.-Oct. | 1.9±0.3 | 0.2 NS | 0.1(short term exposure 1hr) |
| | Nov.-Dec. | 1.15±0.15 | | |
| $CO_2$ (ppm) | Sep.-Oct. | 836±415 | 0.9 NS | Less than 1000ppm |
| | Nov.-Dec. | 789±207 | | |

* significant differences, NS= Non-significant

**Table 3**. Mean of air pollutants inside Children Welfare Teaching Hospital during the study period

| Parameter | Study period | Mean±S.E. | P value | WHO levels [22, 29, 32] |
|---|---|---|---|---|
| Temperature (°C) | Sep.-Oct | 26.875±0.718 | 0.6 NS | 20-24 |
| | Nov.-Dec. | 26.25±0.946 | | |
| Humidity (%) | Sep.-Oct | 44.375±5.09 | 0.2 NS | 30-60 |
| | Nov.-Dec. | 36±3.028 | | |
| HCHO (µg/$m^3$) | Sep.-Oct | 114.75±20.508 | 0.47 NS | 100 |
| | Nov.-Dec. | 98.25±5.528 | | |
| VOC (ppm) | Sep.-Oct | 0±0 | 0.36 NS | Below 0.1222 |
| | Nov.-Dec. | 0.001±0.001 | | |
| $NO_2$ (ppm) | Sep.-Oct | 1.275±0.048 | 0.14 NS | 0.1(short term exposure 1hr) |
| | Nov.-Dec. | 1.125±0.075 | | |
| $CO_2$ (ppm) | Sep.-Oct | 1030±155 | 0.4 NS | Less than 1000ppm |
| | Nov.-Dec. | 889±67 | | |

* significant differences, NS= Non-significant

**Table 4**. Mean of air pollutants inside Ghazi Al-Hariri Hospital for surgical specialties during the study period

| Parameter | Study period | Mean±S.E. | P value | WHO levels [22, 29, 32] |
|---|---|---|---|---|
| Temperature (°C) | Sep.-Oct | 26.5±0.65 | 0.8 NS | 20-24 |
| | Nov.-Dec. | 26.25±0.95 | | |
| Humidity (%) | Sep.-Oct | 36.125±2.164 | 0.19 NS | 30-60 |
| | Nov.-Dec. | 32±1.73 | | |
| HCHO (µg/$m^3$) | Sep.-Oct | 120.5±15.88 | 0.47 NS | 100 |
| | Nov.-Dec. | 105.25±11.99 | | |
| VOC (ppm) | Sep.-Oct | 0.027±0.015 | 0.9 NS | Below 0.1222 |
| | Nov.-Dec. | 0.024±0.016 | | |
| $NO_2$ (ppm) | Sep.-Oct | 1.45±0.087 | 0.26 NS | 0.1(short term exposure 1hr) |
| | Nov.-Dec. | 1.275±0.111 | | |
| $CO_2$ (ppm) | Sep.-Oct | 1142.5±77.89 | 0.06 NS | Less than 1000ppm |
| | Nov.-Dec. | 871±88.35 | | |

* significant differences, NS= Non-significant

## 4. Discussion

Indoor air quality (IAQ) is a complicated and dynamic problem in hospitals and is predominantly influenced by various factors: outdoor air quality, the widespread use of alcohol-based cleaning products and disinfectants, ventilation practice, the presence of anesthetic gases, and the chemicals employed in laboratory settings [8, 20].

It was previously stated that all sites are located within the same geographic area (Medical city); therefore the observed variations in temperature cannot be attributed to seasonal differences but rather to poor performance and malfunctioning of the central cooling units. Furthermore, Baghdad Teaching Hospital was established in 1970, Ghazi Al-Hariri Hospital in 1987, and Child Welfare Hospital in 1984. As for the Dialysis Center, it was opened at the end of 2022. Among these, the center is the smallest and the closest to the street. It is noteworthy that all these hospitals were crowded, with Baghdad and Children Welfare hospitals being the most crowded and frequented because they are teaching hospitals, whereas Gazi Al-Hariri Hospital experienced lower, yet still considerable, levels of crowding. The area in general is characterized by heavy vehicular traffic. All these factors influence the concentration and quality of indoor air within these hospitals.

The results of this research show high temperatures with minimal variation in the hospitals during the study period compared to the levels suggested by WHO inside healthcare settings (20_24 C) to ensure optimal comfort and health outcomes. For summer, recommended hospital temperatures can extend up to 27 $^{o}$C in some areas (such as emergency rooms and certain inpatient/outpatient areas. Previous researchers indicated that seasonal fluctuations in temperature and humidity can influence patient outcomes, especially for respiratory and cardiovascular diseases [21, 22].

The HCHO and VOC values are higher in Sep.-Oct. than in Nov.-Dec., which is likely due to increased temperatures enhancing the off-gassing of formaldehyde and VOCs from building materials, furnishings, and cleaning agents and poor ventilation [23]. Previous investigations based on the chemical characterization of hospitals' indoor air have highlighted that the use of disinfectants and sterilizers is associated with the emission of aldehydes (glutaraldehyde, formaldehyde) and alcohols (ethanol, isopropanol), the latter representing the main components of alcohol-based hand-rubbing solutions [24, 25].

Formaldehyde concentrations in indoor air, such as in hospitals, generally vary but are often found below occupational safety limits. For example, average indoor levels in some monitored environments are around 10 to 50 ppb (0.01 to 0.05 ppm), with occasional peaks depending on the presence of emission sources [26]. Prolonged exposure to formaldehyde above 0.1 mg/m³ is frequently used as a benchmark for indoor air quality, which can cause sensory irritation in the nose, eyes, and throat and may exacerbate respiratory conditions [27].

According to the WHO, the recommended indoor air quality limit for formaldehyde to protect patients and all building occupants is 0.1 mg/m³ (approximately 0.08 ppm) as a 30- minute average, while the Occupational Safety and Health Administration (OSHA) sets a permissible exposure limit (PEL) of 0.75ppm as an 8-hour time-weighted average for workplace air, including healthcare facilities [28]. The TVOC levels are within or near the acceptable range; cumulative and chronic exposure, especially in sensitive environments such as hospitals, should be minimized [29, 30].

The present study aligns with the findings of two investigations [31,32], which confirm that indoor HCHO levels in hospitals often exceed WHO guidelines, particularly in poorly ventilated or high-activity areas. It was found that HCHO levels in neonatal incubators varied seasonally but often approached or exceeded international recommendations. Nevertheless, this finding was inconsistent with the latter finding of an inverse correlation between temperature and HCHO/VOC levels, with higher concentrations in Nov.-Dec., possibly due to reduced ventilation, whereas the current investigation found elevated levels of HCHO in summer, which may reflect elevated off-gassing from building materials or variations in ventilation practices.

$CO_2$ serves as a key indicator of ventilation adequacy and occupancy levels. The heightened summer $CO_2$ levels at Baghdad Teaching Hospital may indicate an increase in patient or visitor numbers, reduced ventilation rates, or both. A study revealed that significant correlations were observed between $CO_2$ and $NO_2$ concentrations, with exposure levels differing between susceptible and general populations due to indoor environmental factors (temperature, relative humidity, seasons, and facility type) [19], leading to disproportionate health impacts on children compared to adults [33].

Indoor $CO_2$ values above 1000 ppm reflect inadequate ventilation, which can lower occupants' productivity and performance. Consequently, organizations like the CDC and the French Public Health Council acknowledge indoor $CO_2$ levels as an indicator of ventilation quality, especially relevant during the COVID-19 pandemic [34].

Comparing the $NO_2$ levels with other investigations conducted in Baghdad, similar trends and concentration ranges have been reported. For example, a study monitored indoor air quality in Baghdad hospitals and observed that $NO_2$ levels tend to decrease during the cold season, yet remain higher in hospitals situated in areas with high traffic, dense urban development, or widespread use of onsite electricity generators, which explains the increased $NO_2$ levels noted in this research [31]. Moreover, the $NO_2$ concentrations measured in this study are substantially higher than the WHO-recommended limits of 0.01 ppm, indicating a serious concern for indoor air quality [8, 35].

## 5. Conclusion

The study evaluates the air quality within three hospitals and one center located in Medical City, Baghdad. The Medical City Dialysis Center consistently recorded elevated levels of temperature, formaldehyde, VOCs, and $NO_2$, especially during Sept.-Oct. The Children Welfare Teaching Hospital, on the other hand, exhibited the lowest pollutant values and higher humidity. Throughout the year, Ghazi Al-Hariri Hospital had relatively consistent air pollutant levels. This highlights the importance of air quality control and ventilation enhancement to protect the patients and healthcare workers.

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## Conflict of Interest

The authors declare that they have no conflicts of interest.

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## Ethical Clearance

Approval has been obtained from the hospitals of the Medical City in Baghdad to measure the pollutant parameters from within the hospital environment (code: 22970- 4/7/2024)

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