Original Article

Indoor Air Quality and Environmental Safety in Neonatal Intensive Care Unit in Al-Najaf, Iraq: A Cross-Sectional Study of Incubators and Surrounding Air

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ABSTRACT

Objective: To measure selected indoor air quality parameters within neonatal incubators and neonatal intensive care unit rooms using a calibrated digital monitoring device

Study Design: Descriptive analytical cross-sectional study

Place and Duration of Study: This study was conducted at the neonatal intensive care unit of Al-Zahraa Teaching Hospital in Al-Najaf, Iraq, from 1st October 2024 to 31st March 2025.

Methodology: The study included 12 active neonatal Incubators and two neonatal intensive care unit rooms. Air quality parameters including temperature, relative humidity, particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}), carbon dioxide, formaldehyde, and total volatile organic compounds, were measured using a portable monitoring device. Measurements were conducted during peak working hours at different locations within the rooms and incubators.

Results: The research results demonstrated that the majority of air quality indicators met international standards for acceptable levels. The temperature and carbon dioxide levels met the recommended values, but relative humidity fell below the recommended threshold. The $PM_{2.5}$ and PM_{10} levels remained within acceptable range while formaldehyde and total volatile organic compounds gaseous pollutants appeared at extremely low levels. The two rooms showed no significant statistical differences between them ($P>0.05$).

Conclusion: The neonatal intensive care unit indoor air quality assessment showed acceptable results although the facility needed humidity level improvements. The establishment needs continuous air quality assessment together with control systems to maintain protection for neonates

Key Words: Indoor air quality, Neonatal incubators, Particulate matter, Environmental monitoring.

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INTRODUCTION

Indoor air quality (IAQ) establishes an essential health standard which applies to all environments but healthcare facilities need special consideration because they serve vulnerable patient groups who spend all their time indoors. The term IAQ describes indoor air conditions present in various buildings which include hospitals and homes and schools because multiple physical and chemical and biological elements affect its measurement. The rising use of cleaning products and disinfectant materials and synthetic substances leads to indoor environments where pollutants reach levels that are two to five times higher than outdoor air pollution, especially in locations with poor ventilation systems.[1,2]

In healthcare facilities, optimal IAQ maintenance serves as a critical factor that protects against infections while ensuring patient safety. The combination of inadequate ventilation and inappropriate temperature and humidity settings together with poor air filtration system maintenance creates an environment where dangerous airborne substances including particulate matter and microbial agents can build up.[2,3] Ventilation systems equipped with high-efficiency particulate air (HEPA) filters function as essential components that decrease airborne particles while preventing infection spread in critical care settings like neonatal intensive care units (NICUs).[4,5]

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Carbon dioxide (CO_2) acts as a ventilation efficiency measurement tool because its high level indicates that ventilation systems fail to provide proper air circulation, which leads to increased indoor pollutant buildup.[6,7] Airborne particle levels in hospital units rise because of human presence together with daily clinical work that includes staff movement and equipment transport activities.[8]

Indoor air pollution in indoor spaces consists mostly of particulate matter, especially the smaller $PM_{2.5}$ and PM_{10} particles. The particles can stay airborne for long periods because they enter the respiratory system, which creates major health hazards. The World Health Organization[1] reports that people who experience high levels of PM exposure face greater chances of developing respiratory and cardiovascular diseases. The risk for NICU patients increases because preterm infants lack fully developed respiratory systems and immune systems, which makes them vulnerable to airborne pollutants and infectious diseases.

The hospital air contains a combination of airborne particles and chemical substances and microorganisms. The healthcare environment contains airborne bacteria which include Staphylococcus and Bacillus and Pseudomonas as common findings that demonstrate their capacity to spread healthcare-associated infections.[9,10] A study carried out in NICUs showed significant air contamination together with the detection of multidrug-resistant organisms which confirmed that environmental air functions as an infection transmission path.[11] A recent systematic review of research from 2019 to 2024 confirmed that indoor air quality (IAQ) in healthcare settings shows inconsistent results because healthcare facilities do not follow recommended standards in their compliance practices.[12]

Iraqi research conducted at the local level has found that hospital indoor air quality shows high levels of indoor air pollution which includes both particulate matter and CO_2 and volatile compounds. The results indicate that there might be problems with both the ventilation systems and the control systems.[13-16] A recent study conducted in Karbala hospitals, which was published in Al-Furat Journals for health and medical sciences, documented various neonatal health conditions among hospitalized newborns while showing how healthcare environment affects neonatal health outcomes.[17]

The research project intends to evaluate indoor air quality in neonatal incubators and their surrounding neonatal care areas through measurements of particulate matter and gaseous pollutants and environmental conditions which will help identify possible exposure hazards in NICUs.

METHODOLOGY

A descriptive analytical cross-sectional study conducted in the Neonatal Intensive Care Unit of Al-Zahraa Teaching Hospital in Al-Najaf, Iraq 1st October 2024 to 31st March 2025 letter No. 3434/QM/Approval/ JSDJNEHU dated 7th September 2024. The NICU composed two active rooms containing incubators in use. During the study period, 12 incubators were actively in use. Indoor air samples were collected from active neonatal incubators and surrounding NICU rooms. Active incubators and operational NICU rooms were included. Non-operational incubators and inactive rooms were excluded.

Air quality was monitored using a portable air quality monitor (Model: PV28-CW, manufactured in China). The device is capable of measuring temperature, relative humidity, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, HCHO, TVOC, and CO_2. It utilizes a laser scattering sensor for particulate matter, a semiconductor sensor for gaseous pollutants. The device was calibrated according to the manufacturer's instructions for prior to use. Measurements were conducted in the two active NICU rooms and for all active incubators n =12. In each room, measurements were taken at three different locations: near the sink, at the center of the room, and at the far end, to represent the overall environmental conditions. The parameters measured in the rooms included temperature, relative humidity, particulate matter (PM_{10} and $PM_{2.5}$), HCHO, and TVOC.

For incubators measurements were taken for all incubators when the incubator was temporarily unoccupied, in coordination with the healthcare staff, to ensure patient safety and avoid any interference with neonatal care. The parameters measured included temperature, relative humidity, particulate matter ($PM_{1.0}$, $PM_{2.5}$), HCHO, TVOC and CO_2. All measurements were taken during peak working hours (10:30 AM to 12:00 PM). The device was placed at each location for approximately 10 minutes before recording the readings to ensure stability and accuracy. For statistical analysis, parameters with established reference values were compared to international guidelines using a one-sample t-test. A P-value equal to or less than 0.05 was considered statistically significant.

RESULTS

The mean temperature was 30.0±2.13C ranging from 27.0-33.0C. The mean relative humidity was 38.08±3.87 with values between 32.0% 43.0 % indicating slight variation. The average CO_2 concentration was 726.33±94.63 ppm. $PM_{2.5}$ showed a mean of 14.92±16.17 $\mu g/m^3$, with values between 1.0 and 48.0 $\mu g/m^3$. The mean HCHO concentration was 0.002±0.003 mg/m^3 (range: 0.001-0.013 mg/m^3). Likewise, TVOC levels were low, with a mean of 0.014 ±0.043 mg/m^3 and a range of 0.001-0.152mg/m^3. There were non-statistically significant (P>0.05) differences between room1 and room2 regarding air quality parameters (Table 1).

Table No. 1: Air quality parameters measured inside neonatal incubators

Parameter	Neonatal Incubator Room 1		Neonatal Incubator Room 2		Total		P value
	Mean± D	Range	Mean±SD	Range	Mean±SD	Range	
Temp (C)	30.0±1.89	27.0-33.0	30.0±2.53	27.0-33.0	30.0±2.13	27.0-33.0	1.000
Hum (%)	39.5±3.51	34.0-43.0	36.67±3.98	32.0-42.0	38.08±3.87	32.0-43.0	0.220
CO_2 (PM)	734.5±118.41	616-960	718.17±74.28	653-850	726.33±94.63	616-960	0.781
$PM_{2.5}$ (µg/m^3)	12.83±17.48	1.0-48.0	17.0±16.11	4.0-41.0	14.92±16.17	1.0-48.0	0.677
HCHO (mg/m^3)	0.003±0.005	0.001-0.013	0.002±0.001	0.001-0.003	0.002±0.003	0.001-0.013	0.526
TVOC (mg/m^3)	0.026±0.062	0.001-0.152	0.003±0.001	0.001-0.005	0.014±0.043	0.001-0.152	0.369

The mean temperature (30.0±2.13C) did not differ significantly from the reference value (30C) (P=1.000). In contrast, relative humidity (38.08±3.87%) was significantly lower than the reference value 45% (P<0.001). The mean CO_2 concentration (726.33±94.63 ppm) showed no statistically significant differences when compared to the reference value of 800 ppm (P= 0.056). $PM_{2.5}$ levels (14.92±16.17µg/m^3) did not differ significantly from the reference value of 15 µg/m³ (P=0.825). HCHO (0.002±0.003 mg/m^3), and TVOC (0.014±0.043 mg/m^3) were significantly (P<0.001) lower than their respective reference values (Table 2).

Table No. 2: One sample t. test of comparison between the value of air quality parameters and reference values

Parameter	Mean± SD	Reference Value	P value
Temp (C)	30.0±2.13	30°C	1.000
Hum (%)	38.08±3.87	45	<0.001
CO_2 (ppm)	726.33±94.63	800 ppm	0.056
$PM_{2.5}$ (µg/m³)	14.92±16.17	15 µg/m³	0.825
HCHO (mg/m³)	0.002±0.003	0.1 mg/m³	<0.001
TVOC (mg/m³)	0.014±0.043	0.3 mg/m³	<0.001

One sample t. test

The $PM_{1.0}$ level showed a mean value of 12.08±12.48 µg/m³ indicating variability in ultrafine particle levels detection throughout measurements. The $PM_{1.0}$ parameter was analyzed descriptively due to the absence of established international reference values (Table 3).

The mean temperature was 24.67±1.51C, ranging from 23.0 to 27.0C. The mean relative humidity was 42.50±1.23%, with values ranging from 41.0 to 44.0%. For particulate matter, the mean PM_{10} level was 12.60±3.73 µg/m^3, while $PM_{2.5}$ had a mean of 8.97±4.32 µg/m^3, ranging from 1.0 to 14.0 µg/m^3. The mean formaldehyde (HCHO) concentration was 0.004±0.007 mg/m^3, with a range of 0.001-0.019 mg/m^3. TVOC levels showed a mean of 0.038±0.086 mg/m^3, ranging from 0.001 to 0.214 mg/m^3. While There were non-statistically significant (P>0.05) differences between room1 and room2 regarding air quality parameters (Table 4).

The temperature did not differ significantly from the reference value (P=0.611). Relative humidity was significantly lower than the reference value (P=0.004). PM_{10} and $PM_{2.5}$ levels were significantly lower than their respective reference values (P=0.005 and P=0.019, respectively). HCHO, and TVOC were significantly (P<0.001) lower compared to the reference value (Table 5).

Table No. 3: The descriptive statistical of $PM_{1.0}$ level inside neonatal incubators

$PM_{1.0}$	Mean± SD	Measurement unit
	12.08±12.48	µg/m^3

Table No. 4: Air quality measurements in neonatal rooms

Parameter	Room 1		Room 2		Total		P value
	Mean± D	Range	Mean±SD	Range	Mean±SD	Range	
Temp (C)	25.67±1.16	25.0-27.0	23.67±1.16	23.0-25.0	24.67±1.51	23.0-27.0	0.101
Hum (%)	43.33±0.58	43.0-44.0	41.667±1.16	41.0-43.0	42.50±1.23	41.0-44.0	0.089
PM_{10} (µg/m^3)	14.20±0.20	14.0-14.4	11.0±5.19	5.0-14.0	12.60±3.73	5.0-14.4	0.347
$PM_{2.5}$ (µg/m^3)	9.27±0.252	9.0-9.5	8.667±6.81	1.0-14.0	8.97±4.32	1.0-14.0	0.886
HCHO (mg/m^3)	0.001±0.001	0.001-0.002	0.007±0.010	0.01-0.019	0.004±0.007	0.001-0.019	0.363
TVOC (mg/m^3)	0.002±0.002	0.001-0.005	0.074±0.122	0.001-0.214	0.038±0.086	0.001-0.214	0.367

Table No. 5: One sample t. test of comparison between the value of air quality parameters and reference values

Parameter	Mean ± SD	Reference Value	P value
Temp (C)	24.67±1.51	25°C	0.611
Hum (%)	42.50±1.23	45	0.004
PM_{10} (µg/m³)	12.60±3.73	45 µg/m³	0.005
$PM_{2.5}$ (µg/m³)	8.97±4.32	15 µg/m³	0.019
HCHO (mg/m³)	0.004±0.007	0.1 mg/m³	<0.001
TVOC (mg/m³)	0.038±0.086	0.3 mg/m³	<0.001

DISCUSSION

This study evaluated indoor air quality in neonatal incubators and NICU rooms, finding that most parameters met international standards except for relative humidity which showed substantial decreases from normal levels. The results show that most conditions are acceptable, with specific areas requiring improvemen.[2]

The temperature readings in both incubators and room areas matched the established standards which demonstrated proper temperature control throughout the NICU. Maintaining appropriate temperature is essential for neonatal stability, especially for preterm infants with immature thermoregulation.[5]

The relative humidity level was found to be lower than 45% which is the recommended threshold, and this condition may harm neonatal health because it increases their risk of developing skin dryness and mucosal irritation and becoming more vulnerable to infections. In healthcare settings, which lack proper humidity control, similar results have been documented.[3]

The carbon dioxide levels stayed within safe limits because they did not differ from established reference values which proved that ventilation systems operated effectively. The standard practice for assessing ventilation performance uses CO^2 levels which indicate adequate air exchange when measurements fall below 800 ppm.[7]

The air quality of the incubators and rooms showed effective performance because the $PM_{2.5}$ and PM_{10} particulate matter levels stayed below the maximum allowed limits. International research evidence supports these findings by showing that hospitals need to control airborne particles to reduce their patients' respiratory health risks.[1,7]

Gaseous pollutants formaldehyde HCHO and total volatile organic compounds TVOC were present at extremely low levels which fell far below established reference values. The results show minimal chemical contamination which demonstrates effective ventilation and disinfectant control in the NICU environment. Hospital-based research showed the same results because VOC levels remained low while proper ventilation and environmental management systems were in place.

Due to the lack of standardized reference values, PM1.0 was analyzed descriptively. The observed variability results from changes in human activities and equipment usage which previous studies have documented in the NICU environment.[7]

The two NICU rooms showed no important differences which indicated that the unit maintained consistent environmental control methods throughout the facility. Regional studies demonstrated identical results because they found that hospital units maintained stable environmental conditions even though their building structures differed.[13,16]

The majority of incubators achieved acceptable air quality standards which confirmed that indoor air quality maintained sufficient levels for medical use. The ongoing drop in humidity levels shows that better environmental control methods must be developed. These findings are consistent with previous Iraqi study which demonstrated that hospital environmental conditions directly affect neonatal health outcomes.[17]

CONCLUSION

The most measured environmental parameters were within acceptable international standards. Temperature, carbon dioxide, particulate matter ($PM_{2.5}$ and PM_{10}), formaldehyde, and total volatile organic compounds were generally within safe limits, indicating adequate environmental control within the unit. However, relative humidity was consistently below the recommended level, highlighting a potential risk factor that may affect neonatal comfort and vulnerability to infection. Overall, the findings suggest that while the neonatal intensive care unit environment is generally safe, continuous monitoring and improvement of humidity control and ventilation systems are essential to ensure optimal protection for neonates.

Author's Contribution:

Concept & Design or acquisition of analysis or interpretation of data:	Zainab Hassan Ghazai, Fulath Abdul-Redah Muhsin
Drafting or Revising Critically:	Zainab Hassan Ghazai, Fulath Abdul-Redah Muhsin
Final Approval of version:	All the above authors
Agreement to accountable for all aspects of work:	All the above authors

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