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Indoor Air Pollutants, Microclimatic Conditions and Respiratory Morbidity among Adults in Ibadan, Southwest Nigeria: A Cross-sectional Study

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ABSTRACT

Indoor air pollution and adverse microclimatic conditions are important environmental determinants of respiratory health, particularly in rapidly urbanising settings where housing conditions, ventilation and household energy use may increase exposure to airborne pollutants. Evidence combining objective measurements of residential indoor air quality with respiratory health outcomes remains limited in many Nigerian urban communities. This study assessed indoor concentrations of particulate matter, carbon monoxide, and carbon dioxide, as well as temperature and relative humidity. It examined their associations with respiratory morbidity among adult residents of Ibadan South-West Local Government Area, Nigeria. A descriptive cross-sectional study was conducted among adult residents of Ibadan South-West Local Government Area. Respiratory health information was collected using a semi-structured interviewer-administered questionnaire adapted from the European Community Respiratory Health Survey. Indoor particulate matter with aerodynamic diameters ≤2.5 μm ($PM_{2.5}$) and ≤10 μm (PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), temperature, and relative humidity were measured in selected residences. Environmental measurements were obtained at three indoor locations during morning (09:00–11:00) and afternoon (13:00–15:00) periods, three days per week over a two-week monitoring period. Data were analysed using STATA MP/17. Descriptive statistics, tests of association and logistic regression were used to examine relationships between indoor environmental conditions and respiratory morbidity. Statistical significance was set at $p<0.05$. The analytical results comprised 215 adults, of whom 134 (62.3%) were classified as having respiratory issues. Mean indoor $PM_{2.5}$ concentrations increased from 42.2 ± 11.5 μg/m^3 in the morning to 55.1 ± 16.7 μg/m^3 in the afternoon, while PM_{10} increased from 137.9 ± 38.5 to 188.1 ± 48.4 μg/m^3. Mean CO concentrations increased from 0.22 ± 1.1 ppm in the morning to 1.3 ± 4.3 ppm in the afternoon, and CO_2 increased from 520.2 ± 164.5 to 618 ± 341 ppm. Mean temperature increased from 24.4 ± 1.3°C to 28.0 ± 1.0°C, whereas relative humidity decreased from 64.4 ± 3.0% in the morning to 50.8 ± 9.2% in the afternoon. Above-optimum afternoon relative humidity was associated with increased odds of respiratory morbidity (OR=3.91; 95% CI: 1.65–9.27; p=0.002). Unexpected inverse associations were observed between respiratory morbidity and higher afternoon PM_{10} concentrations (OR=0.33; 95% CI: 0.14–0.74; p=0.007) and between respiratory morbidity and normal versus low afternoon CO_2 concentrations (OR=0.31; 95% CI: 0.11–0.92; p=0.034). $PM_{2.5}$, CO and most morning environmental indicators were not significantly associated with respiratory morbidity. Indoor environmental conditions varied between morning and afternoon monitoring periods, with higher mean concentrations of particulate matter, CO, and CO_2, and higher temperatures observed in the afternoon. Above-optimum afternoon relative humidity was positively associated with respiratory morbidity. The inverse associations observed for afternoon PM_{10} and CO_2 should be interpreted cautiously given the cross-sectional design, categorical exposure classification and limited duration of environmental monitoring. Longer-term studies using continuous exposure measures and repeated-measures modelling are warranted.

Keywords: *Indoor air pollution; $PM_{2.5}$; PM_{10}; relative humidity; respiratory morbidity; indoor air quality; Nigeria; Ibadan.*

1. Introduction

Indoor environmental quality is an important determinant of respiratory health. Residential environments can expose occupants to particulate matter, combustion products, excess moisture, and other contaminants capable of initiating or aggravating respiratory symptoms and diseases. Fine particulate matter, particularly $PM_{2.5}$, can penetrate deeply into the respiratory tract, while larger respirable particles such as PM_{10} may contribute to airway irritation and respiratory symptoms. Combustion processes within or near households may additionally produce carbon monoxide and other pollutants, while inadequate ventilation can contribute to the accumulation of contaminants indoors.

The World Health Organization recognises adequate ventilation, thermal comfort and control of dampness and indoor air pollution as important components of healthy housing [1, 2]. Household air pollution represents a particular concern in low- and middle-income countries, where housing quality, household energy sources and everyday activities may influence residential exposures. Across sub-Saharan Africa, rapid urbanisation and the growth of inadequately serviced residential areas have occurred alongside continued use of polluting household energy sources and suboptimal ventilation [3]. Biomass combustion and other household activities can generate particulate matter, CO and volatile combustion products, with poorly ventilated spaces potentially increasing exposure among household members [4, 5]. Environmental conditions within buildings may also modify these exposures. Temperature and relative humidity influence indoor thermal conditions and may affect pollutant behaviour and biological contaminants. Excess moisture, in particular, can support conditions conducive to microbial and mould growth, with potential implications for respiratory health [6, 7, 8]. Nigeria faces substantial housing and environmental-health challenges associated with rapid population growth and urbanisation. Residential environments in many Nigerian cities are characterised by varying degrees of ventilation, crowding, structural quality and proximity to outdoor pollution sources [9]. Household air pollution has also been documented in southwestern Nigeria, including exposure to combustion-related pollutants within residences [10]. In Ibadan, environmental and housing conditions may be influenced by a combination of household activities, traffic-related pollution, seasonal dust, and climatic conditions. Previous work in Ibadan has linked residential environmental conditions and indoor air pollution with respiratory health concerns [11, 12]. Despite these concerns, objective household air-quality measurements linked directly with respiratory health information remain useful for understanding the nature of residential exposures in rapidly urbanising Nigerian communities. Studies based solely on questionnaire-reported housing characteristics may not adequately characterise the concentrations of pollutants and microclimatic conditions actually present within homes. Simultaneous assessment of particulate matter, gaseous indicators, temperature, relative humidity and respiratory health can therefore provide additional evidence regarding potential environmental determinants of respiratory morbidity. This study assessed indoor $PM_{2.5}$, PM_{10}, CO and CO_2 concentrations and indoor temperature and relative humidity in residential buildings in Ibadan South-West Local Government Area, Nigeria. It further described morning and afternoon patterns in these environmental indicators and examined their associations with self-reported respiratory morbidity among adult residents.

2. Methods

2.1 Study area

The study was conducted in Ibadan South-West Local Government Area (LGA), Oyo State, Nigeria. Ibadan South-West is one of the local government areas within the Ibadan metropolis and includes residential districts with diverse socioeconomic and housing characteristics. The study covered residential locations including Oluyole Estate, Odo-Ona, Oke-Bola, Oke-Ado, Iyagankun GRA, Ring Road, Gege, Foko, Born Photo, Joyce B, Agbokojo, and Imalefalafia.

2.2 Study design and population

A descriptive cross-sectional design was used. The study population consisted of adult men and women aged 18 years and above residing in residential buildings within Ibadan South-West LGA. Individuals were eligible if they were adults residing within the study area and provided informed consent. Residents of buildings not primarily used for residential purposes and persons who could not provide informed consent were excluded. The original sample-size calculation used the single-proportion formula and a prevalence estimate of 10%. Following adjustment for 10% anticipated non-response, a minimum sample size of 152 was estimated. The results chapter, however, reports an analytical sample of 215 participants.

2.3 Sampling procedure

Ibadan South-West LGA comprises 12 wards. Simple random sampling was used to select residential buildings across the study locations. Buildings were numbered and selected using a ballot procedure. The head of household in each selected building was approached for participation; where the head of household was unavailable, an eligible adult resident of the household was selected.

2.4 Data collection

Data collection consisted of questionnaire administration, observation of residential conditions and indoor environmental monitoring. Data were collected by the principal investigator with assistance from a trained research assistant.

2.5 Assessment of respiratory health

A semi-structured interviewer-administered questionnaire adapted from the European Community Respiratory Health Survey was used. The questionnaire contained sections on sociodemographic characteristics, housing characteristics, occupant activities, and respiratory health outcomes. The respiratory-health section assessed major respiratory symptoms and conditions reported by participants.

For the present study, the primary outcome was the binary variable reported as “respiratory issues,” categorised as present or absent.

2.6 Indoor particulate matter monitoring

Indoor $PM_{2.5}$ and PM_{10} were measured using a handheld HTI HT-9600 Particle Counter based on laser-scattering detection. Measurements were taken at three locations within each selected residence to obtain an average indoor particulate-matter level. Monitoring was conducted during two daily periods: 09:00–11:00 hours in the morning and 13:00–15:00 hours in the afternoon. Measurements were obtained three days per week over a two-week monitoring period. $PM_{2.5}$ and PM_{10} concentrations were reported in $\mu g/m^3$. The instrument was standardised and equilibrated before use.

Carbon monoxide monitoring

Indoor CO was measured using a Klein Tools ET110 Carbon Monoxide Meter. Measurements were taken at three indoor locations and recorded after instrument readings had stabilised. Monitoring was conducted in both morning and afternoon periods, three days per week for two weeks. CO concentration was expressed in parts per million (ppm). The equipment was calibrated before sampling.

Carbon dioxide monitoring

Indoor CO_2 was measured using a Telaire Carbon Dioxide Meter. Measurements were obtained at three indoor locations and recorded after readings had stabilised. Monitoring followed the same morning and afternoon schedule used for the other environmental measurements, three days per week over two weeks. CO_2 concentrations were expressed in ppm, and the instrument was calibrated before sampling.

Temperature and relative humidity

Indoor temperature and relative humidity were measured concurrently with particulate-matter monitoring. Temperature was recorded in degrees Celsius and relative humidity as a percentage.

Exposure classification

For inferential analyses, environmental measurements were grouped in the study into categories such as below/above threshold, nondetectable/below/above, low/normal/high and optimum/above optimum, depending on the environmental variable.

Statistical analysis

Data were checked for completeness and analysed using STATA MP version 17. Continuous environmental variables were summarised using means and standard deviations, while categorical data were summarised using frequencies and percentages. Associations between categorical environmental exposure variables and respiratory morbidity were evaluated using tests of association. Logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for the relationship between indoor environmental indicators and respiratory morbidity. Statistical significance was determined at $p<0.05$.

3. Results

3.1 Participant characteristics and respiratory morbidity

The analytical results presented in the study comprised 215 adult participants. Of these, 134 (62.3%) were female, and 81 (37.7%) were male. Participants had a mean age of 34.9 ± 12.4 years. Overall, 134 participants (62.3%) were classified as having respiratory issues, while 81 (37.7%) were classified as not having respiratory issues.

3.2 Indoor air pollutants and microclimatic conditions

Table 1 summarises measured indoor air pollutants and environmental conditions during the morning and afternoon monitoring periods.

Table 1: Indoor air pollutants and microclimatic conditions during morning and afternoon monitoring

Environmental indicator	Morning, mean ± SD	Afternoon, mean ± SD
$PM_{2.5}$ (μg/m^3)	42.2 ± 11.5	55.1 ± 16.7
PM_{10} (μg/m^3)	137.9 ± 38.5	188.1 ± 48.4
Carbon monoxide (ppm)	0.22 ± 1.1	1.3 ± 4.3
Carbon dioxide (ppm)	520.2 ± 164.5	618 ± 341
Relative humidity (%)	64.4 ± 3.0	50.8 ± 9.2
Temperature (°C)	24.4 ± 1.3	28.0 ± 1.0

Mean $PM_{2.5}$ concentration was higher during afternoon monitoring than during morning monitoring, increasing from 42.2 to 55.1 μg/m^3. A similar pattern was observed for PM_{10}, which increased from a morning mean of 137.9 μg/m^3 to an afternoon mean of 188.1 μg/m^3. Mean CO concentration increased from 0.22 ppm to 1.3 ppm, while mean CO_2 increased from 520.2 ppm to 618 ppm.

Indoor temperature was also higher in the afternoon, increasing from a mean of 24.4°C in the morning to 28.0°C in the afternoon. In contrast, relative humidity decreased from 64.4% in the morning to 50.8% in the afternoon. These values demonstrate descriptive morning–afternoon variation in the measured indoor environment. No paired statistical comparison of morning and afternoon means was reported; consequently, these differences should not be interpreted as statistically significant temporal changes.

3.3 Indoor environmental conditions and respiratory morbidity

Morning PM_{10} concentrations were not significantly associated with respiratory morbidity ($\chi^2=0.324$; $p=0.569$).

Respiratory morbidity was reported by 63.8% of respondents in the below-threshold category and 60.0% of those in the above-threshold category. Morning CO was also not significantly associated with respiratory morbidity ($p=0.965$), nor was morning CO_2 ($p=0.328$). Morning relative humidity showed a higher prevalence of respiratory morbidity among individuals in the above-optimum category than among those in the optimum category. Still, the association did not reach statistical significance ($p=0.143$).

In the afternoon, the $PM_{2.5}$ category was not significantly associated with respiratory morbidity ($p=0.646$). Respiratory morbidity occurred among 63.0% of those in the below-threshold $PM_{2.5}$ category and 58.8% of those in the above-threshold category.

The afternoon PM_{10} category was significantly associated with respiratory morbidity ($\chi^2=6.234$; $p=0.013$), although the direction was contrary to the conventional exposure-response hypothesis. Respiratory morbidity was reported by 75.0% of respondents in the below-threshold category compared with 57.0% of respondents in the above-threshold category.

Afternoon CO was not significantly associated with respiratory morbidity ($p=0.109$), and the overall categorical association for afternoon CO_2 was also not statistically significant ($p=0.178$).

Relative humidity showed the clearest positive association with respiratory morbidity. Among participants classified as exposed to optimum afternoon relative humidity, 56.6% had respiratory morbidity, compared with 81.6% among those exposed to above-optimum afternoon relative humidity ($\chi^2=10.075$; $p=0.002$). Afternoon temperature category was not significantly associated with respiratory morbidity ($p=0.343$).

3.4 Logistic regression analysis

Table 2 presents logistic regression estimates for environmental conditions and respiratory morbidity.

Table 2: Logistic regression analysis of indoor environmental conditions and respiratory morbidity

Environmental exposure	Comparison	OR	95% CI	p-value
Morning PM_{10}	Above vs below	1.35	0.67–2.74	0.406
Morning CO	Below vs nondetectable	0.97	0.30–3.16	0.954
Morning CO	Above vs nondetectable	3.08	0.14–70.33	0.480
Morning CO_2	Normal vs low	3.33	0.44–25.31	0.244
Morning CO_2	High vs low	3.92	0.14–108.15	0.420
Morning relative humidity	Above optimum vs optimum	1.02	0.37–2.85	0.965
Afternoon $PM_{2.5}$	Above vs below	1.03	0.45–2.33	0.947
Afternoon PM_{10}	Above vs below	0.33	0.14–0.74	0.007
Afternoon CO	Below vs nondetectable	0.60	0.27–1.37	0.227
Afternoon CO	Above vs nondetectable	0.22	0.04–1.22	0.083
Afternoon CO_2	Normal vs low	0.31	0.11–0.92	0.034
Afternoon CO_2	High vs low	0.72	0.17–2.95	0.644
Afternoon relative humidity	Above optimum vs optimum	3.91	1.65–9.27	0.002
Afternoon temperature	Above optimum vs optimum	0.54	0.27–1.05	0.070

Above-optimum afternoon relative humidity was associated with approximately fourfold greater odds of respiratory morbidity compared with optimum relative humidity (OR=3.91; 95% CI: 1.65–9.27; $p=0.002$).

Higher afternoon PM_{10} category was inversely associated with respiratory morbidity (OR=0.33; 95% CI: 0.14–0.74; $p=0.007$). Similarly, respondents exposed to the normal afternoon CO_2 category had lower odds of respiratory morbidity than those classified in the low CO_2 category (OR=0.31; 95% CI: 0.11–0.92; $p=0.034$). These inverse relationships were unexpected and were therefore interpreted cautiously.

No statistically significant association was observed between afternoon $PM_{2.5}$ and respiratory morbidity (OR=1.03; 95% CI: 0.45–2.33; p=0.947). Neither morning nor afternoon CO categories were significantly associated with respiratory morbidity. The wide confidence intervals observed for some CO and CO_2 estimates, particularly morning high-exposure categories, indicate substantial statistical imprecision.

4. Discussion

This study characterised indoor particulate pollution, gaseous indicators and microclimatic conditions in residences in Ibadan South-West LGA and examined their relationships with respiratory morbidity among adult occupants. Three findings are particularly relevant. First, mean concentrations of $PM_{2.5}$, PM_{10}, CO, and CO_2, and mean indoor temperature were descriptively higher during afternoon than morning monitoring, whereas relative humidity was lower in the afternoon. Second, above-optimum afternoon relative humidity was consistently associated with respiratory morbidity in both the categorical analysis and logistic regression. Third, statistically significant inverse associations were observed for afternoon PM_{10} and normal-range afternoon CO_2, findings that require cautious interpretation rather than being considered evidence of protective effects.

The observed PM concentrations indicate a substantial particulate burden within the monitored residential environments. Mean $PM_{2.5}$ increased from 42.2 μg/m^3 during morning monitoring to 55.1 μg/m^3 in the afternoon, while PM_{10} increased from 137.9 to 188.1 μg/m^3. Household particulate pollution may arise from several indoor and outdoor sources, including cooking, resuspension of settled dust, combustion processes, and penetration of outdoor pollution into buildings [13]. Household air pollution is an established environmental-health concern in low- and middle-income countries, particularly where ventilation is limited or polluting fuels and combustion activities are common [4, 5, 14]. Studies from Nigeria have similarly identified indoor air-pollution concerns within residential environments [10, 11].

The higher afternoon mean PM concentrations observed in this study may reflect temporal variation in household activities, ventilation patterns, resuspended dust, or infiltration of outdoor pollutants. The study design, however, did not quantify activity-specific pollutant sources at the time of each measurement, and no formal paired test of morning and afternoon measurements was reported. The results should therefore be viewed as descriptive evidence of temporal variability rather than definitive evidence of a statistically significant diurnal increase.

Although international air-quality guidelines provide important health-based reference values for $PM_{2.5}$ and PM_{10} [2, 9], direct comparison should be undertaken carefully. The WHO guideline values are based on specified averaging periods, while measurements in this study were collected during discrete monitoring periods within residences. Consequently, the observed short-period or spot measurements should not automatically be interpreted as equivalent to 24-hour personal or household exposure averages. Future monitoring incorporating continuous 24-hour or multi-day measurements would provide a stronger basis for comparison with health-based guideline concentrations.

A central finding was the association between above-optimum afternoon relative humidity and respiratory morbidity. Respondents exposed to above-optimum afternoon relative humidity had almost four times the odds of respiratory morbidity compared with those in the optimum category. This result was consistent with the categorical analysis, in which 81.6% of those in the above-optimum humidity category had respiratory morbidity compared with 56.6% in the optimum category. Excess indoor moisture can create conditions that favour mould, microbial growth and other biological agents capable of irritating or sensitising the respiratory tract. Meteorological and humidity conditions have previously been recognised as relevant to asthma, allergic disease and susceptibility to respiratory infection [6, 8].

The humidity finding should nevertheless be interpreted in the context of the study's overall microclimatic pattern. Mean relative humidity was actually lower during afternoon monitoring than during the morning. The regression result refers to differences between households or participants falling into categorical humidity classifications during the afternoon rather than a simple relationship between the overall morning and afternoon means. It therefore suggests that occupants of residences remaining in the above-optimum humidity category during afternoon measurement had a greater burden of respiratory morbidity. More detailed longitudinal measurement would help determine whether persistent household dampness or humidity, rather than a single monitoring-period classification, better predicts respiratory symptoms.

The inverse association between higher afternoon PM_{10} category and respiratory morbidity was unexpected. Respondents classified in the higher PM_{10} category had lower odds of respiratory morbidity than those in the lower category. This finding is inconsistent with the established understanding that particulate pollution is generally detrimental to respiratory health and should not be interpreted as evidence that PM_{10} exposure is protective. A number of features of the study may have contributed to this pattern. The cross-sectional design does not establish whether the measured exposure preceded the reported respiratory outcome. Short environmental monitoring periods may not represent participants' long-term exposure, particularly where household activity and outdoor pollutant infiltration vary from day to day or season to season. Categorisation of a continuous pollutant measurement may also obscure exposure-response relationships or create unstable comparisons when observations cluster around a cut-point.

Behavioural adaptation or reverse causation may also be relevant. Individuals with existing respiratory symptoms may alter their activities, improve ventilation, avoid smoky environments or spend less time in particular areas of the home, potentially producing lower measured exposures at the time of monitoring despite a history of greater exposure. Such explanations remain speculative because they were not directly tested in the study. The PM_{10} finding therefore warrants replication using continuous exposure variables, longitudinal follow-up, and models incorporating household characteristics and participant-level confounders.

An inverse association was also observed for normal versus low afternoon CO_2. CO_2 in residential indoor-air studies is often interpreted primarily as an indicator related to occupancy and ventilation rather than as a direct cause of respiratory morbidity at typical household concentrations. The categorical pattern observed here may therefore reflect differences in occupancy, ventilation, household activity, or the small number of observations in some exposure categories rather than a direct physiological effect.

The absence of a significant effect for the high CO_2 category further argues against a straightforward dose-response interpretation.

CO concentrations were not significantly associated with respiratory morbidity in either monitoring period. Some estimates had very wide confidence intervals, particularly for higher morning CO exposure, indicating limited precision and sparse observations in particular categories. Lack of statistical significance should not be interpreted as evidence that CO exposure is harmless; rather, the present dataset did not demonstrate a clear association between the measured CO categories and the respiratory outcome.

Similarly, afternoon $PM_{2.5}$ was not significantly associated with respiratory morbidity despite the measured particulate burden. Respiratory morbidity reflects cumulative and potentially long-term exposure, while environmental monitoring captured selected periods over a relatively short interval. A participant's historical exposure, occupational exposure, outdoor-air exposure, and previous housing conditions may therefore contribute to respiratory symptoms without being represented by the short-term indoor measurement. Individual susceptibility and unmeasured confounding may further weaken cross-sectional associations.

The study contributes useful evidence by combining respiratory-health assessment with objective measurements of multiple environmental parameters within residences—simultaneous measurement of $PM_{2.5}$, PM_{10}, CO, CO_2, temperature and relative humidity provides a broader characterisation of indoor environmental quality than reliance on self-reported housing conditions alone. The morning and afternoon measurements also provide information on within-day environmental variation in an urban Nigerian setting where residential monitoring data remain comparatively limited.

Several limitations are important. First, the cross-sectional design prevents establishment of temporality or causality. Second, respiratory outcomes were self-reported and may be affected by recall or reporting bias. Third, the environmental monitoring period was relatively short, and measurements were limited to selected morning and afternoon periods; therefore, they may not represent long-term, overnight, or seasonal exposure. Fourth, the environmental variables were categorised for regression analysis, potentially reducing information contained in the original continuous measurements. Fifth, the study does not provide sufficient information in its current form to determine how repeated measurements were aggregated before participant-level analysis. Finally, potential confounding by housing characteristics, smoking, occupational exposures, cooking practices, and socioeconomic characteristics requires clearer consideration in a final multivariable analysis.

Future studies should incorporate continuous or 24-hour indoor monitoring over longer periods and across different seasons. Analyses should preserve pollutant concentrations as continuous variables where appropriate and account for repeated measurements within households. Multilevel or mixed-effects approaches may be particularly useful where several measurements are nested within homes. Prospective assessment of respiratory symptoms or objective measures such as spirometry would also strengthen evidence regarding the respiratory consequences of household environmental exposures.

Conclusion

Residential indoor environmental conditions in Ibadan South-West LGA showed marked descriptive variation between morning and afternoon monitoring periods. Mean $PM_{2.5}$, PM_{10}, CO, CO_2, and temperature were higher during afternoon monitoring, while mean relative humidity was lower. Above-optimum afternoon relative humidity was associated with substantially greater odds of respiratory morbidity and represents the most consistent positive environmental-health association identified in the study.

Unexpected inverse associations were observed between respiratory morbidity and afternoon PM_{10} and between respiratory morbidity and normal versus low afternoon CO_2. These findings should not be interpreted as protective effects and require confirmation using longer-term exposure assessment, continuous pollutant measures and analytical approaches capable of addressing repeated measurements and potential confounding. The findings support continued attention to indoor environmental quality, moisture control and improved residential exposure assessment in urban Nigerian populations.

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