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ABSTRACT: This community-based cross-sectional study was conducted to investigate the indoor concentration of carbon monoxide (CO) and associated factors in residential buildings of Gondar town, northwest Ethiopia. Data were collected from 384 occupied buildings and occupants using CO meter, interviewers administered questionnaire, and observation checklists. Multivariable binary logistic regression analysis was used for controlling the possible effect of confounders and to identify factors associated with indoor concentration of CO on the basis of adjusted odds ratio (AOR) with 95% confidence interval (CI) and $P < .05$. The current study revealed that 224(58.3%) occupied buildings had the concentration of CO above the permissible value for 15 minute exposure for living rooms (100 mg/m^3). Indoor concentration of CO was significantly associated with access to health information [AOR = 0.081, 95%CI = (0.008, 0.803)], number of rooms [AOR = 0.016, 95% CI = (0.001, 0.279)], area of occupied room [AOR = 0.019, 95% CI = (0.001, 0.237)], buildings located away from main roads/garages [AOR = 0.045, 95% CI = (0.005, 0.415)], clean energy sources [AOR = 0.010, 95% CI = (0.001, 0.123)], presence of separate kitchen [AOR = 0.030, 95% CI = (0.004, 0.221)], no incensing in the room [AOR = 0.055, 95% CI = (0.006,0.499)] and measurements in the afternoon [AOR = 0.114, 95% CI = (0.013, 0.965)]. Residents, therefore, need to use clean energy sources, construct a kitchen with a properly constructed chimneys away from the main building, and avoid incensing inside the indoor environment.

KEYWORDS: Carbon monoxide, indoor concentration, occupied rooms, permissible value for 15 minute exposure

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Introduction

Indoor air pollution is a major environmental problem affecting both the developing and developed countries. The air we breathe contains emissions from many different sources: industry, motor vehicles, heating and commercial sources, garages, household fuels as well as tobacco smoke and may have pollutants, such as CO, CO2, NO2, SO2, PM2.5 (particulate matter with a mean aerodynamic diameter below 2.5 µ) and VOCs (volatile organic compounds), which can cause adverse health problems.[1-4]

CO is one of the most widely distributed indoor air pollutants and it is a poisonous, colorless, odorless, and tasteless gas that is produced as a by-product of incomplete combustion of carbon-based fuels such as natural or liquefied propane gas, kerosene, oil, gasoline, wood, or coal. CO exposure is still one of the leading causes of poisoning, and it causes a large number of deaths annually.[5,6] Inhalation of air with a volumetric concentration of 0.3% CO can result in death within 30 minutes. CO is responsible for hundreds of deaths and thousands of nonfatal poisonings each year[7,8] and it increases the relative risk of daily mortality and morbidity of the population by 0.9% to 4.7%.[9]

The health effects of CO are associated with its concentration and exposure time. Prolonged exposure beyond the permissible concentration has deleterious health effects. Therefore, establishing air quality guidelines and educating the public to regulate indoor air quality and to avoid exposure to concentrations higher than the guideline concentration is important. Based on the 2010 European air quality guidelines, the permissible concentration of CO is 100 mg/m^3 for 15 minutes, 35 mg/m^3 for 1 hour, 10 mg/m^3 for 8 hours, and 7 mg/m^3 for 24 hours.[10] However, there are no local guidelines for CO and its concentration in the indoor air is not known in the study area. This study was, therefore, conducted to investigate the indoor concentration of CO and associated factors in residential buildings of Gondar town, northwest Ethiopia.

Methods

Study design and data collection procedures

A community-based cross-sectional survey with structured observations was used to assess the indoor concentration of CO and associated factors among residential buildings in Gondar town from February to April, 2015. All residential buildings in Gondar town were taken as source population and the selected residential buildings occupied by one or more occupants were taken as study population. Air samples were taken from a total of 384 occupied residential buildings. Systematic random sampling technique was used to select the occupied residential buildings.

Once the residential buildings were selected, the concentration of CO was measured using CO meter (specification: manufacturer: Xintest, operating temperature: 0°C-50°C, operating humidity: 0%-99%, measurement range: 0-1000 Parts per Million (PPM) and accuracy: ±5%). Measurements were taken by putting the CO meter at the center of the room at a height of 1.5 m from the floor for about 15 minutes and the readings were taken after a 15 minutes exposure time. To minimize the dilution of contaminants, windows and doors were closed during the measurement. Possible sources of CO such as cook stoves being used at the time of the survey were put off. Measurements were also taken away from any sources that could directly influence the readings. Measurements were taken 2 times from 1 building and the average concentration was compared with the World Health Organization (2010) air quality guidelines for Europe for living areas for 15 minute exposure (ie, 100 mg/m^3, which is equivalent to 87.3 PPM.[10] Conversion formula: concentration (mg/m3) = 0.0409 × concentration (ppm) × molecular weight, where the molecular weight of CO = 28.01 g/mol).[11]

Study variables

Indoor concentration of CO was the outcome variable for this study. The concentration was taken as high if it is above the permissible value for 15 minute exposure for living rooms (ie, 100 mg/m^3). Socio-demographic factors (such as family size, educational status, information on sources of CO, and regulation methods of indoor air); housing conditions (such as number of rooms, area of rooms, method of ventilation, number of functional windows and availability of separate kitchen, location of residential buildings from main roads or garages and other possible outdoor sources like garages or industrial stacks); energy source of the family (such as wood, charcoal, kerosene, electricity); and personal habits(such as habits of opening the window incensing or smoking in the room; and time of measurement) were the exposure variables included in this study.

The recommended number and area of rooms was defined based on the following recommendations. Minimum number of rooms recommended: 1 room for 2 persons, 2 rooms for 3 persons, 3 rooms for 5 persons, 4 rooms for 7, and a half person. Children under 10 years of age and over 1 year counts as half a person. Minimum area of habitable rooms are recommended: 50 m^2 for a family of 3, 55-60 m^2 for a family of 4, 70 m^2 for a family of 5.[12]

Data quality management

To ensure the quality of data, a structured questionnaire and obserbational checklists were developed from related published studies with little modification. Besides, a calibrated and validated CO meter was used. Data were collected by MSc students in Environmental Health Science. Two days intensive training was provided for the data collectors and field supervisors on data collection tools and interview techniques. We pretested the tools and necessary corrections were done after the pretest. The data collection process was closely supervised by field supervisors. Field supervisors checked the completeness of the data on a daily basis. The completed checklist/questionnaires were handled by the supervisors. After checking for consistency and completeness, the supervisors had submitted the filled checklists/questionnaire to the principal investigator.

Data management, processing and analysis

Data were entered and analyzed by SPSS version 20.0. For most variables, data were presented by frequency and percentage. Univariable binary logistic regression analysis was used primarily to choose variables for the multivariable binary logistic regression analysis on the basis of crude odds ratio (COR) and $P < .05$. Variables which had P-value less than .05 were then analyzed by multivariable binary logistic regression for controlling the possible effect of confounders and finally the variables which had significant association were identified on the basis of AOR with 95% CI and $P < .05$. Hosmer and Lemeshow goodness of test was used to check model fitness.

Results

Indoor concentration of CO

Data were collected from 384 occupied buildings and a total of 1918 occupants lived in 384 buildings. Measurements of CO were taken in the morning and in the afternoon from 202 (52.6%) and 182(47.4%) residential buildings, respectively. Of the 384 occupied buildings, 160 (41.7%) of the occupied buildings had the concentration of CO within the limit (ie, 100 mg/m^3). The rest 224 (58.3%) had the concentration above the limit. The minimum and maximum concentrations were 1.7 mg/m^3 and 126 mg/m^3, respectively.

Housing condition

Housing conditions like number of rooms, area of occupied room/s, ventilation of occupied room/s, methods of ventilation and separate bed room/s from the occupied room, distance from the main road or garages, distance from outdoor sources(such as gas stations and industrial stacks), separate kitchen and energy source of the family were assessed. Compared with the number of occupants and number and area of rooms, 231 (60.2%) and 226 (58.9%) residential buildings had room number and area below the recommended number and area of rooms respectively. In this study, none of the observed residential buildings were mechanically ventilated and none had a heating systems. Two hundred fourteen (55.7%) buildings had a kitchen constructed attached to the main building. Biomass fuel was the major energy source for 208 (54.2%) households (Table 1).

Table 1. Conditions of residential buildings in Gondar town, northwest Ethiopia, 2015.

HOUSING CONDITIONS	FREQUENCY	%
Number of rooms		
Below the recommended number	231	60.2
Recommended number	153	39.8
Area of habitable room		
Below the recommended area	226	58.9
Recommended area	158	41.1
Number of functional windows		
Only 1	214	55.7
Two or more	170	44.3
Habits of opening window/s		
Some times	219	57.0
Frequently	165	43.0
Separate kitchen		
No	214	55.7
Yes	170	44.3
Energy source/s		
Biomass	208	54.2
Electricity	176	45.8
Incensing or smoking in the room		
No	128	33.3
Yes	256	66.7
One or more car/s		
No	372	96.9
Yes	12	3.1
Distance from the main roads or garages		
1-200 m	180	46.9
Beyond 200 m	204	53.1
Outdoor sources within 200 m radius		
No	364	94.8
Yes	20	5.2

Information about sources of CO and and methods to regulate indoor air quality

To analyze the effect of information on the concentration of CO, we have assessed whether the occupants had information on the sources of CO and methods to regulate indoor air quality. This study showed that 170 (44.3%) of the respondents had information about sources and methods to regulate indoor air quality and the rest 214 (55.7%) had not any information. Respondents who had information about sources and methods to regulate indoor air quality had been asked to mention the common sources of CO. Vehicle smoke, cooking inside the living room, and utilization of kerosene for cooking were mentioned as sources. Moreover, respondents who had information about CO reported that cooks outside the living room, having a separately constructed kitchens with chimneys, ventilating the building, and utilization of clean energy sources could regulate indoor air quality.

Factors associated with indoor concentration of Carbon Monoxide

This study revealed that information about sources of CO and methods to regulate indoor air quality [AOR = 0.081, 95% CI = (0.008, 0.803)], number of rooms [AOR = 0.016, 95% CI = (0.001, 0.279)], area of occupied room [AOR = 0.019, 95% CI = (0.001, 0.237)], location of buildings away from main roads [AOR = 0.045, 95% CI = (0.005, 0.415)], utilization of clean energy sources [AOR = 0.010, 95% CI = (0.001, 0.123)], presence of separate kitchen [AOR = 0.030, 95% CI = (0.004, 0.221)], no incensing or smoking in the room [AOR = 0.055, 95% CI = (0.006, 0.499)], and measurement of CO in the afternoon [AOR = 0.114, 95% CI = (0.013, 0.965)] were significantly associated with indoor concentration of CO (Table 2).

Discussion

This study found that 160 (41.7%) of habitable buildings had concentrations of CO within the permissible value for 15 minute exposure for living rooms and 224 (58.3%) the occupied buildings had concentrations above the permissible value. It may be due to the fact that the indoor air quality regulation system in Ethiopia is very poor and most buildings are substandard and have no heating, ventilation, and air conditioning(HVAC) system. There is also significant increment in vehicle population in major cities like Gondar town and almost all occupants used biomass fuel as energy source.

This study depicted that having information about the sources of CO and methods of regulating indoor air quality had a significant effect on the indoor concentration of CO. Other similar studies conducted in US and England have identified information about sources of CO and methods of regulating indoor air quality as a significant factor for indoor concentration of CO.[5,6,13] This is due to the fact that health information promotes good behavior of the occupants and the use of different indoor air quality improvement strategies.[14]

Number of rooms and the area of habitable rooms were statistically significant with the indoor concentration of CO. The result of this study was consistent with the findings of other studies.[15,16] This is due to the fact that the volume of a room

Table 2. Factors associated with indoor concentration of CO in residential buildings of Gondar town, northwest Ethiopia, 2015.

VARIABLES	AVERAGE CONCENTRATION		COR WITH 95% CI	AOR WITH 95% CI
	<100 mg/m³	>100 mg/m³		
Information about sources of CO and methods to requalate indoor air quality				
No	33	181	1.00	1.00
Yes	127	43	0.062 (0.037, 0.103)	0.081 (0.008, 0.803)*
Number of rooms				
Below the recommended	55	176	1.00	1.00
Recommended	105	48	0.143 (0.091, 0.225)	0.016 (0.001, 0.279)**
Area of habitable room				
Below the recommended	20	206	1.00	1.00
Recommended	140	18	0.012 (0.006, 0.024)	0.019 (0.001, 0.237)**
Number of functional windows				
Only 1	49	165	1.00	1.00
Two and above	111	59	0.158 (0.101, 0.247)	4.373 (0.476, 40.180)
Distance from the main road or garages or industrial stacks				
1-200 m	23	157	1.00	1.00
Beyond 200 m	137	67	0.072 (0.042, 0.121)	0.045 (0.005, 0.415)*
Energy source/s				
Biomass and fuel	5	203	1.00	1.00
Electricity	155	21	0.003 (0.001, 0.009)	0.010 (0.001, 0.123)***
Separate kitchen				
No	27	187	1.00	1.00
Yes	133	37	0.040 (0.023, 0.069)	0.030 (0.004, 0.221)**
Habits of opening window/s				
Some times	123	96	1.00	1.00
Frequently	37	128	4.432 (2.818, 6.971)	0.203 (0.015, 2.736)
Incensing or smoking in the room				
Yes	57	199	1.00	1.00
No	103	25	0.070 (0.041, 0.118)	0.055 (0.006, 0.499)**
Time of measurement				
Morning	28	174	1.00	1.00
Afternoon	132	50	0.061 (0.036, 0.102)	0.114 (0.013, 0.965)*

Hosmer and Lemeshow test = 0.357.
**P*-value < .05. ***P*-value < .01. ****P*-value < 0.001.

has an important impact on the concentration of a contaminant in the air. In wider rooms, pollutants are dispersed because of turbulent diffusion and bulk airflow.[17]

This study reported that distance from main roads or garages or industrial stacks was statistically associated with the indoor concentration of CO. This finding is in line with the findings of other studies.[18-21] This is due to the fact that the concentration of a pollutant decreases as it travels from the site of release because the pollutant spreads out or diluted.[22]

The type of household energy sources was identified as associated factors with the concentration of CO in this study, which is consistent with the findings of other studies.[16,18,23]

The effect of household energy sources and the concentration of CO can be justified that clean energy sources prevent the emission of CO[2,24] and other sources like biomass fuel are the commonest sources of indoor air pollutants.

This study revealed that a kitchen constructed separated from the main building had a significant effect on the indoor concentration of CO. This result is in line with the findings of other studies.[16,25] This is due to the fact that if there is adequate distance between the kitchen and the main building, smokes generated from the incomplete combustion of biomass, coal, and fuel products could dilute or dispersed.[22]

This study found that incensing or smoking in the room significantly associated with the concentration of CO. Other studies also reported the same result.[18,23,26] This is due to the fact that incensing or smoking is incomplete combustion and incomplete combustion is the common source of CO.[27-29]

This study investigated that the concentration of CO was lower in the afternoon than the morning. This finding is consistent with the findings of another study.[30] This might be due to metrological factors such as radiation inversion. During the evening and morning, when the earth's surface becomes cool, a radiation inversion is formed and this phenomenon increases the surface concentration of CO, and when the earth surface becomes warm, this inversion will be broken and the trapped air will be diluted.[31]

As a limitation, this study had not investigated the effect of weather conditions on the indoor concentration of Carbon Monoxide and the concentration of CO was measured for 15 minutes exposure time, which is a short time exposure. We also compared the average concentration with European guideline because of the absence of local guidelines. We recommend other researchers to assess the effect of weather conditions on the concentration of CO and to measure CO for 8 hours or 24 hours exposure time or beyond that.

Conclusion

Higher number of occupied rooms had an indoor concentration of CO above the permissible value for 15 minutes exposure. Access to health information, number of rooms, area of occupied room, distance from main road or garages, energy sources, presence of a separate kitchen, incensing or smoking in the room, and time of measurement were factors associated with indoor concentration of CO. The residents, therefore, need to use clean energy sources, construct a kitchen with a properly constructed chimneys away from the main building, and avoid incensing or smoking inside the living rooms to reduce emissions of indoor air pollutants or to regulate the quality of the indoor air. The local health department also needs to dessiminate health information about the sources of CO and methods to improve the indoor air quality.

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Author Contributions

Both authors actively participated during conception of the research issue, development of the research proposal, data collection, analysis and interpretation, and writing various parts of the research report. This final manuscript is prepared by ZG. Both authors read and approved the final manuscript.

Availability of Data and Materials

Data will be made available upon requesting the primary author.

Ethical Approval and Consent to Participate

Ethical approval was obtained from the institutional review board of University of Gondar and official letter was submitted to the town administrators. The data collection tools were proved not to affect the morale and personality of the study subjects. The materials used for this research purpose had no any health hazards. There is no risk in participating in this research project and the collected data were used only for this research purpose. Data were collected after getting informed verbal consent from the owner of the occupied buildings. Confidentiality and privacy were granted.

Consent for Publication

This manuscript does not contain any individual person's data.

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