An appraisal of air quality, thermal comfort, acoustic and health risk of household kitchens in a developing country

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Abstract

Few studies have documented the air quality, noise, thermal comfort, and health risk assessment of household kitchens related to Sub-Sahara Africa. In this paper, air quality (CO and $PM_{2.5}$), thermal comfort (relative humidity (RH) and temperature), noise, and health risk in urban household kitchens with kerosene-fuelled stoves were presented. This study was carried out during the dry season (summer) in the Southwestern part of Nigeria. At the breathing zone, $PM_{2.5}$ and CO concentrations in the assessed kitchens were measured. In addition, the noise level, RH, and air temperature in the assessed kitchens were also determined. Furthermore, an evaluation of the heat index and health risk of the exposed population to the kerosene-fuelled stove kitchens was carried out. During cooking, average CO and $PM_{2.5}$ concentrations were 24.77 ± 1.05 ppm and 138.10 ± 2.61 μg/m^3, respectively, while the RH was 68.34 ± 0.73%, noise level was 51.14 ± 1.08 dB, and temperature was 29.86 ± 0.23 °C. The CO and noise levels were relatively slightly lower and $PM_{2.5}$ was significantly higher than the thresholds recommended by World Health Organisation. In most of the kitchens, the heat index evaluation revealed the possibility of heat exhaustion, heat cramps, and sunstroke with prolonged exposure of the vulnerable group. The air quality index depicted unhealthy (CO exposure) and very unhealthy ($PM_{2.5}$ exposure) while the hazard quotient (> 1) implied possible health risk concerning exposure by inhalation. Better design of kitchen with adequate ventilation and improved stoves are suggested.

Keywords Household kitchens; Air pollutants; Kerosene stoves; Thermal comfort; Developing country; Health risk

Introduction

The trio of thermal, air, and noise pollution are linked to cooking activities in kitchens (household and commercial), of which air pollution via the release of particulates and gaseous pollutants is pronounced and injurious. The concentrations and types of pollutants emanating from kitchens due to cooking activities are primarily and strongly related to the food materials (types and constituents), ingredients, cooking methods, and fuel (type and quality) (Alves et al., 2021; Giwa et al., 2019). Secondarily, the stove type and condition also influence the pollutant types and concentrations (Alves et al., 2021). Notable pollutants from the cooking of food materials are polyaromatic hydrocarbons (PAHs), alkanes, esters, ketones, alcohols, heterocyclic compounds, etc., whereas PAH, CO, volatile organic compounds, NO_x, SO_x, PM, CO_2, O_3, etc., are mainly emitted from fuels (Abdullahi et al., 2013; Giwa et al., 2019). Long and short term human exposure to the pollutants released into the kitchens has been established to cause cough, phlegm, tuberculosis, cataracts, heart and lung disease, asthma, lung cancer, cardiopulmonary disease, respiratory tract infections, and diseases, etc., leading to mortality and morbidity (Giwa et al., 2019; Lam et al., 2012; Li et al., 2016).

Literature in the open domain showed that numerous studies have been conducted on the pollution of household kitchens in most developed countries (Alves et al., 2021; de Kluizenaar et al., 2017; Johnson et al., 2011; Poon et al., 2016; Singer et al., 2017) and some developing countries (Abdullahi et al., 2013; Dasgupta et al., 2015; Kong et al., 2021; Pokhrel et al., 2015; Sharma & Jain, 2019; Sidhu et al., 2017) with limited studies in Sub-Sahara Africa (SSA) in this regard (Agbo et al., 2021). Muindi et al. (2016) studied kitchen air pollution in two slums (Viwandani and Korogocho) located in Nairobi, Kenya by measuring the $PM_{2.5}$ concentrations of 72 kitchens. They showed that the utilization of LPG and electric stoves yielded the lowest $PM_{2.5}$ concentrations while the highest $PM_{2.5}$ concentrations were connected to the use of wood and charcoal stoves. Woolley et al. (2020) studied the CO concentration in the student and staff kitchens and canteens of a University in Uganda using charcoal stoves. They reported maximum and 1-h average CO concentrations of 208.5 ppm and 76.3 ppm (staff kitchen) and 255.5 ppm and 76.3 ppm (student kitchen), respectively. The 8-h average CO concentration of the student kitchen (41 ppm) was observed to exceed the WHO recommendation.

Agbo et al. (2021) measured the SO_2, NO_2, and O_3 concentrations in the indoor environment of household kitchens, living rooms, and bedrooms in 20 locations (10 rural and 10 urban) at Nsukka, Nigeria. The use of firewood, LPG, and charcoal as cooking fuels was considered the main source of IAP. The utilization of firewood, charcoal, and LPG resulted in NO_2 concentrations of 101 – 722 $\mu g/m^3$, 134 – 356 $\mu g/m^3$, and 19 – 174 $\mu g/m^3$, respectively. Coffey et al. (2021) measured the kitchen air quality of 62 household kitchens (37 urban and 25 rural) for two seasons in Northern Ghana using a low-cost $PM_{2.5}$ sensor. The kitchens used biomass and propane gas for cooking. They reported that 84% and 43%, 100% and 62%, 100%, and 67%, and 100% and 92% of the studied rural and urban kitchens have $PM_{2.5}$ concentrations exceeding the 24-h average WHO interim target 1 (75 $\mu g/m^3$), 2 (50 $\mu g/m^3$), 3 (37.5 $\mu g/m^3$), and air quality guideline (25 $\mu g/m^3$), respectively.

Nakora et al. (2020) investigated the $PM_{2.5}$, heavy metals, and CO concentrations in 60 kitchens located in the Mbarara Municipality of Uganda, using charcoal stoves. The average 24-h $PM_{2.5}$ concentrations were 526 $\mu g/m^3$ (dry season) and 449 $\mu g/m^3$ (wet season) while the

CO concentration was 41.5 ppm. Both pollutants were found to exceed the WHO 24-h threshold for $PM_{2.5}$ and CO whereas the heavy metals in the $PM_{2.5}$ were within the recommended limits. Vliet et al. (2013) examined the personal and kitchen exposure of black carbon (BC) and $PM_{2.5}$ in 36 biomass-fuelled kitchens in the Brong Ahafo Region, Ghana. They found that the average 24-h $PM_{2.5}$ (446.8 $\mu g/m^3$) and BC (128.5 $\mu g/m^3$) concentrations of the kitchens were considerably above that of personal exposure ($PM_{2.5}$ = 14.5 $\mu g/m^3$ and BC = 8.8 $\mu g/m^3$). Rim-Rukeh (2015) investigated the air quality in the kitchen areas and living rooms of 60 households in Warri, Delta State, Nigeria by measuring six pollutants (NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3, and CO) released via the utilization of sawdust, charcoal, and firewood for cooking purpose. The PM, NO_2, and CO were observed to be above the recommended limits and thus, the air quality is unhealthy for human exposure. In addition, the kitchens were noticed to release more $PM_{2.5}$, PM_{10}, and CO than the living room for all the studied households with no distinct pattern for the NO_2, SO_2, and O_3 released into the kitchens and living rooms.

Pilishvili et al. (2016) studied the improvement in the household air quality using six different improved cookstoves over the traditional 3-stone stove in 45 households in Nyanza province of Kenya. They showed that average $PM_{2.5}$ and CO in the examined kitchens were reduced by 11.9% – 42.3% and -5.8% – 34.5% for the improved cookstoves compared with those of the traditional stove. Using biogas, biogas-firewood, and firewood as fuels in 14 institutional kitchens located in Kampala, Uganda, McCord et al. (2017) examined the air quality in the kitchens by measuring $PM_{2.5}$, SO_2, H_2S, and CO. They reported the highest concentrations of $PM_{2.5}$, SO_2, and CO for firewood kitchens, followed by biogas-firewood and biogas kitchens. The $PM_{2.5}$ and CO for firewood and biogas-firewood kitchens and SO_2 for all the studied kitchens exceeded the WHO air quality guidelines. Recently, Berumen-Rodríguez et al. (2021) and de León-Martínez et al. (2021) investigated the environmental concentrations and biomarkers exposure of brick-kiln workers (to $PM_{2.5}$, PM_{10}, lead, OH-HAPs, etc.) and four different precarious workers to (PAHs). They observed the adverse health condition of these vulnerable on exposure to the working environment and the need monitor to monitor and evaluate their health status by health authorities.

The above-surveyed literature shows the scarcity of documentation concerning the indoor air quality quantification and characterization of household kitchens in the urban areas of SSA using kerosene, LPG, and electric stoves. Lam et al. (2012) and Muindi et al. (2016) have stressed the need for studies on the kitchen air pollution of households in developing countries, especially SSA. Household kitchen air quality data for kerosene-fuelled stoves is lacking in SSA and calls for intensive studies as further reiterated by (Lam et al., 2012). In addition, household kitchen air pollution is a highly ranked leading risk for girls, children under five years, and women in SSA (Lam et al., 2012). Nigeria has been reported by WHO to record the highest number of deaths in SSA (396,000) as a result of household air pollution from kitchens, which prompted this present study (Omole et al., 2016). Kerosene-fuelled stoves are predominantly used in urban and rural areas of southwest Nigeria and urban populations of developing countries (Lam et al., 2012; Omole et al., 2016). Owing to the dearth of documentation on the noise, air quality, and thermal comfort of urban household kitchens with kerosene-fuelled stoves, this present study has been conducted.

Methodology

Study area

Due to economic status and urban lifestyle, urban household kitchens using kerosene stoves (in southwestern Nigeria) were chosen as the study target. The work was conducted in Sango, Ado-Odo/Ota Local Government Area (LGA) of Ogun State, Nigeria. These choices agreed with the literature regarding the utilization of kerosene as cooking fuel amongst the urban population of developing countries (NBS 2012; Lam et al., 2012). The study area is located on latitude 6° 58' N and longitude 3° 41' E and it covers an area of 878 square kilometers. It is currently the industrial hub of the country. It has a population of 601,640 people according to national statistics (NBS, 2011). The map of the study area is presented in Figure 1.

Kitchens selection

Of the 50 surveyed kitchens (using kerosene stoves) in the study area, 38 kitchens were used for this study. The kitchens assessed were with different designs, sizes, and shapes of kerosene stoves (wick type). The choice of kerosene as cooking fuel conformed with the literature (national statistics and scientific study) showing that kerosene was used more than solid fuels by urban residents in Nigeria (Abiem et al., 2016; NBS, 2012). National statistics revealed that 317.46 million liters of kerosene were imported in 2018 (DPR, 2018). The urban kitchen characteristics include: (1) the attachment of kitchens to the main building, (2) the kitchen walls were made of perforated concrete blocks (either plastered without painting or plastered and painted, (3) the ventilation of the kitchens were with doors and windows only, (4) the infiltrations and ventilation of the kitchens were not altered, (5) various kitchen designs, configurations, and sizes were assessed randomly, (6) the materials in the assessed kitchens were left unaltered during the study.

Materials and instruments

This study engaged $PM_{2.5}$ monitoring device (TES-5321/5322; 0 – 500 μg/m^3) and CO meter (CEM CO-180; 0 – 1000 ppm) to measure $PM_{2.5}$ and CO concentrations in the kitchens, respectively. The $PM_{2.5}$ device was also engaged to measure the RH and air temperature of the kitchens. The noise level in the examined kitchens was determined using a sound level meter (model WENSEN/WS1361 with a measuring range of 30 – 130 dB). Power banks, laptop, data, and electric cables were also used in the setup for measuring the thermal comfort (temperature, and RH), air quality ($PM_{2.5}$ and CO), and noise level parameters. To ensure uniformity, the data of the measured parameters (CO, noise level, temperature, RH, and $PM_{2.5}$) were taken at the same time interval. The measuring devices were all self-calibrating and need not be calibrated. They were only examined to be in good working conditions prior to their use in the kitchens. The measuring devices were all stabilized prior to data acquisition.

Experimental detail

This study was carried out using 38 urban household kitchens with kerosene stoves. The thermal comfort (temperature and RH), noise, and air quality (CO and $PM_{2.5}$) of the kitchens were examined. These parameters were measured prior and during cooking activities in the assessed kitchens. Measurements were undertaken 20 min prior to cooking (lighting of the stoves) to determine the background values of measured parameters. In addition, measurements were obtained during cooking (from stove lighting to quenching when cooking is over) which is a function of the cooking method and type of food cooked. The cooking method is that of African cuisines related to the people of Southwestern Nigeria. During cooking, readings of measured parameters were taken every 10 min starting from when the stoves were lit. For the background measurement (before cooking), data were taken at 5 min intervals. This enabled at least three datasets prior to cooking and during cooking. The measurements were taken at 1.5 m from the ground (breathing zone) and 1 m from the kerosene stoves (Pokhrel et al., 2015). Data acquisition lasted between 49 min to 158 min in all the assessed kitchens, which was as a result of the types of food cooked. It is pertinent to mention that most data were collected in the morning (5.45 am – 10.00 am) and evening (5.30 pm – 8.30 pm) owing to the schedule of the occupants of the buildings assessed. The average of the measured parameters was obtained and compared with recommended threshold stipulated by global standard organizations for indoor air conditions and earlier studies published in this regard. It is worthy to note that this study was conducted in kitchens with similar stove types and kitchen facilities for a good representation of the assessed kitchens in the study area. During the experiments, data acquisition was carried out with minimum disturbances in the kitchens.

Data and uncertainty analysis

The collected and collated data (CO, $PM_{2.5}$, RH, noise level, and temperature) from the assessed kitchens in this study were statistically analyzed using average, minimum, maximum, range, standard error, correlation, standard deviation, t-test, and analysis of variance (ANOVA). Microsoft® Excel (2016) was used as the statistical tool.

The accuracies of CO (± 10 ppm or ± 5%), $PM_{2.5}$ (± 10% when $PM_{2.5} > 50\ \mu g/m^3$ or $\pm 5\ \mu g/m^3$ when $PM_{2.5} \leq 50\ \mu g/m^3$), and noise level (± 1.5% dB) reported by the manufacturers were used to estimate the uncertainty related to each measured parameter. The RH and the air temperature were measured with an accuracy of ±3% and ±0.8 °C, respectively. Uncertainty is used to check how reliable a measured quantity is. According to Equation (1), the uncertainty of each parameter was evaluated based on the accuracy and average measured value of the specific parameter.

$$U(\%) = \frac{\Delta V}{V} \times 100 \qquad (1)$$

Where:

$U(\%)$ = uncertainty of measured parameter;

ΔV = accuracy of the specific instrument as given by the manufacturer;

V = average of the measured parameter.

Heat index

To indicate how an average person would perceive temperature and RH (in a kitchen space) and the capability of the human body to cool itself, a heat index is employed as an indicator. With the measured kitchen air temperature and RH, the heat index of the assessed kitchens was evaluated using the expression given in Equation (2) from the literature (Engineering toolbox, 2005).

$$t_{HI} = -42.379 + 2.049T + 10.143RH - 0.225T * RH - 6.838\ \times 10^{-3}T^2 - 0.0548RH^2 + 1.229 \times 10^{-3}T^2 * RH + 8.528 \times 10^{-4}T * RH^2 - 1.99 \times 10^{-6}(T * RH)^2 \qquad (2)$$

Where:

t_{HI} = heat index (°C)

T = heat index (°C)

Health risk assessments

The environmental health risks related to the kerosene stoves utilization and connected to the vulnerability of the exposed population to CO and $PM_{2.5}$ in the assessed household kitchens were evaluated using different indicators. These indicators were the Exposure Index (EI), the Personal Exposure (PE) or $PM_{2.5}$ Exposure, the Hazard Quotient (HQ), and the Air Quality Index (AQI). Of these health risk indicators, only AQI evaluates health risk relating to CO and $PM_{2.5}$ while the others link health risk to $PM_{2.5}$ only. The mean concentrations of $PM_{2.5}$ and CO for the kerosene stoves obtained in this work were used in Equations (3) – (7) to estimate EI, PE, IC, HQ, and AQI as provided in the literature (Li et al., 2016; Rim-Rukeh, 2015; Sidhu et al., 2017).

In this present work, the population exposed to CO and $PM_{2.5}$ in the kitchens are the children, women, and other inhabitants of the assessed households. The women are of primary concern as they are responsible for daily cooking. Concerning this study, the exposure pathway to these pollutants is via inhalation which is strongly linked to the exposure duration, activity pattern, and exposure frequency. To estimate the indicators (EI, PE, and CI), the exposure time (3.5 h), frequency (365 days/year), duration (30 years), and average time (70 years x 365 days/year) were considered according to the literature (Li et al., 2016) and adopted in this work. The inhalation of $PM_{2.5}$ by humans has been classified to be carcinogenic by the International Agency for Research on Cancer (Gordon et al., 2014). As in most cases of $PM_{2.5}$ concentration exceeding the recommended threshold, the health implication is mainly dependent on the magnitude, duration, and frequency of the dose exposed to, which has been reported to cause severe chronic and acute health conditions (Gordon et al., 2014). According to the United States Environmental Protection Agency (USEPA), the HQ technique is recommended to estimate of the toxicological risk of inhaling $PM_{2.5}$ on exposure (USEPA, 2009). The procedure provided by Sidhu et al. (Sidhu et al., 2017) was adopted in this present study.

$$EI = \frac{C_i t_i}{C_g t_a} \tag{3}$$

$$PE = \frac{C_i t_i}{24} \tag{4}$$

$$IC = \frac{C_i t_i E_f E_d}{AT} \tag{5}$$

$$HQ = \frac{IC}{C_g} \tag{6}$$

$$\mathrm{I_p} = \left(\mathrm{C_p} - \mathrm{BP_L}\right)\left(\frac{\mathrm{I_H} - \mathrm{I_L}}{\mathrm{BP_H} - \mathrm{BP_L}}\right) + \mathrm{I_L} \tag{7}$$

Where:

C_i = concentration of $PM_{2.5}$ in the microenvironment i (μg/m^3);

t_i = total duration a person stays in the microenvironment i (3.5 h/day);

C_g = guideline value of $PM_{2.5}$ (25 μg/m^3 for daily exposure);

t_a = total duration of pollutants' measurement (1 h);

E_f = frequency of exposure (365 days/yr);

E_d = duration of exposure (30 yr);

AT = average exposure time (70 yr x 365 days/yr (a lifetime));

i = kitchen;

I_p = pollutant's AQI;

C_p = pollutant's rounded concentration;

BP_H = breakpoint greater than or equal to C_P;

BP_L = breakpoint greater than or equal to C_P;

I_H = AQI value matching BP_H;

I_L = AQI value matching to BP_L;

EI = exposure index;

PE = personal exposure (μg/m^3);

IC = intake concentration (μg/m^3);

HQ = health quotient.

The ranges of values for AQI, $PM_{2.5}$, CO, and classified health risks are stated in the columns of Table 1. The average concentrations of CO and $PM_{2.5}$ for the kerosene stoves obtained in this study were used along with the values of the CO and $PM_{2.5}$ given in Table 1 to estimate the AQI of $PM_{2.5}$ and CO separately. Corresponding health risk (last column of Table 1) subject to exposure to each pollutant was apportioned using the estimated value of AQI for the said pollutant in the third column of Table 1 (AQI column).

Results and discussion

Kitchen noise level

Noise generated from cooking-related activities in the kitchens, most especially, household kitchens have not been readily documented in the literature. Studies on kitchens (commercial or household) of developing countries grossly lack consideration of the noise emanating from these kitchens with very few works carried out in this regard in developed countries (Di Loreto, Serpilli, Lori, & Squartini, 2020). Cooking activities, operation of exhaust hood or fan, and other electronic devices are primary sources of noise in the kitchen outside the outdoor noise. With 38 household kitchens assessed in this present study, average noise levels of 40.22 ± 0.68 dB and 51.14 ± 1.08 dB were recorded before cooking and during cooking scenarios in the kerosene-fuelled stove kitchens (Table 2). During cooking, the maximum and minimum noise levels were 74.1 dB and 40.3 dB while in the absence of cooking activities, the maximum and minimum noise level was 52.7 dB and 33.8 dB, respectively (Table 2). The uncertainty related to the measurement of kitchen noise was 1.5% and it is indicated by the error bars in Figure 2.

According to WHO threshold recommendations of 45 dB (night-time) and 55 dB (daytime), it can be observed that prior to cooking the average noise level of the kitchens satisfied these recommendations (WHO, 1999). However, during cooking, only the daytime recommendation was complied with. The average noise level of the individual kitchen examined is presented in Figure 2. Apparently, cooking in all the assessed kitchens is observed to increase the background noise level (Figure 2). An increase of 9.59% – 63.37% of the background noise level of the kitchens was caused by cooking. It can be noticed that only four kitchens did not satisfy the WHO recommendations prior to cooking activities. This could be as a result of external influence, that is, the noise outside the kitchens. During cooking, six kitchens satisfied the WHO recommendations with 10 kitchens not complying with the recommendations. This shows that 22 kitchens fall between the two recommendations and this implies that these kitchens failed the daytime recommendation of 55 dB and satisfied the night-time recommendation (45 dB). It can be deduced from the peak and average noise level of the kitchens during cooking that the noise from the kitchens cooking (with kerosene stoves) does not pose danger to the vulnerable groups of children and women who were the main occupants.

Kitchen thermal comfort

Kitchen air temperature

Thermal comfort in the kitchens as related to the air temperature is very important. The uncertainty associated with kitchen air temperature was estimated to be 2.83% (before cooking) and 2.68% (during cooking). In this present study, the average air temperature was 29.86 ± 0.24 °C with minimum and maximum air temperature of 25.80 °C and 32.77 °C, respectively, during cooking in the kitchens. However, prior to cooking, average, maximum, and minimum air temperatures were 28.30 ± 0.23 °C, 30.57 °C, and 25.1 °C, respectively. These values as given in Table 2 showed that cooking activities in the assessed kitchens led to a slight increase in the kitchen air temperature. This agreed with a previous study in which cooking increased the air temperature in commercial kitchens (Li et al., 2012). The background and cooking-related air temperatures in the assessed kitchens are presented in Figure 3. It can be noticed that the air temperature of all the assessed kitchens was above the background air temperature.

These can be linked to the thermal energy released during the cooking activities via the combustion of kerosene in the stoves which consequently heated the air around the stove and cooking area via convection, conduction, and radiation. The background air temperature was found to be increased by 0.86% – 19.94% during cooking in the assessed kitchens. The obtained air temperature in this work (25.80 – 32.77 °C) was found to be within the range (28.4 – 37.8 °C) reported by Ravindra et al. (2019) for kitchens in the rural households of India (during summer) using LPG and biomass stoves for cooking.

Kitchen relative humidity

RH is another crucial parameter associated with thermal comfort. In this work, average, minimum, and maximum RH was 68.34 ± 0.83%, 55.1%, and 76.8% for kitchens during cooking and 61.48 ± 0.73%, 49.1%, and 69.9% for kitchens before cooking, respectively (Table 2). Apparently, cooking activities can be observed to influence the RH of the kitchens. From Figure 4, the RH of the assessed kitchens showed that cooking increased the kitchen RH. The RH of the kitchens during cooking was noticed to be higher than the background RH of the kitchens, and this trend is observed in all the assessed kitchens. However, Li et al. (2012) published a reduction in the RH of commercial kitchens during cooking in comparison with the background RH which was due to the use of exhaust hood (providing fresh air) in the kitchens. Considering 40% – 60% RH for thermal comfort (under indoor condition) as prescribed by ASHRAE (American Society for Refrigeration and Air-conditioning Engineers), only three kitchens were noticed to satisfy this recommendation (ASHRAE, 2013). Cooking was found to increase the background RH of the kitchens by 0.31% – 37.8%. This can be linked to the water vapor released via the combustion of kerosene in the stoves and cooking activities as the food materials and ingredients contained certain amounts of moisture content. The release of water vapor into the kitchen space is expected to increase the moisture level in the kitchen air and thus increasing the RH of the kitchen. The RH recorded in this study (55.10%

– 76.80 °C) was found to be slightly higher than the range (13.70% – 63.80%) reported by Ravindra et al. (2019) in the rural household kitchens of India (during summer) using LPG and biomass stoves.

Kitchen heat index

As an indicator to examine the perception and ability of the kitchen users to cope with the prevailing kitchen air temperature and RH exposed to, the heat index of each assessed kitchen was evaluated prior to cooking and during cooking. Figures 5 and 6 present the heat index of all the assessed kitchens prior to cooking and during respectively. From Figure 5, it can be observed that the heat index of most of the assessed kitchens falls into the "caution" classification (26 – 32 °C) in which fatigue is possible with protracted physical activity and exposure. Out of the 38 kitchens examined in this work, seven kitchens (with heat index >32 °C but <39 °C) lie in the "extreme caution" category while the rest (with heat index <32 °C) fit into the "caution" category. This shows that only 18.4% of the kitchens fall into the "extreme caution" category which implies that heat cramps, sunstroke, and heat exhaustion are likely with prolonged physical activity and exposure of the vulnerable group.

As can be seen in Figure 6, cooking in the assessed kitchens is observed to alter the air temperature and RH values leading to a corresponding change in the heat index. It has been earlier reported in this study that during cooking the air temperature and RH of the kitchens are higher than the background air temperature and RH of these kitchens (Sub-Sections 3.2.1 and 3.2.2). The heat index pattern for the prior cooking scenario as displayed in Figure 5 is noticed to be different from the during cooking heat index (Figure 6). In Figure 6, the heat index of the assessed kitchens is spread across three categories such as "caution", "extreme caution", and "danger". Four (10.5%), 27 (71.1%), and seven (18.4%) kitchens are in the "caution" (26 – 32 °C), "extreme caution" (26 – 39 °C), and "danger" (39 – 54 °C) categories, respectively, according to the heat index classifications. This implies that the use of kerosene stoves for cooking in the assessed kitchens increased the heat index and therefore shifts the health implication of exposed kitchen occupants of most of the kitchens from “caution” to “extreme caution” and from “extreme caution” to “danger”. By the danger classification, heatstroke is said to be possible with prolonged physical activity or exposure.

Kitchen air quality

Kitchen CO concentration

The uncertainty associated with the measurement of CO was ±5%. From Table 2, the average CO concentration in the assessed kitchens prior to cooking was 7.74 ± 0.38 ppm. The maximum CO concentration was 13.34 ppm while the minimum CO concentration was 4.80 ppm. During cooking, the average CO concentration was 24.77 ppm with maximum and minimum values of 46.54 ppm and 15.46 ppm, respectively. It shows that prior to cooking, all the kitchens fulfilled the WHO threshold value of 30 ppm for 1 h exposure to CO (WHO, 2010) while this is not true for the case of CO concentration in the kitchen during cooking. Since the average, maximum, and minimum CO concentration due to cooking is higher than 6 mg/m^3 (5.24 ppm), this work is in consonance with a previous study (Lam et al., 2012). Figure 7 presents the kitchen CO concentration prior to and during cooking. The background CO concentration of the kitchens can be noticed to be significantly increased during cooking. This is due to the release of CO from the combustion of kerosene, kerosene wick, food materials, and ingredients. The CO concentration of the kitchens prior to cooking was found to be increased by 42.50% – 658.41% through cooking activities. Additionally, it can be seen in Figure 7 that the assessed kitchens satisfied the WHO limit for 1 h exposure to CO prior to the cooking. However, during cooking, seven kitchens (18.4%) have CO concentrations higher than the WHO limit and therefore did not fulfilled this prescribed limit.

Kitchen PM$_{2.5}$ concentration

The estimated uncertainty of $PM_{2.5}$ measurement was ±10%. Prior to cooking, the range of the measured $PM_{2.5}$ concentration for the assessed kitchens was 63.80 – 102.40 $\mu g/m^3$ with an average of 89.16 ± 1.26 $\mu g/m^3$. During cooking, the $PM_{2.5}$ concentration range of 96.90 – 186.67 $\mu g/m^3$ with an average of 138.10 ± 2.61 $\mu g/m^3$ was recorded for the assessed kitchens. The higher values of $PM_{2.5}$ concentration (during cooking) over those obtained prior to cooking showed the effect of cooking on the $PM_{2.5}$ concentration in the kitchens (Figure 8). Cooking was found to increase the background $PM_{2.5}$ concentration of the kitchens by 34.54% – 104.76%. Since the $PM_{2.5}$ concentration measured in this work is for the period of cooking which was less than 3 h, it could not be compared with WHO limits of 25 $\mu g/m^3$, 37.5 $\mu g/m^3$, 50 $\mu g/m^3$, and 75 $\mu g/m^3$ for daily air quality guideline, interim-target 3, interim-target 2, and interim-target 1, respectively (Coffey et al., 2019). The $PM_{2.5}$ concentration range obtained in this present work is lower than the range (300 – 750 $\mu g/m^3$) reported by (Abdullahi et al., 2013) and around the average value (169 $\mu g/m^3$) published by (Pokhrel et al., 2015) for kitchen households in Nepal.

Evaluation of health risk in kitchens

The health risk connected to the average concentration of $PM_{2.5}$ and CO released into the assessed kerosene-stove kitchens was evaluated using four indicators. Equations 3 – 4, and 6 – 7 were used to estimate the four indicators of EI, PE, HQ, and AQI, respectively. The average EI, PE, and HQ for the kitchens were 0.81, 20.14 $\mu g/m^3$, and 1.38, respectively. The AQI for exposure CO was 262.59 while that for $PM_{2.5}$ was 192.90. According to Sharma and Jain (2019), an EI of less than 6 indicates a low $PM_{2.5}$ exposure index which reveals that with the EI = 0.81 obtained in this study, the kitchen users' exposure to $PM_{2.5}$ is less risky. This result agreed with a previous study which reported EI = 17 for kitchens using solid fuels and EI = 5 for kitchens using LPG/biogas stoves (Sidhu et al., 2017). It is pertinent to report that the $PM_{2.5}$ quantity for solid fuel and LPG/biogas stoves is higher than what is obtained in this study which influences their EI value according to Equation 3. A comparison of the estimated PE value in this work with a previous study shows that our result (20.14 µg/m^3) is lower than the values (54 µg/m^3 – males and 64 – µg/m^3 females) reported for the exposure of females and males aged 15 – 64 years to $PM_{2.5}$ for the use of coal, gas and electricity stoves in kitchens (Li et al., 2016).

From Equation 7, the HQ value (1.38) of all the assessed kitchens was found to be slightly higher than unity, revealing that the exposure of the kitchen operators to $PM_{2.5}$ could considerable impact on their health. A value lower than unity indicates a less significant health effect on the exposed population, primarily the women. The obtained result fell within an earlier study with HQ = 0.42 for LPG-stove kitchens and HQ = 2.09 for kitchens using solid biomass as fuel (Sidhu et al., 2017). The use of the calculated AQI (from Equation 7) in Table 1 to rank the health risk associated with the kerosene-stove kitchens revealed "very unhealthy" for CO exposure and "unhealthy" for $PM_{2.5}$ contact. The high $PM_{2.5}$ and CO concentrations in the kitchens from the use of kerosene stoves were responsible for the high AQI values and health risk status. It is sufficing to mention that this indicator, AQI, as expressed in Equation 7 does not consider the frequency and duration of exposure of the exposed population to CO and $PM_{2.5}$ concentrations but the levels of pollutants' concentration only.

Data analysis

The data of $PM_{2.5}$, RH, air temperature, CO, and noise obtained for the assessed kitchens during and before cooking were statistically analyzed. The results of the correlation and t-test analysis were presented in Table 3. The correlation coefficients of noise, CO, RH, temperature, and $PM_{2.5}$ for before and during cooking scenarios were 0.613, -0.089, 0.325, 0.776, and 0.356, respectively. These values showed a negative relationship only between CO before cooking and CO after cooking. A moderate and positive correlation was found to exist for noise and temperature during and before cooking scenarios. Considering the one-tail and two-tail t-test analysis for the noise, CO, RH, temperature, and $PM_{2.5}$, it can be noticed that the means of these measured parameters for the assessed kitchens were significantly and statistically the same as $t_{observed} > t_{critical}$ (see Table 3) with P-value less than 0.0001. With the ANOVA results of the analysis of the obtained data shown in Table 3, it can be noticed that the variance of the data for all measured parameters is significant (p-value <0.0001) and statistically identical ($F_{critical} < F_{observed}$).

Conclusion

A study of the thermal comfort, noise level, air quality, and health risk of urban household kitchens using kerosene stoves was conducted. Data of CO, $PM_{2.5}$, noise level, RH, and temperature before and after cooking in all the assessed kitchens were measured. Average CO (24.77 ppm), $PM_{2.5}$ (138.10 $\mu g/m^3$), RH (68.34%), noise level (51.14 dB), and temperature (29.86 °C) during cooking were noticed to be above the background values of these parameters. For this study, the CO and noise level relatively conformed to the WHO maximum limits while the $PM_{2.5}$ was above the maximum WHO threshold. Most of the assessed kitchens during cooking have heat index values implying the likelihood of heat exhaustion, heat cramps, and sunstroke upon prolonged exposure of the users. On exposure of the vulnerable group to $PM_{2.5}$ and CO released into the kitchens via the use of kerosene stoves, the obtained AQI values implied unhealthy (192.90) and very unhealthy (262.59) status, respectively. The HQ = 1.38 evaluated in this work implied possible health risk on exposure of the kitchen users to $PM_{2.5}$. These metrics indicate a relatively unsafe kitchen environment when kerosene stoves are used. There is a need for a robust government policy and regulatory standards on household kitchen fuels, kitchen design with adequate ventilation, and improved and efficient stoves.

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Ethical Approval

Not applicable

Consent to participate

Not applicable

Consent to publish

Not applicable

Authors contributions

S.O. Giwa conceived the idea, performed part of the experiment, analyzed the obtained data, and wrote the final draft of the manuscript. **C.N. Nwaokocha** performed part of the experiment and wrote the first draft of the manuscript. **M. Sharifpur** provided direction prior and during the study and proofread the final manuscript.

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No competing interests

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Tables

Table 1. Statistical description of obtained data

Parameters	**Condition**	**Noise (dB)**	**CO (ppm)**	**Relative humidity (%)**	**Temperature (°C)**	**$PM_{2.5}$ ($\mu g/m^3$)**
Average	Before	40.22	7.74	61.48	28.30	89.16
	During	51.14	24.77	68.34	29.86	138.10
Standard deviation	Before	4.21	2.37	4.49	1.48	7.79
	During	6.68	6.47	5.11	1.42	16.07
Standard error	Before	0.68	0.38	0.73	0.23	1.26
	During	1.08	1.05	0.83	0.24	2.61

Table 2. Result of t-test analysis of obtained data

Parameters	**Noise (dB)**	**CO (ppm)**	**RM (%)**	**Temperature (°C)**	**$PM_{2.5}$ ($\mu g/m^3$)**
Correlation coefficient	0.613	-0.089	0.325	0.776	0.356
t (observed)	-12.747	-14.819	-7.549	-10.276	-19.905
P-value (one tail)	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
t (critical) – one tail	1.687	1.687	1.687	1.687	1.687
P-value (two tail)	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
t (critical) – two tail	2.026	2.026	2.026	2.026	2.026
Remark	Significant	Significant	Significant	Significant	Significant

Table 3. ANOVA of obtained data

Parameters	**Noise (dB)**	**CO (ppm)**	**Relative humidity (%)**	**Temperature (°C)**	**$PM_{2.5}$ ($\mu g/m^3$)**
F_{obs}	72.67	232.27	38.63	23.70	285.54
F_{cri}	3.97	3.97	3.97	3.97	3.97
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

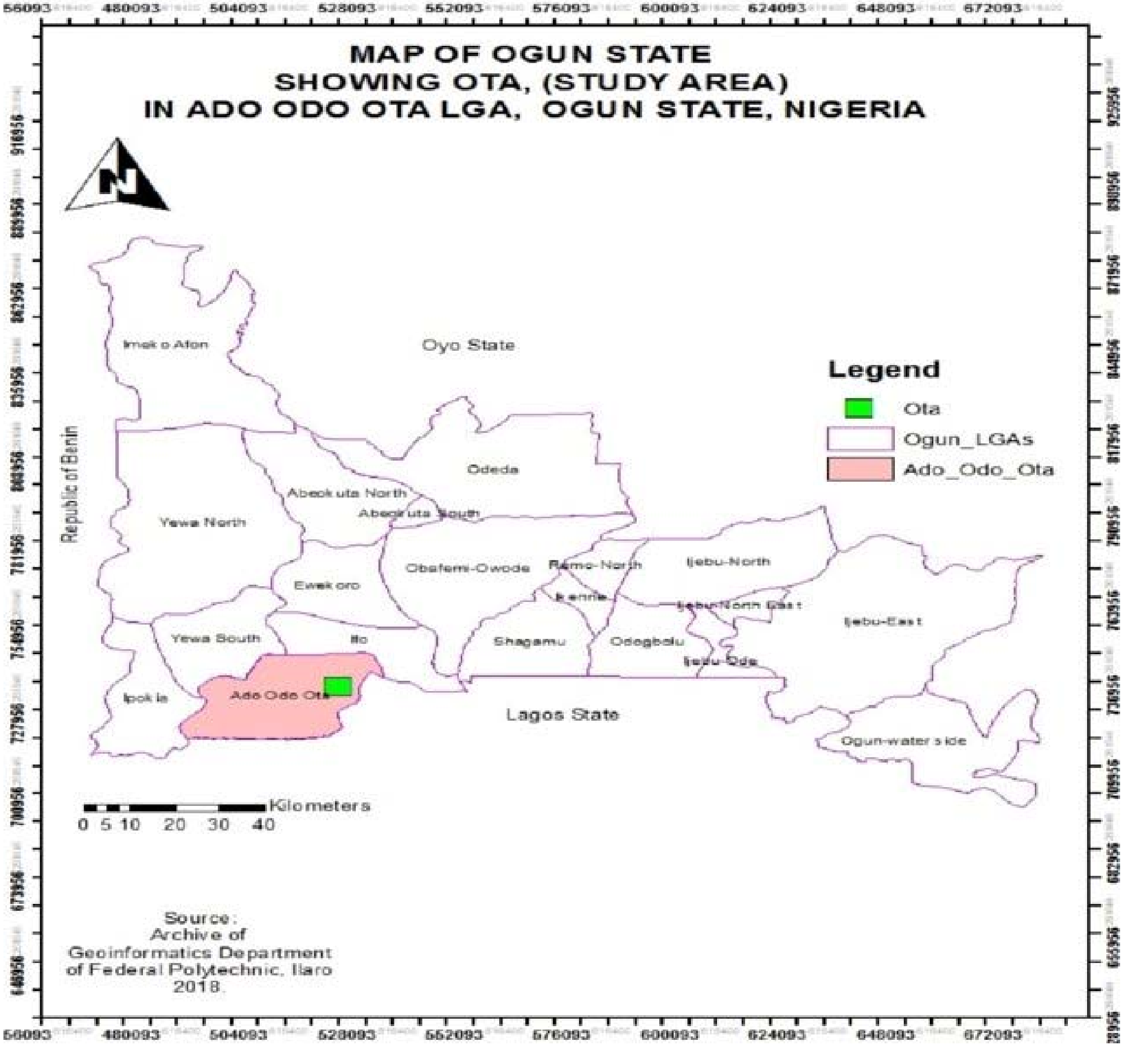

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Figure 1. Map of area of study (Ado-Odo/Ota local government area)

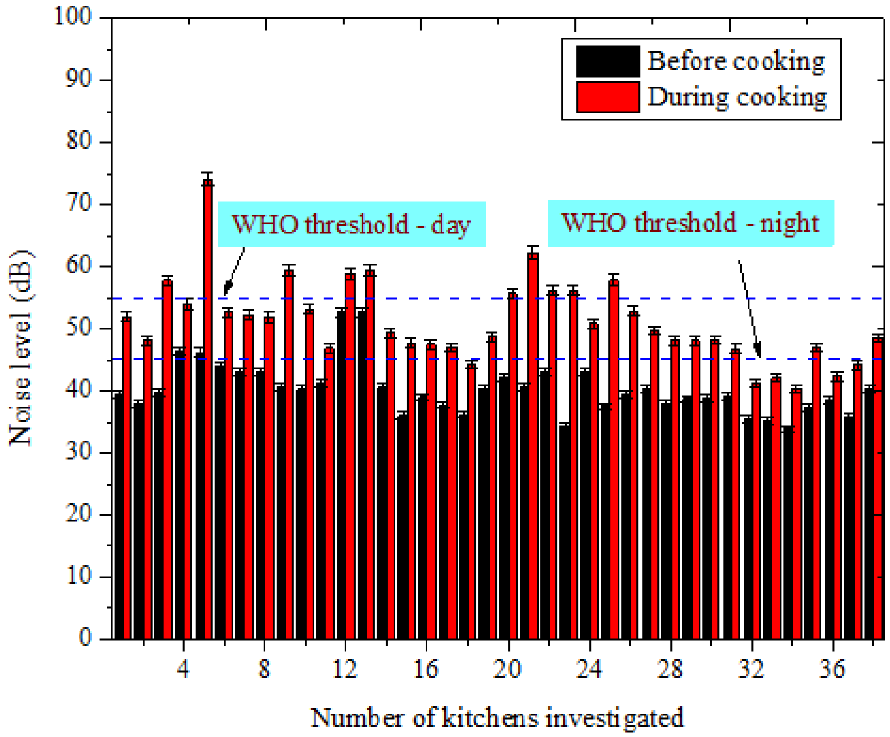

Figure 2. Noise level of kitchens before and during cooking activities

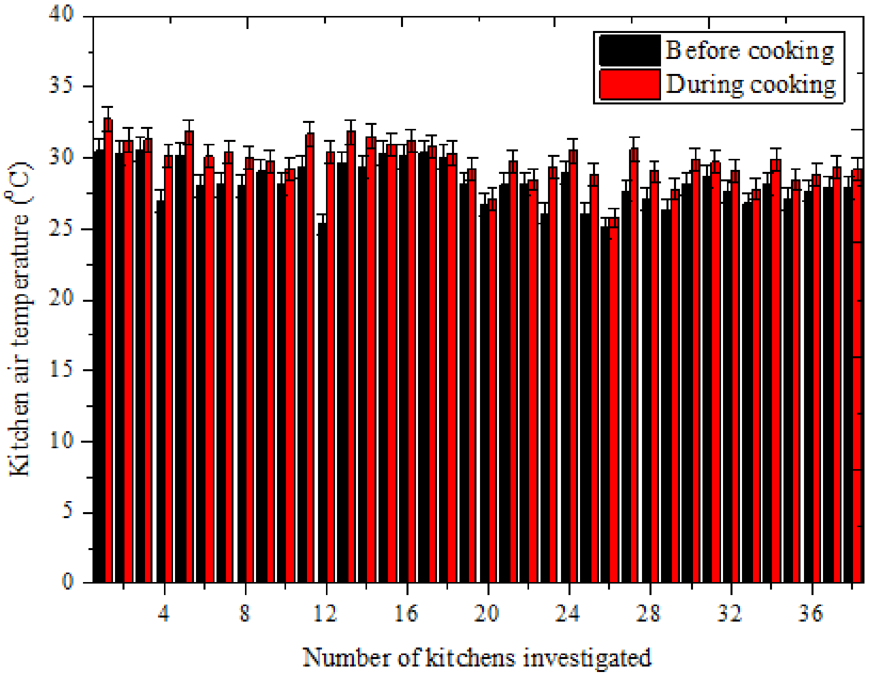

Figure 3. Air temperature of kitchens before and during cooking activities

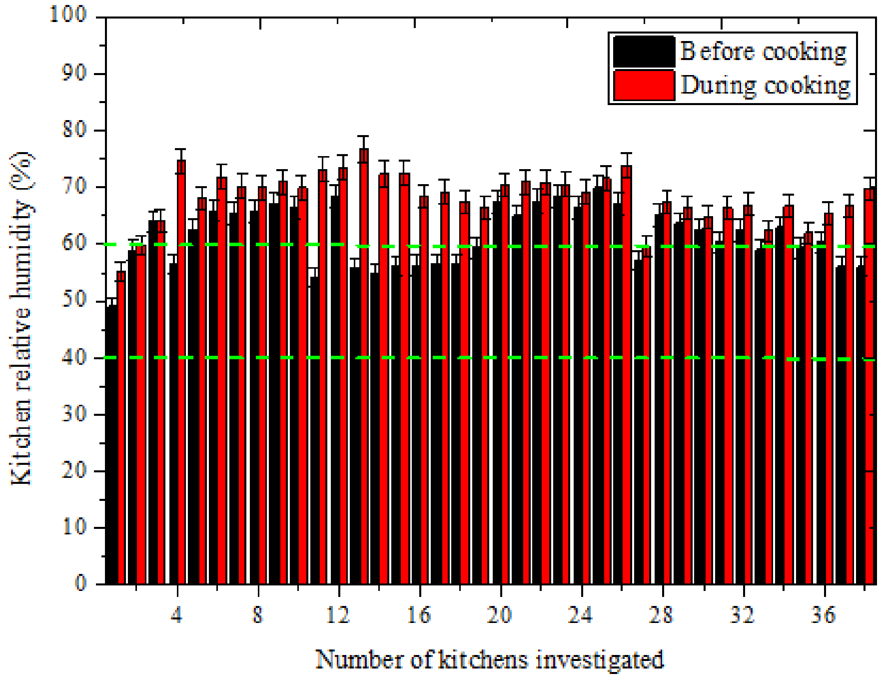

Figure 4. Relative humidity of kitchens before and during cooking activities

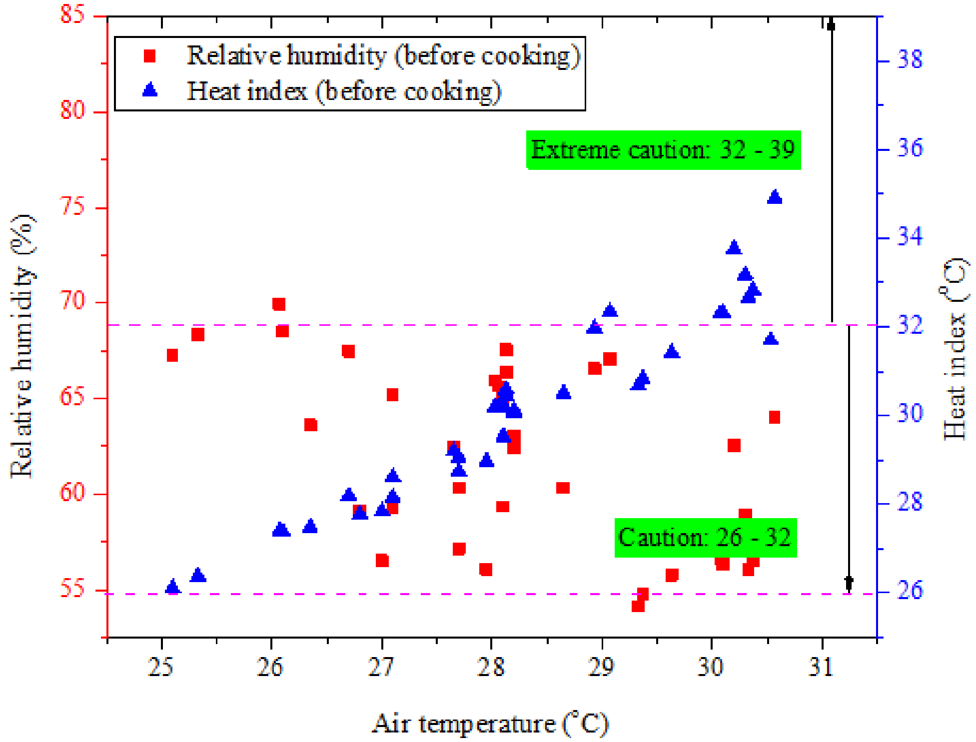

Figure 5. Heat index of kitchens before cooking activities

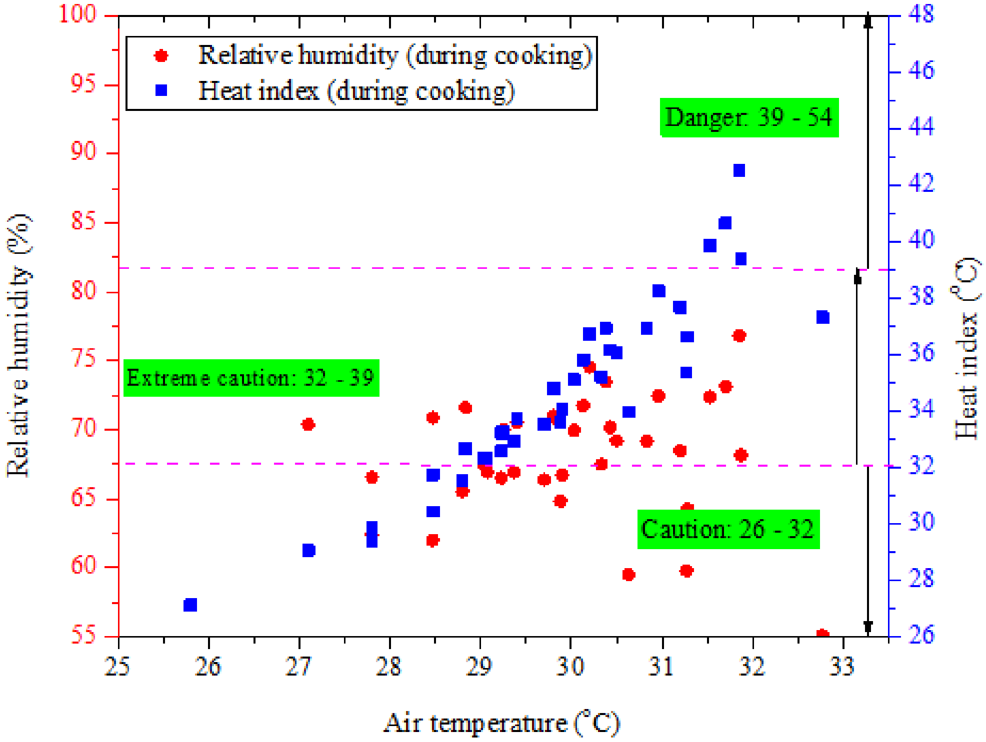

Figure 6. Heat index of kitchens during cooking activities

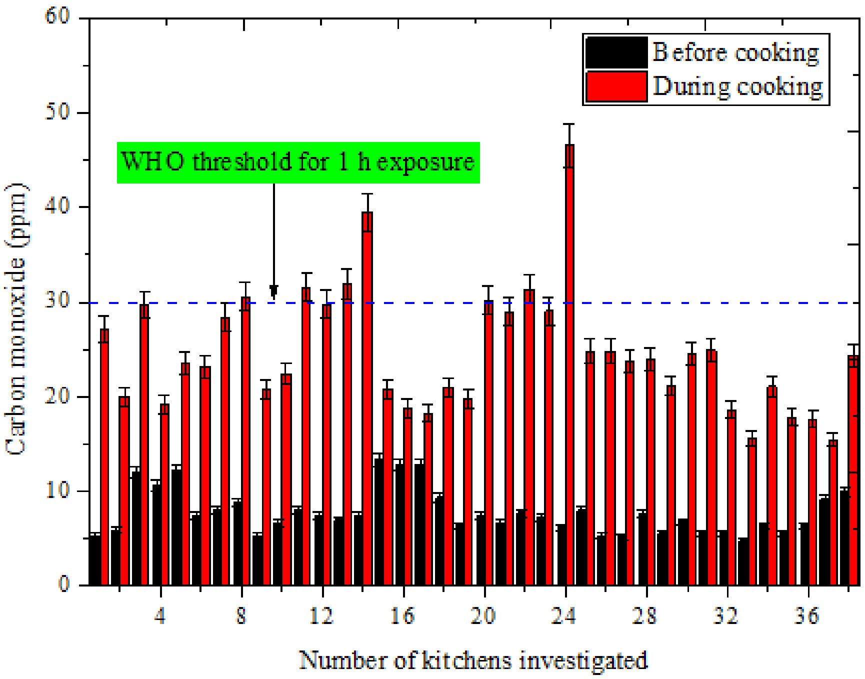

Figure 7. Carbon monoxide concentrations in kitchens before and during cooking activities

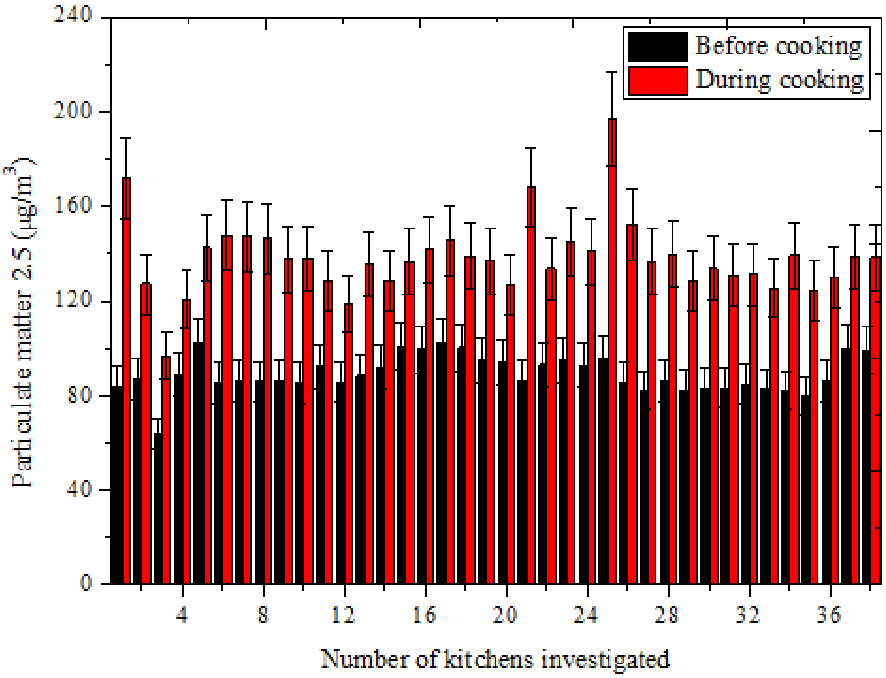

Figure 8. PM$_{2.5}$ *concentrations in kitchens before and during cooking activities*