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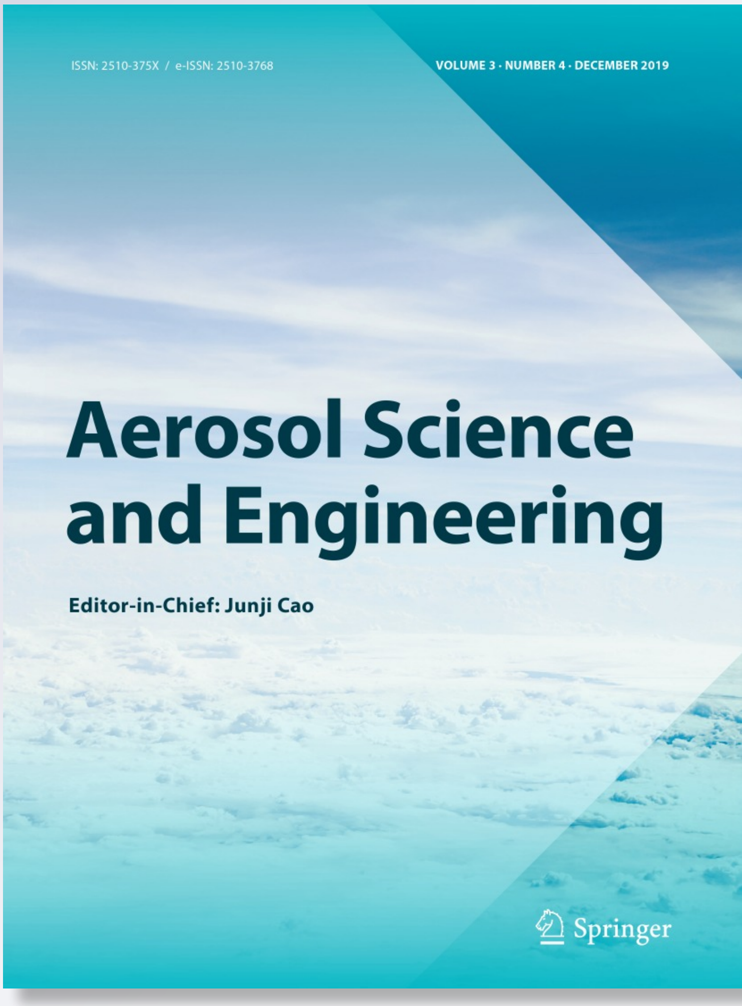

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ORIGINAL PAPER

Investigation into Trace Elements in PM_{10} from the Baking of *Injera* Using Clean, Improved and Traditional Stoves: Emission and Health Risk Assessment

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Abstract

Particulate matter with aerodynamic diameters < 10 µm (PM_{10}) emitted during the baking of Ethiopian's traditional staple food *Injera* (a flatbread mostly made from *Teff* flour and baked upon a circular griddle) was collected for analysis. Emissions of inhalable particles from three types of stoves, clean, improved, and traditional stoves, were tested to determine the elemental composition and to assess the short-term exposure and health risk of the particles in the indoor microenvironment. The PM_{10} was collected with the help of a portable sampling unit with multi-fraction dust samplers, and its elemental composition was determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES). The mean concentration of PM_{10} pollutant using clean, improved, traditional stoves were 139, 259 and 571 µg m^{-3}, respectively. The concentrations of trace elements (Fe, Cd, As, Cr, Pb, B, Ni, Co, Sn, Cu and Zn) bound in PM_{10} during the use of improved, traditional stove and clean stoves ranged from below detection limit (BDL) to 632, BDL to 0.499 and BDL to 0.078 µg m^{-3}, respectively. The carcinogenic and non-carcinogenic risks of the exposed person to trace elements bound in PM_{10} were assessed according to the US Environmental Protection Agency prescription. Although the US National Quality Standard is 150 µg/m^3 for 24 h, the results showed that the likelihood that an average person has either carcinogenic or non-carcinogenic health impacts by using any of the three stoves over a lifetime at a frequency of twice a week is very low. However, the PM_{10} contribution of wood-burning stoves to the total daily exposure is high.

Keywords *Injera* · Biomass · PM_{10} · Elemental composition · Health risk assessment · Ethiopia

1 Introduction

Fossil fuel-burning vehicles such as cars, buses, and motorbikes, and the use of different biomass fuels, including agriculture waste, tree leaves and branches, wood, and animal dungs, are the predominant air pollution sources in developing countries. Studies have shown that more than 40% (> 3 billion peoples) of the world's population relies on unprocessed biomass fuels (wood, charcoal, agricultural residues, and animal dung) for their daily household cooking (Adeniji et al. 2015; Anenberg et al. 2013; Kena et al. 2013; Pope et al. 2015; Thompson et al. 2011; Umoh and Peters 2014). A large amount of these types of fuels is used in developing countries as compared to developed countries. About 90% of domestic energy depends on biomass fuels in sub-Saharan Africa, where cooking takes a significant share. In Ethiopia, more than 90% of the population uses biomass fuel for cooking, heating, and lighting, in which 99% of this fuel is derived from firewood, charcoal, crop residue, and

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leaves, with firewood occupying the leading position. The different types of pollutants emitted from such biomass fuels can cause various health problems (Biruck et al. 2011; Hassena et al. 2016).

The type of diseases caused by air pollution depends on the pollutant concentration, types, composition of the pollutant (which is affected by its sources), and the length of time that an individual remains in a polluted microenvironment (Falta et al. 2008; Faris 2002). Among the substances in polluted air, particulate matter with different aerodynamic diameter is the major component and the health concern in the world nowadays. This is because particulate matter contains many hazardous heavy metals such as iron, nickel, vanadium, copper, cobalt, cadmium, and chromium (Schwarze et al. 2006). The heavy metals bound in the airborne particulate matter can affect the normal development and growth of body tissues and their proper functioning such as aggravation of carcinogenesis, teratogenesis and mutagenesis, which are mainly due to the presence of toxic trace elements in the particulate matter (Mohanraj et al. 2004). Thus, the chemical characterization of particulate matter is vital for understanding their effect on humans and the environment. More importantly, investigation of trace elements bound in particulate matter is useful for the identification of their sources in addition to the health impact estimation due to their exposure (Salcedo et al. 2014). The distribution of elements across the size of particulate matter varies. Studies have shown that 70–90% of the heavy metals (such as Cu, Cd, Ni, Zn, and Pb) are found in PM_{10} fraction (Mohanraj et al. 2004). Thus, the present study is focused on the investigation of trace elements in PM_{10}.

Particulate matter with different aerodynamic diameter released during the combustion of biomass fuel and traffic emissions is a significant problem in the developing world in general (Do et al. 2013; Int Panis et al. 2010). The use of biomass fuels in open fireplaces, consisting of such simple arrangements as three rocks, a U-shaped hole in a block of clay, a pit in the ground, or in poorly functioning earthen or metal stoves, is a common practice in the majority of households in developing countries in general, and particularly in Ethiopia. The combustion of biomass fuel is incomplete in most of these stoves, which produce high levels of indoor pollution. Hence, the use of such stove types can make the level of exposure worse as compared to using clean stoves (Anenberg et al. 2013; Boadi and Kuitunen 2006; Nigel et al. 2000).

In general, most of the previous air pollution and its health impact relation studies conducted in developing countries were based on the measurement of the air pollutants at fixed places, which did not predict an accurate exposure assessment. This is because the pollutant concentration varies across time and space. Using personal exposure data at different microenvironments rather than fixed monitoring data is the better method in exposure assessment and in identifying the role of each microenvironment to the total personal exposure (Cattaneo et al. 2010; Devi et al. 2009; Levy et al. 2000; Rabinovitch et al. 2016). A few studies were conducted in Ethiopia related to exposure assessment based on 24 h measurement at selected indoor sites. Earlier studies did not show the real exposure assessment of the exposed person, since a person may not be at home or outdoors for 24 h or the air quality conditions may not remain constant for ventilated microenvironments. Also, studies confirmed that exposure to a high level of particulate matter for a short period ranging from one to several hours could cause different health problems (Gulliver and Briggs 2004; Int Panis et al. 2010; Son and Bell 2013). However, studies conducted in Ethiopia lack detailed composition and nature of pollutant assessment of short-term exposure to particulate matter. The studies were limited due to lack of information in the identification and determination of potentially toxic elements bound in particulate matters.

Therefore, in this work, pollutant emission during the baking of *Injera* using different types of stove (clean, improved, and traditional) was selected. This is because *Injera* is the most frequently and widely consumed food item in Ethiopia. Baking *Injera* needs a large amount of fuel that might lead to high indoor air pollution (Kume et al. 2010). Recently, Downward et al. (2018) reported that personal exposure to $PM_{2.5}$ during the baking of *Injera* using biomass cooking stove was double from that of an electric stove. Therefore, this study is focused on short-term exposure assessment and elemental analysis of indoor PM_{10} (the respirable particulate matter) sampled during the baking of *Injera*.

2 Materials and Methods

2.1 Description of the Study Area

Ethiopia is the second most populous country in Africa (105 million, 2017), while the estimate for 2019 is 112 million. Addis Ababa is a metropolitan city of Ethiopia that has a population exceeding 3 million (ECSA 2012). The city has been growing at a rate of 2.1% from 1994 to 2010 (Do et al. 2013). Addis Ababa is situated at the central highland plateau of the country at an altitude varying between 2200 and 2800 m, and between latitude 9.0300°N and longitude 38.7400°E. The average minimum and maximum annual temperatures range from 9.53 to 23.2 °C, and the average annual rainfall is 1170 mm (Sanbata et al. 2014).

The city of Addis Ababa is divided into ten boroughs, call sub-cities that involve different socioeconomic activities. Since the level of outdoor pollution can influence indoor air pollution, the selection of sub-cities sampling locations before choosing households was vital. Thus, based on the altitude differences, socioeconomic activities and population density, the three representative sub-cities (namely: Arada, Gulelle, and Akaki Kality) from different districts were selected as sampling sites. Arada sub-city is mainly characterized by high population density, medium traffic intensity, a limited number of manufacturing industries; Gulelle sub-city is characterized with very few industries, medium traffic intensity, higher altitude, and lower population density than Arada sub-city. Akaki Kality sub-city is characterized by lower population density than the other two sub-cities; low altitude, heavy industrial activities, and high traffic congestion are its main characteristics.

In addition to outdoor pollution sources, the major factors affecting indoor pollution are vital in selecting the indoor microenvironment (ME) for this study. Thus, kitchen's ME during the baking of *Injera* using different types of stoves was selected for this study, where, all households considered in this study are at a private level. The household kitchens considered in this study are similar to their construction materials (wood wall, soil floor, and roof of corrugated iron). The elected homes are typical representatives of families with low and middle income in Addis Ababa and also in most of the Ethiopian cities. The stove type used and the willingness of families to allow the researcher in their house for measurement were considered during the selection. A total of 45 households (15 households from each sub-city) were selected randomly due to general procedure similarity in the baking of *Injera*.

2.2 *Injera* Baking Techniques

The people in Ethiopia rely on *Injera* as their primary staple food. It is a flat bread mostly made from *Teff* flour that is baked on a griddle, which is most often heated by means of different fuel types. Baking of *Injera* is performed by using different types of stoves, namely clean, improved, and traditional stoves, where the pollutant levels released from each stove might be different.

The variations in these stoves are either in the design or in the type of fuel used. Thus, the clean stove (*Electric Midja*, in Amharic) looks like a griddle made from a circular-shaped clay that contains electric resistance heating wire coils embedded inside and used as a source of heating. The improved stove (*Mirt Midja*, in Amharic) is similar in design to the clean stove with some differences that it has a chimney or flue, which allows for the removal of fumes outside the kitchen and a small hole used for adding fuel. Likewise, the traditional stoves (three stone triangular supports also called *Midja*, in Amharic) have a different design from both clean and improved stoves in which the stove is supported on three stone legs and open fire is applied. Only a small fraction of the heat from the open fire is used in the traditional stove, used for baking *Injera* (*Mitad*, in Amharic), making it the most inefficient of the three types. Both improved and traditional stoves can be used with similar types of biomass fuel sources. Figure 1 shows the picture of the three types of stoves used for the baking of *Injera*.

2.3 Sampling and Mass Determination

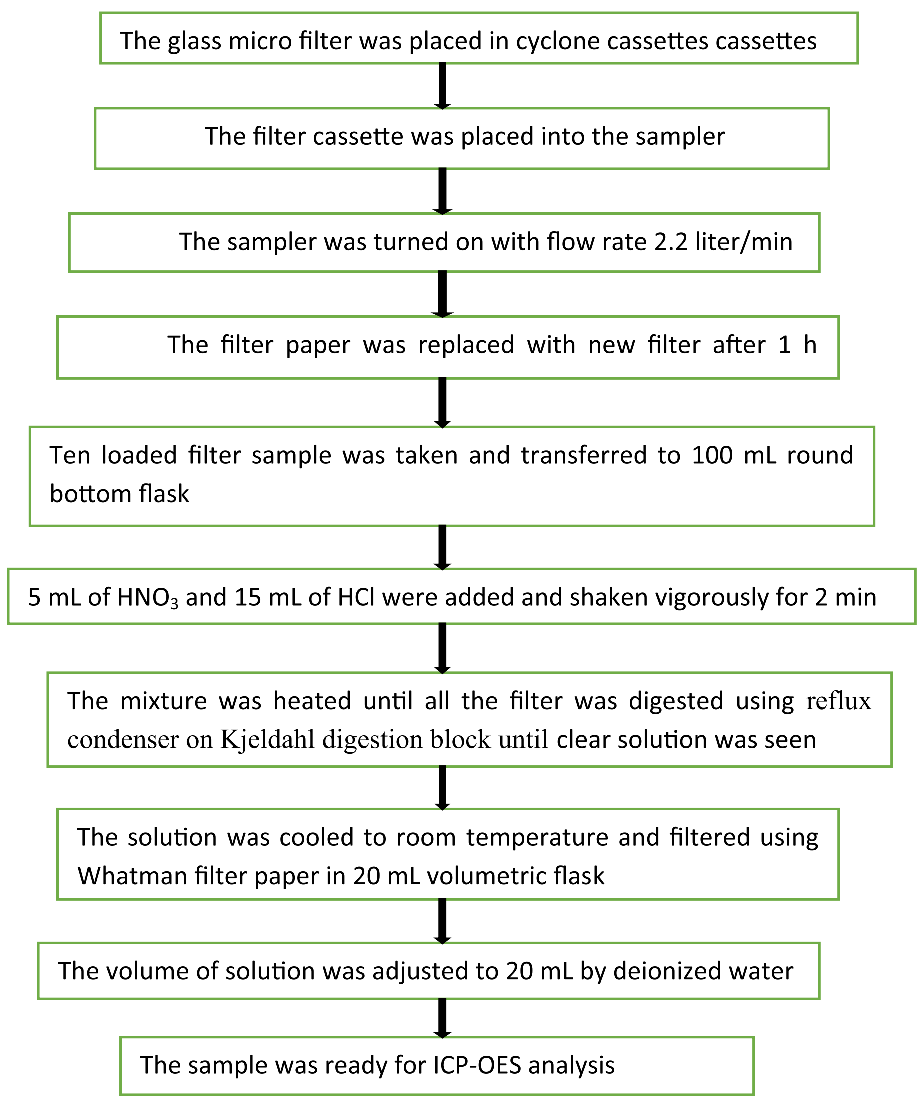
The samples for PM_{10} analysis were collected using equipment that consisted of a portable sampling unit equipped

Fig. 1 The three different types of stove used for the baking of *Injera*. **a** Traditional open wood-burning stove, **b** improved-efficiency wood-burning stove, **c** high-efficiency electric stove

with multi-fraction dust samplers from the Institute of Occupational Medicine (IOM) (Universal air pump, SKC 224-PCTX4 Model, SKC Ltd, UK). The unit has a vacuum pump, an internal flow regulator, a timer, and an airflow calibration unit. A high-precision rotameter was used to adjust the airflow to 2.2 L min^{-1} in the laboratory before being taken into the field for sample collection. The airflow rate was checked immediately upon return to the laboratory. The sampling was carried out between July 1 and September 30, 2016, for the wet season and November 15, 2016 and March 10, 2017, for the dry season. The vacuum pump was placed at the waist of the baker, and the inlet cyclone was assigned to the collar, close to the breathing zone. This is the most appropriate breathing zone of the baker. The sampling duration during the baking of *Injera* was started on starting the baking and ended when the activity was completed. The sampling of the filter was carried out in three rounds, where the types of biomass used for improved and traditional stoves were similar. The masses of biomass used were different and might depend on the efficiency of the stove and the moisture content of the fuel. The number of *Injera* baked during each round was the same and was used as a benchmark for all the stoves. The sampling and sample preparation have been outlined in the form of a flowchart in Scheme 1.

Glass microfiber filters with a diameter of 25 mm GF/A (Whatman®, GE Healthcare UK Limited, Amersham Place, UK) were used to collect PM_{10}, which was put inside the universal sampler. Each filter was oven dried at a temperature of 150 °C for 2 h before sampling to remove moisture and volatile organic compounds. After the sampling was over, the filter was placed in aluminum foil, returned to the laboratory, and placed in a desiccator. The mass of the particulate matter was measured gravimetrically, using an analytical balance with 0.001 mg sensitivity (AT 250, Mettler-Toledo, USA). The difference between the weight of the filter before and after sampling was considered as the

Scheme 1 A flowchart showing the sampling and sample preparation



mass of particulate matter collected during a given time. The results were expressed as micrograms of PM_{10} per cubic meter of air.

2.4 Determination of Trace Elements

Analysis of 11 elements (Mn, Cd, Co, B, As, Ni, Cr, Pb, Zn, Cu, and Fe) in the PM_{10} was conducted following a standard method developed by the US EPA (Method 6010D) (US EPA 2017), which mainly uses aqua regia mixture for digestion. A mixture of 5 mL concentrated nitric acid (69–71% Sigma-Aldrich, Germany) and 15 mL concentrated hydrochloric acid (37%, Sigma-Aldrich, Germany) was used to prepare the sample extracts for elemental analysis. A round bottom flask (100 mL) fitted with a reflux condenser and Kjeldahl digestion block (Kjeldatherm, Gerhardt GmbH, and Co. KG, Type KB 40 S, Bonn, Germany) was used for the digestion of all the PM_{10}-loaded filter papers. After cooling, the extracted solution was filtered on the cellulose filter (Whatman 1) and adjusted to a final volume of 20 mL using deionized water. Finally, it was kept in a pre-cleaned polyethylene bottle and refrigerated until analysis. Triplicate filter and reagent blanks were also processed following a similar procedure for sample treatment (Leili et al. 2008). The concentrations of the 11 elements were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES; Model Arcos FH2, 22-09-2010, Spectro Analytical Instrument GMDH, Baush strass, 10.47533, Klev, Germany) instrument in Horticoop (Horticulture) Ethiopia PLC located at Debrezeyt (Bishoftu). The calibration solutions were prepared by diluting a commercial 1000 mg/L standard solution of each element (UNI-CHEM, chemical reagents). Standard solutions were prepared by the appropriate dilution of 1000 mg mL^{-1} element stock solution in 2% HNO_3. The concentrations of each element bound in PM_{10} were obtained using Eq. 1.

$$C\,(\mu\text{g m}^{-3}) = \frac{(C_1 - C_b)}{V_o} \times V, \quad (1)$$

where C_1 is the element concentration in the solution of the sample (μg m^{-3}), C_b is the element concentration in the solution of the blank filter (μg m^{-3}), V is the sample solution volume (20 mL), and V_o is the sampling air volume (m^3).

The calibration curves showed linearity ($r^2 > 0.989$) of the detector response for the quantified elements found in the samples. The limit of detection (LOD) was determined using each analyte element based on three times the standard deviation (3σ) of the blank. The calibration curves and the LOD for detected elements are summarized in Table 1. The performance of the method was verified by a recovery test through standard addition. The results were in the range of 92–110%, which falls within an acceptable range.

Table 1 The calibration equation for the quantification of elements in PM_{10} using ICP-OES

Type of element	Calibration equations	Correlation coefficient (r^2)	LOD in μg mL^{-1}
Fe	y = 0.36x + 1027	0.9997	0.054
Cu	y = 0.92x + 4470	0.9989	0.028
Mn	y = 1.71x + 782	0.9999	0.007
B	y = 0.08x + 892	0.9976	0.195
Zn	y = 0.21x + 1034	0.9919	0.027
Pb	y = 0.05x + 633	0.9897	0.857
Cr	y = 0.46x + 998	0.9912	0.089
Cd	y = 1.47x + 626	0.9973	0.070
Sn	y = 0.07x + 198	0.9975	1.368
As	y = 0.08x + 144	0.9975	0.647
Ni	y = 0.24x + 1445	0.9952	0.520
Co	y = 0.11x + 1085	0.9975	0.044

The spiking measurement was performed in triplicate. The average percent recovery and standard deviation of each element was: Fe (101 ± 1.2), Cu (102 ± 4.6), Mn (98.4 ± 6.0), B (105 ± 1.5), Zn (92 ± 4.2), Pb (109 ± 1.8), Cr (110 ± 1.2), Cd (102 ± 4.3), Sn (99.6 ± 6.2), As (106 ± 4.3), Ni (108 ± 3.5), and Co (109 ± 3.9).

2.5 Statistical Package Used in Data Analysis

SPSS version 20.0, Microcal™Origin version 16.0 (Micrical software, Inc. USA) and Microsoft Excel 2013 were used for the data analysis. Analysis of variance (ANOVA) was used to evaluate the significance of the differences in concentration of PM_{10} and elements bound in PM_{10} across the stove types. Generally, the significant difference for all the tests was set to 0.05.

2.6 Risk Analysis

Both epidemiological and toxicological studies have shown that inhalation of metal-containing particulates in polluted air can cause significant health effects such as several types of cancer and respiratory and cardiovascular diseases such as bronchitis, cardiac arrhythmia, lung inflammation, lung fibrosis, and deep vein thrombosis. The health risk of different element species varies due to the mixed toxicity, amount, and mobility behaviors. Therefore, the estimation of their association to cancer and non-cancer risk is vital to the prioritization of individual metal species as related to the total risk contributions and to take remediation and emission control at a particular level (Chalvatzaki et al. 2019; Izhar et al. 2016).

Cancer and non-cancer risk can develop due to elements bound in particulate matter (Benson et al. 2017; Liu et al.

2017, 2018). Lifetime cancer risk analysis is a method of estimating the probability of a person to develop cancer over his/her lifetime as a result of exposure to the identified carcinogens, whereas non-carcinogenic effects means the likelihood of a person to develop health problems other than cancer during the exposure to contaminants (Benson et al. 2017). Exposure of trace elements found in the particulate matters can occur through the inhalation, ingestion, and dermal absorption routes (Sidhu et al. 2017). The health impacts of elements contained in the particulate matter pollutants under consideration can be carcinogenic or non-carcinogenic. According to the Integrated Risk Information System (IRIS), Cu, Fe, Zn, and Mn are classified as non-carcinogenic; Cd, As, Pb, Cr, and Ni are classified as carcinogenic metals (Kushwaha et al. 2012; Liu et al. 2017, 2018).

In this study, carcinogenic and non-carcinogenic risks of chronic exposure to stove emissions due to elements in PM_{10} for both children and adults via direct inhalation, ingestion, and dermal absorption were assessed in the kitchen micro-environment during the baking of *Injera*. This assessment enhances the understanding of the severity of the health risks and helps to identify appropriate remedial actions that can be implemented. The health risk assessment due to the PM_{10} bound elements exposure were calculated using US EPA's methodology as expressed in Eqs. 2–7 (Liu et al. 2018).

$$D_{\mathrm{inh}} = \frac{C \times \mathrm{InhR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}}, \tag{2}$$

$$D_{\mathrm{ing}} = \frac{C \times \mathrm{IngR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{6}, \tag{3}$$

$$D_{\mathrm{der}} = \frac{C \times \mathrm{AF} \times \mathrm{SA} \times \mathrm{ABS} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{6}, \tag{4}$$

$$\mathrm{HQ} = \frac{D}{\mathrm{RfD}}, \tag{5}$$

$$\mathrm{HI} = \sum \mathrm{HQ}, \tag{6}$$

$$\mathrm{LCR\ or\ CR} = D_{\mathrm{inh}} \times \mathrm{IUR} = D_{\mathrm{ing}} \times \mathrm{SF} = D_{\mathrm{der}} \times \left(\frac{\mathrm{SF}}{G}\right), \tag{7}$$

where C is the concentration of the elements (μg m^{-3} or mg kg^{-1}), D_{inh}, D_{inge}, and D_{der} are the daily dose through inhalation (mg kg^{-1} day^{-1}), through ingestion (mg kg^{-1} day^{-1}) and through dermal contact (mg kg^{-1} day^{-1}), respectively; InhR is the inhalation rate (m^3 day^{-1}), ED is the exposure duration (years), EF is exposure frequency (day $year^{-1}$), BW is body weight (kg), AT is average time (years), LCR is lifetime cancer risk, IUR is the inhalation unit risk ((μg $m^{-3})^{-1}$), RfD refers to the reference dose of each intake path (mg kg^{-1} day^{-1}), SF is the slope factor (mg kg^{-1} d^{-1}), AF is skin adherence factor (mg cm^{-2} day^{-1}), ABS is dermal absorption factor (unitless), SA is surface area (cm^2), and G is the gastrointestinal absorption factor. The parameters considered for health risk assessments due to trace element concentration at the three MEs (during using of clean, improved, and traditional stoves) in this study are given in Tables 2 and 3.

US EPA has developed a standard guideline value for the exposed person to the trace element contaminants. Hence, the total cancer risks associated with exposure to trace element contaminants over a lifetime more significant than 1×10^{-4} are generally considered unacceptable. However, the US EPA's threshold range indicated for tolerable risk is between 1×10^{-4} and 1×10^{-6} (i.e., the probability of 1 in 10,000 to 1 in 1000,000 that an individual may develop cancer from lifetime exposure to a carcinogen) as a commonly referenced benchmark for the protection of public health (Benson et al. 2017; Izhar et al. 2016; Liu et al. 2018). Therefore, these values were used as threshold values for this study.

3 Results and Discussion

3.1 Characteristics of the Kitchen

The detailed information of the kitchen characteristics (such as fuel type, ventilation type, the size of the kitchen, family size) for the selected households is given in Table 4. From the sampled households, 23.3% of the households used wood only, 7.78% of the households used combined wood and leaves, 7.78% of the households used combined leaves

Table 2 The constant values used in risk calculation (Benson et al. 2017; Kushwaha et al. 2012; Liu et al. 2018)

Parameter	Fe	Cu	Mn	B	Zn	Pb	Cr	Cd	As	Ni
RfD										
Inhalation		0.04	0.00005		0.04	0.0035	0.0004	0.00001	0.000015	0.00005
Ingestion	07	0.04	0.14	0.2	0.3	0.0035	0.0003	0.001	0.015	0.05
Dermal		1	1		1	1	0.025	0.025	1	0.04
IUR						0.00008	0.012	0.0018	0.043	0.0024
SF						0.28	0.5	0.64	1.5	0.084
G						1	0.025	0.025	1	0.04

Table 3 The exposure parameters for health risk assessments (Benson et al. 2017; Liu et al. 2018; Walpole et al. 2012)

Parameters	Values	
	Children	Adults
InhR (m^3 day^{-1})	7.6	20
ED (year)	6	30
EF (days $year^{-1}$)	(6/6/5)[a]	(6/6/5)[a]
AT (days)		
For non-carcinogenic	ED × 365	ED × 365
For carcinogenic	70 × 365	70 × 365
IngR (mg day^{-1})	200	100
SA (cm^2)	1077.5	2011.25
AF (mg cm^{-2} day^{-1})	0.02	0.07
ABS	As (0.03), Cd (0.001) and others (0.01)	As (0.03), Cd (0.001) and others (0.01)
BW (kg)	15	60.7

[a]Indicates the exposure of frequency in using improved stove/traditional stove/clean stove

and sawdust, 33.3% of the households used electricity, and 27.8% of the households used leaves only as fuel in both the wet and dry seasons during the measurement period. As far as the kitchen location was concerned, 8 kitchens were located in the living room and 37 kitchens were found separately from the living room. The main ventilation aspects in cooking rooms of the selected households included: 16 homes had only a single door, 2 homes had a single window and 27 homes had both a window and door ventilation. The household family size ranged from two to seven people and the kitchen size for selected households varied from 7 to 56 m^3, respectively. The average frequencies of *Injera* baking were approximately two times per week.

3.2 PM_{10} Concentration

The mean concentrations of PM_{10} emitted during the use of clean, improved, and traditional stoves are given in Table 5. The concentrations of PM_{10} measured for the clean, improved, and traditional stoves were 139, 259 and 571 μg m^{-3}, respectively. The maximum PM_{10} emission values (571 μg m^{-3}) were observed using the traditional stove, whereas the minimum (139 μg m^{-3}) was found for the clean stoves. The level of PM_{10} emitted in the traditional stove was almost double as compared to the improved stove. A similar result was reported by Downward et al. (2018) in $PM_{2.5}$ concentration measurement during commercial *Injera* baking. This might be due to the chimney used in the improved stove that removes the pollution from the stove to outside. The use of the improved stove is better than the traditional stove in minimizing exposure during cooking (Albalak et al. 2001). For instance, a study conducted in urban homes in Kenya showed using improved stove reduced indoor air pollution levels of $PM_{2.5}$ as compared to the traditional stove (Yip et al. 2017). This study also showed similar trends in reducing the exposure of PM_{10} pollutant during the baking of *Injera* using improved and clean stoves instead of a traditional stove, such that the use of improved and clean stove was associated with 54.6% and 75.4% lower level of PM_{10} during the baking of *Injera*. A similar trend was observed in the study conducted at Honduran, Central America (Clark et al. 2009). The major factors for variation in the level of PM_{10} emission during *Injera* baking using the three types of stove might be due to variation in the duration of baking, room temperature and kitchen size, ventilation type (natural or mechanical), wind direction, kitchen location (air exchange rate), fire condition (smolder or fast burring), and fuel type and moisture content of fuel in addition to resuspension and deposition velocity (Bo et al. 2017; Zhao et al. 2013).

A one-way ANOVA based on the *F* test was used to detect significant differences among the clean, improved, and traditional stoves. The results showed a significant difference in their concentration across each stove type ($p < 0.05$). However, the difference was not recognized where it occurred. Therefore, ANOVA post hoc test was further applied by selecting the case. Thus, except clean stove vs. improved stove, all the separate comparisons (clean vs. the traditional stove and improved stove vs. the traditional stove) showed a significant difference in concentration of PM_{10} ($p < 0.05$).

3.3 Trace Element Concentration in PM_{10}

The concentrations of selected trace elements found in PM_{10} sampled during *Injera* baking using clean, improved, and traditional stoves were determined and the results are summarized in Table 5. The trace elements found in PM_{10} using improved stove were found in the range of below the detection limit (BDL)-0.632 μg m^{-3}, where B is the highest concentration element (0.632 μg m^{-3}) observed. Similarly, the concentration range of the trace elements bound in PM_{10} using traditional and clean stoves were: BDL—0.499 and BDL—0.078 μg m^{-3}, respectively. The highest concentrations of B (0.499 μg m^{-3}) and Fe (0.078 μg m^{-3}) were obtained in traditional and clean stoves, respectively. Cu (BDL) was the lowest concentration element obtained for all types of stoves. The sources of trace metal are not solely from biofuel mass, but can also come from the baking process itself. For example, the baker uses a powder of mustard seed (Gomenzer, in Amharic) (*Brassica carinata*) for softening of griddle before they pour the dough on the griddle. During this process, *Brassica carinata* undergoes combustion that might be one cause for the release of trace element during baking *Injera* in any of stove. The

Table 4 Some characteristics of kitchens in the selected households at different sampling sites

Site code	Fuel type		Ventilation type	Kitchen position	Family size	Size of kitchen (m^3)
	Wet season	Dry season				
ar1A	Electricity	Electricity	Both window and door	LR	6	7.5
ar1B	Electricity	Electricity	Both window and door	LR	2	21.0
ar1C	Electricity	Electricity	Window only	NLR	4	10.2
ar1D	Electricity	Electricity	Both window and door	LR	5	20.9
ar1E	Electricity	Electricity	Both window and door	LR	4	16.8
ar2A	Wood and leaves	Leaves and sawdust	Door only	NLR	3	21.1
ar2B	Leaves only	Leaves and sawdust	Door only	NLR	5	11.0
ar2C	Leaves only	Leaves only	Door only	NLR	3	15.0
ar2D	Leaves only	Wood only	Door only	NLR	5	10.1
ar2E	Leaves only	Leaves and sawdust	Door only	NLR	4	28.0
ar3A	Leaves only	Wood only	Door only	NLR	4	10.2
ar3B	Wood and leaves	Leaves only	Door only	NLR	2	10.2
ar3C	Wood only	Leaves only	Both window and door	NLR	4	42.0
ar3D	Wood only	Leaves only	Both window and door	NLR	7	13.3
ar3E	Wood and leaves	Leaves only	Door only	NLR	4	11.3
gu1A	Electricity	Electricity	Door only	NLR	4	13.8
gu1B	Electricity	Electricity	Window only	LR	5	22.5
gu1C	Electricity	Electricity	Both window and door	NLR	5	42.0
gu1D	Electricity	Electricity	Both window and door	LR	7	42.0
gu1E	Electricity	Electricity	Door only	LR	4	25.2
gu2A	Wood and leaves	Leaves only	Both window and door	NLR	7	15.0
gu2B	Wood only	Wood and leaves	Both window and door	NLR	5	14.3
gu2C	Leaves and sawdust	Wood only	Door only	NLR	4	15.4
gu2D	Leaves only	Wood only	Door only	NLR	5	21.7
gu2E	Leaves only	Wood only	Door only	NLR	5	7.98
gu3A	Leaves only	Leaves only	Door only	NLR	4	13.5
gu3B	Wood and leaves	Leaves only	Door only	NLR	4	11.9
gu3C	Leaves only	Wood and leave	Door only	NLR	4	56.0
gu3D	Leaves and sawdust	Wood only	Both window and door	NLR	4	18.9
gu3E	Wood only	Leaves only	Both window and door	NLR	4	9.5
ak1A	Electricity	Electricity	Both window and door	LR	3	15.0
ak1B	Electricity	Electricity	Both window and door	NLR	5	12.2
ak1C	Electricity	Electricity	Both window and door	NLR	3	28.0
ak1D	Electricity	Electricity	Both window and door	NLR	5	23.2
ak1E	Electricity	Electricity	Both window and door	NLR	3	17.4
ak2A	Wood only	Leaves only	Both window and door	NLR	5	15.6
ak2B	Wood only	Leaves only	Both window and door	NLR	3	19.4
ak2C	Wood only	Wood only	Both window and door	NLR	3	18.7
ak2D	Wood only	Wood only	Both window and door	NLR	5	25.6
ak2E	Wood only	Wood only	Both window and door	NLR	5	20.9
ak3A	Leaves and sawdust	Leaves only	Both window and door	NLR	4	10.0
ak3B	Leaves only	Leaves only	Both window and door	NLR	2	12.5
ak3C	Leaves only	Leaves and sawdust	Both window and door	NLR	3	15.0
ak3D	Wood only	Leaves only	Both window and door	NLR	5	21.0
ak3E	Wood only	Wood only	Both window and door	NLR	4	18.0

Site code: ar = Arada sub-city; gu = Gulelle sub-city; ak = Akaki Kality sub-city; 1, 2 and 3 = indicates stove types clean, improved (merit), and traditional (3 stone), respectively; A, B, C, D, and E represent different households in each sub-city; LR = kitchen located in living room; NLR = kitchen found separate from living room

Table 5 PM_{10} elemental composition (mean ± SD, in μg m^{-3}) during the baking of *Injera* using improved, traditional, and clean stoves

Metal type	Improved stove	Traditional stove	Clean stove
PM_{10}	259 ± 31.7	571 ± 18.6	139 ± 41.0
Fe	0.254 ± 0.003	0.082 ± 0.002	0.078 ± 0.006
Cu	BDL	BDL	BDL
Mn	0.005 ± 0.004	0.004 ± 0.001	0.007 ± 0.005
B	0.632 ± 0.010	0.499 ± 0.072	0.042 ± 0.044
Zn	0.351 ± 0.070	0.106 ± 0.018	0.064 ± 0.028
Pb	0.009 ± 0.001	0.008 ± 0.002	0.011 ± 0.005
Cr	0.011 ± 0.008	0.010 ± 0.008	0.010 ± 0.0008
Cd	0.008 ± 0.001	0.005 ± 0.001	0.007 ± 0.002
Sn	0.008 ± 0.005	0.007 ± 0.004	0.007 ± 0.006
As	0.003 ± 0.001	0.002 ± 0.002	0.006 ± 0.007
Ni	0.007 ± 0.005	0.009 ± 0.001	0.007 ± 0.004
Co	0.009 ± 0.006	0.009 ± 0.003	0.008 ± 0.007

It should be noted that PM_{10} determined was the total emission from both the baking process and the biofuel combustion; BDL is below the detection limit

concentration of the measured elements in this study was found to be lower than from a similar study conducted in Delhi (Nagar et al. 2014). The trend of element concentration (in μg m^{-3}) in the improved stove was B (0.632) > Zn (0.351) > Fe (0.254) > Cr (0.011) > Co (0.009) = Pb (0.009) > Sn > (0.008) = Cd (0.008) > Ni (0.007) > Mn (0.005) > As (0.003) > Cu (BDL), using traditional stove was B (0.499) > Zn (0.106) > Fe (0.082) > Cr (0.010) > Co (0.009) = Ni (0.009) > Pb (0.008) > Sn (0.007) > Cd (0.005) > Mn (0.004) > As (0.002) > Cu (BDL); using clean stove was Fe (0.078) > Zn (0.064) > B (0.042) > Pb (0.011) > Cr (0.010) > Co (0.008) > Ni (0.007) = Sn (0.007) = Cd (0.007) = Mn (0.007) > As (0.006) > Cu (BDL). The trend of overall mean concentration (in μg m^{-3}) of the elements during the baking of *Injera* was: B (0.391) > Zn (0.174) > Fe (0.138) > Cr (0.010) > Pb (0.009) = Co (0.009) > Ni (0.008) > Sn (0.007) = Cd (0.007) > Mn (0.005) > As (0.004) > Cu (BDL). B is the component of the plant cell wall that might be the reason for its highest presence using traditional and improved stoves, whereas the highest value of Fe (0.078 μg m^{-3}) found using clean stove might predominantly come from resuspension of dust from the floor or from the *Injera* itself (Irfan et al. 2019; Shaaban 2010). The variation in the concentration of each element across the stove type might be due to the variation in the fuel type used and other factors such as age of construction, furnishing and carpet materials, cooking temperature, and types of paint used. Therefore, further study is needed to know the exact factor (Gorjinezhad et al. 2017; Kulshrestha et al. 2014). Although the type and mass of the biomass used are similar, different factors such as room size, air rate exchange, surface area of natural ventilation (such as window, eves, door), and moisture content of biomass are also major factors for variation in the level of trace elements in the PM_{10} emission. In addition, the level of contamination of the trace metals also varies, because of the origin of the biomass from different sources and variation in their processing condition and state of fire (either smoldering or fast burning).

It should be noted that one may think that it is appropriate to compare clean stove with other stoves because the electricity using clean stove is considered as clean energy that does not emit trace elements. Hence, the pollutants from clean stove burning just come from *Injera* themselves. Therefore, the pollutants emitted from using clean stove could be considered as background value of the baking of *Injera* to correct the impact of *Injera* emission for improved and traditional stoves. However, the results on the level of trace elements emission using the three types of stoves given in Table 5 do not support this opinion. The level of emission of most of the elements using clean stove (electricity) are either higher or comparable to that of improved and traditional stoves used for baking *Injera.* Therefore, further studies are necessary to determine the exact source of emission of trace elements during the baking of *Injera* using different types of stoves.

A one-way ANOVA test was applied to the element concentration across all the stove types, and B, Fe, and Zn concentrations showed a significant difference ($p < 0.05$), whereas other element concentrations did not show a significant difference ($p > 0.05$) across the stove types. Since the difference was not recognized where it occurred, individual comparisons of stoves were performed. Thus, the levels of Cd, Zn, B, and Fe showed a significant difference ($p < 0.05$) between improved and traditional stoves. Similarly, improved versus clean stove also showed a significant difference ($p < 0.05$) for Fe, B, Zn levels, whereas the difference in other elements was not significant. The level of B showed a significant difference ($p < 0.05$) when traditional and clean stoves were compared, but other elements did not show a significant difference.

The total sum of the levels of the 11 analyzed elements is shown in Fig. 2. The highest concentration was observed using improved stove, followed by traditional and clean stove, respectively. This might be due to the fact that improved stove uses sawdust biomass fuels, which is a by-product of wood-based furniture that are likely contaminated with heavy metal-rich paints. However, further study is required to identify the exact cause for this variation.

3.4 Health Risk Assessment

The carcinogenic and non-carcinogenic risks were estimated for inhabitants who bake *Injera* using different types of stove and stay at the baking area. The results are given in Table 6. Inhalation and ingestion exposure pathway of

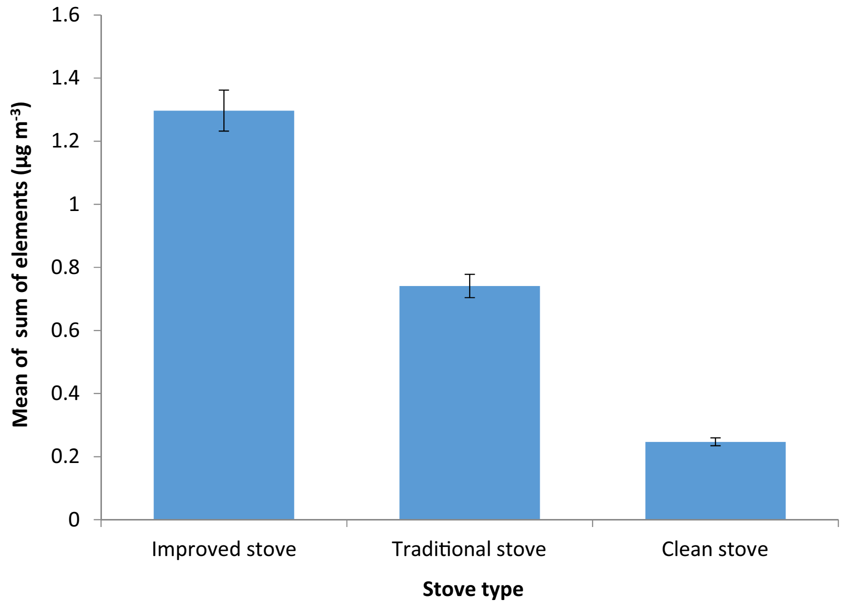


Fig. 2 The total concentration of elements contained in particulate matters emitted from the three types of stoves

metals including Pb, Cr, Cd, As, and Ni in children during the baking of *Injera* using improved stoves showed cancer risk values below the tolerable range. Similarly, inhalation and ingestion exposure of Cr, Cd, As, Ni and Pb for adults were at levels that are unlikely to cause adverse cancer health effects over a lifetime of the exposure. All the elements were below the allowable range in the dermal contact exposure pathway for both children and adults. In addition, exposure to metals including Pb, Cd, As, Cr, and Ni through inhalation, ingestion, and dermal contact pathways for both children and adults during baking of *Injera* using traditional stoves showed cancer risk values below the tolerable range. A similar trend was seen using a clean stove for the baking of *Injera*. As seen in Table 6, while using clean stove the carcinogenic risk was predominantly caused by the ingestion exposure pathway, followed by dermal contact and inhalation pathways for children, whereas inhalation was through ingestion and dermal contact pathway for adults.

The non-carcinogenic risk caused by the inhalation exposure pathway is the predominant path followed by the ingestion and dermal contact paths for both children and adults during the baking of *Injera* across all types of stoves. Both individual and total non-carcinogenic risk values of the measured elements through inhalation, ingestion, and dermal contact during the baking of *Injera* using clean, improved, and traditional stoves were found to be below one for both children and adults. Thus, the results indicate that elemental exposure bound in PM_{10} found in this study during baking of *Injera* may not induce any non-cancer health problems.

The total non-carcinogenic health risk due to elemental exposure through the three pathways during the baking of *Injera* using improved, traditional, and clean stoves were calculated by considering the HQ sum of each element obtained at each pathway in each stove. Thus, the results of total HI for children using improved, traditional, and clean stoves found were: 0.02, 0.01 and 0.02, respectively. The results for improved, traditional, and clean stoves confirmed that children could not have a likelihood to be affected by non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI) using improved stove was calculated and showed that inhalation, ingestion, and dermal contact exposure pathways for children were 63.2, 36.7 and 0.04%, respectively. Similarly, the percent contribution of inhalation, ingestion, and dermal contact exposure pathways for children using traditional and clean stoves were: 61.5, 30.8, 7.7% and 58.8, 35.3, 5.9%, respectively.

A similar calculation was made for adults, and the results of total HI using improved, traditional, and clean stoves were: 0.009, 0.006, and 0.007, respectively, which showed an adult person who stays in the baking area using all the three types of stove could not have a likelihood to be affected by non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI) using the improved stove was calculated and showed that the inhalation, ingestion, and dermal contact exposure pathways accounted for 88.9, 8.9, and 2.2%, respectively. The percent contribution of inhalation, ingestion, and dermal contact exposure pathways for adults using traditional and clean stoves were 83.3, 10.0, 6.7% and 85.7, 11.4, 2.9%, respectively.

The risk assessment indicates that when any of the risk values are lower than the threshold values, the probability of an individual to develop cancer or non-cancer risk from lifetime exposure is low and not significant than when any of the risk values exceeds the threshold values.

Table 6 Carcinogenic and non-carcinogenic risks of each element for children and adults via inhalation, ingestion, and dermal exposure during baking of *Injera* using clean, improved, and traditional stoves

Type of metal	Improved				Traditional				Clean stove			
	Adult		Children		Adult		Children		Adult		Children	
	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Inhalation exposure												
Mn		5.42×10^{-4}		8.33×10^{-4}		4.33×10^{-4}		6.66×10^{-4}		6.32×10^{-4}		9.72×10^{-4}
Zn		6.32×10^{-6}		9.71×10^{-6}		1.91×10^{-6}		2.93×10^{-6}		9.60×10^{-7}		1.48×10^{-6}
Pb	3.00×10^{-9}	1.38×10^{-5}	5.54×10^{-10}	2.13×10^{-5}	2.67×10^{-9}	1.2310^{-5}	4.92×10^{-10}	1.89×10^{-5}	3.06×10^{-9}	1.41×10^{-5}	5.64×10^{-10}	2.17×10^{-5}
Cr	5.50×10^{-7}	6.00×10^{-4}	1.01×10^{-7}	9.12×10^{-4}	5.0×10^{-7}	5.41×10^{-4}	9.23×10^{-8}	8.3×10^{-4}	4.17×10^{-7}	4.53×10^{-4}	7.69×10^{-8}	6.94×10^{-4}
Cd	6.75×10^{-8}	0.005	1.25×10^{-8}	0.007	3.75×10^{-8}	0.003	6.92×10^{-9}	0.004	4.37×10^{-8}	0.0031549	8.07×10^{-9}	0.005
As	5.37×10^{-8}	0.001	9.92×10^{-9}	0.002	3.58×10^{-8}	7.21×10^{-4}	6.61×10^{-9}	0.001	8.96×10^{-8}	0.0018	1.65×10^{-8}	0.003
Ni	7.00×10^{-9}	7.58×10^{-4}	1.29×10^{-9}	0.001	9.00×10^{-9}	9.75×10^{-4}	1.66×10^{-9}	0.001	5.83×10^{-9}	6.32×10^{-4}	1.08×10^{-9}	9.72×10^{-4}
Sum (HI)	6.81×10^{-7}	0.008	1.26×10^{-7}	0.012	5.85×10^{-7}	0.005	1.08×10^{-7}	0.008	5.59×10^{-7}	0.007	1.03×10^{-7}	0.01
Ingestion exposure												
Fe		9.83^{-6}		7.95×10^{-5}		3.17×10^{-6}		2.57×10^{-5}		2.51×10^{-6}		2.04×10^{-5}
Mn		9.67^{-7}		7.83^{-6}		7.74×10^{-7}		6.26×10^{-6}		1.13×10^{-6}		9.13×10^{-6}
B		8.56^{-5}		6.93×10^{-4}		6.76×10^{-5}		5.47×10^{-4}		4.74×10^{-6}		3.84×10^{-5}
Zn		3.17^{-5}		2.5644		9.57×10^{-6}		7.74×10^{-5}		4.81×10^{-6}		3.90×10^{-5}
Pb	4.87×10^{-8}	6.96^{-5}	4.73×10^{-8}	5.636	4.33×10^{-8}	6.19×10^{-5}	4.21×10^{-8}	5.00×10^{-4}	4.96×10^{-8}	7.09×10^{-5}	4.82×10^{-8}	5.74×10^{-4}
Cr	1.06×10^{-7}	9.93^{-5}	1.03×10^{-7}	8.04×10^{-4}	9.67×10^{-8}	9.03×10^{-5}	9.39×10^{-8}	7.31×10^{-4}	8.06×10^{-8}	7.52×10^{-5}	7.83×10^{-8}	6.09×10^{-4}
Cd	1.11×10^{-7}	2.44×10^{-4}	1.08×10^{-7}	0.002	6.19×10^{-8}	1.35×10^{-4}	6.01×10^{-8}	0.001	7.22×10^{-8}	1.58×10^{-4}	7.01×10^{-8}	0.001
As	8.70×10^{-8}	2.71×10^{-4}	8.45×10^{-8}	0.002	5.80×10^{-8}	1.81×10^{-4}	5.64×10^{-8}	0.001	1.45×10^{-7}	4.51×10^{-4}	1.41×10^{-7}	0.004
Ni	1.14×10^{-8}	3.79×10^{-6}	1.10×10^{-8}	3.07×10^{-5}	1.46×10^{-8}	4.87×10^{-6}	1.42×10^{-8}	3.95×10^{-5}	9.48×10^{-9}	3.16×10^{-6}	9.21×10^{-9}	2.56×10^{-5}
Sum (HI)	3.65×10^{-7}	8.15×10^{-4}	3.54×10^{-7}	0.007	2.75×10^{-7}	5.54×10^{-4}	2.67×10^{-7}	0.004	3.57×10^{-7}	7.72×10^{-4}	3.47×10^{-7}	0.006
Dermal contact exposure												
Mn		1.91×10^{-9}		1.42×10^{-10}		1.53×10^{-9}		9.45×10^{-10}		9.53×10^{-10}		4.13×10^{-8}
Zn		1.34×10^{-7}		9.95×10^{-9}		4.04×10^{-8}		2.50×10^{-8}		2.22×10^{-9}		9.64×10^{-8}
Pb	7.39×10^{-10}	3.43×10^{-9}	5.49×10^{-11}	2.55×10^{-10}	6.57×10^{-10}	3.05×10^{-9}	4.88×10^{-11}	1.89×10^{-9}	7.53×10^{-10}	3.50×10^{-9}	3.92×10^{-9}	1.52×10^{-7}
Cr	6.45×10^{-8}	4.13×10^{-8}	4.80×10^{-9}	3.12×10^{-9}	5.87×10^{-8}	3.81×10^{-8}	4.36×10^{-9}	2.36×10^{-8}	4.89×10^{-8}	3.18×10^{-8}	2.54×10^{-7}	1.38×10^{-6}
Cd	6.76×10^{-9}	1.37×10^{-8}	5.02×10^{-10}	1.02×10^{-9}	3.75×10^{-9}	7.66×10^{-9}	2.79×10^{-10}	4.72×10^{-9}	4.38×10^{-9}	8.90×10^{-9}	2.28×10^{-8}	3.86×10^{-7}
As	3.96×10^{-9}	3.43×10^{-9}	2.94×10^{-10}	2.55×10^{-10}	2.64×10^{-9}	2.29×10^{-9}	1.96×10^{-10}	1.42×10^{-9}	6.60×10^{-9}	5.72×10^{-9}	3.43×10^{-8}	2.48×10^{-7}
Ni	4.31×10^{-9}	6.67×10^{-8}	3.20×10^{-10}	4.96×10^{-9}	5.54×10^{-9}	8.58×10^{-8}	4.12×10^{-10}	5.31×10^{-8}	3.59×10^{-9}	5.56×10^{-8}	1.87×10^{-8}	2.41×10^{-6}
Sum (HI)	8.03×10^{-8}	2.65×10^{-7}	5.97×10^{-9}	1.97×10^{-8}	7.13×10^{-8}	1.79×10^{-7}	5.30×10^{-9}	1.11×10^{-7}	6.42×10^{-8}	1.09×10^{-7}	3.34×10^{-7}	4.71×10^{-6}

4 Conclusion and Recommendations

4.1 Conclusion

The present study has assessed the level of PM_{10} and trace elements bound in PM_{10} during the baking of *Injera* using clean, improved, and traditional stoves. The amounts of PM_{10} emissions found in this study using the clean stove was lower than the levels found using the improved and traditional stoves. Thus, the *Injera* baker is subjected to a lower degree of PM_{10} pollutant exposure using clean stove and hence less susceptible to health risk due to PM_{10}. The concentration of PM_{10} found in the traditional stove was high, such that the contribution to the total chronic intake was very high. Hence, the long-term consequence of these exposures to women, who do most of the *Injera* baking using traditional stove, could be significant. The health risk assessment due to the inhalation of emitted PM_{10} bound heavy metals for the limited exposure period showed that the LCR of the three types of stoves were unlikely to cause adverse health effects. Furthermore, both individual and total non-carcinogenic risk values of the measured elements through inhalation, ingestion, and dermal contact during the baking of *Injera* using clean, improved, and traditional stoves were found below 1 for both children and adults, which indicates that elemental exposure bound in PM_{10} found in this study during baking of *Injera* may not induce any non-cancer health problems.

4.2 Recommendations

Indoor air quality can be improved through changes in fuels used (such as reduction of biomass fuel), improving of ventilation of the kitchen, and using improved combustion technology. This study has provided the information related to the exposure level of PM_{10} during the baking of *Injera* and estimating of the health impacts of the baker due to lifelong exposure to the selected trace elements bound in PM_{10}, despite some shortcomings. First, although measuring the pollutant levels and exposure levels along with examining the different hazards was more realistic to estimate the health impacts of the exposed person, this study has some limitations. The health impact estimates were limited to the concentration measurement of trace inorganic elements bound to PM_{10} only. Organic pollutants, such as polyaromatic hydrocarbons, are frequently detected in particulate matter emitted from biomass combustion. Second, the amount and the type of chemical substance present in the smoke of biomass fuel (wood, leaves, sawdust, tree branch) depend on the moisture content of the fuel, the species of plant that the fuel originated from, and the amount of fuel used. However, these aspects were not studied and this shortcoming will be addressed in a future work. Third, biomass smoke can emit different pollutants other than PM_{10} and the trace elements measured. Further work should be done on the health aspects of chronic exposure to other substances bound in PM_{10} (such as polyaromatic hydrocarbons) along with the measurement of some health issues. Fourth, there are other traditional cooking activities other than baking *Injera* (such as traditional coffee ceremony, distillation, and making processes of traditional alcoholic beverages including *Tella*, *Areki*, *Keribo*, and others), which might have high indoor air pollution contribution. So, further work should be done in the measurement of different pollutants along with different health examinations during such cooking activities.

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Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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