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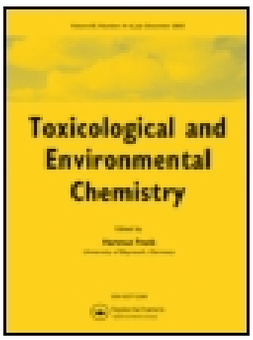
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Health risk assessment of trace elements through exposure of particulate matter-10 during the cooking of Ethiopian traditional dish sauces

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ABSTRACT

This study was aimed to analyze trace elements in the particulate matter-10 and evaluate their health risks during the cooking of the most widely consumed Ethiopian traditional dish sauces (*Wots*) using charcoal, kerosene and electricity stoves. The trace elements (iron, cadmium, arsenic, chromium, lead, boron, nickel, cobalt, tin, copper and zinc) in the particulate matter-10 were found in the range 0.001–0.175 μg m^{-3}. The human health risk assessment has done based on the United States Environmental Protection Agency prescription. The hazard quotient and hazard index values using charcoal, kerosene and electricity stoves were found below 1. This result showed that the inhabitants stay at any of these three microenvironments has no likelihood to have non-cancer health problems. In addition, the life time cancer values for all trace elements were below the tolerable range set by United States Environmental Protection Agency, except chromium, cadmium and arsenic which were found within the tolerable range. Furthermore, the total sum of eleven determined elements was calculated, and the highest concentration was observed using kerosene stove followed by charcoal and electricity stoves, respectively. The use of kerosene and charcoal stove were not the recommended stove as compared to electricity stove for the cooking of *Wot*.

Abbreviations: AT: averaging time; AF: adherence factor; ABS: absorption factor; ANOVA: analysis of variance; BW: body weight; CME: charcoal microenvironment; Dinh: doses through inhalation; Dinge: doses through ingestion; Dder: doses through dermal contact; ED: exposure duration; EF: exposure frequency; ELCRi: excess lifetime cancer risk for trace metal i; EME: electricity microenvironment; G: gastrointestinal absorption factor; HI: hazard index; HQ: hazard quotient; InhR: inhalation rate; IUR: inhalation unit risk;

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Sauces; Wot; particulate matter; elemental composition; health risk assessment; fuel type

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LOD: limit of detection; LCR: lifetime cancer risk; LCR: lifetime cancer risk; MEs: microenvironments; PAHs: polycyclic aromatic hydrocarbons; PM_{10}: particulate matter-10; RfD: reference dose; SA: surface area; SF: slope factor; KME: kerosene microenvironment

1. Introduction

Indoor air can be polluted from different sources such as combustion of biomass fuels, tobacco smoking, outdoor air pollutants, emissions from construction materials and furnishings, products for household cleaning and maintenance, cosmetics for personal care, combustion of oil, kerosene and coal (WHO 2010; Ferrante et al. 2015; Godson Rowland, Mayowa, and Adekunle 2015; Onabowale and Owoade 2015). Among these sources, cooking using biomass fuel especially in a low efficient stove can emit large amount of pollutants that makes the indoor air pollution concentration high (Balakrishnan et al. 2004; Leung 2015; Bo et al. 2017).

In Ethiopia, biomass wood is the primary fuel used in rural area for cooking activities, whereas charcoal is the second fuel next to electricity in urban areas for cooking. Kerosene is also used as a major fuel source by the residents in capital Addis Ababa which is around 42% of the total fuel used in the city (Kebede and Kiflu 2014; Tefera et al. 2016).

The prominent air pollutants resulted from large incomplete combustion of the biomass fuel and biofuels were particulate matters, black carbon, nitrous oxides, sulfur oxides and polycyclic aromatic hydrocarbons (PAHs) (Ranabhat et al. 2015; Shen et al. 2015). Particulate matter contains many hazardous chemical substances including volatile or semi-volatile organic species (e.g. PAHs, nitro-PAHs, quinones), transition metals (iron, nickel, vanadium, copper, etc.), ions (sulfate, nitrate, acidity), and reactive gases (ozone, peroxides, aldehydes). Because of this particulate matter with different aerodynamic diameter are the major health concern of the world now a days (Schwarze et al. 2006; Crilley et al. 2014; Zajusz-Zubek, Kaczmarek, and Mainka 2015). Aggravating carcinogenesis, teratogenesis and mutagenesis are the major health problems caused by the chemical constituents of particulate matter called trace elements (Mohanraj, Azeez, and Priscilla 2004; Chen et al. 2015; Cheng et al. 2017, 2018). The type and the amount of elements found in particulate matter are the major factors to determine the type and the severity of infected person. The trace element determination and the identification in particulate matter are so vital for understanding their effect on human health. The concentrations of trace elements vary across the size of particulate matter (Mohanraj, Azeez, and Priscilla 2004).

Mohanraj, Azeez, and Priscilla (2004) reported that 70–90% of the heavy metals (such as Cu, Cd, Ni, Zn, and Pb) are found in PM_{10} fraction, such that (Mohanraj, Azeez, and Priscilla 2004) the present study was focused on the determination of the concentration of various trace elements bound in PM_{10}. That is why this study is focused in PM_{10}.

Nowadays, studies on the air pollution and its health impact relation are focused on pollutants measurement at different microenvironments (MEs). This is because the measurement of air pollutants at a fixed place does not predict accurate exposure assessment. In addition, the role of each microenvironment to the exposed person using fixed place measurement is not well known. This is because, the person is not staying at the fixed place for 24 h. The best solution to overcome to such problems is doing personal exposure assessment at different microenvironments (Levy et al. 2000; Devi et al. 2009; Cattaneo et al. 2010; Rabinovitch et al. 2016).

Estimating the health burden of exposed person, calculating the contribution level of various activities to the total daily exposure and developing strategies for the management at the individual activities were vital for exposure assessments. Nevertheless, most of the previous works conducted in Ethiopia have demonstrated the exposure assessment at fixed site measurement (Etyemezian et al. 2005; Gebre, Feleke, and Sahle-Demissie 2010; Sanbata, Asfaw, and Kumie 2014). In addition, they have a limited information related to the quantification and assessment of short-term exposure (from one hour to several hours) to trace elements bound in PM_{10} that come from different cooking activities. Among the cooking activities, cooking *Wot* is the most frequently and widely practiced in almost all households in Ethiopia (Kume et al. 2011). Therefore, in this work, cooking *Wot* using different fuel types has been selected to investigate the mass concentration of PM_{10} and amount trace elements bound in it. The carcinogenic and non-carcinogenic health risk assessments due to the trace elements in PM_{10} were also investigated in this work.

2. Materials and methods

2.1. Description of the study area

Addis Ababa (the capital city of Ethiopia) is the center of political, economic, cultural, and transportation in the central part of Ethiopia. Approximately 5 million peoples are living in the city. The growth rate of the city has estimated as 2.1% (Do et al. 2013; Aschale et al. 2017). Both small- and large-scale industries are found in Addis Ababa. It is situated at an altitude varying between 2200 and 2800 m, and between

latitude 9.0300°N and longitude 38.7400°E. The city is surrounded by mountains in the north and northwest. Average minimum and maximum annual temperatures range from 9.53 to 23.2 °C, and the average annual rainfall is 1170 mm (Sanbata, Asfaw, and Kumie 2014).

The three representative sub-cities (namely Arada, Gulelle and Akaki Kality) were selected as sampling sites based on altitude differences, socio-economic activities and population density variation. Arada sub-city is manly characterized by high population density, relatively medium traffic intensity, medium altitude and no industries. Gulelle sub-city is characterized with very few industries, medium traffic intensity, high altitude, low population density than Arada sub-city, whereas Akaki Kality sub-city is characterized by low population density than from all sub-cities, low altitude, heavy industrial activities and high traffic congestion (Embiale et al. 2019a). A total of 45 private households (15 households from each sub-city) were selected randomly. The kitchens' construction materials were wood wall, ceramic floor and roof of corrugated iron, which are typical for low- and middle-income people in Addis Ababa and also in most Ethiopian cities. The preliminary survey showed that lentil (*Misir Wot, in Amharic*), pea (*Shiro Wot, in Amharic*) and potato (*Dinich Wot, in Amharic*) were the most commonly sauce consumed by most of low- and middle-income people. Thus, only these types of sauces were considered in this work.

2.2. Sampling and mass determination of PM_{10}

A total of 180 samples (60 samples for each stove) were collected between 15 June and 30 August 2017 for the wet season and 30 September and 15 November 2017 for the dry season in 4 rounds. The dry and wet seasons were selected because the concentration of pollutants highly depends on seasonal variation. A portable Institute of Occupational Medicine (IOM) multi-fraction dust samplers called Universal Air Pump (SKC 224-PCTX4 Model, SKC Ltd, Blandford Forum, UK) was used to collect the PM_{10}. A vacuum pump (used to suck the air), an internal flow regulator (used to indicate the flow), timer and air flow calibration unit (rotameter) are its main components. A high-precision rotameter) was used to adjust the air flow (to 2.2 L min^{-1}) in the lab before it was taken to the field. The flow rate was also checked immediately on return to the laboratory.

The cooking of *Wot* was performed at sitting position. Hence, the sampler was put 1 m above the ground, 1 m from the stove (to protect the sampler damage) during sampling, which is considered as the most appropriate breathing zone of cooker. The sampling time was started

1 min after starting cooking and ended when the cooking was finished. All other activities other than cooking *Wot* were stopped to prevent their interferences. The sampling event was lasted 3, 3.5 and 3.4 h per day at electricity, charcoal and kerosene stove, respectively.

PM_{10} were loaded on the glass microfiber filters with a diameter of 25 mm GF/A (Whatman®, GE Healthcare Limited, Amersham, UK), which was put inside the universal sampler. The filters used for sampling and blank were oven dried at 150 °C for 2 h before going to field for sampling to remove the humidity and volatile organic compounds on it. After the sampling was over, both the loaded and unused filters were wrapped in aluminum foil and returned to the laboratory and put it in a desiccator after measuring their masses by using an analytical balance with 0.001 mg sensitivity (AT 250, Mettler-Toledo, Toledo, OH). The mass of PM_{10} collected during a given period of time was obtained from the difference between the weight of the filter before and after sampling, and the results were expressed as micrograms of PM_{10} per cubic meter.

2.3. Sample preparation method for elemental analysis

The eleven trace elements (Mn, Cd, Co, B, As, Ni, Cr, Pb, Zn, Cu and Fe) in PM_{10} were extracted by using the standard procedure developed by US EPA, which mainly uses aqua-regia mixture for digestion. The total 60 filters were divided into three to start the extraction procedure. The PM_{10}-loaded Whatman glass microfiber filter papers were taken into round bottom flask (100 mL) fitted with reflux condenser and Kjeldahl digestion block (Kjeldatherm, Gerhardt GmbH and Co.KG, Type KB 40 S, Bonn, Germany). The mixture of 5 mL concentrated nitric acid (69–71% Sigma-Aldrich, Darmstadt, Germany) and 15 mL concentrated hydrochloric acid (37%, Sigma-Aldrich, Darmstadt, Germany) were added. The mixture was heated at 150 °C for 1 h, and the extracted solution was filtered using the cellulose filter (Whatman I), and adjusted to a final volume of 20 mL using de-ionized water. Finally, the solution was put in refrigerator until the trace elements were analyzed 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). The triplicate unused filter blanks were also processed following the similar procedure for sample treatment (Leili et al. 2008). Commercial 1000 mg L^{-1} standard solution of each element (UNI-CHEM, chemical reagents) was used for the preparation of the calibration solutions. The concentrations of each element bound in PM_{10} were obtained using Equation (1). The humidity and the temperature were monitored using an Electronic Thermo-5 Hygrometer (Thermo, Waltham, MA):

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

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

2.4. Trace elements determination

A series of working standard solution of elements 0, 0.5, 1, 2, 3, 4 and 5 μg mL^{-1} for Cu, Mn, Cd, Sn, As, Ni, Pb, Fe, Cr, Co and 0, 1, 2, 3, 6, 8 and 10 μg mL^{-1} for B were prepared by appropriate dilution with 2% HNO_3 of 1000 mg mL^{-1} stock solution. The linearity of calibration curves (the detector response) for quantified elements at all microenvironments were $r^2 > 0.9897$. Limit of detection (LOD) was determined using each analyte ion based on three times the standard deviation (3σ) of the blank. The calibrations curve and LOD for detected elements are summarized in Table 1. The performance of the method was tested by recovery test through standard addition, and the results were found in the range of 92–110%. The average recoveries of each element corresponding with their standard deviation were 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. Health risk assessment

Hazard identification, exposure assessment, dose–response (toxicity) and risk characterization are the major steps followed in health risk

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 m^{-3}
Fe	$y = 0.36x + 1027$	0.9997	0.0001
Cu	$y = 0.92x + 4470$	0.9989	0.00007
Mn	$y = 1.71x + 782$	0.9999	0.00002
B	$y = 0.08x + 892$	0.9976	0.0005
Zn	$y = 0.21x + 1034$	0.9919	0.00007
Pb	$y = 0.05x + 633$	0.9897	0.001
Cr	$y = 0.46x + 998$	0.9912	0.0002
Cd	$y = 1.47x + 626$	0.9973	0.0002
Sn	$y = 0.07x + 198$	0.9975	0.003
As	$y = 0.08x + 144$	0.9975	0.002
Ni	$y = 0.24x + 1445$	0.9952	0.001
Co	$y = 0.11x + 1085$	0.9975	0.0001

assessment. The cancer and non-cancer risk assessment were performed. Cancer in general and lung cancer in particular is the major cause for the deaths of many peoples around the globe. Heavy metals found in the polluted air are one of the causes for lung cancer, even they are found in trace levels. The different element species have different toxicities, concentration and mobility behavior in air (Mohanraj, Azeez, and Priscilla 2004; Izhar et al. 2016; Bamuwamye et al. 2017; Benson et al. 2017; Liu et al. 2017; Liu, Shang, and Wan 2018). The extent of risk due to polluted air depends on the exposure pathways. Inhalation, ingestion and dermal adsorption routes are the three exposure pathways of trace elements found in the air (Sidhu et al. 2017). The elements under consideration in this study were classified as carcinogenic (Cd (Group B1, probable human carcinogen), As and Cr(VI) (Group A, human carcinogen), Pb (Group B2, probable human carcinogen) and Ni (Group A, human carcinogen)) and noncarcinogenic (Cu, Fe, Zn, B and Mn) (Kushwaha et al. 2012; Ali et al. 2017; Liu et al. 2017; Liu, Shang, and Wan 2018).

The carcinogenic and non-carcinogenic risks of children and adults at the sampling ME due to elements in PM_{10} were assessed. Hazard index (HI) and the hazard quotient (HQ) method were used for the estimation of non-cancer risk of elements bound in PM_{10}. Hazard index (HI) deals about the exposure risk evaluation of only one element. Whereas, hazard index (HI) indicates the sum of risks of multiple elements. According to US EPA, if the HQ is <1 then non-cancerous effects are unlikely, if the HQ is ≥ 1, then adverse health effects might be possible. If the HQ is >10, then it suggests the high chronic risk. Total excess lifetime cancer risk (LCR) is used for carcinogens at the equivalent of hazard index (HI) which is used for non-carcinogens effect. The US EPA's methodology as expressed in Equation (2–8) were used for calculating HQ and HI (Zmijková, Koliba, and Raclavsky 2017; Liu, Shang, and Wan 2018; Chalvatzaki et al. 2019). The assessment helps to understand the severity of the health risks at each stove type during cooking *Wot* and to take a remedial action.

The threshold values for cancer risk due to trace metal exposure were given by US EPA. Thus, a total cancer risk associated with exposure to contaminants over a lifetime is greater 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 (Izhar et al. 2016; Benson et al. 2017; Liu, Shang, and Wan 2018):

$$D_{inh} = \frac{C \times InhR \times ED \times EF}{BW \times AT} \quad (2)$$

$$D_{ing} = \frac{C \times IngR \times ED \times EF}{BW \times AT} \times 10^{6} \quad (3)$$

$$D_{der} = \frac{C \times AF \times SA \times ABS \times ED \times EF}{BW \times AT} \times 10^{6} \quad (4)$$

$$HQ = \frac{D}{RfD} \quad (5)$$

$$HI = \sum HQ \quad (6)$$

$$ELCR_{tot} = \sum ELCR_{i} \quad (7)$$

$$LCR \ or \ CR = D_{inh} \times IUR = D_{ing} \times SF = D_{der} \times \left(\frac{SF}{G}\right) \quad (8)$$

where ED is the exposure duration (years); D_{inh}, D_{inge} and D_{der} are daily doses through inhalation (mg kg^{-1} day^{-1}), ingestion (mg kg^{-1} day^{-1}) and dermal contact (mg kg^{-1} day^{-1}), respectively; InhR is the inhalation rate (m^3 day^{-1}), C is the concentration of elements (μg m^{-3} or mg kg^{-1}), EF is the exposure frequency (day $year^{-1}$), BW is the body weight (kg), AT is the averaging time (years), LCR is the lifetime cancer risk; SF is the slope factor (mg kg^{-1} d^{-1}); AF is the skin adherence factor (mg cm^{-2} day^{-1}); 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}) which is used to estimate the daily exposure below which adverse non-cancer health effects are unlikely; $ELCR_i$ is the excess lifetime cancer risk for trace metal I; ABS is the dermal absorption factor (unitless), SA is the surface area (cm^2)and G is the gastrointestinal absorption factor. The parameter considered for health risk assessments due to trace element concentration at all microenvironments are given in Tables 2 and 3.

2.6. Statistical package used in data analysis

The obtained data analysis was carried out using IBM SPSS version 20.0, Microcal™Origin version 16.0 (Miracle Software Inc., Novi, MI) and Microsoft Excel 2013. Analysis of variance (ANOVA) was also used to evaluate the PM_{10} and trace elements concentration differences across

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

	Values	
Parameters	Children	Adults
InhR (m^3 day^{-1})	7.6	20
ED (year)	6	30
EF (days $year^{-1}$)	(50/50/43)[a]	(50/50/43)[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]The exposure of frequency in using charcoal/kerosene/electricity.

stove type during the cooking of *Wot*. The significant difference for all the tests was set to 0.05.

3. Results and discussion

The amount of PM_{10} and elements bound in PM_{10} were reported in the three microenvironments (MEs). The classification was based on the fuel type used (namely: room using charcoal (CME, charcoal microenvironment), room using kerosene (KME, kerosene microenvironment) and room using electricity (EME, electricity microenvironment)).

3.1. The characteristics of the households and type of Wot

The ventilation type, kitchen volume and location of kitchen from living room were recorded. Of the total number of kitchens, 43 of the kitchen have used only door ventilation, whereas 2 of the kitchen used window ventilation in addition to door during the sampling time. The family size and the kitchen volume were ranged 1–6 and 4.36–46.9 m^3, respectively. As far as the location of the cooking place is concerned, 12 cooking sites were found in the separated area from the living room and the rest of the cooking places were found inside the living room. The temperature and the humidity of the kitchen room during the sampling time at CME, KME and EME were 22.0, 21.5, 21.7 °C and 57.2%, 55.0%, 51.4%, respectively.

Moreover, regarding the type of *Wot*, 32, 9, 4 and 31, 10, 4 households were preparing *Shiro*, *Misir* and *Dinich Wot* during the dry and the wet season, respectively. The details of ventilation type, the ventilation area and the condition of the ventilation were reported at the previous work (Embiale et al. 2019b).

Table 4. PM_{10} bound elemental composition (mean ± SD, in μg m^{-3}) and PM_{10} mass concentration (μg m^{-3}) during the cooking of Wot at CME, KME and EME, and the guidelines of different metals set by different organization (Lopez et al. 2005).

Pollutants	CME	KME	EME	Guideline values
PM_{10}	173 ± 42.8	161 ± 5.61	91.0 ± 17.8	
Fe	0.023 ± 0.006	0.023 ± 0.008	0.013 ± 0.005	
Cu	0.005 ± 0.001	0.01 ± 0.005	0.008 ± 0.011	
Mn	0.001 ± 0.0004	0.004 ± 0.004	0.001 ± 0.0004	0.15[a]
B	0.109 ± 0.105	0.025 ± 0.006	0.052 ± 0.0368	
Zn	0.020 ± 0.006	0.175 ± 0.009	0.058 ± 0.091	
Pb	0.007 ± 0.008	0.016 ± 0.001	0.003 ± 0.002	1.5[b]
Cr	0.003 ± 0.002	0.006 ± 0.004	0.002 ± 0.001	
Cd	0.003 ± 0.002	0.01 ± 0.003	0.0007 ± 0.0005	0.005[a,c]
Sn	0.003 ± 0.001	0.009 ± 0.007	0.001 ± 0.0007	
As	0.002 ± 0.002	0.019 ± 0.003	0.005 ± 0.004	1[a], 0.006[c]
Ni	0.006 ± 0.004	0.025 ± 0.001	0.004 ± 0.005	0.02[c], 1[a]
Co	0.003 ± 0.002	0.003 ± 0.003	0.001 ± 0.003	

[a]The guideline set by WHO at 2010.
[b]The guideline set by National Ambient Air Quality Standard.
[c]The guidelines set by European Commission.

3.2. Pm_{10} concentration

The concentrations of PM_{10} measured at the EME, KME and CME were 91, 161 and 173 μg m^{-3}, respectively. The maximum PM_{10} emission value was observed at CME, whereas the minimum was found at EME. One-way ANOVA, based on the *F*-test, was used to detect significant differences in concentration among the microenvironments, which showed a significant difference between EME from KME and CME. However, PM_{10} mass concentration at KME and CME showed that it was not significant. The mean concentration of PM_{10} and trace elements bound in PM_{10} at EME, KME and CME are given in Table 4.

3.3. Trace element concentration

The concentration of trace elements found in PM_{10} sampled during the cooking of *Wot* using biomass (particularly charcoal), fossil fuels (particularly kerosene) and electricity was 001–0.109; 0.003–0.175 and 0.0007–0.058 μg m^{-3}, respectively. B is found to be the highest amount of elements during the use of charcoal, whereas Zn is the highest during the use of kerosene and electricity. The lowest concentration of elements found during the use of charcoal, kerosene and electricity was Mn, Co and Cd, respectively. The details of the result are given in Table 4. The general patterns of each element's concentration followed in CME, KME and EME were Mn < Cr < Cd < Co < As < Sn < Cu < Ni < Pb < Zn < B; Co < Mn < Cr < Sn < Cu < Cd < Pb < As < Fe < B < Ni < Zn and Cd < Co < Mn < Sn < Cr < Pb < Ni < As < Cu < Fe < B < Zn, respectively. This trend showed that most of the toxic trace elements including Cd, Mn, Sn, Cr, As, Cu were high at KME. Cd, As and Ni concentration

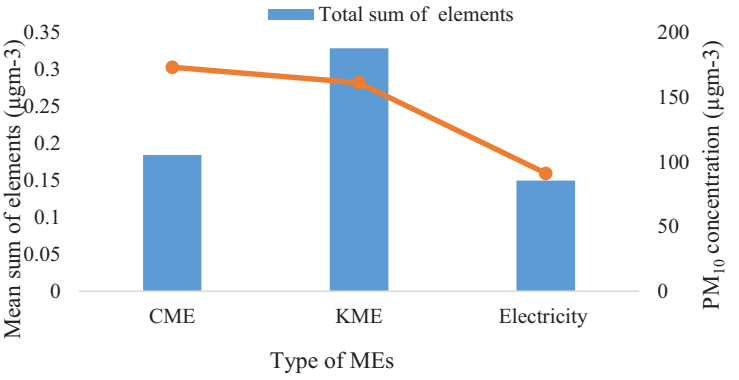


Figure 1. The total sum concentration of elements across fuel types.

at KME were found above the acceptable values set by WHO and National Ambient Air Quality Standard (Lopez et al. 2005).

The trace elements concentration found at CME, KME and EME were compared using ANOVA. The results indicate that the means of Cd, Zn, As and Ni showed a significantly different ($p < 0.05$) across fuel types, however, the difference is not recognized where it occurred. Thus, a separate comparison was done, and Zn, Cd, As and Ni showed a significant difference ($p < 0.05$) when charcoal and kerosene fuel were compared. Pb, Cd, As and Ni have also shown a significant difference ($p < 0.05$) when kerosene was compared with electricity. The comparison of charcoal fuel to electricity fuel showed no significant difference in their elemental concentration emissions. The variation in concentration across the tasted microenvironments might be due to difference in infiltration from outdoor through natural and mechanical ventilation, decomposition of trace elements containing paints and from resuspended of soil dust (Estokova, Stevulova, and Kubincova 2010).

The total sum of eleven analyzed elements (Σelements) is shown in Figure 1. The highest concentration is observed in kerosene followed by charcoal and electricity, respectively. However, the highest concentration of PM_{10} is observed in charcoal fuel followed by kerosene and electricity.

3.4. Carcinogenic and non-carcinogenic risk assessment at CME, KME and KME

The carcinogenic and non-carcinogenic risk at different pathways were calculated for inhabitants at different age groups that spent some of his/her daily time during the cooking of *Wot* using charcoal, kerosene and electricity. The details of the results are given in Table 5.

Table 5. Carcinogenic and non-carcinogenic risks of each element for children and adults via inhalation, ingestion, and dermal exposure during the cooking of *Wot* using charcoal, kerosene and electricity fuels.

Charcoal					Kerosene				Electricity			
Adults			Children		Adults		Children		Adults		Children	
Types of element	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Inhalation exposure												
Cu		5.64×10^{-6}		8.68×10^{-6}		1.12×10^{-5}		1.73×10^{-5}		7.76×10^{-6}		1.19×10^{-5}
Mn		4.51×10^{-4}		6.94×10^{-4}		0.004		0.006		7.76×10^{-4}		0.001
Zn		3.00×10^{-6}		4.61×10^{-6}		2.62×10^{-5}		4.04×10^{-5}		7.48×10^{-6}		1.15×10^{-5}
Pb	1.94×10^{-8}	8.98×10^{-5}	3.59×10^{-9}	1.38×10^{-4}	4.44×10^{-8}	2.05×10^{-4}	8.20×10^{-9}	3.15×10^{-4}	7.17×10^{-9}	3.31×10^{-5}	1.32×10^{-9}	5.0910^{-5}
Cr	1.25×10^{-6}	0.001	2.31×10^{-7}	0.002	2.50×10^{-6}	0.003	4.61×10^{-7}	0.004	7.17×10^{-7}	7.76×10^{-4}	1.32×10^{-7}	0.001
Cd	1.87×10^{-7}	0.01	3.46×10^{-8}	0.021	8.12×10^{-7}	0.059	1.50×10^{-7}	0.090	5.37×10^{-8}	0.004	9.92×10^{-9}	0.006
As	4.48×10^{-7}	0.009	8.26×10^{-8}	0.014	2.84×10^{-6}	0.057	5.23×10^{-7}	0.088	6.42×10^{-7}	0.013	1.18×10^{-7}	0.020
Ni	5.00×10^{-8}	0.005	9.23×10^{-9}	0.008	2.08×10^{-7}	0.023	3.84×10^{-8}	0.035	2.87×10^{-8}	0.003	5.29×10^{-9}	0.005
Sum (HI)	1.95×10^{-6a}	0.030	3.61×10^{-7a}	0.046	6.40×10^{-6a}	0.145	1.18×10^{-6a}	0.223	1.45×10^{-6a}	0.022	2.67×10^{-7a}	0.033
Ingestion exposure												
Fe		$7.42 \times 10^{--6}$		6.00×10^{-5}		7.42×10^{-6}		6.00×10^{-5}		3.60×10^{-6}		2.92×10^{-5}
Cu		2.82×10^{-5}		2.28×10^{-4}		5.64×10^{-5}		4.57×10^{-4}		3.88×10^{-5}		3.14×10^{-4}
Mn		8.06×10^{-7}		6.52×10^{-6}		6.45×10^{-6}		5.21×10^{-5}		1.38×10^{-6}		1.12×10^{-5}
B		1.22×10^{-4}		9.95×10^{-4}		2.82×10^{-5}		2.28×10^{-4}		5.04×10^{-5}		4.08×10^{-4}
Zn		1.50×10^{-5}		1.22×10^{-4}		1.32×10^{-4}		1.07×10^{-4}		3.75×10^{-5}		3.04×10^{-4}
Pb	3.16×10^{-7}	4.50×10^{-4}	3.07×10^{-7}	0.004	7.22×10^{-7}	0.001	7.01×10^{-7}	0.008	1.16×10^{-7}	1.66×10^{-4}	1.13×10^{-7}	0.001
Cr	2.42×10^{-7}	2.26×10^{-4}	2.35×10^{-7}	0.002	4.84×10^{-7}	4.51×10^{-4}	4.70×10^{-7}	0.004	1.39×10^{-7}	1.29×10^{-4}	1.35×10^{-7}	0.001
Cd	3.10×10^{-7a}	6.77×10^{-4}	3.01×10^{-7a}	0.005	1.34×10^{-6a}	0.003	1.30×10^{-6a}	0.024	8.88×10^{-8a}	1.94×10^{-4}	8.62×10^{-8a}	0.002
As	7.25×10^{-7}	0.002	7.05×10^{-7}	0.020	4.59×10^{-6}	0.014	4.46×10^{-6}	0.116	1.04×10^{-6}	0.003	1.01×10^{-6}	0.026
Ni	8.12×10^{-8}	2.70×10^{-5}	7.89×10^{-8}	2.19×10^{-4}	3.39×10^{-7}	1.13×10^{-4}	3.28×10^{-7}	9.13×10^{-4}	4.66×10^{-8}	1.56×10^{-5}	4.52×10^{-8}	1.26×10^{-4}
Sum (HI)	1.67×10^{-6a}	0.004	1.63×10^{-6a}	0.031	7.48×10^{-6a}	0.019	7.26×10^{-6a}	0.154	1.43×10^{-6a}	0.004	1.39×10^{-6a}	0.031
Dermal contact exposure												
Cu		1.58×10^{-8}		9.84×10^{-9}		3.17×10^{-8}		1.97×10^{-8}		2.19×10^{-8}		1.48×10^{-8}
Mn		1.59×10^{-9}		9.84×10^{-10}		1.27×10^{-8}		7.87×10^{-9}		2.73×10^{-9}		1.85×10^{-9}
Zn		6.35×10^{-8}		3.94×10^{-8}		5.56×10^{-7}		3.44×10^{-7}		1.58×10^{-7}		1.07×10^{-7}
Pb	4.79×10^{-9}	2.22×10^{-8}	3.56×10^{-10}	1.38×10^{-8}	1.09×10^{-8}	5.08×10^{-8}	8.14×10^{-10}	3.15×10^{-8}	1.77×10^{-9}	8.19×10^{-9}	1.43×10^{-10}	5.55×10^{-9}
Cr	1.47×10^{-7}	9.53×10^{-8}	1.09×10^{-8}	5.90×10^{-8}	2.93×10^{-7}	1.91×10^{-7}	2.18×10^{-8}	1.18×10^{-7}	8.41×10^{-8}	5.46×10^{-8}	6.83×10^{-9}	3.69×10^{-8}
Cd	1.89×10^{-8}	3.81×10^{-8}	1.40×10^{-9}	2.36×10^{-8}	8.13×10^{-8}	1.65×10^{-7}	6.05×10^{-9}	1.02×10^{-7}	5.38×10^{-9}	1.09×10^{-8}	4.37×10^{-10}	7.40×10^{-9}

(*continued*)

Table 5. Continued.

Charcoal					Kerosene				Electricity			
Adults			Children		Adults		Children		Adults		Children	
Types of element	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
As	3.30×10^{-8}	2.85×10^{-8}	2.45×10^{-9}	1.77×10^{-8}	2.09×10^{-7}	1.81×10^{-7}	1.55×10^{-8}	1.12×10^{-7}	4.73×10^{-8}	4.10×10^{-8}	3.84×10^{-9}	2.77×10^{-8}
Ni	3.08×10^{-8}	4.76×10^{-7}	2.29×10^{-9}	2.95×10^{-7}	1.28×10^{-7}	1.98×10^{-6}	9.53×10^{-9}	1.23×10^{-6}	1.77×10^{-8}	2.73×10^{-7}	1.43×10^{-9}	1.85×10^{-7}
Sum (HI)	2.34×10^{-7a}	7.41×10^{-7}	1.74×10^{-8a}	4.60×10^{-7}	7.23×10^{-7a}	3.17×10^{-6}	5.37×10^{-8a}	1.96×10^{-6}	1.56×10^{-7a}	5.71×10^{-7}	1.27×10^{-8a}	3.86×10^{-7}

[a]represents for $ELCR_{tot}$.

3.4.1. Carcinogenic risk assessment at CME, KME and KME

The carcinogenic risk for adults was predominantly caused by inhalation pathway followed by ingestion exposure and dermal contact pathways during the use of charcoal, whereas ingestion is followed by inhalation and dermal contact pathway for children. The metals including Pb, Cr, Cd, As and Ni exposure through inhalation, ingestion and dermal contact showed a cancer risk values below tolerable range for both children and adults at CME. However, the LCR values for the element Cr, As and Cd for adult; Cd and As for children at KME and As at EME were found within the tolerable range.

The carcinogenic risk at KME is predominantly caused by ingestion exposure pathway followed by inhalation and dermal contact pathways for both children and adult. The heavy metals including Cd and As exposure through ingestion pathway for children showed a cancer risk values within the tolerable range, where other metals including Ni, Cr and Pb were below tolerable range in exposure through both ingestion and dermal contact. Similarly, exposure of Cr and As through inhalation pathway and exposure of Cd and As through ingestion pathway for adult showed carcinogenic risk values within the tolerable range, except Pb and Ni which are below the range in the inhalation and ingestion pathways. Regarding dermal contact exposure pathway, the cancer risk values for Pb, Cd, Cr, As and Ni showed below tolerable range for both children and adults.

Furthermore, the carcinogenic risk at EME is predominantly caused by ingestion exposure pathway followed by inhalation and dermal contact pathways for children, whereas inhalation is followed by ingestion and dermal contact pathway for adults. However, the cancer risk values for Cd, Pb, As and Ni were found below the tolerable range in inhalation, ingestion and dermal contact exposure pathways, except As which is found within the tolerable range in ingestion exposure for both children and adults.

3.4.2. Non-carcinogenic risk assessment at CME, KME and KME

As similar to carcinogenic risk, the non-carcinogenic risks were also varied across the different exposure pathways. The results showed that inhalation exposure pathway is the predominant path followed by ingestion and dermal contact paths for both children and adults at CME, KME and KME. The HQ and HI values of the measured elements through inhalation, ingestion and dermal contact were found below 1 for both children and adults during cooking of *Wot*. This result indicates that both children and adults who stay at CME, KME and KME will not likelihood to have non-carcinogenic health problems.

The total non-carcinogenic health risk due to elemental exposure through the three pathways during cooking of *Wot* at CME, KME and KME were also calculated. The HI sum of each element obtained through each pathway at CME, KME and KME is used for this calculation. Thus, the results of total HI for children at CME, KME and KME were 0.08, 0.38 and 0.06, respectively. This result showed that children could not be induced non-carcinogenic health problems at any of the three MEs. The percent contribution of each exposure pathway for the total risk values (total HI) at CME, KME and KME was also calculated. At CME, inhalation, ingestion and dermal contact exposure pathways for children account to 62.4%, 37.5% and 0.01%, respectively. Similarly, inhalation, ingestion and dermal contact exposure pathways for children at KME and KME were 58.3%, 40.8%, 0.9% and 51.2%, 48.4%, 0.4%, respectively.

A similar calculation was made for adults, and the results of total HI at CME, KME and KME were 0.034, 0.164 and 0.025, respectively. The results showed that adult person stay at CME, KME and KME could not have a likelihood of non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI) is not similar yet. Hence, the inhalation, ingestion and dermal contact exposure pathways account to 88.2%, 11.7% and 0.1%, respectively at CME. Inhalation, ingestion and dermal contact exposure pathways at KME and KME were 85.3%, 12.2%, 2.5% and 80.0, 16.0, 4%, respectively.

4. Conclusion

The total trace elements concentrations in PM_{10} from the sampling ME were in order from the most to the least as follows: KME > CME > EME, whereas, the mass concentration of PM_{10} follows at CME > KME > KME. The finding of the results also confirmed that using electricity is much better in the reduction of exposure to PM_{10} and trace elements in PM_{10}. The inhabitants at KME were more likely affected by non-cancer health problems than at CME. The maximum levels of HI for children and for adults were 0.223 and 0.145, respectively. This result confirmed that children may have more potential non-cancer risk than adults do, although hall values were lower than the acceptable range. The maximum levels of total LCR for adult and children were 6.4×10^{-6} and 1.18×10^{-6} which is above the acceptable level set by US EPA. As a result, a proper care should be taken for minimizing the risks.

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Disclosure statement

The authors declare that there are no conflicts of interest.

Data availability statement

All the data are included in the manuscript. There are no additional data with the authors.

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