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Short-term Exposure Assessments and Elemental Composition of Particulate Matter (PM_{10}) of Urban Indoor and Outdoor Air Pollution at Different Microenvironments in Addis Ababa, Ethiopia

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Short-term Exposure Assessments and Elemental Composition of Particulate Matter (PM_{10}) of Urban Indoor and Outdoor Air Pollution at Different Microenvironments in Addis Ababa, Ethiopia

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This is to certify that the thesis prepared by Asamene Embiale Taye entitled: Short-term Exposure Assessments and Elemental Composition of Particulate Matter (PM_{10}) of Urban Indoor and Outdoor Air Pollution at Different Microenvironments in Addis Ababa, Ethiopia and submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy (Analytical Chemistry) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Chair of Department or Graduate program Coordinator

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II. Abstract

Nowadays air pollution is a major health hazard in the daily life of humans in the world. Estimating personal exposure to air pollution is a crucial thing in identifying high-risk population and identifying controlling strategies. Because of the difficulty of measuring full personal exposure to air pollution patterns of individuals, it is better to measure it at different homogenous microenvironments (MEs) linked with their activities. In this study, short-term exposure and elemental composition analysis of indoor and outdoor air pollutions were carried out at different MEs while doing different activities. A total of 45 households were selected from Akaki Kality, Gulelle and Arada sub-city, Addis Ababa, Ethiopia for the short-term exposure assessment to indoor air pollution. Whereas, ten sub-cities were selected (three sampling points from each) for the exposure assessment to outdoor air pollution during commuting time. The short-term exposure assessment to particulate matter (PMs) in the air samples of different particle size (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} and TSP, total suspended particles) and total volatile organic compounds (TVOCs) under different domestic activities (during baking *Injera*, cooking *Wot*), while sitting at the living room and during commuting time were assessed. PMs and TVOCs were measured by a simple and portable sensor called A ROCET531S and AEROQUAL series 500, respectively. The elemental composition of PM_{10} was analyzed by using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

The level of TVOCs and PMs have been measured during the baking of Ethiopian's traditional staple food *Injera* (a flatbread mostly made from *Teff* flour and baked upon a circular griddle), using electric, improved and traditional stoves. The geometric mean (GOM) of PMs pollutant for the wet and dry seasons during baking *Injera* using clean, improved, traditional stoves were ranged: 37-235; 72.8-462; 50.3-591 μg m^{-3} and 10.8-119; 23.6-265; 36.4-728 μg m^{-3}, respectively.

The GOM of TVOCs for the wet and dry seasons using clean, improved, traditional stoves found were: 1553, 2234, 4421 and 845, 1214, 2662 µg m^{-3}, respectively. The users of clean and improved stoves instead of the traditional stove can reduce the level of exposure to PMs and TVOCs exposure in the range of 12.3-81.7%, which is depending on both the type of pollutant and stove type. Similarly, depending on the type of pollutant, clean stove can reduce the level of exposure to PMs and TVOCs by a minimum of 26.5% and maximum of 51.7% as compared to improved stove.

The GOM of TVOCs and PMs were also measured during cooking of the most widely consumed Ethiopian traditional dish sauces (*Wot,* in Amharic) using different types of fuels namely electricity, charcoal and kerosene. The GOM of PMs for the wet and dry seasons using electricity, kerosene, charcoal fuel were ranged: 11.4-109, 14-134, 21.2-190 µg m^{-3} and 7.68-203, 10.5-198, 15.6-284 µg m^{-3}, respectively. The GOM of TVOCs during the wet and dry seasons using electricity, kerosene and charcoal found were: 350, 706, 1200 and 394, 555, 812 µg m^{-3}, respectively. Using of electricity and kerosene fuels instead of charcoal fuel for cooking *Wot* can reduce the level of exposure to PMs and TVOCs by a minimum of 28.9% and maximum of 62.9%, which is depending on both the pollutant type and fuel type. Similarly, electricity fuel can reduce the level of exposure to PMs and TVOCs by a minimum of 5.23% and maximum of 40.6% as compared to kerosene fuel depending on the type of pollutant.

The GOM of PMs and TVOCs at the living room (when cooking activities were not performed) were also measured and the result of PMs found were ranged: 5.68-99.0 µg m^{-3}, whereas the TVOCs was found 289 µg m^{-3}.

The short-term exposure assessment to outdoor air pollution was also carried out by selecting the sampling points at the main roadside, and the sampling period during the commuting time when

traffic congestion and taxi queue were expected to be high. The GOM of PMs and TVOCs found in the ten sub-cities were ranged 6.79-496 and 220-439 μg m^{-3}, respectively.

The health risk due to exposure to $PM_{2.5}$, PM_{10} and TSP either individual (based on hazard quotient calculation, HQ) or cumulatively (based on hazard index calculation, HI) were performed according to the United States Environmental Protection Agency prescription at each of the selected MEs. Thus, the individual or cumulative $PM_{2.5}$, PM_{10} and TSP exposure during baking *Injera* using any of the stove types (traditional, improved and clean stove) is below one which indicates baking activity only may not have a likelihood to induce health problems. The individual exposure of $PM_{2.5}$, PM_{10} and TSP during coking *Wot* using electricity, kerosene and charcoal fuels also may not have a likelihood to induce health problems, except PM_{10}. Whereas PM_{10} at the individual level can pose non-carcinogenic health problems during cooking *Wot* using the charcoal fuel. However, the cumulative effect might have a likelihood to pose a health impact problems in any of the three fuels types. Similarly, the health risk assessment at the living room was also calculated that both individual and cumulative exposure to $PM_{2.5}$, PM_{10} and TSP at this ME may not have a likelihood to induce any health problems. In addition, both the individual and cumulative exposure to PM_{10} and cumulative exposure to $PM_{2.5}$ and TSP at roadside may have a likelihood to induce health problems to a person who is exposed at least 8 h per day.

Furthermore, trace elements (Fe, Cd, As, Cr, Pb, B, Ni, Co, Sn, Cu and Zn) bound in PM_{10} at kitchen ME during baking of *Injera* using improved, traditional stove and clean stoves were found in the range BLD-632, BLD-0.499 and BLD-0.078 μg m^{-3}, respectively. Whereas their concentration at kitchen ME during cooking of *Wot* using electricity, kerosene and charcoal fuels were found in the range 0.001-0.058, 0.003-0.175 and 0.001-0.109 μg m^{-3}, respectively. Similarly,

their concentration at the living room and at the roadsides MEs were ranged: 0.001-0.026 and 0.013-0.444 μg m^{-3}, respectively.

The carcinogenic and non-carcinogenic risk assessment due to elementals in PM_{10} exposure were also performed at all selected MEs. Hence, Mn, As and Cd are the major elemental pollutants found that have a prominent share in inducing a health problems to exposed children and adults at roadside MEs. Similarly, a person baking *Injera* (using any of clean, improved and traditional stoves), cooking *Wot* (using any of the electricity, charcoal and kerosene fuels) and sitting at living room MEs for an extended period did not have health risk due to measured elements in PM_{10}.

Keywords: fuel type, charcoal, kerosene, electricity, sauces, *Wot*, cook stove, biomass, particulate matter, *Injera*, commuter exposure, elemental composition, health risk assessment, vehicles sources, inductively coupled plasma-optical emission spectroscopy, Addis Ababa, Ethiopia

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V. List of Abbreviations

EPA/USA	Environmental Protection Agency of USA
IAP	Indoor Air Pollution
$\mu g\ m^{-3}$	Microgram per cubic meter
ppm	Parts per million
PMs	PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} and TSP
TVOCs	Total Volatile Organic Compounds
RPM	Respirable Particulate Matter
RSP	Respirable Suspended Particulates
GSD	Geometric Standard Deviation
SSA	Sub-Sahara Africa
TSP	Total Suspended Particles
VOC	Volatile Organic Compound
WHO	World Health Organization
ARI	Acute Respiratory Infection
ALRI	Acute Lower Respiratory Infection
AURI	Acute Upper Respiratory Infection

PM_{10}	Particulate matter with aerodynamic diameter of < 10 microns
$PM_{2.5}$	Particulate matter with aerodynamic diameter of < 2.5 microns
PM_4	Particulate matter with aerodynamic diameter of < 4 microns
PM_7	Particulate matter with aerodynamic diameter of < 7 microns
PM_1	Particulate matter with aerodynamic diameter of < 1 microns
Clean A	Clean stove at Arada sub site
Improved A	Improved stove at Arada sub site
Traditional A	Traditional stove at Arada sub site
Clean G	Clean stove Gulelle sub site
Improved G	Improved stove at Gulelle sub site
Traditional G	Traditional stove at Gulelle sub site
Clean K	Clean stove at Akaki Kality
Improved K	Improved stove at Akaki Kality
Traditional K	Traditional stove at Akaki Kality
Electricity A	Electric fuel at Arada sub site
Charcoal A	Charcoal fuel at Arada sub site
Kerosene A	Kerosene fuel at Arada sub site

Electricity G	Electric fuel at Gulelle sub site
Charcoal G	Charcoal fuel at Gulelle sub site
Kerosene G	kerosene fuel at Gulelle sub site
Electricity K	Electric fuel at Akaki Kality
Charcoal K	Charcoal fuel at Akaki Kality
Kerosene K	Kerosene fuel at Akaki Kality
TR	Temperature of Room
RH	Relative Humidity of Room
GOM	Geometric Mean
GSD	Geometric Standard Deviation
BNEC/ CONAMA	Brazilian National Environmental Council
TB	Tuberculosis
COPD	Chronic Obstructive Pulmonary Diseases
CVD	Cardio Vascular Disease
PAHs	Polyaromatic Hydrocarbons
UFP	Ultra-Fine Particle
EEPA	Ethiopian Environmental Protection Agenesis

ECSA	Ethiopian Central Statistical Authority
USA	United States of America
CA	Clean stove at Arada sub site
IA	Improved stove at Arada sub site
TA	Traditional stove at Arada sub site
CG	Clean stove Gulelle sub site
IG	Improved stove at Gulelle sub site
TG	Traditional stove at Gulelle sub site
CK	Clean stove at Akaki Kality
IK	Improved stove at Akaki Kality
TK	Traditional stove at Akaki Kality
EA	Electric fuel used at Arada sub site
CA	Charcoal fuel used at Arada sub site
KA	Kerosene fuel used at Arada sub site
EG	Electric fuel used at Gulelle sub site
CG	Charcoal fuel used at Gulelle sub site
KG	kerosene fuel used at Gulelle sub site

EK	Electric fuel used at Akaki Kality
CK	Charcoal fuel used at Akaki Kality
KK	Kerosene fuel used at Akaki Kality
GTVOCs	Guidelines for Total Volatile Organic Compounds
ADD	Average Daily Dose
LCR	Life Time Cancer Risk
CR	Cancer Risk
HQ	Hazard Quotient
HI	Hazard Index
RfD	Reference Dose
IUR	Inhalation Unit Risk
SF	Slope Factor
G	Gastrointestinal Absorption Factor.
D_{inh}	Daily Dose through Inhalation
D_{ing}	Daily Dose through ingestion
D_{der}	Daily Dose through dermal contact
ABS	Dermal Absorption Factor

ED	Exposure Duration
EF	Exposure Frequency
AT	Average Time
BW	Body Weight
SA	Exposed Skin Area
AF	Skin Adherence Factor
IngR	Ingestion Rate
InhR	Inhalation Rate
DE	Duration of Exposure
PCA	Principal Component Analysis
ME	Microenvironment
MEs `	Microenvironments

Chapter One: Introduction

1.1 Air Pollution

Human beings cannot survive without air for a maximum of three minutes, but they can survive for three days without water and three weeks without food, (Fortoul *et al.*, 2015). A person can inhale 20000 L of air per day, off this 350 L of air are diffuse to 10000 L of blood flowing through the lung daily (Salvi, 2007; Liu *et al.*, 2018). Air can be polluted with chemicals, physical or biological contaminants. In 2002, US EPA has estimated that the total of 1.1 billion peoples breathe unhealthy air. Air pollution can be classified as indoor and outdoor air pollution. Indoor air pollution means the pollution occurs in closed place/within buildings (such as in houses, office, supermarkets and school classrooms), and outdoor air pollution is a pollution that occurs outside the closed places/buildings (ambient air pollution) (Ekpenyong *et al.*, 2012; Godson Rowland *et al.*, 2015).

The air pollutants may be originated from the anthropogenic or natural sources. Transport facilities (such as cars, aeroplane and motorbikes), combustion of different biomass (such as leaves, tree branches, agriculture waste, wood and animal dungs), various types of industries (such as cement, sugar, pharmaceutical, plastic, paint, cosmetic, soap and detergent industries) and waste incineration are the major anthropogenic sources of air pollution (Arku *et al.*, 2008; Kelly and Fussell, 2012; Mohammed *et al.*, 2012; Omaka *et al.*, 2013; Godson Rowland *et al.*, 2015). Whereas, wind-blown dust, sea salt, volcanic ash, pollens, fungal spores, soil particles, the products of forest fires and the oxidation of biogenic reactive gases are the natural sources of air pollution. The levels of pollutants released from such sources are widely varied in different countries, even, such variation also occurs within a country. This variation might be due to variation in socio-demographic characteristics such

as income and population density, the location of the sources and meteorological factors (Arku *et al.*, 2008; Kelly and Fussell, 2012; Fortoul *et al.*, 2015).

Among the air pollution sources, fossil fuel burning transport facilities (such as cars, buses and motorbikes) and the use of different biomass fuels (such as agriculture waste, tree leaves and branches, wood and animal dungs) are the predominant sources in developing countries. Studies have shown more than 40% (> 3 billion peoples) of the world's population relies on unprocessed biomass fuels (wood, charcoal, agricultural residues, and animal dung) fuels for their daily household cooking needs (Albalak *et al.*, 2001; Ezzati and Kammen, 2001; Thompson *et al.*, 2011; Anenberg *et al.*, 2013; Kena *et al.*, 2013; Umoh and Peters, 2014; Adeniji *et al.*, 2015; Pope *et al.*, 2015). Such type of fuel use is much higher in developing countries than in developed countries. For instance, in Sub-Saharan Africa, 90% to 95% of domestic energy depends on the biomass fuels, where cooking has taken the major share. In Ethiopia, more than 90% of the population use the biomass fuel for cooking, heating and lighting, in which 99% of this fuel is derived from fuelwood, charcoal, crop residue and leaves, fuelwood occupying the leading position (Biruck *et al.*, 2011; Hassena *et al.*, 2016). Studies also showed nearly 2 billion kilograms of biomass are burned every day in developing countries. Similarly, in Ethiopia, the total amount of wood consumed for cooking was estimated, to be 62 million tons per year (Balakrishnan *et al.*, 2002; Gaia, 2012; Kena *et al.*, 2013). Thus, the most significant issue for indoor air quality in developing countries is pollutants released during the combustion of such biomass fuels.

Urbanization increases the health expectancy of the individual and decreases diseases caused by infection and malnutrition. However, expansion of industries, population growth and the increasing number of vehicles combined with the continued use of biomass fuel are the major challenges seen during rapid urbanization of emerging economies. Although, it is known that any transport facilities

is a significant contributor to air pollution, widespread urban sprawl and the slow change in the traditional cooking methods, have become the major factors for the deterioration of urban air quality (Petkova *et al.*, 2013; Morakinyo *et al.*, 2017). The rapid rate of urbanization in Africa is very fast that nearly 60% of the population of Africa is predicted to be living in cities in 2050, compared to less than 40% in 2011. Moreover, the absence of good road network, increasing vehicle ownership and prevalence of old, poorly maintained cars in the urban cities aggravate the level of air pollutants in most of the cities found in developing countries including Ethiopia (Kume *et al.*, 2010; Kinney *et al.*, 2011; Ekpenyong *et al.*, 2012; Tefera *et al.*, 2016). Studies in Addis Ababa showed that 53.5% of vehicles were more than 20 years old, while 29.3% were more than 30 years old (Alok, 2011). Air pollution problems in developing countries due to the transportation might become worse unless the government and other stakeholders formulate transport regulations and policies. Health problems associated with the urban air pollution are becoming a concern to public health officials and the population living in Africa's large metropolitan areas. Despite these, the researches related to urban air pollution of sub-Saharan cities particularly in Ethiopia are very few.

Air pollutants, including organic compounds and particulate matter, introduced into the atmosphere from different sources can harm humans and the environment, even cause for the loss of the biodiversity. This is why air pollution is the major concern in the world nowadays (Ojiodu, 2013; Araújo *et al.*, 2014). For instance, both short- and long-term exposure to high levels of air pollution has been consistently associated with different types of diseases including the risk of respiratory tract infections, exacerbations of inflammatory lung conditions, cardiac events, pregnancy complications, and adverse birth outcomes, eye disease, ischemic stroke, tuberculosis (TB) and cancer (Kilabuko and Nakai, 2007; Fullerton *et al.*, 2008; Kena *et al.*, 2013; Omaka *et al.*, 2013; Guarnieri *et al.*, 2014; Umoh and Peters, 2014; Adeniji *et al.*, 2015; Cosselman *et al.*, 2015; Muralidharan *et al.*, 2015; Pope

et al., 2015; Cepeda *et al.*, 2017). However, the type of diseases caused by air pollution depends on the pollutants concentration in the air, type of pollutants, the composition of the pollutants (which affected by its sources), and the length of time that an individual stay in the polluted air environment. For example, a person exposed to low level of pollution for long period of time can have taken an equivalent amount of pollutants to a person who exposed to high level of air pollution for a short period of time. Thus a report by WHO showed that a women exposed to biomass smoke for 2-4 h during cooking can inhale TSP and benzo(α)pyrene in the amount equivalent to smoking 40 cigarettes in 24 h (Faris, 2002; Falta *et al.*, 2008)

Besides human health, air pollution can impose economic losses and external costs on the metropolitan economy through the damaged building's surface, increase car accidents due to reduced visibility, educational institutions and increase the hospital admissions due to respiratory diseases (Ahmadi *et al.*, 2015). For instance, reports in Ethiopia particularly, in Addis Ababa, have shown acute respiratory infections (ARI) is among the top 20 leading causes of outpatient visits to health centers and hospitals, which might be mostly resulted due to polluted air. The public health data shows that causes of acute respiratory infection were about 148,000 in 2006-2007, which reached up to 207,000 in 2007-2008 (Kumie *et al.*, 2009; Hailu *et al.*, 2013). In general, air pollution can cause biodiversity loss, reduction in crop yields and contribute to climate change (Ahmadi *et al.*, 2015). Moreover, a very recent (in 2016) report by WHO said air pollution can cause for the death of more than seven million peoples per year (around 13 people per min) (Dias and Tchepel, 2018).

Due to the above mentioned problems of air pollution, monitoring of air pollution at country level especially in the urban areas in closely and periodically is vital to see their consequences to human health, to provide information for the government sectors to set guideline, to understand the level of pollution and to take appropriate action in high polluted areas (Kelly and Fussell, 2015). Although

the country has experienced increased in air pollution-related health problems, such types of air pollution monitoring systems have not been established in Ethiopia, (Tefera *et al.*, 2016). Thus, exposure assessment to indoor and outdoor air pollution and the chemical composition analysis of major air pollutants is vital in the context of air pollution-related impacts. Therefore, this study focuses on short-term exposure assessment and elemental analysis of indoor and outdoor air PM_{10} at different microenvironments (MEs) using real-time mobile sensors and ICP-OES.

1.2 Statement of the Problem

Particulate matters (with different micro diameter), carbon monoxide, nitrous oxides, sulphur oxides (principally from coal), TVOCs (such as formaldehyde, benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene)) are the most important substances present in the indoor and outdoor air pollution (Kirk *et al.*, 2000; Nigel *et al.*, 2000; Boadi and Kuitunen, 2006; Fullerton *et al.*, 2008; Jettera and Kariher, 2009; Omaka *et al.*, 2013; Fajola *et al.*, 2014; Umoh and Peters, 2014; Oluwole *et al.*, 2103). Among the substances in polluted air, particulate matter with different aerodynamic diameter and TVOCs are the major components and the health concern in the world. The TVOCs and particulate matter with different aerodynamic diameter released during combustion of biomass fuel and traffic emissions are the significant problems of the developing world in general (Int Panis *et al.*, 2010; Do *et al.*, 2013). Specially, 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, or a pit in the ground, or in poorly functioning earthen or metal stoves are the common practise in majority of households in developing countries in general and particularly in Ethiopia. Therefore, combustion of biomass fuel is incomplete in most of these stoves which produce very high levels of indoor pollution (Nigel *et al.*, 2000; Boadi and Kuitunen, 2006; Anenberg *et al.*, 2013). Similarly, the absence of good

road network, increasing vehicle ownership and prevalence of old, poorly maintained cars in cities aggravate the level of air pollutants increase in most of the cities found in developing countries in general and in Addis Ababa particularly (Kume *et al.*, 2010; Kinney *et al.*, 2011; Ekpenyong *et al.*, 2012; Tefera *et al.*, 2016).

High level of TVOCs and PMs pollutants available in the polluted air can enter into the body through inhalation, ingestion and dermal contact, and can cause different health problems including conjunctive irritation, nose and throat discomfort, headache and sleeplessness, allergic skin reaction, nausea, fatigue and dizziness, leukaemia, anaemia, cancer and damage to liver, kidney and central nervous system (Kataoka *et al.*; Kilabuko and Nakai, 2007; Su *et al.*, 2011; Chekwube *et al.*, 2012; Singh *et al.*, 2012; Do *et al.*, 2013; Ismail and Hameed, 2013; Ojiodu, 2013; Omaka *et al.*, 2013). The comprehensive exposure assessments to particulate matter with different aerodynamic diameter and TVOCs at different microenvironment are used for estimating the health burden of people, assessing the contribution level of various sources and developing strategies for the management. As a result, several known studies on exposure assessment to particulate matter with different aerodynamic diameter and TVOCs at different scenario were carried out around the globe. For instance, the exposure assessments to indoor air particulate matters and TVOCs while conducting different activities were carried out to estimate the contribution of each activity to daily total exposure of particulate matter and TVOCs. Moreover, recently the studies also focused on identification of high pollutant emission activity and personal exposure assessment to these pollutants to design and take intervention action at an individual level. In addition, exposure assessment to outdoor air pollutants at different geographical and land use points (such as at residential places, industrial zone and commercial center) were carried out to estimate the contribution of outdoor air pollution exposure

(Krzemińska-Flowers *et al.*, 2006; Frommea *et al.*, 2007; Singh *et al.*, 2008; Zabiegala *et al.*, 2009; Ahmed *et al.*, 2012; Aryal *et al.*, 2013; Ojiodu, 2013; Uno *et al.*, 2013).

Likewise, a very few cross-sectional and pilot studies were conducted in Ethiopia. Hence, the level of different pollutants such as CO, NO_2, PM_{10}, $PM_{2.5}$ and TSP were reported for indoor and outdoor air. These studies were conducted at different parts of the country (Gonder, Butajira area, Shebidino wereda, rural area of Tigray, Kebribeyah, rural area of Jima, rural area of Wellega and Gimbie and Addis Ababa). Most of the results of these studies were exceeding the United States Environmental Protection Agency (US EPA) and WHO standard, mainly, their levels in indoor were high. This might be due to living in crowded and poorly ventilated housing, type of stove and fuel used, and limited access to separate cooking and living areas in rural and urban homes which is visible features of living conditions in Ethiopia (Albalak *et al.*, 2001; Faris, 2002; Etyemezian *et al.*, 2005; Kumie *et al.*, 2009; Gebre *et al.*, 2010; Graham, 2011; Hailu *et al.*, 2013; Kena *et al.*, 2013).

In general, previously the air pollution and its health impact relation were studied based on the measurement of the air pollutants at a fixed place which does not predict accurate exposure assessment to the pollutants. Thus, 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 personal exposure (Levy *et al.*, 2000; Devi *et al.*, 2009; Cattaneo *et al.*, 2010; Rabinovitch *et al.*, 2016). However, almost in all exposure assessment to particulate matters studies conducted so far in Ethiopia were based on 24 h measurement at a fixed site for indoor and outdoor air that might not show the real exposure of a person. This is because the person is not staying in the home or outdoor for 24 h. Although exposure to high level of particulate matter with short period showed health problems, studies conducted in Ethiopia lacks information related to the quantification and assessing of short-term exposure (from one hour to several hours) to particulate

matter pollutants that come from different activities, more importantly activities which emit high level of pollutants (Gulliver and Briggs, 2004; Int Panis *et al.*, 2010; Son and Bell, 2013). It has also limited information in identification and determination of the potentially toxic metals bound in particulate matters at different MEs. Furthermore, both quantification and short-term exposure to indoor and outdoor TVOCs at different microenvironments have not been reported so far.

Consequently, in this work different microenvironments with both episodes of high and low pollutant emission have been selected to estimate PMs and TVOCs short-term exposure, which will be used as input while formulating guidelines in the future and taking remedial action at the individual level. Hence, baking *Injera* and cooking *Wot* with different types of stove and fuel types were selected as episodes of high pollutants emission. This is due to the fact that *Injera* and *Wot* are the most frequently and widely consumed food items in Ethiopia and large fuel consumption activities which cause for high indoor air pollution. Whereas living room was selected as low emission episode (Kume *et al.*, 2010). Similarly, for short-term exposure assessment to outdoor air roadside is used as microenvironment during high traffic congestion and commuter time (at early morning and late afternoon) was selected.

Furthermore, as different studies have reported, the health impact of particulate matter depends on the chemical composition and size in addition to their amount. The chemical composition analysis, especially determination of potentially toxic metals bound in particulate matter, more importantly at different microenvironment is the cornerstone to estimate their health impact at the individual level (Praveen Kumar *et al.*, 2008; Valavanidis *et al.*, 2008). But, measuring the short-term exposure to particulate matter with different aerodynamic range and determination of potentially toxic metals bound in particulate matters at specified microenvironments has not been studied in Ethiopia. Thus,

this study could provide fundamental understanding of the elemental composition of PM_{10} in different microenvironments and the associated health risks.

As stated above, comprehensive studies related to the analysis of indoor and outdoor air pollutants at different microenvironments in Ethiopia are quite a few. Therefore, the present study focuses on comprehensive measurement of PMs and TVOCs level at different microenvironments (during baking *Injera*, cooking *Wot*, at living room and at roadside) at different seasons; elemental composition analysis of PM_{10} pollutant and comparing their level to standard level and assessment of health risk due to lifelong exposure to PMs and TVOCs.

1.3 Objectives

1.3.1 General Objective

The main objective of the project is to investigate the short-term exposure assessment to both indoor and outdoor PMs and TVOCs pollutants at different microenvironments (during baking *Injera*, cooking *Wot*, sitting at the living room and during commuting at roadside) and to analyze elemental composition in PM_{10} at different microenvironments in Addis Ababa.

1.3.2 Specific Objectives

- To measure the concentration of TVOCs and PMs during the baking of *Injera*, cooking *Wot* and at the typical living room
- To investigate the spatial-temporal exposure variations to PMs and TVOCs pollutants during baking of *Injera* and cooking *Wot.*
- To assess short-term exposure to outdoor PMs and TVOCs at roadside during commuting time.
- To investigate the spatial-temporal exposure variations to outdoor PMs and TVOCs pollutants during commuting time.
- To determine the level of elements in a sample of PM_{10} at selected MEs.
- To estimate non-carcinogenic risk at selected microenvironments due to lifetime exposure of $PM_{2.5}$, PM_{10}, TSP and toxic trace metals (such as Cd, As, Ni, Cr and Pb) bound in PM_{10}.

1.4 The Output of the Research

Generally, the study on the magnitude of exposure to indoor and outdoor pollutants at different MEs is used to estimate the carcinogenic and non-carcinogenic risks and to identify the activities and populations where interventions need to be focused. Hence, the present study will help to take such action by measuring the concentration and their chemical composition analysis of selected pollutants (such as TVOCs, PMs and analysis toxic metals bound in PM_{10}) in indoor and outdoor air at different MEs. The results of the study can help to know the status of pollution level at selected microenvironment in addition to estimate the health impacts due to studied air pollutants. Besides, it will also provide information to environmental monitoring agents, governmental stakeholders and policymakers to take remedial action, to conduct further studies and implement more effective local, national and global policies to reduce air pollution if high. Moreover, it will also be used to inform the public about effective pollution reduction activities and associated health benefits. The study will also identify the stoves and fuel types which cause higher personal exposure while baking *Injera* and cooking *Wot*, under practical/field condition. Besides, the study also assesses the contribution of different microenvironment to a personal daily exposure of indoor and outdoor air pollution of Addis Ababa.

Generally, the study will provide real-time exposure measurement and analysis of the PMs, TVOCs and elemental composition of respirable particulate matter (PM_{10}) in high and low intensity emission episodes during various activities, identify the role of each activities to the PMs and TVOCs exposures, knowing the individual, temporary and special exposure heterogeneity, calculating the time spend in this environment, generalizing the total exposure and finally estimating the health impacts and recommend intervention strategies at individual level.

Chapter 2: Literature Reviews

2.1 Indoor Air Pollution

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 (such as wet and damp carpets, wood processed products, asbestos-containing insulations), products for household cleaning and maintenance (phthalates, bisphenol A, fragrances, pesticides, detergents, chlorine bleach, ammonia), cosmetics for personal care (solvents, phthalates, bisphenol A, fragrances, mineral oil), combustion of oil, kerosene and coal (WHO, 2010; Ferrante *et al.*, 2015; Godson Rowland *et al.*, 2015; Onabowale and Owoade, 2015). Among these sources, cooking using biomass fuel especially in a low efficient stove is the worst one (Leung, 2015; Bo *et al.*, 2017). The prominent air pollutants resulted from large incomplete combustion of and relatively lower burning efficiencies of the residential biomass fuel were particulate matters, black carbon, nitrous oxides, sulphur oxides and polycyclic aromatic hydrocarbons (PAHs). Burning of biomass fuels have contributed 21.4% of primary $PM_{2.5}$, 63% of PAHs, and 28.9% of BC (Ranabhat *et al.*, 2015; Shen *et al.*, 2015).

Many studies confirm that indoor air pollution has become worse than outdoor pollution, this is because people have spent most of their time in households, where there is low air exchange rate, the spatial volume of household is small and use of low fuel efficient stove (Smith, 2002; Devi *et al.*, 2009). For instance, indoor air pollution cause is ranked fourth regarding a global burden when compared with 67 risk factors contributing to the Global Burden of Disease calculations (second among women). Indoor air pollution alone accounted for 4.3 million deaths worldwide in 2012, mostly in low and middle-income countries. Off this death, indoor air pollution caused by burning of biomass fuel has a prominent share (Kooser, 2014; Sidra *et al.*, 2015; Wangchuk *et al.*, 2015; Asante

et al., 2016). A recent report on the global burden of disease indicated that 3.5 million annual deaths and over 110 million disability-adjusted life years were attributable to indoor air pollution caused by burning of biomass fuels only. It has been estimated that 16% of the 3.1 million deaths from outdoor air pollution are attributable to indoor air pollution through its impact on ambient air (Anenberg *et al.*, 2013; Guarnieri *et al.*, 2014; Muralidharan *et al.*, 2015; Pope *et al.*, 2015). This indoor air pollution-related mortality arises mainly from four disease outcomes: chronic obstructive pulmonary disease (COPD), acute lower respiratory infections (ALRI) in children < 5 years of age, and from cardiovascular disease and lung cancer due to particulate matter exposure. For instance, studies indicated that women exposed to indoor air pollution (IAP) developed COPD and comparable levels of mortality and death as tobacco smokers which accounts about 800,000 premature death per year (Ezzati and Kammen, 2001; Pope *et al.*, 2015).

2.2 Outdoor Air Pollution

Like indoor air pollution, ambient or outdoor air pollution is the major problems faced by the world nowadays. Studies have been estimated that 60% of the chronic health impacts are related to environmental factors that account for exposure to urban air pollution (Chen and Goldberg, 2009). The urban outdoor air pollution sources were road traffics (including exhaust and non-exhaust emissions of vehicle combustion, tire wearing and resuspension), power generation plants, industries, and domestic heating systems. Among the sources of urban air pollution, the major particulate matter pollution source in urban areas are automobile exhausts (Cattaneo *et al.*, 2010; Lee *et al.*, 2012; Bo *et al.*, 2017). United Nation Environment Program (UNEP) in 2011 has estimated 90% the urban air pollution in developing countries are attributed to gasoline and diesel motor vehicle emission. From this 90% of the particulate matter is due to diesel exhaust (Kinney *et al.*, 2011; Kelly and Fussell, 2012). The engine type, engine speed and load, fuel composition, lubricating oil type and emission

control technology are the main factors affecting particle size and chemical composition of traffic exhausted emissions (Cattaneo *et al.*, 2010). As a result of this the air pollution level at roadside becomes harsh that peoples in commuting to work, walking, cycling, travelling by car or public transport will be exposed to high level of polluted air, and threatened with different health problems (Ekpenyong *et al.*, 2012; Cepeda *et al.*, 2017).

2.3 Particulate Matter

Particulate matter is the term used to describe for particles (a heterogeneous mixture of solid materials and liquid droplets) found in the air, including dust, soot smoke and liquid droplets. It can vary in mass, number, size, shape, surface area, chemical composition, reactivity, acidity, solubility and origin (Bolong *et al.*; Chen and Goldberg, 2009; Kelly and Fussell, 2012; Fortoul *et al.*, 2015). It is one of the most dangerous pollutants in the atmospheric air in the world (Crilley, 2014; Zajusz-Zubek *et al.*, 2015). Particulate matter can be composed of inert carbonaceous cores with multiple layers of various adsorbed molecules, including metals, acid salts, sulphates, nitrates, hydrogen ions, ammonium, elemental carbon, silica, alumina, organic compounds, particle-bound water and biological elements (such as endotoxins, allergens and pollen fragments) (Araújo *et al.*, 2014; Castellani *et al.*, 2014).

The particle can have different sizes, at which some particles are large or dark enough to be seen as soot or smoke, whereas others are so small that individually they can only be detected with an electron microscope (Bolong *et al.*; Smichowski *et al.*, 2005). Particulate matter is generally classified by size into total suspended particulates (TSP; < 50 μm aerodynamic diameter); respirable particle (PM_{10}; <10 μm aerodynamic diameter); coarse (<10 μm and >2.5 μm aerodynamic diameter), fine ($PM_{2.5}$; < 2.5 μm and > 0.1 aerodynamic diameter), and ultrafine (UFP; < 0.1 μm aerodynamic diameter)

(Smichowski *et al.*, 2005; Schwarze *et al.*, 2006; Araújo *et al.*, 2014; Shen *et al.*, 2014; Cosselman *et al.*, 2015).

The chemical composition of the particle varies across different sizes of particulate matter. For instance, 70-80% of the total $PM_{2.5}$ mass has consisted primarily of nitrate, sulphate and ammonium ions, together with elemental and organic carbon made up. In contrast, these components made up only about 10-20% of the coarse fraction between 2.5 and 10 µm. The coarse fraction was dominated by aluminium, silicon, sulphur, potassium, calcium and iron, which made up 40-50% of its mass (Chen and Goldberg, 2009; WHO, 2018). The most prominent source for coarse particulates are black smoke, soil, dust from roads, industries and building sites, pollen, mould, spores, large salt particles from sea spray, mechanically generated particles, as well as some secondary particles. Whereas for that of fine and ultrafine particles are combustion product from vehicles, industries and biomass fuels (Kelly and Fussell, 2012; Tahri *et al.*, 2013).

Moreover, the deposition from the atmosphere, penetration to the human respiratory system and visibility degradation depend on both size and chemical composition of particulate matter. For example, particles smaller than 2.5 µm penetrate into the alveoli and terminal bronchioles; larger particles of up to 10 µm deposit primarily in the primary bronchi, and much larger particles (up to 100 µm) deposit in the nasopharynx which determine the their impact on health in regardless of chemical composition (Falta *et al.*, 2008; Araújo *et al.*, 2014). Other studies also show that particles in the 2.5- to 10-µm particle size fraction are in most cases deposited in the trachea and the bronchial region, from where they are transported within hours by the so-called mucociliary clearance and adoral are mainly swallowed. This fraction reaches the gastrointestinal tract (GIT), where it comes into contact with gastric juice (Falta *et al.*, 2008). Besides, fine and ultrafine particles have the ability

to remain suspended in the air and travel prolong distance which makes them more toxic (Kelly and Fussell, 2012).

A variety of processes including sea-salt aerosol generation, structural weathering, biologically or physically mediated volatilization, volcanism, biomass burning, fossil fuel combustion, industrial activity and incineration are the major sources of particulate matter in the atmosphere (Schwarze *et al.*, 2006; Praveen Kumar *et al.*, 2008). As shown in Figure 1, indoor air particulate matter concentration is much higher in the developing countries as compared to developed ones. Thus, approximately 76% of all global particulate matter air pollution occurs in indoors in the developing world (Fullerton *et al.*, 2008).

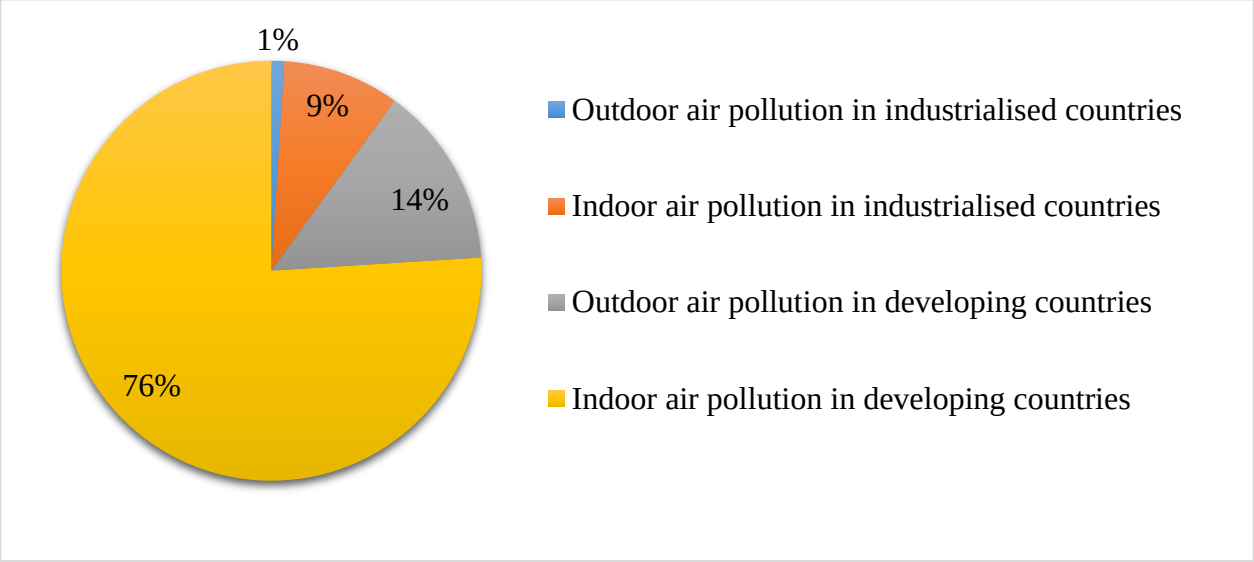


Figure 1. Pie chart showing total global exposure to particulate matter air pollution (Fullerton *et al.*, 2008).

Exposure time, amount and chemical constituents of particulate matter are the major factors that determine their impact on both human and the environment (Praveen Kumar *et al.*, 2008; Crilley, 2014). Studies confirmed that a small change in the amount of particulate matter in the polluted air

can cause a series of health problem. For instance, an increase in PM_{10} by a concentration change of 10 μg m^{-3} can yield 1% increase in overall mortality and 3-6% increase in deaths associated with respiratory disease (Aryal *et al.*, 2013). Other studies also show an increase of 10 μg m^{-3} in annual mean levels of $PM_{2.5}$ was associated with an 8-28% increase in the risk of cardiopulmonary mortality, 15-21% increase mortality due to lung cancer, 12-14% increase overall cardiovascular mortality (Chen and Goldberg, 2009; Cosselman *et al.*, 2015).

Once the air pollutants enter into the body, it has different health impacts as mention above. However, the mechanism by which the influence of air pollutants in general and particulate matter to the different type of disease are still under investigation. For instance, studies suggest that inhalation of particulate matter can attribute either low or medium pulmonary oxidative stress or inflammation, which subsequently aggravate systemic inflammatory responses with a cascade of reactions (a chemical process which comprises at least two consecutive reactions). An introduction of oxidizing species such as redox active transition metals as well as quinones or endotoxin on the particle surface and introduction of surface absorbed PAHs can cause the formation of oxidation stress in the body. Besides, they undergo bio-transformation once they enter to the human body. For instance, they can cause the production and mobilization of proinflammatory leukocytes and platelets into the circulation; increase in circulating inflammatory mediators, such as interleukins (IL)-6; and stimulation of the production of acute phase proteins, such as C-reactive protein and fibrinogen. This induced systemic inflammatory response may, in turn, lead to increased blood coagulability, accelerating atherosclerosis progression, and ultimately precipitating or aggravating cardiovascular events (Chen and Goldberg, 2009).

Although studies showed exposure to particulate matter can cause lung cancer, until now the mechanism which used to illustrate this lung cancer is not presented yet. However, one of the

hypothesis is that lung cancer develops through a series of progressive pathological changes occurring in the respiratory epithelium because of direct genotoxicity effects of particulate air pollution. Whereas, other studies have suggested that polycyclic aromatic hydrocarbons in the particulate matter may cause for cancer mediated through the formation of DNA adducts (Chen and Goldberg, 2009; Kelly and Fussell, 2012).

As described above exposure to particulate matter can cause different health impacts on the human. Thus, setting guidelines for the level of particulate matter is vital for knowing the health status of human and taking intervention action. Hence, some organizations have set guidelines for $PM_{2.5}$, PM_{10} and TSP for ambient air, although the available guidelines have some shortcomings (Ezzati and Kammen, 2001; WHO, 2010). Table 1 shows the standards set by the different organization for selected PMs.

Table 1. Particulate matter threshold values (WHO, 2010; Araújo *et al.*, 2014).

Particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$)	10 μgm^{-3} (annual mean)	World Health Organization (WHO)
	25 μgm^{-3} (24 h mean)	
Particulate matter with a diameter of 10 µm or less (PM_{10})	20 μgm^{-3} (annual mean)	World Health Organization (WHO)
	50 μgm^{-3} (24 h mean)	
Total suspended particulate matter (TSP)	150 (annual geometric mean)	World Health Organization (WHO)
	240 μgm^{-3} (24 h mean)	Brazilian National Environment Council (CONAMA)
PM_{10}	50 μgm^{-3} (annual mean)	Ethiopian Environmental Protection Agency (EEPA)

2.4 Total Volatile Organic Compounds

Total volatile organic compounds (TVOCs) are the sum of all volatile organic compounds (VOCs). VOCs are the important class of air pollutants commonly found in the atmosphere. They cover a broad range of organic compounds including paraffinic, olefinic and aromatic hydrocarbons, and various oxygen-, nitrogen-, sulphur-, and halogen-containing molecules (Ojiodu *et al.*, 2012; Do *et al.*, 2013).

Volatile organic compounds (VOCs) emission results from natural and anthropogenic (man-made) sources. Natural sources of VOCs include vegetation, forest fires and animals. Anthropogenic (man-made) source includes building materials (such as; paints, adhesives, waxes, solvents, detergents), household materials (such as; woods items containing VOCs, carpets, air-conditioners, printers and photocopiers), transportation vehicles and industries. Besides, studies also show that combusted materials used for cooking, lighting and heating can emit large amount VOCs to the environment. For example, the biomass burning contributes to about 45% of the total VOC emitted by anthropogenic sources on the earth (Zabiegala *et al.*, 2009; Evagelopoulos *et al.*, 2010).

Once TVOCs are introduced in the atmosphere, they can play an important role in the chemistry of the atmosphere; their role in the formation of photochemical smog and their associated oxidants, degrading air quality and threatening both human health and ecosystem (Ojiodu *et al.*, 2012; Do *et al.*, 2013). In addition, the majority of the VOCs released into the environment by the industries and combustion of biomass affect both human and animal health. The impact of VOCs depends on the composition, the amount and the time of exposure. Thus, the short-term adverse effects include conjunctive irritation, nose and throat discomfort, headache and sleeplessness, allergic skin reaction, nausea, fatigue and dizziness. While the long-term adverse effects include loss of coordination,

leukaemia, anaemia, cancer and damage to liver, kidney and central nervous system (Evagelopoulos *et al.*, 2010; Ojiodu *et al.*, 2012).

Generally, according to many studies, the concentration of many organic pollutants can be several times higher (it can reach up to 100 times) in indoor air than in outdoor air, although it depends on the sources. This might be due to that many VOCs not only infiltrate from outdoor air into indoor air, but are emitted, at a much higher rate, from endogenous sources such as buildings, finishing and furnishing materials, advanced technological devices (computers, ink, and laser printers), cleaning and personal care agents, heat-insulating materials, air conditioning systems, oil, gas, coal and firewood combustion, and tobacco smoking (Zabiegala *et al.*, 2009; Do *et al.*, 2013). For instance, the PAH level in indoor using biomass fuel as the energy source was found to be in the range 100-10000 ng m^{-3}, compared to 20 ng m^{-3} in traffic areas and 20-100 ng m^{-3} in cigarette smoking areas. Moreover, people spend on the average 80 to 90% of their time indoors might have high health impacts on their health due to the high level of pollutants in indoor (Oanh *et al.*, 1999; Do *et al.*, 2013). Off the VOCs in the air, benzene, 1,2-dichloropropane, trichloroethylene, toluene, chlorobenzene, ethylbenzene, (m+p)-xylene, styrene, o-xylene, α-pinene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene and limonene are the most health impact individual VOCs (Yeung and To, 2008; Evagelopoulos *et al.*, 2010).

Until now, although TVOCs have different health impacts on human and environment, there are no threshold values set by any organization. This is since that their effect is highly dependent on the individual components. However, there is some level of standards that show the different health outcomes. Table 2 shows the level of TVOCs and their level of health impact.

Table 2. The permissible concentrations of TVOC in indoor air for different countries (Zabiegala *et al.*, 2009).

The permissible concentration of TVOC (μg m^{-3})	Level of their effect
< 200	Decreasing feeling of comfort
200-3000	Causing hazard for health
3000-25000	Causing feeling of intense discomfort
> 25000	Toxic concentration

2.5 *Injera* Baking and Cooking *Wot*

2.5.1 *Injera* baking

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

The variations in these stoves are either in the design or in the fuel type they use. Thus, the clean stove (*Electric Midja*, in Amharic) looks like griddle made from a circularly shaped clay that contains an electric resistance heating wire coils embedded inside which is used as a source of heating. Whereas, 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 to outside the kitchen and the small hole used for the fuel addition. Likewise, the traditional stoves (three stone or simply call it *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 the fraction of the heat

from the open fire used in the traditional stove is used for the baking the *Injera* placed on the griddle (*Mitad*, in Amharic). Both improved and traditional stoves can be used similar types of biomass fuel sources. Figure 2 shows the sketch of the three types of stoves used for the *Injera* baking.

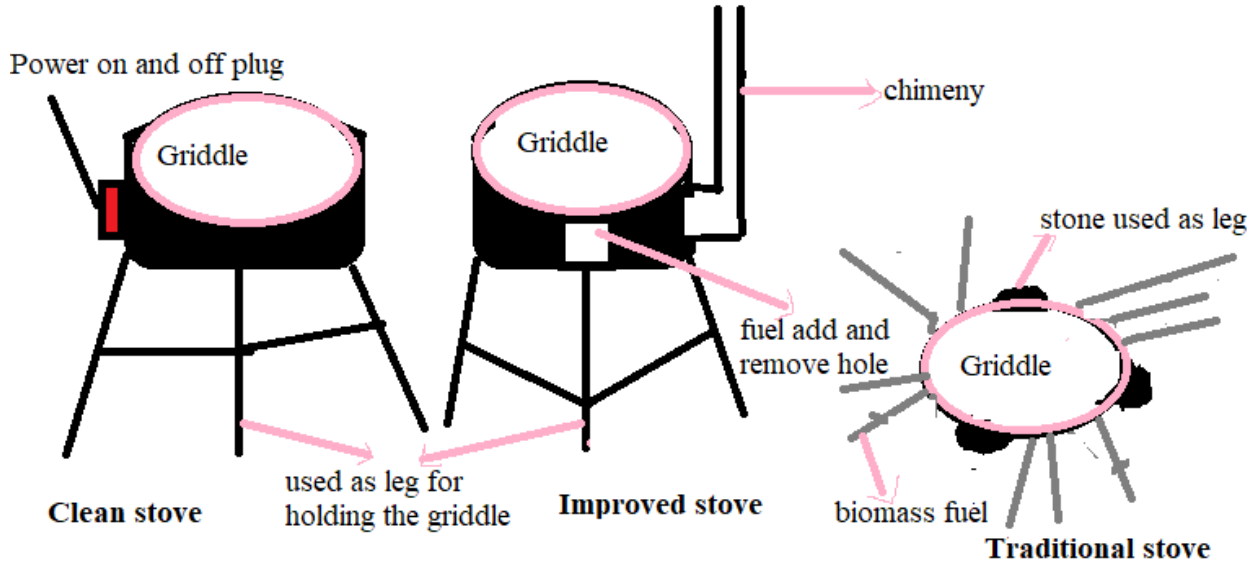


Figure 2. The sketch of three different types of stove used for the *Injera* baking.

2.5.2 *Wot* cooking

In addition to *Injera*, stew (*Wot, in Amharic*) is one of the main constituents of dish for Ethiopian peoples. Even though, studies were not conducted yet, by doing a sample survey information through questioners in Addis Ababa and simple observation, the stew of lentil (*Misir Wot, in Amharic*), pea (*Shiro Wot, in Amharic*) and potato (*Dinich Wot, in Amharic*) was the most widely used stew by most of the Ethiopian people. Powdered chili pepper (*Berbere, in Amharic*), onion (*shinkurt, in Amharic*) and salt (*Chew, in Amharic*) are the primary ingredients used for preparing of lentil (*Misir*), pea (*Shiro*) and potato (*Dinich*) *Wot*. Besides garlic, tomato paste and turmeric are the optional ingredients used while making such types of stew. The name given for each *Wot* is based on the major ingredients

it contains. Thus, lentil-sauce (*Misir-Wot)* contains lentil in large proportion. Similarly, *Shiro Wot* and potato-sauce (*Dinich Wot*) contains the large proportion of powdered pea and small pieces of potato, respectively. The cuisine of such stew has been almost similar, except replacing of its major ingredients. Moreover, these types of stew have been popular and day-to-day food recipe to the Ethiopian. Consequently, peoples who are making such type of stew use different types of fuels that can release different levels of pollutants. Electricity, charcoal and kerosene are the most widely fuel used for cooking of stew/sauce in Ethiopia, more importantly in urban areas (Danielle, 2017).

Chapter 3: Materials and Methods

3.1 Chemicals and Instruments

3.1.1 Chemicals and reagents

Concentrated nitric acid (69-71% Sigma-Aldrich, Germany), hydrochloric acid (37%, Sigma-Aldrich, Germany), deionized water and commercial 1000 ppm standard solution of Mn, Cd, Co, B, As, Ni, Cr, Pb, Zn, Cu and Fe elements (UNI-CHEM, chemical reagents) were used in this study.

3.1.2 Instrumentation

AROCET531S (Met One Instrument., Inc. Grants Pass, OR 07526, USA); AEROQUAL series 500 (Aeroqual Limited, Auckland, New Zealand); round bottom flask (100 mL) fitted with reflux condenser and Kjeldahl digestion block (Kjeldatherm, Gerhardt GmbH and Co.KG, Type KB 40 S, bon, Germany); Universal air pump (SKC 224-PCTX4 Model, SKC Ltd, UK); inductively coupled plasma-optical emission spectroscopy (ICP-OES; Model Arcos FH2, 22-09-2010, Spectro Analytical Instrument GMDH, Baush strass, 10.47533, Klev, Germany) and Glass microfiber filters with a diameter of 25 mm GF/A (Whatman®, GE Healthcare UK limited, Amersham place, UK) were used in this study.

3.2 Description of Study Area

Ethiopia is the second most populous country in Africa (86.6 million, 2012, while the estimate for 2016 is 102.4 million) and metropolitan Addis Ababa 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). Besides, Addis Ababa is situate at the center of the country at an altitude varying between 2200 and 2800 m,

and between latitude 9.0300^{o}N and longitude 38.7400^{o}E. Average minimum and maximum annual temperatures range from 9.53 to 23.2 ^{o}C, and the average annual rainfall is 1170 mm (Sanbata *et al.*, 2014).

Considering the major indoor pollution source and time spent is vital in selecting indoor microenvironments. Thus, we have selected the living room and kitchens (during baking *Injera* using different types of stove type and cooking *Wot* using different fuel type) as a representative of the indoor environments. All households considered in this study for measuring of the exposure assessment to indoor air pollutants are at private level.

The level of outdoor pollution can influence the personal exposure to indoor air pollution so that the selection of sub-cities before household's section is vital. Thus, the three representative sub-cities (namely: Arada, Gulelle and Akaki Kality) were selected as sampling sites based on the altitude differences, socio-economic activities and population density. Arada sub-city is manly characterize by high population density, medium traffic intensity, no industries; Gulelle is characterized with very few industries, medium traffic intensity, high altitude, low population density than Arada, whereas Akaki Kality was characterized by low population density than from all sub-cities, low altitude, heavy industrial activities and high traffic congestion are its main character. Accordingly, Arada, Gulelle and Akaki Kality were selected as sampling sub-cities for the measurement of indoor air pollutants during baking *Injera* and cooking of *Wot* using the different stove and fuel types during the wet and dry seasons. The sampling households for baking *Injera* and cooking *Wot* were selected based on the stove type and fuel type used and the willingness of volunteer to allow me in their house for measurement. A total of 45 households (15 households from each sub-cities) were selected randomly due to general procedure similarity in the baking of *Injera*. The two seasons (the wet and dry) were

selected for this study due to the fact that the concentration of pollutants highly depends on seasonal variation.

On the other hand, outdoor air pollution is mainly affected by geographic location, metrological factors (such as wind, temperature and humidity), potential air pollution sources and major socio-economic activities. Thus, to get a representative sample, all the sub-cities (Arada, Gulelle, Kolfe-Keranio, Lideta, Kerkos, Bole, Nefas Silk-Lafto, Yeka and Akaki Kality sub-cities) were selected for outdoor air pollution measurements. Thirty sampling points (3 sampling points for each sub-cities) were selected as sampling points. Thus, all the thirty sampling point location are given graphically in Appendix IV.

3.3 Sampling Design and Analysis of Air Pollutants

3.3.1 Sampling and measurement method for total volatile compounds of indoor air

The concentration of TVOCs in the kitchen (during baking of *Injera* using clean, improved and traditional stoves and cooking of *Wot* using electricity, charcoal and kerosene fuels) and in the living room (while non-cooking) were measured using a simple and portable sensor called AEROQUAL series 500 (Aeroqual Limited, Auckland, New Zealand) with 2 min interval. It uses photo ionizer detector as a detector. The instrument was calibrated according to the manufacturer procedure, where the zero calibration was done before each measurements using zero grade air cylinder, and the reading is stabilized after 10 min. In addition, the flow rate was 0.5 litrs per minutes, and then the sampler was adjusted prior to the operation that the monitor is first switched on and warmed up for 3 minutes.

TVOCs measurement during baking *Injera* was carried out between July 1 and September 30, 2015 for the wet season and November 15, 2015 and March 10, 2016, for the dry season. Meanwhile,

TOVCs measurement while cooking stew/*Wot* was carried out between July 10 and September 30, 2016, for the wet season and January 10 and March 30, 2017, for the dry season, respectively. However, the sampling for the living room (non-cooking time) was carried out between January 30, 2017 and September 30, 2017. Normally the *Injera* baker remains at standing position during the baking and remained near to the stove until baking is completed. Hence, the sampler was put 1.5 m above the ground and 1 m from the stove during baking *Injera* which is the most appropriate breathing zone of the baker. But only the height of the sampler was changed to 1 m for cooking *Wot*, such that mostly the cookers are sitting during cooking *Wot*. Similarly, most of the time family members are at the sitting potion in the living room, such that the sampler was put 1 m above the ground at the center of the living room for non-cooking time measurement. The instrument used for this analysis is shown in Figure 3 (a).

3.3.2 Sampling and measurement method for particulate matter of indoor air

The level of particulate matter with different aerodynamic diameter, PMs during baking of *Injera* and cooking *Wot* was measured by a portable sensor called AROCET531S (Met One Instrument., Inc. Grants Pass, OR 07526, USA). The instrument contains an ambient air inlet nozzle which is used to reduce the turbulence in the air sample, and it has also a temperature and humidity sensor where it was used for measuring of ambient temperature and relative humidity of the room. The limit of detection of the sensor is 0.1 μg m^{-3}. The measurement was carried out within 2 min interval until baking activity was finalized. Moreover, the instrument use factory calibrated flow rate, which is 2.83 litrs per minute by using flow meter by fitting it to the inlet fitting on the unit. Besides, the zero-count calibration test was performed after each measurement by following the manufacturer's standard

operating procedure. Thus, the zero-count filter was attached to the inlet nozzle until smallest particle size should have a count less than or equal to one.

The particle sensor uses a laser-diode-base optical sensor, in which it uses light scatter technology to distinguish, measure, and count particles. The scattered light by an individual particle is converted to an electric pulse which is proportional to the particle size. This detected information or electric pulse can be altered into particle mass using the mass-density conversion factor, or displayed as particles per size range, depending on how the AROCET531S is configured. The sensor has data logger cable which is used to log the data collected to the computer. The PMs sampler was put side by side to the TVOCs sampling instrument in which it was put 1.5 m above the ground and 1 m from the stove during baking *Injera*. Whereas during cooking *Wo*t, the position was changed to 1 m above the ground and 1 m from the stove. Furthermore, during cooking and baking time all other activities were not done 20 min before starting and during measurement to prevent the interference from other operations. The background concentrations of pollutants were carried out for 10 min before starting baking, and continue the measurement until the cooking/baking was ended. The instrument used for this analysis is shown in Figure 3 (b).

Furthermore, the different characteristic of the house such as the volume of cooking/baking room, the type of ventilation, family size was recorded for the selected households through a face-to-face questionnaire survey. The survey data related to demographic characteristics was also collected by asking the baker/cooker and volume of the cooking/baking room and ventilation type was measured by using tape. The details for baking *Injera* and cooking *W*ot are given in Appendix I and Appendix II, respectively, in the Appendix section.

a b

Figure 3. Air sampler device and assembling a) Aeroqual series 500 and b) AROCET531S.

3.3.3 Sampling and measurement method for PMs and TVOCs of outdoor air

TVOCs and PMs measurements of outdoor air pollution at the roadside were done by using similar instrument and calibration procedure used for indoor air pollution case, except the sampling point and the samplers position. Thus, they were put side by side on kit 1.55 m above the ground and it was put at the roadside 2.5 to 7.6 m from the main roadside where people were standing for waiting for taxi and used by pedestrian. The sampling was carried out between September 30, 2017 and November 15, 2017 from 6:00 am to 10:00 am for morning and 2:00 pm to 6:00 pm for the afternoon, such that it was expected to high traffic congestion and many commuter and pedestrian are available.

3.3.4 Sampling and sample preparation method of PM_{10} for elemental analysis of indoor and outdoor air

The particulate matter used for trace elemental analysis was collected with the help of person-carried equipment, in which the sampling unit comprised of portable Institute of Occupational Medicine (IOM) multi fraction dust samplers called Universal air pump (SKC 224-PCTX4 Model, SKC Ltd,

UK). It has a vacuum pump, an internal flow regulator, timer and air flow calibration unit. The air flow was adjusted to 2.2 L min^{-1} with a high-precision rotameter in the lab before field and checked immediately on return. Both indoor and outdoor PM_{10} was collected at different microenvironments. For outdoor air particulate matter collection, the sampling was carried out during the dry (between September 30, 2017 and November 15, 2017) and the wet (June15, 2017 to August 30, 2017) seasons from 6:00 am to 10:00 am for morning and 2:00 pm to 6:00 pm for afternoon at the roadside. The pump was attached to a belt around individual's the waist or belt, and the inlet cyclone was attached to the collar as close to the breathing zone as possible. Whereas for indoor air PM_{10} collection, the sampler was put 1 and 1.5 m above the ground, 1 m from the stove during cooking *Wot* and baking *Injera*, respectively. Similarly, the sampler was put 1 m above the ground, at the center from the seat during sampling in the living room. This is the most appropriate breathing zone of the person across each microenvironment. The sampling duration during cooking *Wot* and baking *Injera* was started 10 min before starting the activities and ended when the activity was finished. Whereas the sampling duration for the living room was conducted when the member of the family doing their routine activities (eating, watching television, reading and others). The particulate matter was collected separately at the sampling sites.

Glass microfiber filters with a diameter of 25 mm GF/A (Whatman®, GE Healthcare UK limited, Amersham place, UK) was used to collect PM_{10}, which was put inside the universal sampler. Once the sampling is over, the filter was placed in aluminium foil and returned to the laboratory and put it in a desiccator. The filter is oven dried by 150 ^{o}C for 2 h before sampling to remove the humidity and VOCs on the filter.

The standard procedure developed by US EPA was used for the digestion of PM_{10} to determine the concentration of trace elements bound in particulate matter, which mainly uses aqua Regia mixture

for digestion. Hence, in this study, the mixture of 5 mL concentrated nitric acid (69-71% Sigma-Aldrich, Germany) and 15 mL concentrated hydrochloric acid (37%, Sigma-Aldrich, Germany) were used for the extraction of elements. Round bottom flask (100 mL) fitted with reflux condenser and Kjeldahl digestion block (Kjeldatherm, Gerhardt GmbH and Co.KG, Type KB 40 S, bon, Germany) were used for digestion of all PM_{10} loaded filter papers. After cooling, the extracted solution was filtered on the cellulose filter (Whatman I) adjusted to a final volume of 20 mL using de-ionized water. Finally, it was put in a pre-cleaned polyethylene bottle and refrigerated until analyzed. Triplicate filter and reagent blanks were also processed following the similar procedure for sample treatment (Leili *et al.*, 2008). Concentrations of 11 elements (Mn, Cd, Co, B, As, Ni, Cr, Pb, Zn, Cu and Fe) 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 dilution of a commercial 1000 ppm standard solution of each element (UNI-CHEM, chemical reagents). The photo of typical filter paper used for sampling is shown in Figure 4.

Figure 4. The photo of filter paper before and after sampling at Akaki Kality sub-city (Maselitegna sub-site) on October 25, 2017.

3.4 Statistical Package Used in Data Analysis

PMs data were uploaded to a computer from sampling instruments using the cable and software provided by the manufacturer and data filtering and summarizing was done using different software. Whereas, TVOCs were recorded on the notebook at a 2-minute interval and feed to the computer manually. For elemental concentration determination, the data was logged to the computer manually. After entering to the computer, the statistical data analysis was carried out using IBM SPSS version 20.0, Microcal^{TM}Origin version 16.0 (Micrical software, Inc. USA) and Microsoft Excel 2013. Kruskal-Wallis test and Analysis of Variance (ANOVA) were used to evaluate the significance of the differences in concentration of PMs, TVOCs and elements bound in PM_{10} at different circumstance (such as among stove types and fuel types during baking *Injera* and cooking *Wot*), respectively. A Wilcoxon signed-rank statistical test was applied to evaluate significance difference in concentration of PMs and TVOCs across seasons. Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) have used for identification of the possible sources of particulate matter (PM_{10}). Also, a Shapiro-Wilks statistical test was used to determine whether the data fit a normal or log-normal distribution. Thus, if the measurement data was not normally distributed it is better described as log-normally distributed that geometric mean (GOM) and geometric standard deviation (GSD). The significant difference for all the tests was set to 0.05.

Chapter 4: Results and Discussion

In this study, the amount of the PMs and TVOCs were measured at different microenvironments. The indoor air pollutants measurement was carried out at the kitchen room (during baking of *Injera* and cooking *Wot*), in the living room while the members of the household were sitting. Similar pollutants were measured at the roadside during the commuting time for the outdoor air. All the measured data for each microenvironment setting were tested by a Shapiro-Wilks test (Miller and Miller, 2010) which indicates that the PMs and TVOCs data are not normally distributed. Consequently, the data are better described as log-normally distributed and reported as GOM and GSD. However, the level of trace elements bounded in PM_{10} showed a normal distribution, and hence the data are reported as the arithmetic mean and standard deviation. The contribution of each microenvironment for the total exposure was also assessed in addition to the carcinogenic health risk and non-carcinogenic health risk assessment due to exposing to elements bound in PM_{10} and $PM_{2.5}$ PM_{10}, TSP, respectively.

4.1 Spatio-temporal Variations in TVOCs and PMs Pollutants during *Injera* Baking

From the sampled households, 23.3% of the households have used wood only, 7.78% of the households have used combined wood with leaves, 7.78% of the households have used combine leaves with sawdust, 33.3% of the households have used electricity and, 27.8% of the households have used leaves only as fuel in both the wet and dry seasons during measurement period. As far as the kitchen location is concerned, 8 kitchens were found in the living room and that of 37 kitchens were found separately from the living room. Moreover, the main ventilation found in the selected households were recorded, and 16 homes have only a single door, 2 homes have a single window and

27 homes have both a window and a door ventilation. The household family size ranged from 2 to 7 people and the kitchen volume for selected households were varied from 7 to 56 m^3, respectively. The average frequencies of *Injera* baking were approximately two times per week. The detailed information of the kitchen characteristic (such as fuel type, ventilation type, the volume of the kitchen, family size) for the selected households are given in Appendix I.

4.1.1 The levels of PMs and TVOCs across sampling sites during the wet season

The level of indoor air pollution can vary depending on both the dry and wet seasons and activities performed in the indoor. Cooking using different types of fuel and stove type is the major cause of pollutant level variation in indoor. The measurement of pollutant level while cooking is vital predicting the health level of the exposed person. Furthermore, recent studies show that short-term exposure (< 2 h) to particulate matter with different aerodynamic diameter cause different health problems such as the decrease in lung function and airway inflammation (Ryan *et al.*, 2015). The GOM concentration of PMs and TVOCs across the sampling site during *Injera* baking using clean, improved and traditional stoves at three sub-cities sampling sites have been measured in this work, and the results are given in Table 3 and Table 4 for the wet and dry season, respectively.

The GOM level of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs in all the sites were ranged 11.4-124, 26.9-395, 45.4-653, 74.5-805, 106-887, 163-992 and 1472-5979 µg m^{-3}, respectively. The highest values of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP, TVOCs were noticed at Gulelle using the traditional stoves, except PM_1 which is using the improved stove. Whereas the lowest value of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were observed at Akaki Kality using the clean stove. Furthermore, the levels of TVOCs were much higher than the levels of PMs emission from each stove

The test of significant variation in PMs and TVOCs concentration across the sites (by keeping the stove type similar and varying the sites) and within the sites (by keeping the sites similar and varying the stove type) were done using Kurskual-Wallis H independent sample test (Miller and Miller, 2010), respectively. Thus, the concentration of TVOCs (except across clean stoves, $p = 0.1$) and PMs showed a significant difference across and within each site at $p < 0.05$. Some factors such as duration of baking, room temperature and kitchen volume, ventilation type (natural or mechanical), wind direction, kitchen location (air exchange rate), fire condition (smoulder or fast burring) and fuel type and moisture content of fuel might be the cause for the variation in level of PMs and TVOCs. In addition, resuspension and deposition velocity are also factors for variation (Zhao *et al.*, 2013; Bo *et al.*, 2017).

As it can be seen in Figure 5, generally the level of PMs and TVOCs across each site were increased in the order of traditional stove, followed by improved and clean stoves, respectively. The level of TVOCs across the sampling site were decreased in the order of TG > TA > TK > IK > IA > IG >CA >CG > CK, whereas the level of PMs was decreasing in the order of TG > IA > TA > IA >CA >TK > CG > IK> CK. The variation might be due to the type and moisture content of the biomass, ventilation type, the status of the fire or location of the kitchen from ventilation which need further study (Jin *et al.*, 2006; Yeung and To, 2008).

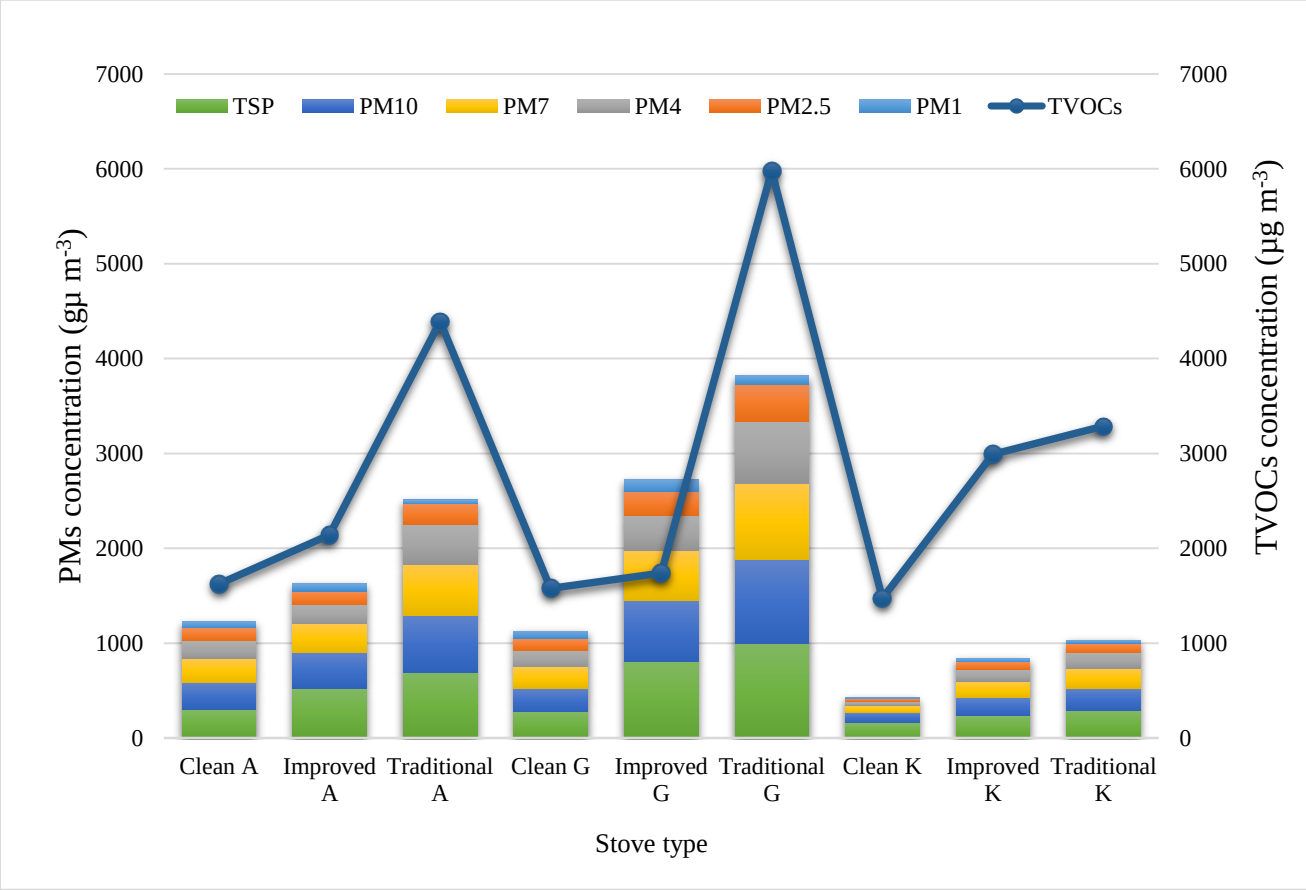


Figure 5. The levels of TVOCs and PMs across sampling sites during the wet season.

Table 3. The GOM concentration of PMs, TVOCs, K-volume, TR, RH and time used for baking of Injera using clean, improved (merit) and traditional (3 stone)) stoves during the wet season (GOM±GSD).

Sites across stove type	PM_1 (μgm^{-3})	$PM_{2.5}$ (μgm^{-3})	PM4 (μgm^{-3})	PM_7 (μgm^{-3})	PM_{10} (μgm^{-3})	TPM (μgm^{-3})	TVOCs (μgm^{-3})	Time (min)	K-volume (m^3)	TR (^oC)	RH (%)
Clean A	68.8±2.0	135 ±2.0	193 ±1.8	251 ±1.7	278±1.8	303±1.7	1625±2.3	59.2±1.2	14.1±1.6	21.8±1.2	59.7±1.2
Clean G	75.8±1.8	127±2.4	175±2.8	225±2.5	249±2.3	277±2.1	1579±2.0	55.2±1.4	15.8±1.5	22.3±1.2	56.0±1.3
Clean K	11.4±1.6	26.9±2.2	45.4±2.8	74.8±2.8	106±2.8	163±2.7	1472±2.3	73.0±1.8	14.6±1.8	24.2±1.4	53.4±1.3
Improved A	84.2±1.6	144±1.8	199±1.7	299±1.7	381±1.6	524±1.6	2140±2.0	71.2±1.3	26.8±1.6	29.7±1.1	36.3±1.1
Improved G	124±1.5	256±2.1	366±2.2	528±2.5	640±2.5	809±2.4	1738±2.1	56.6±1.4	14.2±1.4	24.6±1.3	48.8±1.1
Improved K	37.2±1.7	81.1±2.2	123±2.4	168±2.4	197±2.4	233±2.4	2991±1.9	68.5±1.1	17.4±2.0	24.8±1.3	48.8±1.3
Traditional A	41.9±2.2	221±2.5	420±2.8	534±2.6	599±2.4	695±2.3	4391±2.0	79.3±1.8	18.3±1.4	26.3±1.2	45.1±1.3
Traditional G	90.6±2.9	394±3.5	653±3.7	805±3.5	887±3.4	992±3.3	5979±2.0	66.5±1.3	19.8±1.3	27.1±1.3	41.8±1.4
Traditional K	34.0±1.5	101±2.3	164±2.8	207±2.9	233±2.8	294±2.7	3287±1.8	56.5±1.5	14.8±1.2	27.5±1.2	39.8±1.3

Note: A = Arada sub-city; G = Gulelle sub-city; K = Akaki Kality sub-city; K-volume = kitchen volume

4.1.2 The levels of TVOCs and PMs across sampling sites during the dry season

The GOM level of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs in all sites during the dry season were ranged 7.34-37.7, 15.9-309, 29.1-758, 54.3-1009, 75.9-1146, 111-1295 and 557-3767 µg m^{-3}, respectively. The maximum and the minimum values for both PMs and TVOCs were noticed in Gulelle and Akaki Kality sub-cities, respectively. The variation might be due to the difference in fuel type, status of the fire (whether it was off, starting, burning, or smouldering) and adding or moving fuel while using biomass fuel and ventilation type (Ezzati *et al.*, 2000; Jin *et al.*, 2006; Yeung and To, 2008). As observed in the wet season, the levels of TVOCs in the dry season were also much higher than the levels of PMs emission from each stove.

Kurskual Wallis H independent test was applied to the data for PMs and TVOCs across sites by varying sites and keeping the stove type similar to see their difference in concentration is statistical significant or not. Hence, PMs and TVOCs showed a significant difference in their concentration at $p < 0.05$ across each site within similar stove type except the PM_1 ($p = 0.06$). On the other hand, similar statistical test was applied within sites varying stove type and keeping the sites similar to see their difference in concentration is statistical significant or not. Thus, PMs and TVOCs showed a significant difference in their concentration at $p < 0.05$ across stove types within similar sites, except TVOCs ($p = 0.95$) at Gulelle site while comparing clean and improved stoves.

Moreover, as it can be seen from Figure 6 that, the levels of TVOCs and PMs decreased in the order of TG > TA > IA > TK > IG > CA > CG > IK > CK and TG > TA > TK > IA > IK ≈ IG > CG > CA > CK, respectively. However, the general trend showed the concentration of PMs and TVOCs in the traditional stove is higher than the improved stove, which followed by the clean stove in each site.

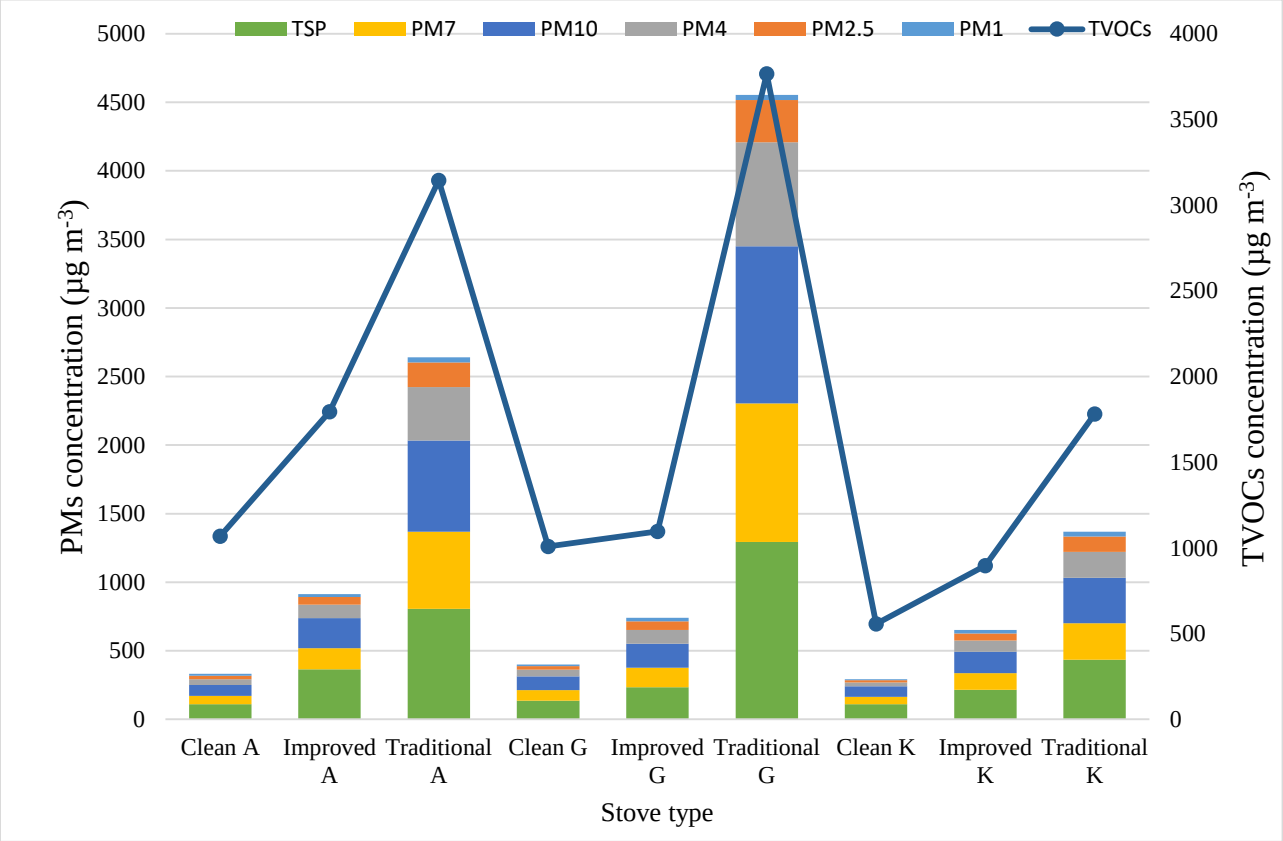


Figure 6. The levels of TVOCs and PMs across sampling sites during the dry season.

Table 4. The GOM concentration of PMs, TVOCs, TR, RH and time used for baking of *Injera* by different types of the stove (clean, improved (merit) and traditional (3 stone)) during the dry season (GOM±GSD).

Stove type across sites	PM_1 ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	PM_4 ($\mu g\ m^{-3}$)	PM_7 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	TSP ($\mu g\ m^{-3}$)	TVOCs ($\mu g\ m^{-3}$)	Time (min)	K-volume (m^3)	TR (°C)	RH (%)
Clean A	14.2±2.0	26.4±3.0	40.3±3.5	61.6±3.2	79.3±2.9	111±2.6	1068±2.0	79.8±1.2	14.1±1.6	26.5±1.2	35.8±1.4
Clean G	10.9±2.1	26.8±2.9	48.2±3.3	77.4±3.0	99.8±2.8	137±2.6	1009±2.4	71.9±1.2	26.8±1.6	24.3±1.2	39.5±1.3
Clean K	17.0±1.4	15.9±2.9	29.1±3.7	54.3±3.3	75.9±2.9	111±2.5	557±2.2	72.2±1.2	18.3±1.4	23.2±1.1	32.6±1.1
Improved A	20.2±1.8	56.7±2.2	96.7±2.9	154±2.9	220±2.9	365±2.9	1795±2.0	84.5±1.1	15.8±1.5	22.3±1.3	43.8±1.5
Improved G	25.5±1.8	63.8±3.1	100±4.4	142±4.6	176±4.5	234±4.0	1097±1.8	80.3±1.3	14.2±1.4	25.9±1.1	31.3±1.3
Improved K	25.8±1.9	52.4±2.2	81.3±2.1	122±1.9	156±1.8	215±1.7	896±1.9	80.0±1.3	19.8±1.2	33.0±1.2	15.9±1.2
Traditional A	37.1±2.2	180±3.3	389±3.4	564±3.1	664±2.9	805±2.7	3144±2.2	77.0±1.2	14.6±1.9	24.5±1.2	34.2±1.3
Traditional G	37.7±1.8	309±2.5	758±2.9	1009±2.8	1146±2.7	1295±2.5	3767±2.3	61.7±1.4	17.4±2.0	24.7±1.2	39.6±1.4
Traditional K	34.8±2.5	111±2.8	188±2.3	266±2.9	332±2.0	436±1.9	1783±1.9	85.1±1.1	14.8±1.3	29.2±1.1	24.7±1.3

Note: A = Arada sub-city; G = Gulelle sub-city; K = Akaki Kality sub-city.

4.1.3 The comprehensive evaluation of indoor air pollution at different stove types during baking *Injera*

The overall GOM of the concentration of PMs and TVOCs in μg m^{-3} using the clean, improved and traditional stoves during the wet and dry seasons are given in Table 5. Thus, the concentration of PMs measured during the wet season for the clean, improved and traditional stoves ranged 37.1-235, 72.8-462 and 50.3-591 μg m^{-3}, respectively. Whereas, the levels of TVOCs were 1553, 2234 and 4421 μg m^{-3} for the clean, improved and traditional stove, respectively. The maximum and the minimum PMs and TVOCs emission values were recorded at the traditional and the clean stoves, respectively. The minimum value of PM_1 was recorded using the traditional stove and the maximum value was seen using the improved stove, respectively. Kurskual-Wallis sample test has applied to the data for the clean, improved and traditional stoves to see their significant difference in PMs and TVOCs concentration. Thus, both PMs and TVOC pollutants showed a significant difference in their concentration across each stove type ($p < 0.05$). However, the difference was not recognized where it occurred. Therefore, Kurskual-Wallis H independent sample test was further applied by selecting the case. Thus, the clean stove was compared to the traditional stove and improved stove separately and the result showed a significant difference in concentration of PMs and TVOCs ($p < 0.05$), except PM_1 ($p = 0.05$) between the clean stove and the traditional stove comparison. Likewise, traditional and improved stoves were compared, and the result showed a significant difference in PMs and TVOCs concentration ($p < 0.05$). Moreover, the average time taken for baking *Injera* during the wet season for selected households using the clean, improved and the traditional stoves were 73.0, 61.7 and 68.5 min, respectively.

On the other hand, the overall geometric mean concentration of PMs for the dry season using the clean, improved and traditional stoves were ranged 10.5-119, 23.6-265 and 36.5-728 µg m^{-3}, respectively. Whereas, the levels of TVOCs were 845, 1214 and 2662 µg m^{-3} for the clean, improved and traditional stove, respectively. Thus, for both pollutants, the lowest amount was measured using the clean stove and the highest amount was measured using the traditional stove.

The amount of time taken for the baking of *Injera* using the clean, improved and traditional stove during the dry season were 75.5, 81.3, 75.9 min, respectively. Similarly to the wet season, Kurskual-Wallis H independent test was also applied to the data for the clean, improved and traditional stoves to see whether there is a significant difference in concentration of PMs and TVOCs pollutants are present or not at the dry season. Hence, the clean, improved and traditional stoves showed a significant difference in concentration of PMs and TVOCs ($p < 0.05$). Moreover, the clean stove was compared to the improved and traditional stoves separately, and the results showed a significant difference in emitted PMs and TVOCs concentration ($p < 0.05$). Similarly, the improved and traditional stove were compared which showed a significant difference in both PMs and TVOCs concentration ($p < 0.05$). Emission levels were modulated by differences in moisture levels of charcoal fuel, the fire status, location of stove and the type of ventilation.

Furthermore, the room temperature and relative humidity during baking using clean, improved and traditional stoves at the dry and wet seasons also recorded. Hence, room temperature using the clean, improved and traditional stoves were 24.7, 26.7, 26.3 and 22.8, 27.2, 26.1 ^{o}C at the dry and wet seasons, respectively. Whereas, the humidity of the room for the clean, improved and traditional stoves were 39.6, 28.1, 38.3 and 57.2, 41.3, 44.8%, respectively.

the level of PMs emissions found in this study using the improved stove was lower than the PMs levels found using the traditional stoves, which have shown the similar trend with the level of particulate matter ($PM_{3.5}$) measured in the Guatemalan community. Thus, the level of $PM_{3.5}$ at Guatemalan community using in the improved stove was lower than that of the traditional stove (Albalak *et al.*, 2001). In a similar manner, the level of $PM_{2.5}$ using improved and traditional stoves found in this study was compared to the previous study conducted in Addis Ababa, and the results showed that the level of $PM_{2.5}$ found in this study is lower than that of an earlier study conducted in Addis Ababa (Sanbata *et al.*, 2014). This variation might be due to the type, the moisture content and amount of biomass fuel used, fire condition/status, location of the sampler and the type of cooking conducted (McDonald *et al.*, 2000; Balakrishnan *et al.*, 2002).

Table 5. The overall GOM concentration of PMs, TVOCs, TR, RH and time taken during baking *Injera* using clean, improved (merit) and traditional (3 stone)) stoves at the wet and dry seasons (GOM±GSD).

Stove type	PM_1 ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	PM_4 ($\mu g\ m^{-3}$)	PM_7 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	TSP ($\mu g\ m^{-3}$)	TVOCs ($\mu g\ m^{-3}$)	Time (min)	K-volume (m^3)	TR (^oC)	RH (%)
Clean D	10.5±2.0	22.4±3.0	38.3±3.6	63.6±3.3	84.1±3.0	119±2.7	845±2.5	75.5±1.2	19.1±1.6	24.7±1.2	35.8±1.3
Clean W	37.0±1.9	74.0±2.2	111±2.5	156±2.5	189±2.4	235±2.4	1553±2.3	73.0±1.2	19.1±1.6	22.8±1.3	56.2±1.3
ID	23.6±1.3	57.4±3.6	92.5±4.2	139±4.0	183±3.8	265±3.5	1214±2.3	83.1±1.2	16.4±1.4	26.7±1.2	28.1±1.4
IW	72.8±1.7	144±2.4	208±2.7	298±2.7	363±2.7	462±2.7	2234±2.6	61.7±1.2	16.4±1.4	26.2±1.2	44.2±1.3
TD	36.4±2.2	174±2.9	356±3.0	498±2.7	594±2.5	728±2.3	2662±2.1	75.9±1.3	15.6±1.7	26.3±1.2	31.5±1.5
TW	50.3±2.5	207±3.1	358±3.3	449±3.1	502±3.0	591±2.1	4421±2.1	68.5±1.3	15.6±1.7	27.0±1.2	42.3±1.4

Note: D = Dry season and W = Wet season, T = Traditional stove, I = improved stove

4.1.4 The temporary variation of PMs and TVOCs in clean, improved and traditional stoves during baking *Injera*

The temporal variation of PMs, TVOCs, TR and RH was calculated using Wilcoxon signed-rank test within clean, improved and traditional stoves, and the results are shown in Table 6. Wilcoxon signed-rank test showed a significant difference in concentration of PMs and TVOCs within each stove type between the dry and wet season at $p < 0.05$, except, PM_4, PM_7 and PM_{10} did not show a significant difference at the traditional stove. The relative humidity and temperature of the baking room also showed the significant difference in the dry and wet seasons within the stove type which might affect resuspension rate or the dispersion of the pollutant. Consequently, the variation in concentration of pollutants might come from this variation. The moisture content of the fuel, status of the fire and the formation of secondary pollutants (through condensation and coagulation) during the measurements might also be the reason for the difference in PMs and TVOCs concentration. Secondary pollutants can be formed with the pollutants released from the baking process itself, without the involvement of any other pollutants emitted from other sources (Sidra *et al.*, 2015).

Table 6. Wilcoxon signed-rank test result for emission of PMs, TVOCs, TR and RH while using the clean, improved and traditional stoves between the dry and wet season.

	Clean stove		Improved stove		Traditional stove	
	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
PM_1 at wet- PM_1 at dry	-18.6[b]	0.00	-16.6[b]	0.00	-8.55[b]	0.00
$PM_{2.5}$ at wet- $PM_{2.5}$ at dry	-18.4[b]	0.00	-12.5[b]	0.00	-5.23[b]	0.00
PM_4 at wet - PM_4 at dry	-17.5[b]	0.00	-10.4[b]	0.00	-2.42[b]	0.02
PM_7 at wet - PM_7 at dry	-16.6[b]	0.00	-10.8[b]	0.00	-1.31[b]	0.19
PM_{10} at wet - PM_{10} at dry	-16.5[b]	0.00	-10.5[b]	0.00	-0.66[b]	0.51
TSP at wet - TSP at dry	-15.9[b]	0.00	-8.9[b]	0.00	-0.33[b]	0.74
TVOCs at wet - TVOCs at dry	-11.6[b]	0.00	-6.57[b]	0.00	-9.11[b]	0.00
TR at wet - TR at dry	-8.93[a]	0.00	-5.26[b]	0.00	-3.00[b]	0.00
RH at wet - RH at dry	-19.4[b]	0.00	-8.44[b]	0.00	-12.2[b]	0.00

Note: a= Based on positive ranks; b = Based on negative ranks.

Moreover, the percentage contribution of each particulate matter and TVOCs across the clean, improved and traditional stoves at different seasons were shown in Figure 7. The patterns followed in percent contribution of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: Improved W > Traditional W > Clean W ≈ Traditional D > Improved D > Clean D; Traditional W > Traditional D > Improved W > Clean W > Improved D > Clean D; Traditional W > Traditional D > Improved W > Clean W > Improved D > Clean D; Traditional D > Traditional W > Improved W > Clean W > Improved D > Clean D; Traditional D > Traditional W > Improved W > Improved D > Clean W > Clean D; Traditional D > Traditional W > Improved W > Clean W > Improved D > Clean D, respectively.

Generally, almost all of the lowest percentage coverage of PMs and TVOCs were recorded at the clean stove during the dry season. The highest percentage coverage of PM_1, $PM_{2.5}$, PM_4, TVOCs were recorded at the improved stove during the wet season. Whereas for PM_7, PM_{10}, TSP the

highest were recorded at the traditional stove during the dry season. Although further study is required for identifying factors contributing to this variation, the moisture content of the fuel, status of the fire, the relative humidity and temperature variation of the room might be the major factors. In addition, the difference might be due to the difference in resuspension of the pollutant and the formation of secondary pollutants in the air which can be determined by the particle size, exchange rate and humidity of the room.

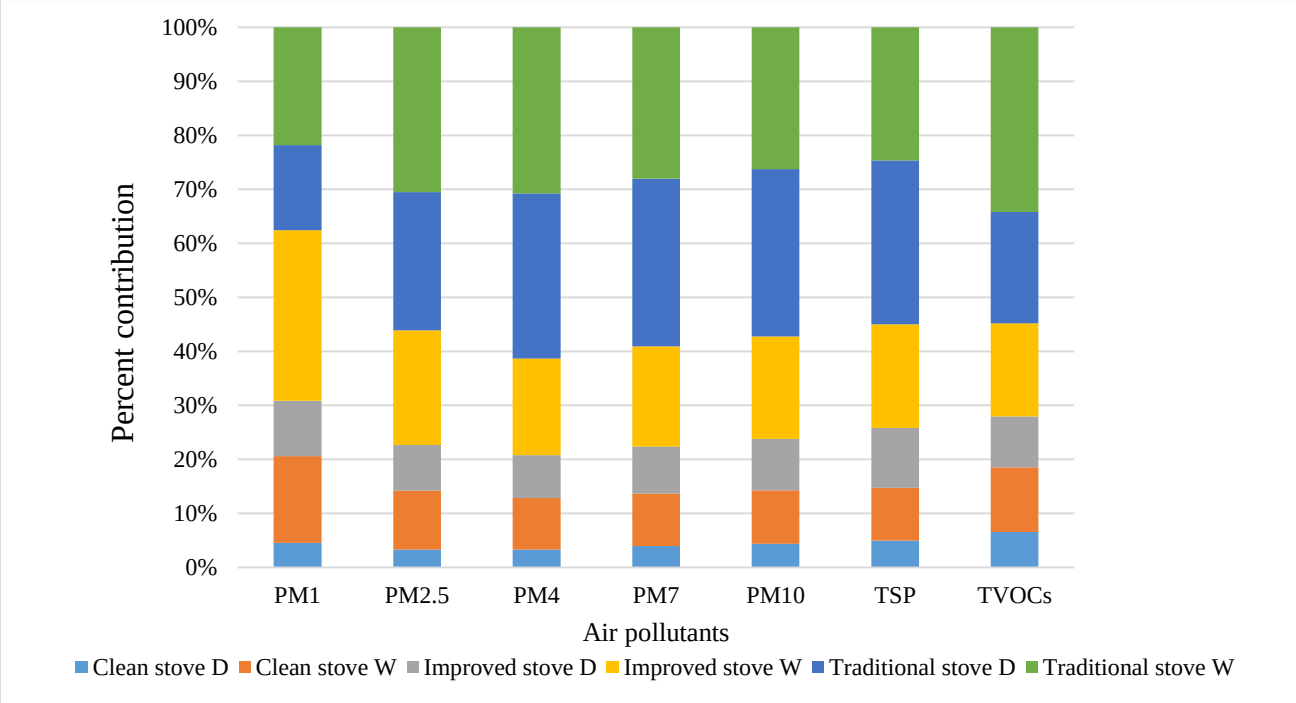


Figure 7. The percentage contribution in PMs and TVOCs across the clean, improved and traditional stoves at different seasons.

4.1.5 Total exposure assessment during baking *Injera*

Based on the concentration of pollutants in the microenvironment, the average breathing rate of an individual and the exposure time, one can estimate the total dose of the pollutant taken by human. The total exposure during baking was calculated by using the overall GOM of both the dry and

wet seasons. Exposure to indoor air pollution patterns varies due to the individual (age and time spent in cooking area) and household differences (fuel/stove type, cookhouse ventilation, outdoor air pollution level) (Boadi and Kuitunen, 2006; Anenberg *et al.*, 2013). Exposure can be measured either directly through personal monitoring or indirectly by combining information on pollutant concentrations in each microenvironment (different episodes of house such as in the kitchen, the living room) where people spend time with information on the activity patterns (Nigel *et al.*, 2000; Kena *et al.*, 2013).

Personal exposure monitoring using indirect method and direct method measurement at fixed-site does not give an accurate and representative data since the pollutant level varies with time and space depending on the sources (Wangchuk *et al.*, 2015). However, the data obtained from direct measurement provide a more realistic assessment of the exposure risk on cohorts or population groups, more importantly at different microenvironments with high pollution levels (Nigel *et al.*, 2000). Besides, the exposure might vary during performing even in a single activity. For example, the variation to exposure to different pollutants while cooking depends on status of fire (whether it was off, starting, burning, or smouldering), adding or moving fuel, the type of food cooked and fuel type used (Ezzati *et al.*, 2000; Balakrishnan *et al.*, 2002; Jin *et al.*, 2006; Yeung and To, 2008). As a result, the level of exposure during baking *Injera* using clean, improved and traditional stoves have been assessed in this work.

The exposure patterns to PMs and TVOCs were different during baking *Injera* using clean, improved and traditional stoves, and the details of the results are summarized in Table 7. The amount of PMs in the clean, improved and traditional stoves were ranged 19.7-167, 37.5-333 and 42.7-656 µg m^{-3}, respectively, whereas, the level of TVOCs for the clean, improved and traditional stoves were 1145, 1558 and 3422 µg m^{-3}, respectively.

Table 7. The GOM mean value of PMs, TVOCs, K-volume, TR, RH and time taking during baking *Injera* using different types of stove (GOM±GSD).

Stove type	PM_1 ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	PM_4 ($\mu g\ m^{-3}$)	PM_7 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	TSP ($\mu g\ m^{-3}$)	TVOCs ($\mu g\ m^{-3}$)	Time (min)	K-volume (m^3)	TR (°C)	RH (%)
Clean	19.7±3.0	40.7±3.0	65.1±2.8	99.5±2.4	126±2.2	167±2.0	1145±2.2	71.8±1.3	19.2±1.6	23.7±1.2	44.8±1.4
Improved	37.5±2.5	83.7±2.8	129±3.0	190±3.0	242±2.8	333±2.7	1558±2.2	69.6±1.3	16.4±1.4	26.5±1.3	33.8±1.6
Traditional	42.7±1.9	190±2.6	357±3.3	473±3.3	547±3.2	656±3.0	3422±2.1	69.7±1.3	15.6±1.7	26.6±1.2	36.4±1.5

Furthermore, studies have shown that using the clean stove and improved stove were better than from that of the traditional stove in minimizing exposure during cooking (Albalak *et al.*, 2001). For instance, a study at Nigeria showed using improved stove decreases the pollution level of $PM_{2.5}$ measured during the cooking time from 1414 to130 $\mu g\ m^{-3}$ (Oluwole *et al.*, 2013). This study also showed similar trends in reducing exposure of PMs and TVOCs pollutants while baking *Injera* using such type of stove. The percent exposure reductions of clean and improved stoves in PMs and TVOCs as comparing of the traditional stove were calculated by using equation (1).

$$\%\ \text{exposure reduction} = \frac{(\text{PTS} - \text{PCSorPIS})}{\text{PTS}} \text{ x } 100 \quad (1)$$

Similarly, their percent reduction of the clean stove as compared to the improved stove was calculated by using equation (2). The results are presented in Table 8.

$$\%\ \text{exposure reduction} = \frac{(\text{PIS} - \text{PCS})}{\text{PIS}} \text{ x } 100 \quad (2)$$

where PTS is the overall GOM concentration of the pollutant in traditional stove taken during both the dry and wet seasons, PCS is the overall GOM concentration of the pollutant in the clean stove taken from both the dry and wet seasons, PIS is the overall GOM concentration of the pollutant in improved stove taken from both the dry and wet seasons.

Depending on both the type of pollutant and the aerodynamic diameter of PMs, a person baking *Injera* who uses the clean stove instead of the traditional stove may reduce the exposure level of PMs and TVOCs pollutants by a minimum of 53.9% and as high as by 81.7%. Likewise, *Injera* bakers can reduce their exposure to PMs and TVOCs by a minimum of 12.3% and by as high as 63.9% by using the improved stove instead of the traditional stove. Meanwhile, an *Injera* baker who use the clean stove instead of the improved stove can reduce their exposure to PMs and TVOCs pollutants with a minimum of 26.5% and a maximum of 51.7%. These results of the study are comparable with other studies conducted in Gansu Province, China, in which the reduction of a PM_4 level by 70%, from 774 to 223 $\mu g\ m^{-3}$ was achieved (Johansson *et al.*, 2009).

Table 8. Comparison of the percentage exposure reduction to PMs and TVOCs by clean and improved stoves as comparing with traditional stove, and clean stove as compared to the improved stove.

PM_1 (%)	$PM_{2.5}$ (%)	PM_4 (%)	PM_7 (%)	PM_{10} (%)	TSP (%)	TVOCs (%)	Remarks
53.9	78.6	81.7	79.0	76.9	74.6	66.6	Clean vs traditional stove
12.3	56.0	63.9	59.9	55.7	49.3	54.5	Improved vs traditional stove
47.4	51.7	49.5	47.6	47.9	49.8	26.5	Clean vs improved stove

Although, setting guidelines for the indoor air pollutants is vital for determining associated human health risks and for taking intervention measures to abate for indoor pollution, until recently no guidelines were set for indoor air pollution level for PMs and TVOCs. However, some organizations have established guidelines for $PM_{2.5}$, PM_{10}, TSP and TVOCs air pollutants for ambient air. The values set by these organizations were formulated based on the exposure-response of pollutants concentration below 200 µg m^{-3}. However, this pollutant concentration is not a representative value of indoor air pollution exposure in developing countries where its level can reach up to several thousand µg m^{-3}. For instance, World Health Organization has set a guideline for ambient $PM_{2.5}$ and PM_{10} for 24 h (25 and 50 µg m^{-3}) and annual (10 and 20 µg m^{-3}) exposures, respectively (Ezzati and Kammen, 2001; WHO, 2010). Meanwhile, guidelines for total volatile organic compounds set a direction for TVOCs in range of concentration which used to indicate the different level of health effect; comfort range (< 200 µg m^{-3}), multifactorial exposure range (200-3000 µg m^{-3}), discomfort range (3000-25000 µg m^{-3}) and toxic range (> 25000 µg m^{-3}) (Zabiegala *et al.*, 2009). Similarly, Brazilian National Environment Council has set a guideline for TSP as 240 µg m^{-3} (Araujo et al., 2014).

Furthermore, though recent studies have shown particulate matter exposure for a short time (in the order of one or more hour) can affect the health of the exposed, guidelines are not available for such type of exposure (Zabiegala *et al.*, 2009). This work focused on the measurements of PMs and TVOCs for a short period (in the order of hours) during the baking of *Injera*, since it might increase the individual long-term exposure (chronic exposure) to the pollutants although baking of *Injera* is discrete event that happen a few times per week.

Therefore, to compare the results of our study to the available guidelines, it is better to calculate the permissible amount of particulate matter inhaled for 24 h by using healthy adult person

respiration rate of 0.014 $m^3 min^{-1}$ (Liu *et al.*, 2018). Assuming all the persons involved in the baking are adult women and assuming all the women are healthy, we can calculate the possible amount of PMs intake in µg for a specific time interval using equation (3). Also, the permissible amount of $PM_{2.5}$, PM_{10} and TSP inhaled for 24 h exposure based on WHO and Brazilian National Environment Council were calculated similarly. The results from clean, improved and traditional stoves were compared with these values. The results are shown in Table 9.

$$\text{PIA (µg)} = \text{AIR } (m^3\ min^{-1}) \text{x Concentration of PMs (µg } m^{-3}) \text{x ED (min)} \quad (3)$$

$$\%\ \text{Contribution for 24 h} = \frac{\text{PAI (µg)}}{\text{PLIA (µg)}} \text{ x } 100 \quad (4)$$

where PAI is the possible amount of intake; AIR is air intake rate, PLIA is permissible intake amount and ED is exposure duration.

Table 9. The possible amount of PMs and TVOCs intake by healthy adult women during baking *Injera* and WHO and Brazilian National Environment Council guidelines.

Stove type	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
Clean stove (µg)	19.8	40.9	65.4	100	127	168	1151
Improved stove (µg)	36.5	81.5	126	185	236	324	1518
Traditional stove (µg)	41.7	185	348	462	533	640	3339
Permissible intake in 24 h (µg)	-	504[a]	-	-	1008[a]	4838[b]	-

[a] WHO guideline; [b] Brazilian National Environment Council

As shown in Table 9, the level of $PM_{2.5}$, PM_{10} and TSP are below the set guidelines. However, their contribution to long-time exposure is high, especially for the traditional stove users. Thus, the percent contribution for the daily total exposure were calculated by using equation (4). The

percent contribution for the daily total exposure to $PM_{2.5}$, PM_{10} and TSP for the clean, improved and tradition stove were: 8.11, 12.6, 3.48; 16.2, 23.4, 6.7 and 36.8, 52.9, 13.2%, respectively.

4.1.5 Health risk assessment due to exposure of $PM_{2.5}$, PM_{10} and TSP during baking of *Injera*

Human health risk assessment due to air contaminants depends on the type of pollutants and the extent of exposure. Hazard identification, dose-response assessment, exposure assessment and risk characterization are the major steps used in health risk assessment (Matooane and Diab, 2003; Kushwaha *et al.*, 2012; Morakinyo *et al.*, 2017). We have gone through each of these steps to estimate the health risk due to PMs exposure during the baking of *Injera*. Hence, although all PMs and TVOCs were identified as hazard contaminants in the air, only $PM_{2.5}$, PM_{10} and TSP were considered due to unavailability of reference dose (RfD) values for other pollutants which are used in the calculation of hazard quotient (HQ) used in health risk assessment steps. In the second step, ADD (average daily intake also called chronic daily intake) (μg $kg^{-1}day^{-1}$) was calculated using equations (5 and 6). Annual threshold values set by world health organization (WHO) and United State Environmental Protection Agency (US EPA) have used as reference dose (RfD) while dealing with a dose-response step; and finally HQ (hazard quotient) was calculated in the risk characterization step at different microenvironments (during the baking of *Injera* using clean, improved and traditional stove) (Matooane and Diab, 2003; Kushwaha *et al.*, 2012; Morakinyo *et al.*, 2017).

Almost in all the time, the Ethiopian females are responsible for the baking of *Injer*a, and they usually start baking at the age of 17 and continue until they are too old baked. The current life expectancy for a female is around 67, exposure frequency of 350 days/year and exposure duration

of 50 years was taken for calculations of HQ and ADD. The air intake rate for an adult is 20 m^3 per day and body weight for adult Ethiopian women is assumed to be African adult weight which is 60.7 kg (EPA, 1989; Walpole *et al.*, 2012). The time spent for baking *Injera* was recorded using clean, improved and traditional stoves while measuring PMs, and the baking was performed twice per week. Thus, 0.34, 0.33 and 0.33 h day^{-1} were used as exposure time for clean, improved and traditional stoves, respectively. Table 10 showed the details considered in HQ calculation.

US EPA classifies the exposure as acute (exposure duration is below two weeks), the sub-chronic exposure duration is above two weeks and below 7 years) and the chronic (exposure duration is above 7 years) types of exposure. The exposure duration of this work is above two weeks and below 7 years, it is classified under the subchronic type of exposure. Hence, RfD for the sub-chronic type of exposure is used, which is the annual average of $PM_{2.5}$ (10 µg m^{-3}), PM_{10} (20 µg m^{-3}) and TSP (150 µg m^{-3}) values set by WHO and US EPA were used to calculate HQ (EPA, 2008; WHO, 2010). The total overall GOM of $PM_{2.5}$, PM_{10} and TSP in regardless of seasons have been used for health risk assessments.

Table 10. Exposure frequency, exposure time, intake rate, body weight, exposure duration and averaging time for adult women.

Stove type	Exposure time (h day^{-1})	Exposure frequency (days $year^{-1}$)	Duration Exposure (years)	Exposure duration (days)	AT (days)	IR (m^3 day^{-1})	BW (kg)
Clean	0.34	350	50	248	18250	20	60.7
Improved	0.33	350	50	241	18250	20	60.7
Traditional	0.33	350	50	241	18250	20	60.7

The following equations are used for calculating of average daily intake (ADD) and HQ to characterize the health risk due to $PM_{2.5}$, PM_{10} and TSP

$$ADD = \frac{\text{CA x IR x ED}}{\text{AT x BW}} \quad (5)$$

$$\text{ED} = \frac{\text{EF x DE x ET x 1 day}}{24\,\text{h}} \quad (6)$$

where ADD is the average daily intake (µg $kg^{-1}day^{-1}$); CA is the contaminant's concentration in air (µg m^{-3}); ET is the exposure time spent (hours day^{-1}); EF is the exposure frequency (days $year^{-1}$); IR is the intake rate (m^3 day^{-1}); ED is the exposure duration (days), DE is the duration of exposure (years); AT is the averaging time (DE x 365 days $year^{-1}$); 1 day 24^{-1} h^{-1} is the conversion factor from hours to days.

$$HQ = \frac{ADD}{RfD} \quad (7)$$

where HQ is the hazard quotient; RfD reference dose (this will convert to the same unit as ADD (µg kg^{-1} day^{-1}), that RfD expressed in µg kg^{-1} day^{-1} would be equal to the RfD in µg m^{-3} multiplied by 20 m^3 air inhaled per person per day divided by 70 kg per person. It should be noted that the average weight of African woman is assumed to be 60.7 kg. However, there is no conversion factor using the weight 60.7 kg for calculating RfD, hence 70 kg per person, the weight used by US EPA was also in this study.

According to US EPA, if the HQ calculated is less than 1, the contaminate could not induce any health impact on the exposed organism (human), whereas its value is greater than 1 the contaminates induce/cause some health impact on the exposed human (EPA, 1989). This work

showed no HQ value is greater than one in all types of pollutants and stove types which confirmed the baking of *Injera* only could not induce any health problems. However, this does not mean that their contribution to the total chronic exposure is small. Thus, the baking of *Injera* using clean, improved and traditional stove can cover the total chronic intake of $PM_{2.5}$ and PM_{10} about 5.6 to 37.3%, whereas 1.5 to 6% for TSP. The highest and the lowest percent contribution to the total chronic intake for all pollutants were seen during the traditional and the clean stove, respectively. The ADD for PMs and TVOCs and hazard quotients for $PM_{2.5}$, PM_{10} and TSP for the clean, improved and traditional stoves used for the baking of *Injera* are given in Table 11.

Table 11. ADD for PMs and TVOCs and hazard quotients for $PM_{2.5,}$ PM_{10} and TSP for the clean, improved and traditional stoves used for the baking of *Injera*.

ADD for PMs and TVOCs (µg kg^{-1} day^{-1})							
ADD across stove type	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADD_{cle}	0.09	0.18	0.29	0.45	0.56	0.75	5.12
ADD_{imp}	0.17	0.37	0.58	0.85	1.08	1.49	6.97
ADD_{tra}	0.19	0.85	1.60	2.12	2.45	2.94	15.3
RfDannual	-	3.24	-	-	6.56	49.4	-
HQ for $PM_{2.5}$, PM_{10} and TSP							
HQ_{cle}	-	0.06	-	-	0.09	0.02	-
HQ_{imp}	-	0.11	-	-	0.17	0.03	-
HQ_{tra}	-	0.26	-	-	0.37	0.06	-

(ADD_{cle} = ADD in using clean stove; ADD_{imp} = ADD using improved stove; ADD_{tra} = ADD using traditional stove; HQ_{cle} = HQ in using clean stove; HQ_{imp} = HQ in using improved stove; HQ_{tra} = HQ in using traditional stove)

In addition to using HQ for health risk assessment, hazard index (HI, which is the sum of HQ of each pollutant) have been used to see the cumulative effect of pollutants. US EPA, explain that if

HI is greater than 1, the exposed person to pollutants can have health problems whereas if HI is less than 1 they have not face any serious health problems (EPA, 1989). Accordingly, HI value for clean, improved and traditional stoves were found to be 0.17, 0.31 and 0.69, respectively. One can conclude that an *Injera* baker may not have develop a non-carcinogenic health problems due to exposure to $PM_{2.5}$, PM_{10} and TSP. The results of this analysis and the assumptions for this estimation should be supported with epidemiological and health data for further validation.

4.2 Spatio-temporal Variations in TVOCs and PMs Pollutants during Cooking of *Wot*

The specific energy of cooking fuels have placed in a hierarchal ladder based on their efficiency and the cost in increasing order of animal dung < crop residues < wood < charcoal < kerosene < gas < electricity. However, there is a need to know the level of exposure from such fuels at a specific activity to estimate the health impact of exposed person by calculating their contribution to total exposure (Singh, 2016). Hence, researchers at different parts of the world have reported the level of indoor air pollutants during cooking time while using different type of fuels (Smith *et al.*, 1983; Saksena *et al.*, 1992; Ellegdrd, 1996; Balakrishnan *et al.*, 2002; Dasgupta *et al.*, 2006; Adeniji *et al.*, 2015). In Ethiopia, biomass wood is the primary fuel used for cooking activities, whereas charcoal fuel is the second most fuels used in urban areas for cooking. On the other hand, Ethiopian Statistical Agency (ESA) in 2004 reported 42% of the residents in capital Addis Ababa was using kerosene as primary fuel (Kebede and Kiflu, 2014; Tefera *et al.*, 2016).

A total of 45 households were selected in three sub-cities based on the fuel type they use for cooking *Wot*. Out of the selected households, each of 15 households have used electricity, charcoal and kerosene as fuel sources. 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. Moreover, the types of *Wot* cooked during the measurement are *Misir*, *Dinich* and *Shiro Wot*. Thus, from the selected households 32, 9, 4 and 31, 10, 4 households were preparing *Shiro*, *Misir* and *Dinich Wot* during the dry and wet season, respectively. Furthermore, the ventilation type, the ventilation area and the condition of the ventilation were noted and the details are given in Appendix II.

4.2.1 The levels of TVOCs and PMs across sampling sites during the wet season

The amount of PMs and TVOCs measured during cooking the different types of *Wot* using electric, charcoal and kerosene fuels at selected sites were recorded. The results are presented and shown in Figure 8 and Table 12, respectively. The GOM level of PM_1, $PM_{2.5}$ PM_4, PM_7, PM_{10}, TSP and TVOCs in regardless of fuel type at all sites were ranged 10.7-25.9, 22.7-57.4, 38.8-99.3, 62.9-155, 73.4-194, 84.7-194 and 261-1698 µg m^{-3}, respectively. The highest emission values were measured in Gulelle sub-city where the charcoal fuel was used, whereas the lowest values for $PM_{2.5}$ PM_4 and PM_7, PM_{10} and TSP at Akaki Kality and Arada sub-cities from the electric fuel, respectively. However, PM_1 showed the lowest value at Akaki Kality emitted from using kerosene fuel. The spatial variation in PMs and TVOCs concentration using electricity, charcoal and kerosene fuels were tested by applying Kurskual-Wallis H independent test. Thus, the test was applied to the data separately in each fuel type by varying sites, and the concentration of PMs and TVOCs showed a significant different across the sampling sites in each of the fuel types, except PM_1 using electricity fuel ($p = 0.07$) and $PM_{2.5}$ using kerosene fuel ($p = 0.55$). However, the test for across fuel type within site showed a significant different ($p < 0.05$)

Table 12. The GOM concentration of PMs, TVOCs, K-volume, TR, RH and the time took for cooking *Wot* using electricity, kerosene and charcoal fuel during the wet season at different sites (GOM±GSD).

Fuel type across sites	PM_1 (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_4 (µg m^{-3})	PM_7 (µg m^{-3})	PM_{10} (µg m^{-3})	TSP (µg m^{-3})	TVOCs (µg m^{-3})	TR (ºC)	RH (%)	Time (min)	K-volume (m^3)
Electricity A	12.5±1.9	26.0±2.4	42.9±2.6	62.9±2.4	73.4±2.3	87.4±2.2	315±1.9	22.2±1.1	56.3±1.2	65.3±1.2	16.6±1.6
Electricity G	11.4±1.5	24.7±2.2	44.8±2.6	69.4±2.6	81.8±2.4	95.0±2.3	261±3.4	19.8±1.1	62.1±1.1	62.3±1.3	16.0±1.2
Electricity K	10.7±2.1	26.3±2.2	55.6±1.9	95.8±1.7	117±1.7	141±1.7	464±2.1	21.7±1.1	62.8±1.2	104±1.1	13.4±2.2
Charcoal A	19.1±2.5	43.1±2.8	73.6±2.8	106±2.7	125±2.6	150±2.5	988±2.3	22.0±1.1	56.7±1.1	93.4±1.1	10.5±1.7
Charcoal G	25.9±1.9	57.4±2.1	99.3±2.2	155±2.0	194±2.0	250±2.0	1698±2.3	21.3±1.1	60.0±1.1	108±1.3	15.3±1.3
Charcoal K	19.3±1.6	37.8±1.7	65.8±1.8	109±1.9	139±1.9	180±1.9	1031±1.6	21.4±1.1	55.8±1.2	106±1.9	16.7±1.8
Kerosene A	13.0±1.6	22.7±1.6	38.5±1.5	65.4±1.9	84.3±1.7	111±1.5	275±1.6	23.7±1.1	52.9±1.1	84.4±1.7	15.0±1.4
Kerosene G	14.4±1.7	27.4±1.7	51.8±1.7	93.8±1.7	123±1.7	163±1.7	1166±2.8	22.5±1.1	48.4±1.2	104±1.4	15.6±1.3
Kerosene K	14.4±1.8	25.7±1.8	44.9±1.7	75.2±1.6	96.9±1.6	126±1.6	868±1.9	21.5±1.1	43.5±1.2	97.2±1.2	23.0±1.9

Note: A = Arada sub-city; G =Gulelle sub-city, and K = Akaki Kality; K-volume = Kitchen volume.

The general trend for the overall GOM of PMs and TVOCs level during the cooking *Wot* were found to be in increasing order charcoal < kerosene < electricity in Arada and Gulelle sub-cities. Whereas in Akaki Kality the order of their levels is charcoal > electricity > kerosene. Moreover, as it can be seen in Figure 8, PMs and TVOCs level across the sampling sites during the cooking of *Wot* are found to be in the decreasing order of CG > CK > CA > KG > EK > KA ≈ KK > EA > EG and CG > CK > KG > CA > KK > EK > EG ≈ KA ≈ EA, respectively.

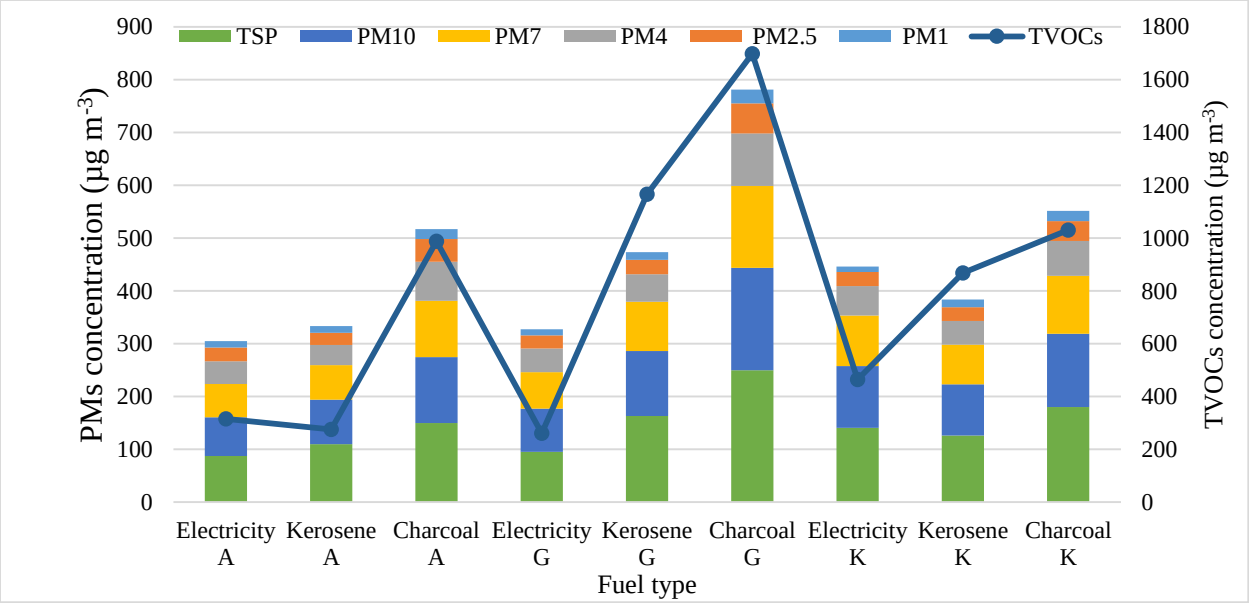


Figure 8. The level of PMs and TVOCs emitted during the cooking of *Wot* during the wet season at selected sites using different types of fuel.

4.2.2 The levels of PMs and TVOCs across sampling sites during the dry season

Like in the wet season, the GOM level of PMS and TVOCs during the cooking of *Wot* using electric, kerosene and charcoal fuels were also measured during the dry season. The levels of each pollutant in each sampled sites are shown in Table 13. Thus, the level of PM_1, $PM_{2.5}$, MP_4, PM_7, PM_{10}, TSP and TVOCs were ranged: 6.6-19.5, 21.1-73.1, 42.8-146, 88.1-229, 126-299, 183-386 and 286-808 µg m^{-3}, respectively. The highest and the lowest values for all types of pollutants were recorded at Gulelle and Arada sub-sites using charcoal and electricity fuels, respectively. Moreover, Kurskual Wallis H independent test was applied to the concentration of PMs and TVOCs across sites and within sites by varying sites and keeping fuel type similar and via versa to see their statistical significances. Hence, both PMs and TVOCs showed a significant different in their concentration across sampling site while using electricity, charcoal and kerosene fuel

separately ($p < 0.05$), except TVOCs which did not show a significant different across sites while using charcoal fuel ($p = 0.10$). Meanwhile, the level of PMs and TVOCs across sampling sites were tested using electricity, charcoal and kerosene for the cooking of *Wot* and the result showed a significant different within sampling sites ($p < 0.05$).

Table 13. The GOM concentration of PMs, TVOCs, K-volume, TR, RH and time took during the cooking of *Wot* using electricity, kerosene and charcoal fuels at selected sub-cities in the dry season (GOM±GSD).

Fuel type across sites	PM_1 (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_4 (µg m^{-3})	PM_7 (µg m^{-3})	PM_{10} (µg m^{-3})	TSP (µg m^{-3})	TVOCs	TR (ºC)	RH (%)	Time (min)
Electricity A	6.60±1.8	21.1±1.9	47.8±1.7	88.1±1.5	126±1.4	183±1.4	286±2.1	22.2±1.2	48.3±1.2	104±1.3
Kerosene A	7.00±1.9	27.1±2.9	58.6±3.4	95.4±3.4	128±3.1	176±3.1	372±2.3	21.5±1.1	51.1±1.4	107±1.2
Charcoal A	14.6±1.7	52.3±1.7	99.7±1.6	153±1.6	193±1.7	232±1.7	753±2.2	19.5±1.1	65.0±1.1	85.3±1.3
Electricity G	8.81±1.5	31.4±1.6	65.9±1.5	109±1.5	149±1.4	206±1.4	449±1.7	23.3±1.2	50.8±1.2	77.7±1.3
Kerosene G	18.1±1.5	72.0±2.1	126±2.1	168±1.9	195±1.9	225±1.9	691±1.9	20.1±1.1	59.3±1.2	71.3±1.5
Charcoal G	19.5±1.5	73.1±1.7	146±1.6	229±1.6	299±1.6	386±1.6	808±2.0	22.8±1.1	44.2±1.2	108.9±1.2
Electricity K	8.14±1.5	29.7±1.8	66.3±1.9	117±1.9	164±1.9	226±1.9	514±1.7	21.7±1.1	61.4±1.1	84.6±1.2
Kerosene K	11.3±1.6	37.9±2.0	71.6±2.0	114±1.9	153±1.8	207±1.7	798±1.8	20.8±1.2	50.0±1.1	75.3±1.1
Charcoal K	13.0±1.5	45.8±1.9	87.6±1.9	133±1.8	176±1.8	237±1.7	883±1.4	20.6±1.1	44.8±1.2	78.5±1.1

Note: A = Arada sub-city; G =Gulelle sub-city, and K = Akaki Kality; K-volume = Kitchen volume.

Furthermore, the general trend of the overall GOM of PMs and TVOCs level during the cooking of *Wot* were founded to be in increasing order of charcoal, kerosene and electricity in Arada and Gulelle sub-cities, whereas the in Akaki Kality, the order of their level is charcoal > electricity > kerosene fuel. As it has seen in Figure 9, PMs and TVOCs level while across the sampling sites during the cooking of *Wot* were found to be in decreasing order of CG > KG > CA ≈ CK > EK ≈ KK ≈ EG > KA ≈ EA and CK > CG > KK > CA > KG > EK > EG > KA > EA, respectively.

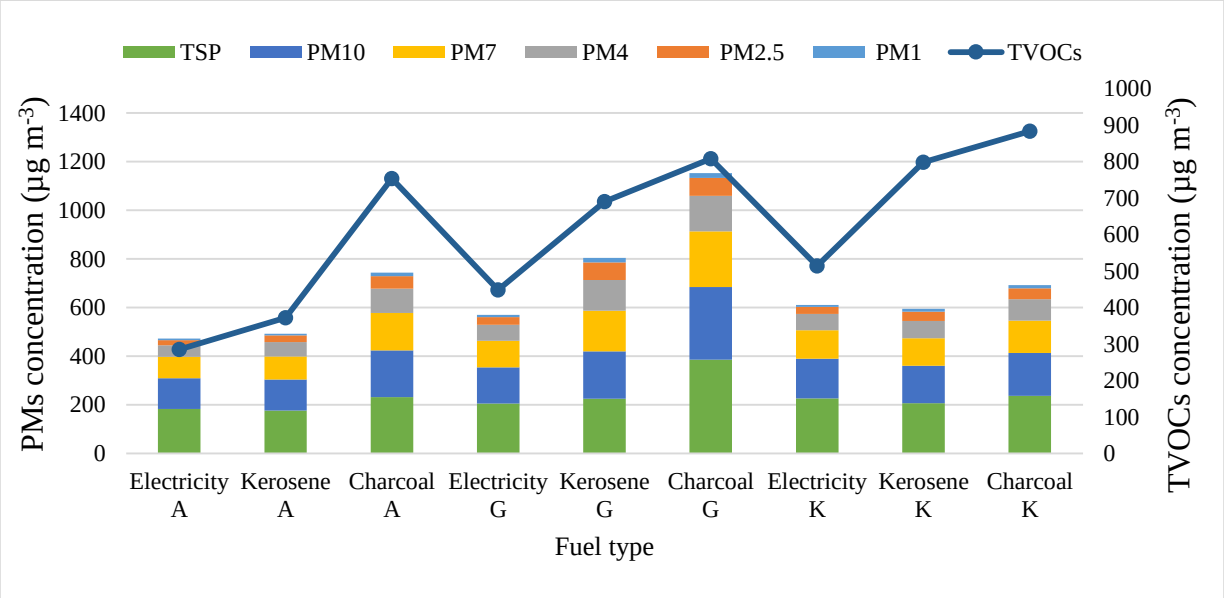


Figure 9. The level of PMs and TVOCs during the cooking of *Wot* during the dry season at selected sites using different types of fuel.

4.2.3 The comprehensive evaluation of indoor air pollution while using different fuel types during cooking *Wot*

The overall GOM concentration of PMs and TVOCs in µg m^{-3} using electric, charcoal and kerosene fuel during the wet and dry seasons from all the sampling sites are given in Table 14. Thus, amount of PM_1, $PM_{2.5}$, MP_4, PM_7, PM_{10}, TSP and TVOCs measured during the wet season were ranged 11.3-21.2, 25.4-45.1, 45.4-77.9, 77.0-122, 91.8-151, 109-190 and 350-1200 µg m^{-3}, respectively. The maximum amount for all types of pollutants was recorded during using charcoal as the fuel sources. Whereas, the minimum values for PM_1, PM_7, PM_{10}, TSP, TVOCs and $PM_{2.5}$, PM_4 were recorded using electricity and kerosene fuels, respectively. Kurskual-Wallis H independent sample test was applied to the data obtained for electricity, charcoal and kerosene fuel type. Both PMs and TVOC pollutants showed a significant difference in their concentration across

each fuel type ($p < 0.05$). However, the difference was not recognized where it occurred. Therefore, Kurskual-Wallis H independent sample test was further applied by selecting the case. Thus, charcoal fuel was compared to electricity and kerosene fuels separately and the result showed a significant different in concentration of emitted PMs and TVOCs ($p < 0.05$). Likewise, electricity and kerosene fuels were compared that $PM_{2.5}$, PM_4, TSP and TVOCs showed the significant difference in their concentration ($p < 0.05$). However, PM_1, PM_7 and PM_{10} did not show a significant difference ($p > 0.12$). Moreover, the average time taken during the cooking of *Wot* at the wet season for sampled households using electric, charcoal and kerosene stove were 78.0, 103 and 96.0 min, respectively.

On the other hand, the overall GOM concentration of PM_1, $PM_{2.5}$, MP_4, PM_7, PM_{10}, TSP and TVOCs during the dry season was in the range of 7.68-15.9, 26.4-57.2, 58.3-111, 103-172, 144-222, 198-284 and 294-812 μg m^{-3}, respectively. Thus, for both pollutants, the lowest emissions were measured using electricity fuel except the TSP level which was detected using kerosene fuel. The highest emission of TSP was measured using charcoal fuel. Similar to the wet season, the amount of time taken was recorded using electricity, charcoal and kerosene fuel during the dry season, and results were 89.4, 91.4 and 86.2 min, respectively. Kurskual-Wallis sample test was also applied to the data for electricity, charcoal and kerosene fuel, and they showed a significant difference in concentration of PMs and TVOCs ($p < 0.05$). Kurskual-Wallis H independent sample test was also carried out for the individual comparison, such that charcoal compared to kerosene and electricity fuels separately, and the results showed a significant difference in PMs and TVOCs concentration ($p < 0.05$). Similarly, electricity and kerosene were compared which showed a substantial difference in both PMs and TVOCs concentration with $p < 0.05$, except PM_{10} and TSP, did not show a significant difference ($p > 0.20$).

Furthermore, the room temperature and relative humidity (RH) during the cooking of *Wot* using electricity, charcoal and kerosene fuels during the dry and the wet seasons were also recorded. The room temperature using electricity, charcoal and kerosene fuels were 22.3, 21.1, 20.9 and 21.3, 21.5, 22.5 ^{o}C at the dry and wet seasons, respectively. Whereas, the humidity of the room using electricity, charcoal and kerosene fuels were 52.9, 50.1, 52.9 and 60.9, 57.4, 47.9 %, respectively.

Table 14. The overall GOM concentration of PMs, TVOCs, TR, RH and time took during the cooking of *Wot* by different types of fuels at the wet and dry seasons (GOM±GSD).

Season type	Fuel type	PM_1 (μg m^{-3})	$PM_{2.5}$ (μg m^{-3})	PM_4 (μg m^{-3})	PM_7 (μg m^{-3})	PM_{10} (μg m^{-3})	TSP (μg m^{-3})	TVOCs (μg m^{-3})	TR (^{o}C)	RH (%)	Time (min)
Wet	Electricity	11.4±2.0	25.8±2.2	48.4±2.2	77.0±2.2	91.8±2.2	109±2.2	350±2.1	21.3±1.1	60.6±1.1	78.0±1.6
	Kerosene	14.0±1.7	25.4±1.7	45.4±1.7	78.5±1.7	102±1.6	134±1.7	706±2.7	22.5±1.1	47.7±1.2	96.0±1.4
	Charcoal	21.2±1.9	45.1±2.3	77.9±2.4	122±2.2	151±2.2	190±2.1	1200±2.2	21.5±1.1	57.4±1.2	103±1.2
Dry	Electricity	7.68±1.6	26.4±2.0	58.3±2.0	103±1.9	144±1.9	203±1.8	394±2.0	22.3±1.2	52.9±1.3	89.4±1.4
	Kerosene	10.5±1.9	39.2±2.5	76.9±2.6	117±2.5	152±2.4	198±2.3	555±2.1	21.0±1.1	52.9±2.3	86.2±1.3
	Charcoal	15.6±1.7	57.2±1.9	111±1.8	172±1.7	222±1.6	284±1.6	812±2.0	21.1±1.1	50.1±1.2	91.4±1.4

Note: D = Dry season and W = Wet season

4.2.4 The temporary variation of PMs and TVOCs during the cooking of *Wot* using electricity, kerosene and charcoal fuels

The temporary variation in the emission of PMs, TVOCs, TR and RH values were calculated using the Wilcoxon signed-rank test across electric, kerosene and charcoal fuels, and the results are given in Table 15. The Wilcoxon signed-rank test showed the significant difference in concentration of PMs and TVOCs across each fuel type between the dry and wet season at $p < 0.05$. However, $PM_{2.5}$ and TVOCs did not show a significant difference using electric fuel only. The relative humidity and the temperature of the cooking room also show a significant difference, which might

affect resuspension rate or the dispersion of the pollutant. Consequently, this variation might contribute to the variation in concentration of PMs and TVOCs. Also, the moisture content of the charcoal fuel, its status of the fire and the formation of secondary PMs during measuring might be the reason for the difference in PMs and TVOCs concentration across seasons.

Table 15. Wilcoxon signed rank test result for PMs, TVOCs, TR and RH using electricity, kerosene and charcoal fuels between the dry and wet seasons.

	Electricity		Charcoal		Kerosene	
	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
PM_1 at dry- PM_1 at wet	-8.01[b]	0.000	-12.5[b]	0.000	-7.02[b]	0.000
$PM_{2.5}$ at dry- $PM_{2.5}$ at wet	-0.004[a]	0.997	-4.53[a]	0.000	-11.8[a]	0.000
PM_4 at dry- PM_4 at wet	-2.70[a]	0.007	-7.78[a]	0.000	-13.3[a]	0.000
PM_7 at dry - PM_7 at wet	-4.54[a]	0.000	-7.96[a]	0.000	-11.2[a]	0.000
PM_{10} at dry - PM_{10} at wet	-8.43[a]	0.000	-8.98[a]	0.000	-11.5[a]	0.000
TSP at dry - TSP at wet	-12.3[a]	0.000	-9.27[a]	0.000	-11.6[a]	0.000
TVOCs at dry - TVOCs at wet	-0.99[b]	0.321	-7.93[b]	0.000	-5.86[b]	0.000
TR at dry - TR at wet	-6.99[a]	0.000	-2.33[b]	0.020	-13.1[b]	0.000
RH at - RH at wet	-14.7[b]	0.000	-12.3[b]	0.000	-9.28[a]	0.000

([a] = based on negative ranks; [b] = based on positive ranks).

Moreover, the percentage contributions of each particulate matter and TVOCs across electricity, charcoal and kerosene at different seasons were determined and the results are shown in Figure 10. The patterns followed in percent contribution of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: Charcoal W > Charcoal D > Kerosene W > Electricity W > Kerosene D ≈ Electricity D; Charcoal D > Charcoal W > Kerosene D > Electricity D > Electricity W ≈ Kerosene W;

Charcoal D > Charcoal W > Kerosene D > Electricity D > Electricity W ≈ Kerosene W; Charcoal D > Charcoal W > Kerosene D > Electricity D > Electricity W ≈ Kerosene W; Charcoal D > Kerosene D ≈ Charcoal W > Electricity D > Kerosene W > Electricity W; Charcoal D > Electricity D ≈ Kerosene D ≈ Charcoal W > Kerosene W > Electricity W and Charcoal W > Charcoal D > Kerosene W > Kerosene D > Electricity D > Electricity W, respectively.

The lowest percentage coverage of PMs (except, PM_1 which is observed using electricity during the dry season) and TVOCs were recorded using both kerosene and electricity fuels during the wet season. Whereas the highest percentage coverage of PM_1, TVOCs and $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP were recorded using charcoal during the wet and dry season, respectively. This change in concentration might be due to the relative humidity and temperature variation of room and the difference in resuspension of the pollutant and the formation of secondary pollutants in the air which depends on the particle size. The air exchange rate can also result in differences.

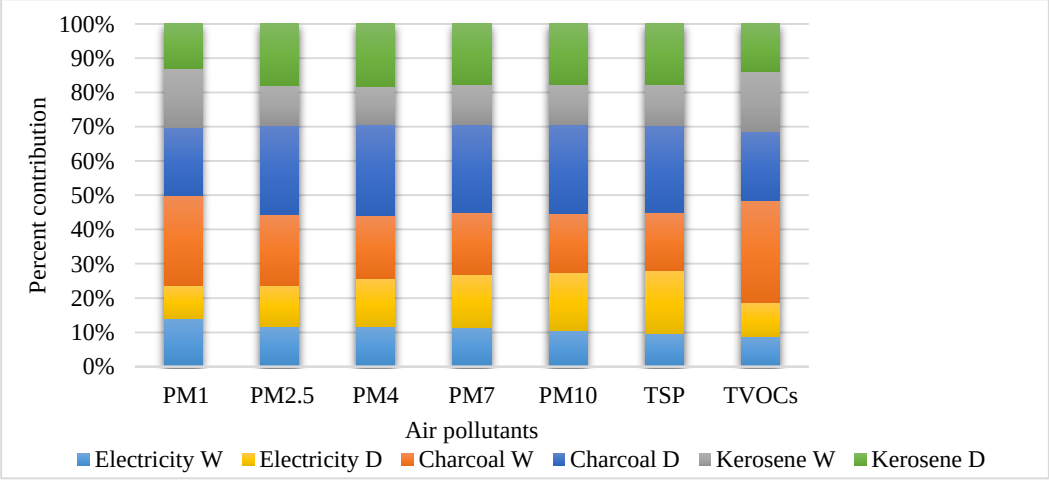


Figure 10. The temporary variation in GOM of PMs and TVOCs across electricity, kerosene and charcoal fuels at the wet and dry seasons during the cooking of *Wot*.

4.2.5 Total exposure assessment during cooking of *Wot*

The overall GOM concentration of PMs emission for all types of *Wot* prepared, at selected sites and seasons cooked using electricity, charcoal and kerosene fuels were used to calculate the total exposure during cooking *Wot*. Several studies have shown that exposure assessment at different microenvironment is vital for estimating the health impact of the exposed person and taking a remedial action at an individual level. Besides, the level of pollutants during cooking depends on status of fire (whether it was off, starting, burning, or smouldering) and adding or moving fuel, the kitchen volume, location of sampler from stove, location of stove from ventilation of kitchen, the type of food cooked and type of fuel used (Ezzati *et al.*, 2000; Balakrishnan *et al.*, 2002; Jin *et al.*, 2006; Yeung and To, 2008). For instance, the level of $PM_{2.5}$ measured for 48 h in 9 households at Addis Ababa by Gaia Association which use charcoal, kerosene and ethanol as fuel was found to be in the ranges 160-1850 for charcoal and kerosene users and 120-770 µg m^{-3} for ethanol users (Association). However, in this study, the concentration of $PM_{2.5}$ emitted from using charcoal and kerosene stoves were lower than from this rang. This might be due to the presences of other activities other than cooking *Wot*, the location of the stove from ventilation, kitchen volume, humidity and temperature of the room. Another similar study on the level of $PM_{2.5}$ for 24 h measurement in 59 households at Addis Ababa using biomass, kerosene and clean fuels reported 1,134, 637, and 335 µg m^3, respectively (Tefera *et al.*, 2016). The overall GOM of PMs and TVOCs in regardless of the season are given in Table 16.

Table 16. The overall GOM value of PMs, TVOCs, time, K-volume, TR and RH at Addis Ababa during the cooking of *Wot* using different types of fuels (GOM±GSD).

Fuel type	PM_1 (μg m^{-3})	$PM_{2.5}$ (μg m^{-3})	PM_4 (μg m^{-3})	PM_7 (μg m^{-3})	PM_{10} (μg m^{-3})	TSP (μg m^{-3})	TVOCs (μg m^{-3})	TR (°C)	RH (%)	Time (min)	K-volume (m^3)
Electricity	9.20±1.9	26.1±2.2	53.5±2.0	90.0±2.0	117±2.0	152±2.0	373±2.0	21.9±1.1	56.3±1.5	84.0±1.5	14.7±1.4
Charcoal	18.6±1.9	50.2±2.2	91.4±2.2	142±2.1	179±2.1	228±2.1	1006±2.3	21.3±1.1	54.0±1.2	97.7±1.3	14.9±1.7
Kerosene	12.2±1.8	31.4±2.2	58.7±2.2	95.5±2.1	124±2.1	162±2.0	628±2.4	21.7±1.1	50.2±1.3	91.1±1.4	16.2±1.8

Furthermore, studies have shown that the use of clean fuels (such as electricity and kerosene) instead of biomass fuels while preparing foods can reduce the level of total exposure. Besides, the amount of their reduction depends on the type food prepared (Balakrishnan *et al.*, 2002; Balakrishnan *et al.*, 2004; Dasgupta *et al.*, 2006; Saksena *et al.*, 2007). Table 17 shows the percent reduction of exposure compared while using electricity and kerosene, kerosene and charcoal, and electricity and kerosene during the cooking of *Wot*. Equations 8 and 9 were used for this calculation, respectively.

$$\%\,\text{exposure reduction} = \frac{(\text{PCF - PEF or PKF})}{PCF} x100 \tag{8}$$

$$\%\,\text{exposure reduction} = \frac{(\text{PKF - PCF})}{PKF} x100 \tag{9}$$

where PCF is the overall GOM concentration of the pollutant using charcoal fuel taken from both the dry and wet seasons, PKF is the overall GOM concentration of the pollutant in kerosene fuel taken during both the dry and wet seasons, PEF is the overall GOM concentration of the pollutant using electricity fuel taken from both the dry and wet season.

Depending on both the type of pollutant and the aerodynamic diameter of PMs, a *Wot* cooker who uses electric fuel instead of charcoal fuel can reduce his/her exposure by a minimum of 33.1% and as high as 62.9%. Likewise, they can reduce their exposure to PMs and TVOCs in the range 28.9-37.6% by using kerosene fuel instead of using charcoal fuel. Moreover, depending on the indoor air conditions, an electric *Wot* cook stove can reduce the emission of air pollutants from 5.23-40.6 % compared to kerosene stoves.

Table 17. Comparison of percentage exposure reduction to PMs and TVOCs by using electricity and kerosene fuel instead of using charcoal fuel, and electricity fuel instead of kerosene fuel during the cooking of *Wot*.

PM_1 (%)	$PM_{2.5}$ (%)	PM_4 (%)	PM_7 (%)	PM_{10} (%)	TSP (%)	TVOCs (%)	Remarks
50.4	48.0	41.5	36.8	34.7	33.1	62.9	Electricity Vs charcoal
34.4	37.4	35.8	32.9	31.1	28.9	37.6	Kerosene Vs charcoal
24.4	16.9	8.79	5.80	5.23	5.82	40.6	Electricity Vs kerosene

Like baking *Injera*, the measured PMs and TVOCs during the cooking of *Wot* were for a short period of time, which is not possibly compared with the available guideline. However, although cooking *Wot* is a discrete event which does not contribute to the continuous exposure, it can increase the individual long-term exposure to the pollutants. Pollutants emitted during the food preparation event would stay trapped in the home for extended periods long after the cooking activity is completed.

Therefore, to compare the results of our study to the available guidelines, the similar trend during baking *Injera* was followed. Thus, it is better to calculate the amount of particulate matter inhaled for 24 h by using healthy adult person respiration rate of 0.014 m^3 min^{-1} (Liu *et al.*, 2018). Assuming all the persons involved in cooking *Wot* are adults women, and assuming all of them are healthy, we can calculate the possible amount of PMs intake in µg for a specific time interval

by equation (3) using the overall GOM regardless of seasonal variation. In addition, the permissible amount of $PM_{2.5}$, PM_{10} and TSP inhaled for 24 h exposure based on WHO and Brazilian National Environment Council were calculated in a similar way, and the results from electricity, kerosene and charcoal fuels were compared with these values. The results are shown in Table 18.

Table 18. Comparison of the level of PMs with WHO and Brazilian National Environment Council Guidelines set for 24 h exposure.

Fuel type	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
Electricity fuel (µg)	21.6	61.4	126	212	275	358	877
Charcoal fuel (µg)	50.7	137	250	388	490	622	2748
Kerosene fuel (µg)	31	80	149	243	315	412	1601
Permissible intake in 24 h (µg)	-	504[a]	-	-	1008[a]	4838[b]	-

([a] WHO guideline; [b]Brazilian National Environment Council).

As shown in Table 18, the level of $PM_{2.5}$, PM_{10} and TSP are below the set guidelines. However, their contribution to long-time exposure is high, especially for charcoal fuel users. Thus, by using equation (4) the percent of the contribution was calculated. The percent contribution for the daily total exposure to $PM_{2.5}$, PM_{10} and TSP were calculated for electricity, kerosene and charcoal fuels, and the results were: 12.2, 27.3, 7.4; 15.9, 31.2, 8.52 and 27.2, 48.6, 12.8%, respectively.

Researchers from the different region of the world have reported levels of indoor air pollutants in the kitchen over 24 h or during cooking using different types of fuels. The summary of the data for some of these studies from developing countries is presented in Table 19.

Table 19. Summary of indoor air pollution in developing countries using different fuel types.

Country	Description	Particulate concentration range (μg m^{-3})	Ref.
Bangladesh	Arial 24 h	PM_{10}: Use of dung (291); Firewood (263); Sawdust (237); Natural gas stove (101); Kerosene stove (134)	(Dasgupta *et al.*, 2006)
Southern India	Aerial 24 h	RSP: Wood (204); Wood chips (266); Agricultural produce (246); Kerosene (78); Gas (78)	(Balakrishnan *et al.*, 2002)
Mozambique	Cooking period	PM_{10} : Wood (1200)	(Ellegdrd, 1996)
Kenya	Daily exposure	PM_{10}: Wood/Charcoal (1000-4800)	(Ezzati *et al.*, 2000)
India, Garhwal Himalaya	The cooking period for 24-h exposures	TSP(GOM): Using wood/shrubs (4,500 (winter); 710–1,960 (winter); 250–1,130 (summer))	(Saksena *et al.*, 1992)
India, Gujrat	The cooking period	TSP: Use of wood (6800)	(Smith *et al.*, 1983)
Nigeria, Ibadan	Twice a day (morning: 7-9 am and evening: 5-7 pm)	PM_{10}: Use of kerosene (231-365)	(Adeniji *et al.*, 2015)
India, Andhra Pradesh	24 h kitchen concentration	RPM(GOM): Dung (470); Wood (340); Kerosene (156) and Gas (61)	(Balakrishnan *et al.*, 2004)
Dominican Republic	Half in kitchen and half in the child's bedroom for 10 h	RPM (GOM): Charcoal (27.9 l); Gas (17.6)	(Leonelo E. Bautista *et al.*, 2009)
India, Delhi	Kitchen during cooking	RPM: LPG (890); Kerosene (690); Wood (1370) and Coal (1090)	(Saksena *et al.*, 2007)
Ethiopia, Addis Ababa	During cooking *Wot* at wet season	PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs (GOM): Electricity (11.3, 25.7, 48.4, 77.0, 91.8, 109 and 350); Charcoal (21.2, 45.1, 77.9, 122, 151, 190 and 1200); Kerosene (14.0, 25.4, 45.4, 78.5, 102, 134 and 706)	This study
	During cooking *Wot* at dry season	Electricity (7.68, 26.4, 58.3, 103, 144, 203 and 394); Charcoal (15.6, 57.2, 111, 172, 222, 283 and 812); Kerosene (10.5, 39.2, 76.9, 117, 152, 198 and 555)	

4.2. 6 Health risk assessment due to exposure of $PM_{2.5}$, PM_{10} and TSP during cooking *Wot*

To calculate the health risk assessment during cooking *Wot*, similar steps used in health risk assessment during the baking of *Injera* have been used, except the exposure time. Hence, the time spent for the measurement of PMs during cooking of *Wot* was recorded using electricity, charcoal and kerosene, and doubling of this value was used as exposure time since the cooking was done two times per day. Thus, 2.8, 3.26 and 3.04 h day^{-1} were used as exposure time for electricity, charcoal and kerosene fuel, respectively. The details considered in HQ calculation are summarized in Table 20.

According to US EPA classification, cooking *Wot* is classified under the chronic type of exposure because the exposure duration of this study is above 7 years. RfD for the chronic type of exposure is used, which is the annual average of $PM_{2.5}$ (10 µg m^{-3}), PM_{10} (20 µg m^{-3}) and TSP (150 µg m^{-3}) values set by WHO and US EPA were used to calculate HQ (EPA, 2008; WHO, 2010). The total overall GOM of $PM_{2.5}$, PM_{10} and TSP in regardless of seasons have been used for the health risk assessments.

Table 20. Exposure frequency, exposure time, intake rate, body weight, exposure duration and averaging time for adult women.

Fuel type	Exposure time (h day^{-1})	Exposure frequency (days $year^{-1}$)	Duration exposure (years)	Exposure duration (days)	AT (days)	IR (m^3 day^{-1})	BW (kg)
Electricity	2.8	350	50	2042	18250	20	60.7
Charcoal	3.26	350	50	2377	18250	20	60.7
Kerosene	3.04	350	50	2217	18250	20	60.7

As it is seen in Table 21, only using charcoal fuel can induce health impacts for the exposed person by PM_{10}, since its HQ value was greater than 1. Whereas kerosene and electricity HQ for both $PM_{2.5}$ and PM_{10} was below 1 which confirmed they could not induce a health problems. However, this does not mean that their contribution to the total chronic exposure is small. Thus, cooking *Wot* using electricity and kerosene fuels can cover the total chronic intake of $PM_{2.5}$ and PM_{10} about 29.6 to 101%, whereas 11.4 to 17% for TSP. The highest and the lowest percent contribution to the total chronic intake for all pollutants were seen using charcoal and electricity fuel, respectively.

Table 21. ADD for PMs and TVOCs and for HQ for $PM_{2.5}$, PM_{10} and TSP using electricity, kerosene and charcoal fuels.

ADD for PMs and TVOCs ($\mu g\ kg^{-1}\ day^{-1}$)							
Average daily intake across fuel type	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADD_{ele}	0.34	0.96	1.97	3.32	4.32	5.62	13.8
ADD_{ch}	0.68	1.85	3.37	5.24	6.61	8.39	37.1
ADD_{ker}	0.45	1.16	2.16	3.52	4.56	5.96	23.2
RfD annual	-	3.24	-	-	6.56	49.4	-
HQ for $PM_{2.5}$ PM_{10} and TSP							
HQ_{ele}	-	0.29	-	-	0.66	0.11	-
HQ_{ch}	-	0.56	-	-	1.01	0.17	-
HQ_{ker}	-	0.35	-	-	0.69	0.12	-

(ADDele = ADD in using electricity fuel; ADDch = ADD using charcoal fuel; ADDker = ADD using kerosene fuel; HQele = HQ in using electricity fuel; HQch = HQ in using charcoal fuel; HQker = HQ in using kerosene fuel)

Furthermore, HI for electric, kerosene and charcoal fuels using HQ of $PM_{2.5}$, PM_{10} and TSP were calculated and the results were found to be 1.03, 1.68 and 1.13, respectively. Thus, although

individual pollutants (except PM_{10} during charcoal use) have no health impact to a cooker, their cumulative effect can induce non-carcinogenic health problems while combined.

4.3 The Levels of PMs and TVOCs at Living Room

The exposure assessments to pollutants at different microenvironments within a home has a vital role to know the proportion of each microenvironment within site to the indoor total exposure (Devi *et al.,* 2009). Although the level of air pollutants at living room is low as compared to the kitchens, many people spent the high portion of their time at this microenvironment. Therefore, this work also focused on the measurement of the amount of the PMs and TVOCs in the living room. In this context, the living room is the place where members of a family can do different activities (such as watching television, eating food, studying, playing with kids and discussion with family members).

In this work, the level of PMs and TVOCs were measured at the living room in 45 households at the selected three sub-cities, and the results are given in Table 22. The level of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were ranged 4.12-7.87, 12.9-27.3, 43.5-86.0, 57.7-108, 74.0-131 and 261-402 µg m^{-3}, respectively. The highest value for PMs and TVOCs were recorded at Gulelle sites, whereas the lowest value for PM_1, $PM_{2.5}$ and PM_4, PM_7, PM_{10}, TSP, TVOCs were noticed at Arada and Akaki Kality, respectively. The room temperature and relative humidity were: 22.7, 22.6, 20.4 ^oC and 46.7, 40.6, 58.0% for Akaki Kality, Arada and Gulelle sub-cities, respectively. The time is taken for measurements and the volume of the living room for Akaki Kality, Arada and Gulelle sub-cities were 119, 128, 122 min and 19.9, 20.1 and 15.4 m^3, respectively.

Moreover, Kurskual Wallis test was applied to PMs and TVOCs, AT, RH and L-volume data to see their significant differences in concentration of PMs, TVOCs and values of AT, RH and L-volume across the sampling sites. The overall test showed the significant difference ($p < 0.05$). However, to determine where the difference has occurred, Kurskual Wallis H independent test was applied between each site. When the test was applied to the data for Arada vs Gulelle and Gulelle vs Akaki Kality showed a significant differences ($p < 0.05$). Besides, Arada vs Akaki Kality also showed a significant difference ($p < 0.05$), except PM_4 ($p = 0.07$) and AT ($p = 0.05$).

Table 22. The level of PMs and TVOCs, TR, RH and L-Volume at Arada, Gulelle and Akaki Kality sub-cites.

Sampling code	PM_1 (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_4 (µg m^{-3})	PM_7 (µg m^{-3})	PM_{10} (µg m^{-3})	TSP (µg m^{-3})	TVOCs (µg m^{-3})	TR (°C)	RH (%)	Time (min)	LR-vol (m^3)
JJ	4.18±1.8	12.9±2.0	29.7±2.0	54.2±2.0	74.9±2.1	99.7±2.2	233±2.1	22.6±1.1	40.6±1.3	128±1.1	20.1±1.9
AA	7.87±1.7	27.3±1.7	55.2±1.0	86.0±1.6	108±1.7	131±1.7	402±1.7	20.4±1.1	58.2±1.2	122±1.1	15.4±1.5
CC	5.69±1.5	14.1±1.6	26.4±1.7	43.5±1.7	57.7±1.8	74.0±1.9	261±1.9	22.7±1.1	46.7±1.3	119±1.1	19.9±2.0

LR-vol = living room volume; JJ = Arada sub-city, AA = Gulelle sub-city, CC = Akaki Kality sub-city

Furthermore, the percent contribution for the total daily permissible intake at this ME was calculated using overall GOM concentration of PMs and TVOCs. Similar to during the baking of *Injera* and the cooking of *Wot*, the WHO and Brazilian National Environment Council guidelines are used as a reference. Hence, the overall GOM for PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: 5.68, 17.0, 35.1, 58.7, 77.6, 99.0 and 289 µg m^{-3}, respectively. The average time spent during measurement of the pollutants was also recorded, and it was 123 min. The average time spent in this ME and overall GOM concentration values were also used in health risk assessments. The possible amount of intake of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: 9.79, 29.2, 60.4, 101, 134, 171 and 498 µg,

respectively. The percent contribution for daily exposure to $PM_{2.5}$, PM_{10} and TSP were 5.8, 13.3 and 3.5%, respectively.

The health risk due to the exposure of PMs and TVOCs at the living room were estimated by using the overall GOM in regardless of sites. All the assumption and equation used in estimating of health risk during baking *Injera* and cooking *Wot* was used in this section, except infant and children at the different age were included in it, because all age groups were spent some of their time in this ME. Moreover, South African infant and child body weight were considered in risk assessment due to no availability of data for Ethiopian (Walpole et al., 2012). The details considered for health risk assessment in the living room are given in Table 23.

Table 23. Exposure frequency, exposure time, intake rate, body weight, exposure duration and averaging time for different exposed groups.

Exposed group	Exposure time (h day^{-1})	Exposure frequency (days $year^{-1}$)	Duration Exposure (years)	Exposure Duration (days)	AT (days)	IR (m^3 day^{-1})	BW (kg)
Infant (birth to 1 yr.)	2.05	350	1	28.9	365	6.80	11.3
Child (2-5 yr.)	2.05	350	5	150	1825	10.0	22.3
Child (6-14 yrs.)	2.05	350	12	359	4380	13.5	45.3
Adult (15-65 yrs.)	2.05	350	50	1495	18250	20.0	60.7

As it is seen in Table 24, HQ for all age groups are below 1 which indicates that any person who stays at living room for 2.05 h per day for his or her lifetime do not have any health problems due to $PM_{2.5}$, PM_{10} and TSP exposure separately. HI for individuals at the different age were calculated, and the results for infants (age between birth- 1 year), child (age between 2-5 years), child (age between 6-14 years) and adults (15-65 years) were found to be: 0.91, 0.66, 0.47 and 0.51,

respectively. Hence, HI is below 1 which confirmed that cumulative exposure of $PM_{2.5}$, PM_{10} and TSP may not induce non-carcinogenic health problems to all age group at this ME who spent 2.05 h per day. However, this does not mean that their contribution to the total chronic exposure is small. Thus, sitting in the living room for 2.05 h per day can cover the total chronic intake of $PM_{2.5}$, PM_{10} and TSP in the range of 13-25, 29-59 and 5-10%, respectively across all age groups.

Table 24. ADD for PMs and TVOCs and for HQ for $PM_{2.5}$ PM_{10} and TSP at the living room

ADD for PMs and TVOCs (µg kg^{-1} day^{-1})							
	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADD_1	0.27	0.81	1.67	2.80	3.70	4.72	13.8
ADD_{1-5}	0.21	0.63	1.29	2.16	2.86	3.65	10.7
ADD_{6-14}	0.14	0.42	0.86	1.43	1.90	2.42	7.06
ADD_{15-65}	0.15	0.46	0.95	1.58	2.09	2.67	7.80
RfDannual	-	3.24	-	-	6.56	49.4	-
HQ for $PM_{2.5}$, PM_{10} and TSP							
HQ_1	-	0.25	-	-	0.56	0.10	-
HQ_{1-5}	-	0.19	-	-	0.44	0.07	-
HQ_{6-14}	-	0.13	-	-	0.29	0.05	-
HQ_{15-65}	-	0.14	-	-	0.32	0.05	-

(ADD_1 = ADD for the infant below 1 yr.; ADD_{1-5} = ADD for the child between1-5 yrs.; ADD_{6-14} = ADD for the child between 6-14 yrs.; ADD_{15-65} = ADD for the adults between 15-65 yrs.; HQ_1 = HQ for the infant below 1 yr.; HQ_{1-5} = HQ for the child between 1-5 yrs.; HQ_{6-14} = HQ for the child between 6-14 yrs.; HQ_{15-65} = HQ for the adults between 15-65 yrs.; yr. = year and yrs. = years).

4.4 Levels of PMs and TVOCs Air Pollutants in Outdoor Air of Addis Ababa

Among the sources of urban ambient air pollution, the major particulate matter pollution sources in urban areas are automobile exhausts (Cattaneo *et al.*, 2010; Lee *et al.*, 2012). Similarly, one of the main problems faced in Addis Ababa nowadays is the availability large number of old and poorly maintained vehicles which can highly pollute the ambient air (Alok, 2011).

Although all peoples in urban residence were affected due to urban air pollutions, peoples' who spent fractions of a day at roadside in urban areas (people waiting around traffic congested streets, people working along busy streets (such as street vendors and street sweeper), people whose homes, shops and other public places overlook onto trafficked roads, people commuting on bicycles or foot and people waiting to use public transport (e.g. buses, taxies)) are the most affected once. This is because, the peak concentration of pollutants tends to occur along busy roads that the pollutants in highly tall and dense building placed in both sides of the street and high traffic congestion are low dispersion rate of pollutants due to the stagnant of air, and it leads to increase the concentration of pollutants. Also, they were doing their activities near to the major sources of urban air pollutions (such as vehicles), that the health risk due to such high concentration of pollutant in the streets are expected to high (Gulliver and Briggs, 2004; Gulliver and Briggs, 2007; de Nazelle *et al.*, 2012; Aziz *et al.*, 2015; Ramos *et al.*, 2016; Shi and Ng, 2017). Some study reported that the contribution to the total daily exposure due to commuting accounts up to 60% of black carbon and 12% of $PM_{2.5}$, despite the time of exposure is short (1-1.5 h) (Karanasiou *et al.*, 2014).

Furthermore, most of the studies conducted on outdoor air pollution and its health impact relation were based on the measurement of the air pollutants at the fixed place which is not enough to

predict/estimate or significantly underestimate the accurate personal exposure assessment to the pollutants. This is because the distribution of emission sources either from point or traffic source become complex or varies at low scale level across space. Hence, recently using personal exposure data at different microenvironments rather than fixed monitoring data are the better method in exposure assessment and in identifying the role of each microenvironment to the personal exposure. For instance, studies in UK, showed the level of exposure to PM_{10} during journey and in-car were 67% and 13% higher than exposure measured at fixed point measurement (Levy *et al.*, 2000; Gulliver and Briggs, 2007; Devi *et al.*, 2009; Cattaneo *et al.*, 2010; Rabinovitch *et al.*, 2016; Shi and Ng, 2017). Besides, exposure measurement of outdoor air particulate matter conducted so far in Ethiopia was based on 24-h measurement at the fixed site selected (Etyemezian *et al.*, 2005; Gebre *et al.*, 2010; Son and Bell, 2013). Therefore, this work was focused on short-term exposure assessment to outdoor PMs (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} and TSP) and TVOCs pollutants at the roadside microenvironment.

4.4.1 Sampling point and land used descriptions

A total of 10 sampling sites (three sampling points in each) were selected, where the distance from the sampling points to the main road is in the range of 2.5 to 7.6 m, whereas the altitude varies between 2146 m (at Akaki Kality sub-city) and 2657 m (at Gulelle sub-city). Generally, the land use characteristics of the sampling sites such as the position of the sampling points (including the distance from the road, major activities performed around sampling points, altitude and geographical locations) were recorded, and the details are given in Appendix III.

4.4.2 Temporary variation in concentration of PMs and TVOCs at different sites

The GOM of PMs, TVOCs, TR and RH were measured at the selected roadside location in 10 sampling sites during morning and afternoon, and the results are given in Table 25. The level of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were ranged 4.96-16.5, 14.3-50.3, 36.7-101, 75.6-216, 116-368, 163-613 and 154-508 µg m^{-3}, respectively. The highest and the lowest values for PM_1 and $PM_{2.5}$ were noticed at Kolfe Keranio during morning time and Nefas Silk-Lafto during afternoon time, respectively. The highest values for PM_4, PM_7, PM_{10}, TSP and TVOCs were seen at Addis Ketema during morning time, whereas their lowest values were seen at Nefas Silk-Lafto A, Arada A, Arada A, Gulelle A and Kolfe Keranio A, respectively. The results of this study showed a similar trend in another study by (Lee *et al.*, 2012). However, the level of PM_1 in the morning is higher than its level in afternoon. Moreover, another study also shows the level of such air pollution is very high during the morning rush time (Aziz *et al.*, 2015).

Kurskual-Wallis H independent sample test was applied to the data for all sub-cities to see whether significance difference in concentration of PMs and TVOCs pollutants are present or not across the sites during each sampling time (morning and afternoon) separately. The test showed that both PMs and TVOCs pollutants have a significant differences in the concentration of at $p < 0.05$ across each sub-cities during each sampling time.

Table 25. The Spatio-temporary level of PMs and TVOCs (GOM ± GSD in μg m^{-3}) for outdoor air at Addis Ababa.

Sub cites	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs	TR (°C)	RH (%)
Addis Ketema A	8.95±1.3	26.7±1.5	63.0±1.5	144±1.5	246±1.6	405±1.7	382±1.5	22.6±1.3	35.4±1.3
Addis Ketema M	14.7±1.5	48.2±1.5	101±1.5	216±1.6	368±1.7	613±1.8	508±1.4	18.2±1.4	42.4±1.4
Akaki Kality A	5.31±1.6	18.0±1.7	56.5±1.6	156±1.7	288±1.8	498±2.0	221±1.5	25.4±1.2	31.3±1.2
Akaki Kality M	9.05±1.6	30.1±1.7	66.5±1.7	140±1.5	229±1.6	360±1.6	232±1.4	17.3±1.2	51.8±1.2
Arada A	7.19±1.7	18.8±1.9	39.4±1.7	75.6±1.9	116±1.9	172±2.0	271±1.4	22.0±1.3	27.8±1.3
Arada M	13.1±1.5	39.6±1.7	77.5±1.6	141±1.6	213±1.7	311±1.8	393±1.3	15.6±1.2	45.4±1.2
Bole A	6.77±1.4	19.9±1.8	48.5±1.5	106±1.5	170±1.5	258±1.5	268±1.3	22.4±1.3	34.0±1.2
Bole M	12.0±1.5	39.4±1.9	86.5±1.9	175±1.9	278±1.9	423±1.9	373±1.3	17.2±1.3	45.5±1.2
Gulelle A	9.05±1.6	24.5±1.8	47.8±2.0	83.3±2.2	118±2.3	163±2.5	238±1.9	22.9±1.3	41.2±1.3
Gulelle M	14.0±1.7	42.9±2.0	77.6±1.9	130±1.8	185±1.8	269±1.8	307±1.4	17.8±1.4	55.2±1.3
Kerkos A	7.99±1.3	20.3±1.5	41.9±1.5	82.6±1.5	130±1.6	196±1.7	378±1.3	24.5±1.2	35.5±1.3
Kerkos M	13.1±1.7	38.8±1.6	77.4±1.7	143±2.0	214±2.3	308±2.6	399±2.7	16.9±1.2	52.0±1.4
Kolfe Keranio A	13.2±1.6	35.6±1.5	75.3±1.4	141±1.3	224±1.4	334±1.5	154±1.6	24.6±1.1	31.0±1.1
Kolfe Keranio M	16.1±1.4	50.3±1.5	98.1±1.6	186±1.7	292±1.8	444±1.8	450±1.3	18.4±1.2	45.4±1.2
Lideta A	9.90±1.8	24.5±1.8	52.6±1.8	107±2.0	170±2.1	256±2.1	406±1.5	23.8±1.1	34.0±1.2
Lideta M	15.2±1.6	43.4±1.7	84.±1.6	153±1.6	230±1.8	329±1.9	379±1.6	18.2±1.2	47.3±1.2
Nefas silk-Lafto A	4.96±1.3	14.3±1.4	36.7±1.4	86.5±1.5	149±1.5	247±1.6	195±1.6	25.4±1.1	29.1±1.2
Nefas silk-Lafto M	8.85±1.3	26.9±1.4	62.3±1.5	137±1.6	229±1.6	376±1.7	244±1.3	18.2±1.1	48.9±1.2
Yeka A	5.83±1.5	17.0±1.6	41.5±1.6	98.6±1.6	172±1.7	289±1.7	271±1.8	23.0±1.2	33.8±1.1
Yeka M	9.75±1.5	28.5±1.6	62.4±1.6	135±1.8	225±1.9	360±2.1	356±1.5	17.8±1.2	49.9±1.2

A = afternoon; M = morning

Furthermore, the temporary variation PMs, TVOCs, TR and RH within each sampling sites were calculated using Wilcoxon signed-rank test in all ten sampling sites, and the results are given in Table 26. Wilcoxon signed-rank test showed a significant difference in concentration of PMs and TVOCs across the sampling sites between morning and afternoon at $p < 0.05$, except PM_{10} and TSP at Akaki Kality. Besides, the relative humidity and temperature also showed a significant difference in the morning and afternoon across the sampling sites which might affect resuspension rate or the dispersion of the pollutant. This variation in temperature and humidity might cause for the variation in concentration of PMs and TVOCs between morning and afternoon.

Table 26. Wilcoxon signed rank test result for PMs, TVOCs, TR and RH at different sub-cities in Addis Ababa.

	Nefas Silk Lafto		Addis Ketema		Akaki Kality		Bole		Arada		Gulelle		Kolfe Keranio		Lideta		Kerkos		Yeka	
	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)	Z	Sig. (2-tailed)
PM_1 at M - PM_1 at A	-10.9[b]	0.000	-12.9[b]	0.000	-14.2[b]	0.000	-12.9[b]	0.000	-13.1[b]	0.000	-12.7[b]	0.000	-4.70[b]	0.000	-13.6[b]	0.000	-11.8[b]	0.000	-13.3[b]	0.000
$PM_{2.5}$ at M - $PM_{2.5}$ at A	-10.8[b]	0.000	-13.0[b]	0.000	-13.2[b]	0.000	-12.5[b]	0.000	-13.0[b]	0.000	-12.2[b]	0.000	-6.57[b]	0.000	-14.5[b]	.000	-12.7[b]	0.000	-11.5[b]	0.000
PM_4 at M - PM_4 at A	-11.1[b]	0.000	-12.6[b]	0.000	-7.56[b]	0.000	-11.2[b]	0.000	-13.0[b]	0.000	-12.1[b]	0.000	-4.89[b]	0.000	-14.3[b]	0.000	-12.5[b]	0.000	-8.67[b]	0.000
PM_7 at M-PM_7 at A	-11.0[b]	0.000	-11.7[b]	0.000	-2.31[b]	0.021	-9.61[b]	0.000	-13.1[b]	0.000	-12.1[b]	0.000	-5.61[b]	0.000	-13.3[b]	0.000	-12.1[b]	0.000	-5.18[b]	0.000
PM_{10} at M - PM_{10} at A	-10.8[b]	0.000	-11.0[b]	0.000	-0.53[b]	0.596	-8.78[b]	0.000	-13.2[b]	0.000	-11.9[b]	0.000	-5.59[b]	0.000	-11.8[b]	0.000	-11.5[b]	0.000	-4.15[b]	0.000
TSPM at M-TSP at A	-10.4[b]	0.000	-10.4[b]	0.000	-.884[a]	0.377	-8.32[b]	0.000	-13.0[b]	0.000	-11.8[b]	0.000	-7.05[b]	0.000	-9.82[b]	0.000	-10.6[b]	0.000	-3.43[b]	0.001
TVOCs at M-TVOCs at A	-5.02[b]	0.000	-12.5[b]	0.000	-10.6[b]	0.000	-10.8[b]	0.000	-12.7[b]	0.000	-8.34[b]	0.000	-12.4[b]	0.000	-2.59[a]	0.010	-2.64[b]	0.008	-4.58[b]	0.000
TR at M- TR at A	-14.0[a]	0.000	-11.4[a]	0.000	-14.6[a]	0.000	-12.5[a]	0.000	-11.9[a]	0.000	-9.39[a]	0.000	-8.39[a]	0.000	-13.9[a]	0.000	-14.8[a]	0.000	-12.4[a]	0.000
RH at M- RH at A	-15.2[b]	0.000	-10.8[b]	0.000	-15.2[b]	0.000	-14.0[b]	0.000	-14.5[b]	0.000	-8.78[b]	0.000	-9.78[b]	0.000	-13.9[b]	0.000	-15.3[b]	0.000	-13.7[b]	0.000

[a] = based on positive ranks; [b] = based on negative ranks; A = afternoon, M =Morning

4.4.3 The overall geometric mean of PMs and TVOCs across sub-cities

The level of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs pollutants in outdoor air for all the ten sub-cities were calculated in regardless of their temporary variation, and the details of the results are summarized and shown in Table 27 and Figure 11. The overall GOM of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were ranged from 6.79-14.4, 20.1-41.2, 48.9-84.6, 104-175, 148-300, 210-496 and 220-439 µg m^{-3}, respectively. The highest and the lowest values for PM_1, $PM_{2.5}$ and PM_4 pollutants were measured at Kolfe Keranio and Nefas Silk-Lafto sub-cities, respectively. Whereas, the highest and the lowest values for PM_7, PM_{10} and TSP were noticed at Addis Ketema and Gulelle sub-cities, respectively. The highest and the lowest values for TVOCs pollutants were noticed at Addis Ketema and Nefas Silk-Lafto sub-cities, respectively. The results of this study were compared with a pilot study conducted on the measurement of PM_{10} and TVOCs in Addis Ababa, and the level of both PM_{10} and TVOCs are higher from the previously reported data which is in the range 35-97 µg m^{-3} and 55-318 µg m^{-3}, respectively (Do *et al.*, 2013). This might be due to the sampling point difference that our sampling points were at the roadsides where the pollutants concentration were expected to high sources (de Nazelle *et al.*, 2012).

Table 27. The overall GOM of PMs, TVOCs, TR and RH at different sub-cities in Addis Ababa.

Each sub-city	PM_1 (μgm^{-3})	$PM_{2.5}$ (μgm^{-3})	PM_4 (μgm^{-3})	PM_7 (μgm^{-3})	PM_{10} (μgm^{-3})	TSP (μgm^{-3})	TVOCs (μgm^{-3})	TR (^oC)	RH (%)
Addis Ketema	11.4±1.6	35.6±1.7	79.3±1.5	175±1.6	299±1.6	496±1.8	439±1.3	20.4±1.2	38.6±1.3
Akaki Kality	7.05±1.6	23.7±1.8	61.6±2.0	147±2.3	254±2.5	419±2.7	227±1.6	20.7±1.3	41.0±1.5
Arada	9.79±1.7	27.5±2.0	55.7±1.9	104±1.8	158±1.8	233±1.8	327±1.5	18.4±1.4	35.7±1.5
Bole	9.05±1.7	28.2±2.0	65.1±1.9	137±1.9	219±2.0	334±2.1	317±1.7	19.5±1.3	39.4±1.3
Gulelle	11.3±1.4	32.5±1.6	61.0±1.6	104±1.6	148±1.6	210±1.7	271±1.5	20.2±1.3	47.7±1.4
Kerkos	10.3±1.6	28.3±1.6	57.3±1.7	109±1.7	168±1.7	247±1.6	389±1.5	20.2±1.3	43.2±1.3
Kolfe Keranio	14.4±1.5	41.4±1.8	84.6±1.6	159±1.6	252±1.6	379±1.6	247±2.9	21.6±1.3	36.6±1.5
Lideta	12.1±1.5	32.2±1.6	65.8±1.5	127±1.4	197±1.4	289±1.4	393±1.3	20.9±1.3	39.8±1.3
Nefas Silk-Lafto	6.79±1.8	20.1±2.0	48.9±1.9	111±1.9	188±2.0	310±2.0	220±1.4	21.2±1.3	38.6±1.4
Yeka	7.80±1.6	22.8±1.7	52.3±1.7	118±1.9	200±1.9	327±2.2	316±1.6	19.9±1.3	42.1±1.3

As it is seen in Figure 11, the general trend for the overall GOM of PMs level at the roadside measurements was founded to be in decreasing order of Addis Ketema > Kolfe Keranio ≈ Akaki Kality > Bole > Yeka ≈ Lideta ≈ Nefas Silk-Lafto > Kerkos > Arada ≈ Gulelle sub-cities, respectively. Whereas, the general trend for the overall geometric mean of TVOCs level was founded to be in decreasing order of Addis Ketema > Lideta ≈ Kerkos > Bole ≈ Arada ≈ Yeka > Gulelle > Kolfe Keranio ≈ Akaki Kality > Nefas Silk-Lafto cities, respectively.

Kurskual-Wallis H independent test was applied to the data for all sub-cities to see whether significance difference in concentration of PMs and TVOCs pollutants are present or not across the sites. The overall test showed a significant differences in the concentration of PMs and TVOCs pollutants at $p < 0.05$ across each sub-cities. However, the difference is not recognized where it was occurred. Thus to do this, the data were normalized using the natural logarithm, since the original data were not normally distributed. After this, the multivariate analysis test (post hock test

using Tukey statistical test) was applied to the log transform data. Thus, PM_1 showed a high significant difference across each site ($p < 0.05$), except during comparing of Gulelle vs Addis Ketema ($p = 1$); Arada vs Kerkos ($p = 0.67$) and Gulelle vs Lideta ($p = 0.14$); Arada vs Bole ($p = 0.08$); Addis Ketema vs Lideta ($p = 0.34$) and Akaki Kality vs Nefas Silk-Lafto ($p = 0.91$). Besides, $PM_{2.5}$ showed a significant difference across each site ($p < 0.04$), except during comparison of Gulelle vs Lideta ($p = 1$); Gulelle vs Addis Ketema ($p = 0.14$); Arada vs Bole ($p = 0.999$); Arada vs Kerkos ($p = 0.998$) and Bole vs Kerkos ($p = 1$) and Yeka vs Akaki Kality ($p = 0.96$). In addition, PM_4 showed a significant difference across each site ($p < 0.05$), except during comparison of Kolfe Keranio vs Addis Ketema ($p = 0.55$); Gulelle vs Kerkos ($p = 0.64$); Gulelle vs Akaki Kality ($p = 1$); Gulelle vs Bole ($p = 0.56$); Gulelle vs Lideta ($p = 0.33$); Gulelle vs Arada ($p = 0.12$); Arada vs Kerkos ($p = 0.99$); Arada vs Yeka (p = 0.56); Lideta vs Bole ($p = 1$); Akaki Kality vs Bole ($p = 0.72$); Yeka vs Kerkos ($p = 0.08$); Yeka vs Nefas Silk Lafto ($p = 0.50$); Akaki Kality vs Lideta ($p = 48$) and Akaki Kality vs Kerkos ($p = 0.33$). Moreover, PM_7 showed a significant difference across each site ($p < 0.04$), except during comparing of Kolfe Keranio vs Addis Ketema ($p = 0.1$); Kolfe Keranio vs Akaki Kality ($p = 0.26$); Gulelle vs Kerkos ($p = 0.89$); Gulelle vs Arada ($p = 1$); Gulelle vs Nefas Silk-Lafto; Gulelle vs Nefas Silk-Lafto ($p = 0.63$); Arada vs Kerkos ($p = 0.86$); Nefas Silk-Lafto vs Arada ($p = 0.56$); Bole vs Lideta ($p = 0.32$); Bole vs Akai Kality ($p = 0.36$); Yeka vs Lideta ($p = 0.34$); Yeka vs Kerkos ($p = 0.37$), Yeka vs Nefas Silk-Lafto ($p = 0.69$) and Kerkos vs Nefas Silk-Lafto ($p = 1$).

PM_{10} showed a significant difference across each site ($p < 0.04$), except comparing of Kolfe Keranio vs Akaki Kality ($p = 1$); Gulelle vs Arada ($p = 0.69$); Arada vs Kerkos ($p = 0.69$); Bole vs Yeka ($p = 0.22$); Yeka vs Lideta ($p = 1$); Nefas Silk-Lafto vs Yeka ($p = 0.66$) and Lideta vs Nefas Silk Lafto ($p = 0.93$).

TSP also showed a significant difference across each site ($p < 0.05$), except during comparing of Kolfe Keranio vs Akai Kality ($p = 0.15$); Gulelle vs Arada ($p = 0.12$); Arada vs Kerkos ($p = 0.80$); Bole vs Yeka ($p = 1$); Bole vs Nefas Silk Lafto ($p = 068$); Yeka vs Nefas Silk-Lafto ($p = 0.91$) and Lideta vs Nefas Silk-Lafto ($p = 0.55$).

TVOCs showed a high significant difference across each site ($p < 0.05$), except during comparing of Kolfe Keranio vs Gulelle ($p = 0.07$); Kolfe Keranio vs Akaki Kality ($p = 0.08$); Arada vs Bole ($p = 0.98$); Bole vs Yeka ($p = 0.96$); Lideta vs Kerkos ($p = 1$) and Akaki Kality vs Nefas Silk Lafto ($p = 0.98$).

The percent contribution for the total daily permissible intake at this ME was calculated using overall GOM concentration of PMs and TVOCs. WHO and Brazilian National Environment Council guidelines are used as a reference in the similar manner used during baking *Injera*, cooking *Wot* and at the living room. Hence, the overall GOM for PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: 9.67, 28.4, 62.1, 127, 203, 314 and 308 μg m^{-3}, respectively. The average time spent during measurement of the pollutants was also recorded, and it was 480 min. Hence, the possible amount of intake of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were: 65, 191, 417, 854, 1369, 2112 and 2069 μg, respectively. The percent contribution for daily exposure to $PM_{2.5}$, PM_{10} and TSP were 37.9, 136 and 43.7%, respectively

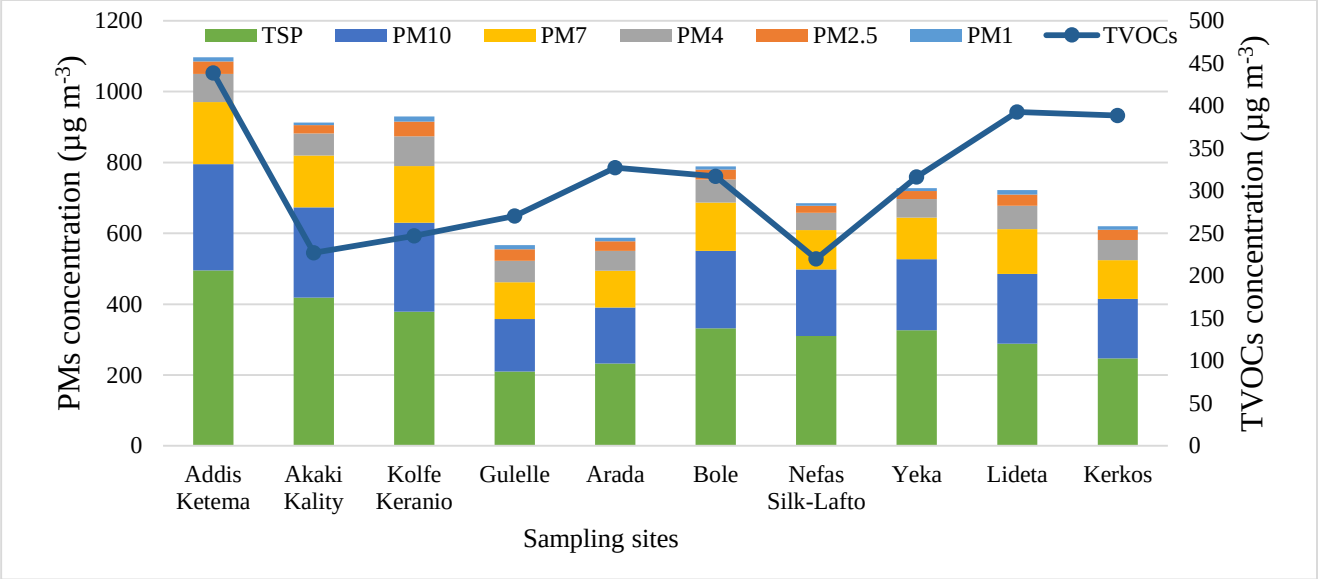


Figure 11. The spatial variation of PMs and TVOCs at different sub-cities in Addis Ababa.

The overall GOM concentration of PM_{10} investigated in this study has been generally higher than the values reported in traffic police officer personal exposure assessment in Milan, Italy (Cattaneo *et al.*, 2010). Previous studies showed the range of PM_{10} and the average of TSP pollutants measured for 24-h in Addis Ababa were found to be 17-285 and 195 µg m^{-3}, respectively (Tefera *et al.*, 2016). However, the level of TSP found in this study is higher which was found in the range of 210-496 µg m^{-3}, whereas, the level of PM_{10} found was comparable for the maximum value. The variation might be due to the sampling time, the sampling points distance from expected sources and other meteorological factors. Thus, the sampling for this study was carried out near the roadside whereas the sampling in previous studies was far from the expected main sources (from the roadside where many vehicles are available) (Tefera *et al.*, 2016). The result of this study also showed $PM_{2.5}$ level is lower than the similar study conducted in Nigeria (Kinney *et al.*, 2011). The variation might be due to the sampling point (such as the distance from roadway), the dispersion

of pollutants factors (such as buildings, weather condition and pollution source), traffic volume, and composition of the fleet (gasoline, diesel) (Ragettli *et al.*, 2013; Ramos *et al.*, 2016).

Furthermore, researchers from different region of the world have reported on the level of particulate matter measured at the roadside. The comparison of our data from some of the report data are summarized in Table 28. Hence, the result of the present study was in comparable with some study reported literature, whereas some of the present study was below from some of the reported one.

Table 28.The comparison of particulate matter level at roadside measured from different region.

Countries	Description of sampling sites and time	Particulate matter concentration ($\mu g\ m^{-3}$)	Ref.
Marquês de Pombal, Portugal	At road tunnel, At roadside, and At urban background [at morning (8:00–10:00) and in the late afternoon (17:00–19:00)]	At road tunnel; PM_{10}: 541-1340 and $PM_{2.5}$: 450-1061 17-31 times higher than from tunnel 15-23 times lower than from tunnel	(Alves *et al.*, 2016)
Beijing, China	close vicinity of the north–eastern fourth–ring avenue [annual mean]	Overall mean PM_{10} is 175 and $PM_{2.5}$ is 99	(Wang *et al.*, 2014)
Macao, Taipa	A background site on the roof and at roadside [hourly average]	$PM_{2.5}$: 1.1-53.3 for background and 6.4-68.7 for roadside	(Song *et al.*, 2014)
Dares-Salaam, Tanzania	Far from main roadside [morning, afternoon, and evening sampling were done between 6:30 and 8:30 a.m., 12:01 and 2:00 p.m., and 5:00 and 7:00 p.m.]	TSP (98-1161)	(Jackson, 2005)
Macao, China	The sampler was put near the driver's breathing position	PM_1 (79-1680); $PM_{2.5}$ (94-2090); PM_{10} (140-3050) and PM_{10}-$PM_{2.5}$ (46-97)	(Tang and Wang, 2012)
Addis Ababa, Ethiopia	The sampler was put 2.5-7.6 m from main road side for 8 h [between 6:00 am to 10:00 am for morning and 2:00 to 6:00 pm for afternoon]	PM_1 (6.79-14.4); $PM_{2.5}$ (20.1-41.2); PM_4 (48.9-84.6); PM_7 (104-175); PM_{10} (148-300) and TSP (210-496)	This study

4.4.4 Health risk assessment of $PM_{2.5}$, PM_{10} and TSP exposure at the roadside

In this work, human health risk assessment of a person due to exposing to traffic-related particulate matter during the commuter time and working at the roadside was assessed using similar steps and equations used in health risk assessment at kitchen microenvironment during baking *Injera* and cooking *Wot*, except that some assumption was changed.

The EF, ET and ED for an exposed person were determined based on different assumptions as shown in Table 29. The assumption considered includes the absence of an exposed person in the study area, age, and inhalation rate. Adults (age above 19) were considered. The exposure frequency of 350 days/year assuming a person is not present in study area for 15 days in a year, and exposure duration of 46 years was taken by assuming the exposed person start his/her job at the age of 19 until she/he resign his/her job at age of 65. Moreover, air intake rate for an adult is 20 m^3 per day and body weight, and adult Ethiopian is assumed to be African adult weight which is 60.7 kg (EPA, 1989; Walpole *et al.*, 2012). The averaged time for concentration measurement of PMs was 8 h, which used as exposure time. Table 29 showed the details considered in HQ calculation.

According to US EPA classification, this work exposure is classified under chronic type of exposure. RfD for chronic type of exposure is used, which is annual average of $PM_{2.5}$ (10 µg m^{-3}), PM_{10} (20 µg m^{-3}) and TSP (150 µg m^{-3}) values set by WHO and United States of environmental protection agency (US EPA) were used to calculate HQ (EPA, 2008; WHO, 2010). The total overall GOM of $PM_{2.5}$, PM_{10} and TSP in regardless of sampling sites have been used for health risk assessments.

Table 29. Exposure frequency, exposure time, intake rate, body weight, exposure duration and averaging time.

Exposure time (h day^{-1})	Exposure frequency (days $year^{-1}$)	Duration exposure (years)	Exposure duration (days)	AT (days)	IR (m^{-3} day^{-1})	BW (kg)
8	350	46	5367	16790	20	60.7

The result showed no HQ value is greater than one for $PM_{2.5}$ and TSP, which confirmed $PM_{2.5}$ and TSP could not induce any health problems. However, the value of HQ for PM_{10} was greater than one, which indicates that PM_{10} can introduce health problems to the exposed person. Moreover, as it can be seen in Table 30, PM_{10} can induce the highest health problems as compared to $PM_{2.5}$ and TSP. Beside HQ, HI due to $PM_{2.5}$, PM_{10} and TSP also calculated, and the result (HI = 4.87) confirmed that peoples spent 8 h per day in the roadside can have develop different non-cancer health problems due to exposure of these pollutants.

Table 30. ADD for PMs and TVOCs and for hazard quotients for $PM_{2.5}$, PM_{10} and TSP.

ADD for PMs and TVOCs (μg kg^{-1} day^{-1})							
	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADD	1.02	2.99	6.54	13.4	21.5	33.1	32.4
RfDannual	-	3.24	-	-	6.56	49.2	
HQ for $PM_{2.5}$, PM_{10} and TSP							
HQ	-	0.92	-	-	3.28	0.67	-

4.4.5. The comparison and integrated exposure assessments of PMs and TVOCs for selected MEs

According to International Society of Exposure Analysis exposure is defined as the "concentration or amount of a particular agent that reaches a target organism, system, or (sub) population in a specific frequency for a defined duration" (Dias and Tchepel, 2018). Since the amount of the pollutant and the time spent at the particular location varies across the site, peoples' exposure level also varies. Thus, researchers calculated total exposure as the sum of the product of time spent by a person in different microenvironments and the time-averaged air pollution concentrations occurring in those microenvironments. The mathematical representation of the concept is given in equation 10 (Branco *et al.*, 2014; Dias and Tchepel, 2018).

$$E_i = \frac{1}{T}(\sum_{j=1}^{m} C_{ij} t_{ij} \quad (10)$$

where E_i is the exposure concentration of the ith individual, C_{ij} is the concentration of the pollutant measured in the jth microenvironment of the ith individual, t_{ij} is the time spent by the ith individual in the jth microenvironment, T is the total time spent in all microenvironment and *m* is the number of different microenvironments (MEs).

The microenvironments (MEs) assessed in this study were grouped in nine combinations and symbolized as A, B C, D, E, F, G, H and I microenvironment based on the probability of a person spent his/her time in each microenvironment. The time recorded for measurement of PMs and TVOCs were used as time spent by an exposed person in each MEs except outdoor MEs where a total of 4 h per day (2 h for morning and 2 h for the afternoon) were assumed in the calculation of total exposure concentration. Accordingly, the average daily time spent in A, B C, D, E, F, G, H and I MEs were 10.1, 10.3, 10.5, 10.0, 10.3, 10.5, 10.0, 10.3 and 10.5 h, respectively. The exposure

frequency of a person also calculated based on baking activities which were done two times per day. In addition to understanding the daily bases of exposure in each MEs, percent covered in this study were calculated. Thus, peoples can spend 42, 43, 44, 42, 43, 44, 42, 43 and 44% of their daily time in A, B C, D, E, F, G, H and I MEs, respectively.

The assumption considered for HQ calculation, total exposure concentration and ADD for PMs and TVOCs results are summarized in Table 31. As it is seen in Table 31, depends upon the type of pollutants and the time of exposure, the total exposure concentration in A, B C, D, E, F, G, H and I MEs were ranged from 8.59-710 $\mu g\ m^{-3}$. The highest and the lowest exposure were occurred in PM_1 and TVOCs, respectively.

Table 31. The assumption considering for HQ calculation, total exposure concentration and ADD for PMs and TVOCs at different MEs

The assumption for considering for HQ calculation						
Exposure time (h day-1)	Exposure frequency (days year-1)	Duration Exposure (years)	Exposure duration (days)	AT (days)	IR (m^3 day-1)	BW (kg)
10.1	105	50	2209	18250	20	60.7
10.3	105	50	2253	18250	20	60.7
10.5	105	50	2297	18250	20	60.7
10.0	105	50	2188	18250	20	60.7
10.3	105	50	2253	18250	20	60.7
10.5	105	50	2297	18250	20	60.7
10.0	105	50	2188	18250	20	60.7
10.3	105	50	2253	18250	20	60.7
10.5	105	50	2297	18250	20	60.7

Total exposure concentration = [Sum(CijxTij)]/T							
MEs	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
A	8.59	10.6	46.9	86.6	128	189	367
B	8.99	11.1	47.4	86.9	128	186	403
C	9.90	15.3	52.1	93.6	135	193	459
D	10.7	24.2	54.4	97.4	142	206	415
E	11.0	24.4	54.5	97.0	141	204	448
F	11.9	28.2	59.1	103	148	218	504
G	11.2	119	80.6	130	177	243	635
H	11.5	117	80.3	129	175	241	658

I	12.4	119	84.3	135	185	248	710

ADD for PMs and TVOCs (μg kg^{-1} day^{-1})

MEs	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
A	0.343	0.423	1.870	3.456	5.099	7.413	14.6
B	0.366	0.453	1.929	3.537	5.201	7.553	16.4
C	0.411	0.632	2.160	3.868	5.598	8.022	19.05
D	0.421	0.955	2.148	3.845	5.596	8.121	16.38
E	0.446	0.991	2.218	3.946	5.726	8.303	18.20
F	0.492	1.170	2.452	4.282	6.131	8.785	20.89
G	0.444	4.698	3.190	5.139	6.987	9.600	24.90
H	0.470	4.75	3.266	5.249	7.126	9.791	26.77
I	0.515	4.93	3.498	5.583	7.529	10.30	29.44
RfD_{anuall}		3.24			6.56	49.4	

(A = clean stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside MEs, B = clean stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside MEs, C = clean stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside MEs, D = Improved stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside MEs, E = Improved stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside MEs, F = Improved stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside MEs, G = Traditional stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside MEs, H = Traditional stove for *Injera* + kerosene for *Wot* + living room + outdoor at roadside MEs and I = Traditional stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside MEs

Since the people have spent some fraction of a day in each MEs, their overall health risk assessment due exposure to $PM_{2.5}$ PM_{10} and TSP at each MEs were calculated using HQ and HI by equations 6-7, and the results are given in Table 32. However, the only adults are considered since they are most frequent population spent in such microenvironment and involved in various activities. Accordingly, HQ of $PM_{2.5}$ PM_{10} and TSP across MEs were ranged: 0.130-1.52, 0.777-1.148 and 0.150-0.208, respectively. The highest and the lowest HQ value were observed at microenvironment I and A related to $PM_{2.5}$ levels, respectively. The cumulative impacts of $PM_{2.5}$ PM_{10} and TSP were assessed by HI which was found in the range 1.058 to 2.878. The highest and

the lowest HI were seen at I and A ME, respectively. Generally, the results of HQ indicate that a person spent in G, and H, I can have health problems due to exposing to PM_{10} and $PM_{2.5}$ (except A, B, C, D, E and MEs which HQ values were less than 1 for PM_{10} and $PM_{2.5}$). Besides, one cannot face non-carcinogenic health problems due to TSP. However, HI which is the cumulative effect showed potential health risks for people who spend the long hour in any of these environments.

Table 32. HQ and HI of $PM_{2.5}$, PM_{10} and TSP at different MEs.

	HQ			HI (sum of HQ of each pollutant)
	$PM_{2.5}$	PM_{10}	TSP	
A	0.130	0.777	0.150	1.058
B	0.140	0.793	0.153	1.086
C	0.195	0.853	0.162	1.211
D	0.295	0.853	0.164	1.312
E	0.306	0.873	0.168	1.347
F	0.362	0.935	0.178	1.474
G	1.450	1.065	0.194	2.709
H	1.469	1.086	0.198	2.753
I	1.522	1.148	0.208	2.878

On the other hand, since *Wot* cooking, sitting at living room and commuting to work is a daily activity for most of adult women that, the exposure frequency should be 365 days per year and the exposure time are 8.85, 9.28 and 9.08 h for AA, BB and CC MEs, respectively. In addition, the duration of exposure for a person used as 50 years, the total exposure duration for AA, BB and CC MEs were found 6730, 7056 and 6904 days. Hence, there is a need to calculate the health risk assessment excluding exposure during baking *Injera*. Hence the microenvironments in this regards

were symbolized as AA (Electricity fuel for *Wot* + living room + outdoor at roadside environment), BB (charcoal for *Wot* + living room + outdoor at roadside MEs) and CC (Kerosene for *Wot* + living room + outdoor at roadside MEs). The exposure concentration of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs found in the range: 0.868-1.425, 0.860-2.19, 5.42-7.49, 10.4-13.4, 15.6-19.4, 2.30-27.8 and 32.2-66.1, respectively. The highest and the lowest was measured at CC and AA MEs, respectively. The HQ values for AA, BB and CC MEs for $PM_{2.5}$, PM_{10} and TSP were: 0.265, 0.490, 0.677; 2.38, 2.65, 296 and 0.470, 0.510, 0.56, respectively. Hence, PM_{10} at all MEs can induce health problems. HI values also calculated and the result for ME AA, BB and CC were 3.11, 3.65 and 4.20, respectively which indicates a person in any of these MEs have faced health problems due to the cumulative effect of $PM_{2.5}$, PM_{10} and TSP.

As it can be seen in Figure 12, the approximate general concentration trend of PMs and TVOCs across MEs were: MELR (ME at indoor living room) < MEEF (ME at indoor during cooking *Wot* using electric fuel) < MEKF (ME at indoor during cooking *Wot* using kerosene fuel) ≈ MECS (ME at indoor during baking *Injera* using clean stove) < MECF (ME at indoor during cooking *Wot* using charcoal fuel) < MEOR (ME at outdoor roadside) < MEIS (ME at indoor during baking *Injera* using improved stove) < METS (ME at indoor during baking *Injera* using traditional stove). The highest and the lowest concentration of all pollutants were observed at MELR and METS, respectively. The patters of each pollutants across each MEs followed in decreasing order of: PM_1 (MELR < MEEF < MEOR < MEKF < MECF < MECS < MEIS < METS); $PM_{2.5}$ (MELR < MEEF < MEOR < MEKF < MECS < MECF < MEIS < METS); PM_4 (MELR < MEEF < MEKF < MEOR < MECS < MECF < MEIS < METS); PM_7 (MELR < MEEF < MEKF < MECS < MEOR < MECF < MEIS < METS); PM_{10} (MELR < MEEF < MEKF < MECS < MEOR < MEIS < METS), TSP

(MELR < MEEF < MEKF < MECS < MEOR < MEIS < METS) and TVOCs (MELR < MEOR < MEEF < MEKF < MECF < MECS < MEIS < METS), respectively.

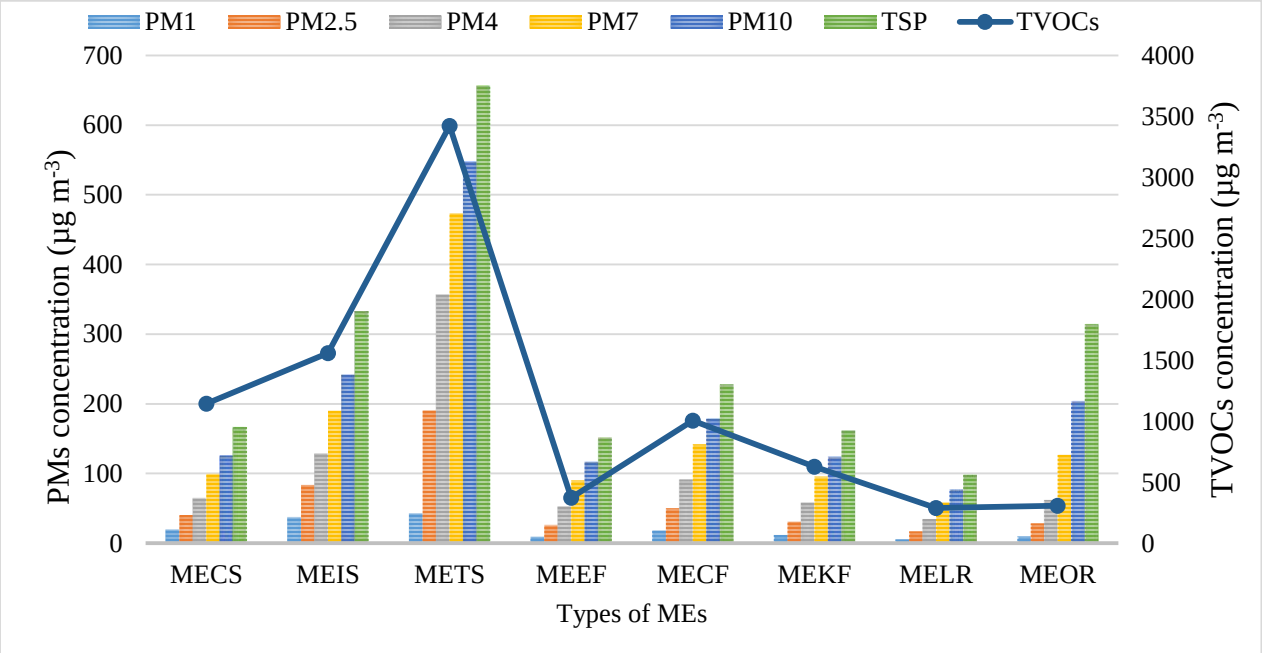


Figure 12. The level of pollutant concentration across each microenvironment.

4.5 Trace Elements Determination Bound in PM_{10} at Different MEs

Air pollution can contain more than 87 hazard chemicals including trace metals (such as arsenic, lead, cadmium), pollutant gases, solvents, particulate matter, and pesticides (Young *et al.*, 2012). Among this pollutants, particulate matter is the major health concern now a days because of it contains many hazard 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), reactive gases (ozone, peroxides, aldehydes), particle core of carbonaceous material (mainly from combustion processes and vehicular exhaust particles), materials of biologic origin (endotoxins, bacteria, viruses, animal and plant debris), and minerals (quartz, asbestos, soil dust) (Schwarze *et al.*, 2006).

Studies have shown that heavy metals bound in the airborne particulate matter can pose different health problems on normal development and growth of body tissues and their proper functioning. For instance, the presence of toxic trace elements in particulate matter aggravates carcinogenesis, teratogenesis and mutagenesis (Mohanraj *et al.*, 2004). Thus, the chemical characterization of particulate matter is vital for understanding their effect on human and environment. More importantly, determination of trace elements bound in particulate matter is useful in identification of the sources in addition to the health impact estimation due to their exposure (Salcedo *et al.*, 2014). The fossil fuel combustion, vehicular traffic, electroplating and metal alloy industries were some of the sources that can increase the introduction of trace metals in the body through polluted particulate matter suspendered in the air (Basha *et al.*, 2006; Schwarze *et al.*, 2006). The distribution of metals across the size of particulate matter varies such that studies have shown 70-90 % the heavy metals (such as Cu, Cd, Ni, Zn, and Pb) are found in PM_{10} fraction (Mohanraj *et al.*, 2004). Therefore, this study was focused on the determination of the concentration of various trace elements bound in particulate matter (particularly PM_{10}) sampled at different MEs.

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 10% HNO_3 of 1000 mg mL^{-1} elements stock solution. The concentration of each element bound in particulate matter in all microenvironments was obtained by using equation 11.

$$C(\mu g m^{-3}) = \frac{(C_1 - C_b)}{V_o} xV \qquad (11)$$

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

The calibration curve showed linearity (r^2 > 0.9897) of the detector response for quantified elements at all microenvironments. Limit of detection (LOD) was determined using each analyte ions based on 3 times the standard deviation (3σ) of the blank. The calibrations curve and LOD for detected elements are summarized in Table 33. The performance of the method was tested by recovery test through standard addition, and the results were found in the range of 92-110% which is between acceptable ranges. The spiking measurement was performed in triplicate. 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).

Table 33. 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

4.5.1 Trace elements concentration determination bound in PM_{10} at the roadside ME

Traffic-related emissions are the prominent source of trace elements in urban areas (Duong and Lee, 2011; Crilley, 2014). Trace elements measurement is used to determine the contribution of various sources (such as traffic, industrial or other) to the total overall compositions of airborne particles (Krzemińska-Flowers *et al.*, 2006; Crilley, 2014). For instance, high level of Ti, Mn, Pb and Br obtained in particulate matter indicates their origin is most probably from vehicle exhausting emission. Meanwhile, the most probable sources of V and Ni; Cr and Sr; K; Co, Cd, Pb, Hg in particulate matter were oil combustion emission, petrochemicals and cement industries, biomass combustion and industries, respectively (Zereini *et al.*, 2005; Crilley, 2014; Fortoul *et al.*, 2015). Since the main inorganic constituents of tire rubber are Cu, Fe, Mn, Pb and Zn, vehicle brake wear emission contributed to the significant level of these metals in the urban particulate matter (Kelly and Fussell, 2012). Exhaust catalysts in automobiles are also the main sources of Pt, Pb, Ce, and Rh (Zereini *et al.*, 2005).

In this work, the total elemental concentration of, Fe, Cu, Mn, B, Zn, Pb, Cr, Cd, Sn, As, Ni and Co in PM_{10} were determined using ICP-OES. Table 34 shows the analytical results (mean ± standard deviation (SD)) for elements in PM_{10} sampled from Arada, Gulelle, Addis Ketema, Bole, Akaki Kality, Nefas Silk-Lafto, Kolfe Keranio, Yeka, Lideta and Kerkos sub-cities. The patterns concentration of the elements across sub-cities are shown in Figure 13.

Table 34. The elements concentrations (mean ± SD, in μg m^{-3}) in PM_{10} at Addis Ababa.

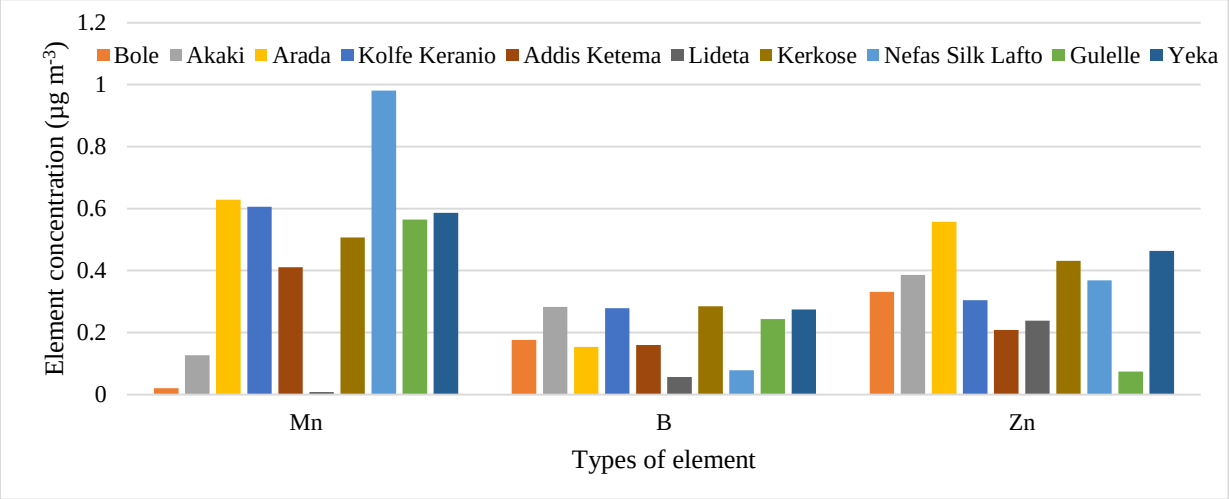
Analyte type	Bole	Akaki	Arada	Kolfe Keranio	Addis Ketema	Lideta	Kerkos	Nefas Silk Lafto	Gulelle	Yeka
Fe	0.068±0.002	0.058±0.020	0.020±0.001	0.119±0.007	0.117±0.007	0.197±0.037	0.054±0.008	0.098±0.040	0.095+0.013	0.103±0.018
Cu	0.005±0.002	0.032±0.002	BLD	BLD	0.219±0.004	0.116±0.003	0.055±0.004	BLD	BLD	0.142±0.006
Mn	0.020±0.003	0.127±0.002	0.628±0.005	0.606±0.001	0.411±0.033	0.008±0.008	0.507±0.014	0.981±0.002	0.565+0.002	0.587±0.001
B	0.176±0.150	0.282±0.222	0.154±0.140	0.279±0.094	0.159±0.138	0.057±0.075	0.284±0.062	0.078±0.041	0.244±0.110	0.274±0.009
Zn	0.331±0.320	0.386±0.045	0.557±0.110	0.304±0.780	0.208±0.192	0.239±0.068	0.431±0.008	0.369±0.124	0.074±0.039	0.463±0.118
Pb	0.099±0.004	0.097±0.001	0.114±0.100	0.160±0.002	0.062±0.870	0.140±0.059	0.173±0.040	0.073±0.010	0.152±0.002	0.023±0.003
Cr	0.015±0.001	0.023±0.001	0.022±0.007	0.007±0.006	0.003±0.003	0.001±0.002	0.017±0.005	0.017±0.004	0.013±0.002	0.007±0.004
Cd	0.021±0.003	0.005±0.003	0.055±0.003	0.033±0.002	0.003±0.001	0.009±0.009	0.064±0.003	0.049±0.002	0.019±0.001	0.013±0.003
Sn	0.113±0.003	0.114±0.001	0.089±0.007	0.004±0.001	0.130±0.033	0.122±0.020	0.093±0.039	0.163±0.0003	0.231±0.0003	0.142±0.003
As	0.023±0.001	0.027±0.002	0.040±0.110	0.053±0.001	0.059±0.009	0.027±0.021	0.038±0.002	0.052±0.018	0.038±0.011	0.002±0.001
Ni	0.040±0.002	0.041±0.002	0.011±0.04	0.012±0.001	0.036±0.026	0.032±0.008	0.050±0.018	0.075±0.003	0.042±0.002	0.096±0.002
Co	0.001±0.0001	0.090±0.002	0.020±0.002	0.100±0.110	0.084±0.005	0.057±0.005	0.019±0.005	0.010±0.002	0.007±0.004	0.013±0.002

BLD = below dtection limit.

The concentration of Fe, Cu, Mn, B, Zn, Pb, Cr, Cd, Sn, As, Ni and Co were found in the range 0.02-0.197, below detectable limit (BDL)-0.981, 0.057-0.284, 0.05-0.284, 0.074-0.557, 0.023-0.177, 0.003-0.023, 0.003-0.064, 0.004-0.231, 0.002-0.059, 0.011-0.096 and 0.001-0.096 μg m^{-3}, respectively. The maximum concentration of Fe, Cu, Mn, B, Zn, Pb, Cr, Cd, Sn, As, Ni and Co were noticed at Lideta, Addis Ketema, Nefas Silk-Lafto, Kerkos, Arada, Kerkos, Akaki Kality, Kerkos, Gulelle, Addis Ketema, Yeka and Kolfe Keranio sub-city, respectively. Whereas their minimum values were obtained at Arada, Lideta, Lideta, Gulelle, Yeka, Addis Ketema, Addis Ketema, Kolfe Keranio, Yeka, Arada and Bole sub-city, respectively, except Cu where its minimum value is obtained as BLD at Arada, Kolfe Keranio, Nefas Silk-Lafto and Gulelle sub-cities.

ANOVA test was applied to the data for elements to see their concentration variation across the studies sub-cities, and the results showed all elemental concentration have a significant difference across sub-cities with $p < 0.05$, except B which did not show a significant difference ($p = 0.19$).

(a)



(b)

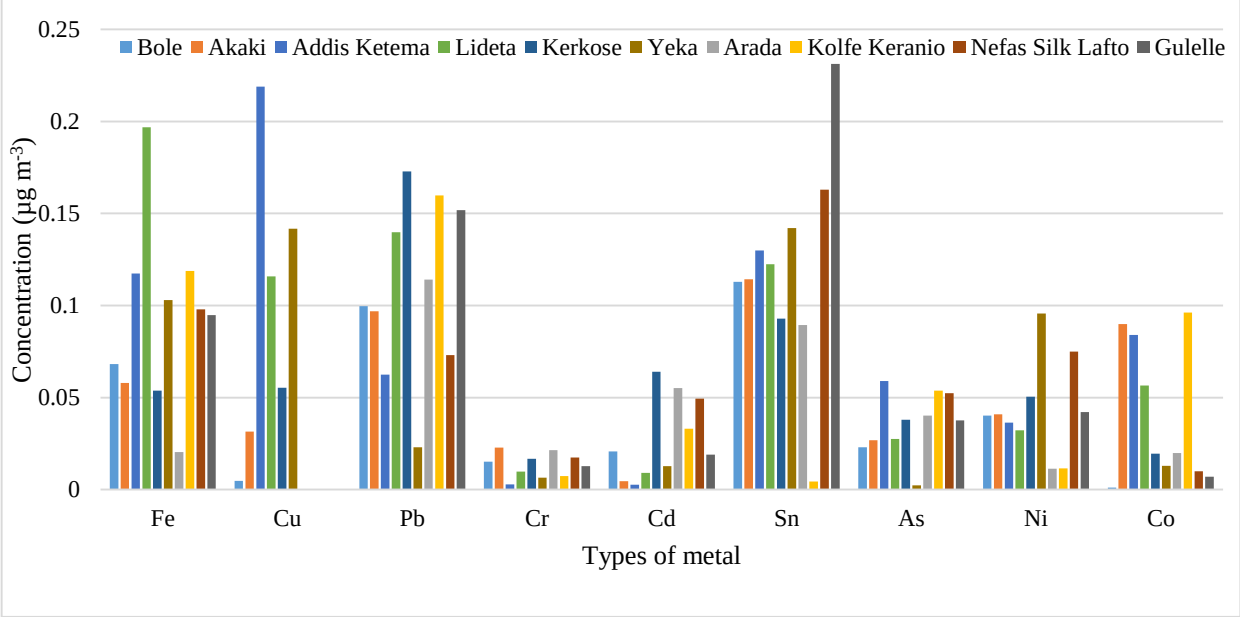


Figure 13. Elemental composition of PM_{10} from different sub-cities (a) for Mn, B, and Zn, (b) patterns of Fe, Cu, Pb, Cr, Cd, Sn, As, Ni.

Generally, as it is see in Figure 13, the overall patterns of elements bound in PM_{10} in regardless of the sampling sub-cities were found in increasing order of Cr < Cd < As < Co < Ni < Cu < Fe < Pb < Sn < B < Zn < Mn. The results of similar trend obsrved with a minor change from a previously reported data (Gebre *et al.*, 2010). The discrepancies might be due to the sampling points and sampling time, location of sampler, predominant sources variation in time and others.

In the Bole sub citiy, the elemental concentration patterns found in PM_{10} was in the order of: Co < Cu < Cr < Mn < Cd < As < Ni < Fe < Pb < Sn < B < Zn where the minimum concentration is observed for toxic elements (Co, Cu and Cr) while the highest concentration is obsreved for Zn and B. The elemental concentration patterns in Akaki Kality sub-city is Cd < Cr < As < Cu < Ni < Fe < Co < Pb < Sn < Mn < B < Zn where the minimum concentration was obsrved for trace toxic elements (such as Cd, Cr and As) while the maximum concentration is seen for Mn, B and Zn. Moreover, the elemntal concentration patterns in other sub cites were also determined and the results followed the patterns in decreasing order of Ni < Co < Fe < Cr < As < Cd < Sn < Pb < B < Mn; Sn < Cr < Ni < Cd < As < Co < Fe < Pb < B < Zn < M); Cd < Cr < Ni < As < Pb < Co < Fe < Sn < B < Zn < Cu < Mn; Mn < Cd < Cr < As < Ni < Co < B < Cu < Sn < Pb < Fe < Zn; Cr < Co < As < Ni < Fe < Cu < Cd < Sn < Pb < B < Zn < Mn; (Co < Cr < Cd < As < Pb < Ni < B < Fe < Sn < Zn; Co < Cr < Cd < As < Ni < Zn < K < Fe < Pb < Sn < B < Mn and As < Cr < Cd < Co < Pb < Ni < Fe < Cu < Sn < B < Zn < Mn for Arada, Kolfe Keranio, Addis Ketema, Lideta, Kerkos, Nefas Silk-Lafto, Gulelle and Yeka sub-city, respectively.

4.5.1.1 Principal component analysis

A possible source of particulate matter can be estimated and identified by a multivariate technique called principal component analysis (PCA). It can be used to reduce the large number of variables to a smaller set of factors that retain most of the information in the original data set, where a set of multiple correlated variables are transformed to a small number of independent variables by orthogonal transformations (Shah *et al.*, 2012; Rao *et al.*, 2015; Tahri *et al.*, 3013).

PCA based on the correlation matrix that was conducted for our data to estimate the sources of elements and to classify the correlated elements. The principal component loadings of the elements during the study periods with corresponding variances are given in Table 35. The results demonstrated that 88.6% of the data variance was explained by the first five components. Thus, as it is noticed in Table 37, 27.5% of the total variance of the data was explained by PC1 with positive loading of Zn (0.433), Cr (0.409) and Cd (0.477), in which the main source of these elements might be tired and break abrasion (Jandačka and Ďurčanská, 2014). The second component (PC2) is dominated by Pb (0.437) which has been reported that it is mainly originated from industries and suspended of soil dust at the roadside (Crilley, 2014; Fortoul et al., 2015; Zereini et al., 2005). Similarly, PC3 is dominated by As (0.483) and Mn (0.496), PC4 is by Mn (0.446) and PC5 is B (0.770) in which the sources are associated with dust resuspension, industries and, biomass and biofuel combustion, respectively (Crilley, 2014; Jandačka and Ďurčanská, 2014).

Table 35. Principal component analysis (PCA) results of elements in PM_{10} at the roadside.

	PC1	PC2	PC3	PC4	PC5
Fe	-0.482	-0.026	0.163	0.060	-0.178
Mn	0.271	-0.063	**0.483**	**0.446**	0.218
B	0.123	0.059	-0.408	0.172	**0.770**
Zn	**0.433**	-0.033	-0.289	0.284	-0.389
Pb	0.049	**0.437**	0.103	-0.424	0.285
Cr	**0.409**	0.050	-0.110	-0.423	-0.174
Cd	**0.477**	0.162	0.285	0.027	-0.024
Sn	-0.082	-0.432	0.298	-0.374	0.222
As	-0.024	0.389	**0.496**	0.186	0.018
Ni	0.050	-0.544	0.032	0.225	0.118
Co	-0.287	0.371	-0.223	0.322	-0.023
Eigenvalue	3.030	2.649	1.715	1.310	1.038
Percentage of variance	27.5%	24.1%	15.6%	11.9%	9.44%
Cumulative	27.5%	51.6%	67.2%	79.1%	88.6%

Bold data are the main contribution elements to the component.

Furthermore, to demonstrate the correlation between trace elements and the sampling sub-cities biplot graph was constructed using two PCs (PC1 and PC2). The results are shown in Figure 14.

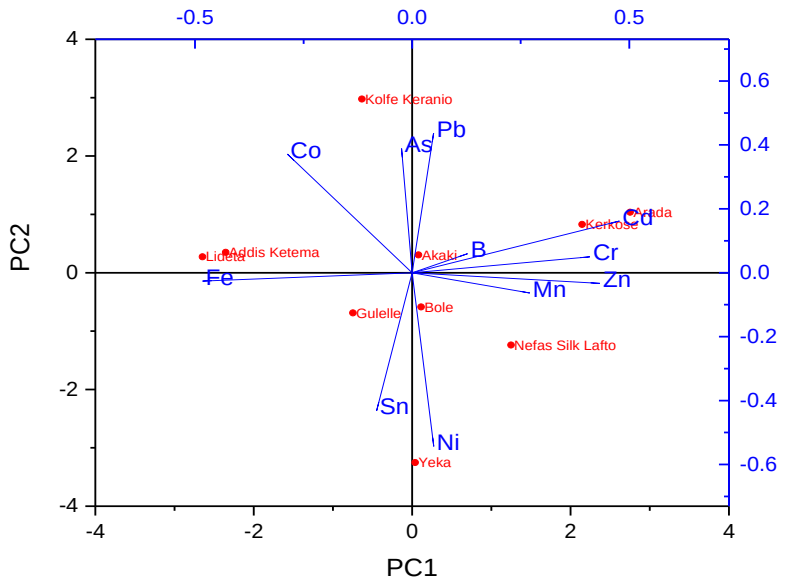


Figure 14. Biplot of scores and loadings matrices for the first two PCs of PM_{10} sampled at the roadside.

As it can be seen from the bi-plot in Figure 14, PCs associated with Mn, Zn, Cr and Co were characterized to Kerkos and Arada sub-cities, whereas Sn and Ni; As and Pb are associated with Yeka and Kolfe Keranio sub-cities, respectively. Similarly, Fe is associated to Lideta and Addis Ketema sub-cities, while B is associated with Akaki Kality sub-cities.

In this work, the hierarchical cluster analysis was carried out to detect the multivariate similarity in elements. The cluster analysis was carried out in 11 (Cd, Zn, Sn, Pb, Co, Fe, Ni, B, Cr, Mn and As) variables at 10 sampling sites. The corresponding cluster analysis dendrogram derived is shown in Figure 15. Four clusters were identified as cluster 1 (Fe, Pb, As and Co); cluster 2 (Mn, Cd, Zn, Cr); cluster 3 (B) and cluster 4 (Sn and Ni) at 1cm. Furthermore, from the cluster analysis, it can be concluded that there is a strong correlation between As-Co, Mn-Cd, Zn-Cr, Sn-Ni which shows their sources of origin might be similar.

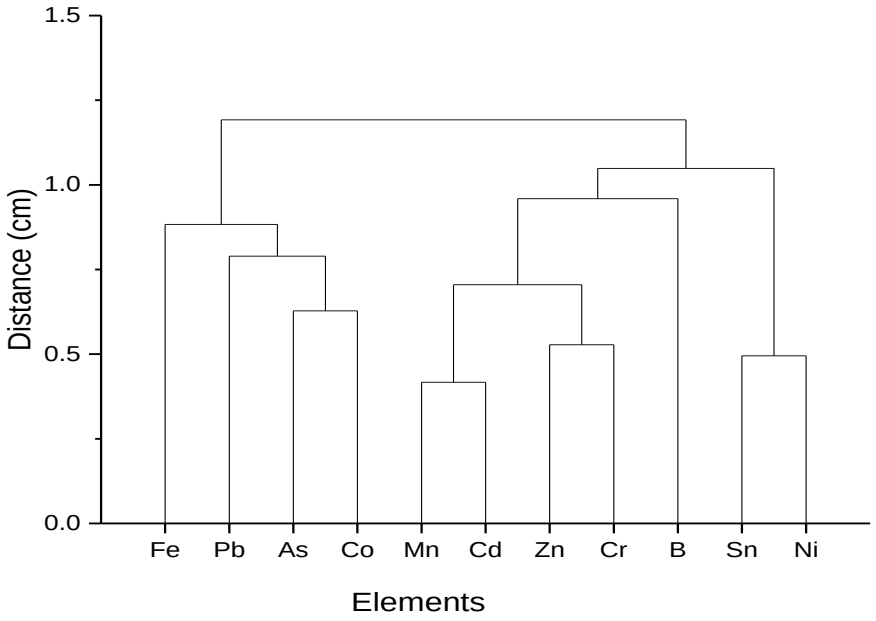


Figure 15. Dendrogram from the cluster analysis of 11 elements in 10 sampling sites at Addis Ababa.

4.5.2 Trace element concentration determination in PM_{10} at kitchen ME during the baking of *Injera*

Biomass fuel is the main energy sources in the baking of *Injera*. Different elements are present in the wood, off which carbon is its major constituent (45-50%) followed by hydrogen (6%). Besides, the other major elements in wood fuels follow the patterns: nitrogen (N) < calcium (Ca) < potassium (K) < sodium (Na) < magnesium (Mg) < manganese (Mn) < iron (Fe) < aluminium (Al). Moreover, minor elements such as cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), arsenic (As), mercury (Hg) and lead (Pb) also exist in the wood fuels. Although the elemental composition of wood fuel varies in plant species, each plant can uptake these elements from varies sources such as uptake from the soil while growth and contaminated during processing (such as painting and contact with contaminated soil). In addition to the plant species, the type of stove determines the amount of particulate matter bound metals released. Hence, the present study focused on measurement of selected elements bound in PM_{10} using different combustion appliance (improved and traditional) stove during the baking of *Injera* (Ncube and Phiri, 2015). In addition, burning of municipals waste containing materials such as discarded Ni and Cd batteries, plastics containing Cd are also sources of these metals to the particulate matter. People use plastics and other synthetic combustible materials used as igniters to start burring of charcoal and wood biomass (Awan *et al.*, 2011). Generally, trace elements bound in the particulate matter at indoor ME originate from biomass combustion, infiltration from outdoor through natural and mechanical ventilation, decomposition of trace elements containing paints and from resuspended of soil dust in indoor.

The concentration of selected trace elements found in PM_{10} sampled during *Injera* baking using clean, improved and traditional stoves were investigated, and the results are summarized in Table

36. The trace elements found in PM_{10} using improved stove were found in the range of 0.003-0.632 µg m^{-3}, where the highest and the lowest concentration was obtained for B and As elements, respectively. Similarly, the concentration range of the trace elements bound in PM_{10} using traditional and clean stoves were found between 0.002-0.499 and 0.006-0.775 µg m^{-3}, respectively. B and Fe were the highest concentration obtained in traditional and clean stoves, respectively. As is the lowest concentration element obtained for both traditional and clean stoves.

ANOVA test was applied to the element concentration across all the stove types, and B, Fe and Zn have shown a significant difference ($p < 0.05$), whereas other elements did not show a significant difference ($p > 0.06$) across the stove types. However, the difference is not recognized where it occurred, hence individual comparisons of stoves were performed. Thus, the level 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 were not showed significantly. Moreover, 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.

Table 36. 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
Fe	0.254±0.003	0.082±0.002	0.078±0.006
Cu	BLD	BLD	BLD
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

BLD is below the detection limit.

The patterns of each element concentration bound in PM_{10} during the baking of *Injera* using improved, traditional and clean stove are shown in Figure 16. Based on the elemental concentration, the patterns of the element in PM_{10} during improved stove used was: As < Mn < Ni < Sn < Cd < Co < Pb < Cr < Fe < Zn < B. Similarly, their patterns during traditional and clean stove used were: As < Mn < Cd < Sn < Pb < Co < Ni < Cr < Fe < Zn < B and As < Sn < Mn < Ni < Cd < Co < Cr < Pb < B < Zn < Fe, respectively.

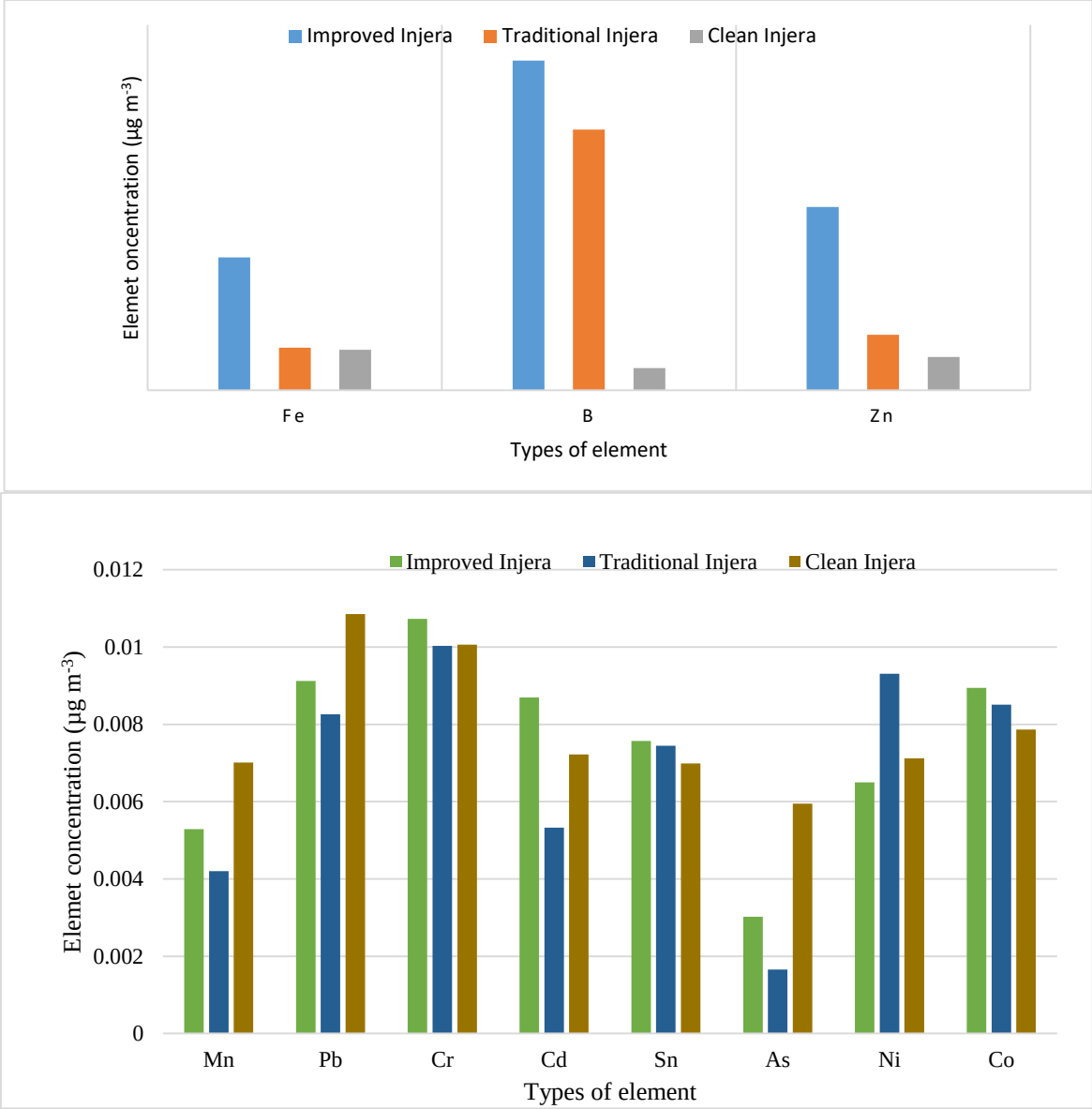


Figure 16. The patterns of Fe, Mn, B, Zn, Pb, Cr, Cd, Sn, As, Ni and Co across the stove type.

4.5.3 Trace element concentration determination in PM_{10} at kitchen ME during the cooking of *Wot*

The main sources of elements for outdoor particulate matter are gasoline additives, industrial activities and fossil fuel combustions. Thus, use of fossil fuels such kerosene for cooking

purpose might cause for the formation of elemental rich indoor air particulate matter (Estokova, et al, 2010).

The concentration of trace elements found in PM_{10} sampled during the cooking of *Wot* using charcoal, kerosene and electricity fuels were determined, and the results found were in the range 0.001-0.109; 0.003-0.175 and 0.0007-0.058 μg m^{-3}, respectively. The highest concentration obtained is B during charcoal used and Zn during kerosene and electric fuels used, whereas the lowest concentration of elements found during using of charcoal, kerosene and electric fuels are Mn, Co and Cd, respectively. The details of the result are given in Table 37.

The results of elements concentration in particulate matter sampled during cooking *Wot* using charcoal, kerosene and electricity fuels are compared using ANOVA. The results indicate that the means of Cd, Zn, As and Ni showed a significantly different ($p < 0.05$) across fuel type, 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 compared. Pb, Cd, As and Ni has also shown a significant difference ($p < 0.05$) when kerosene compared with electricity. The comparison of charcoal fuel to electricity fuel showed no significant difference in their elemental concentration emissions.

Table 37. PM_{10} bound elemental composition (mean ± SD, in µg m^{-3}) during the cooking of *Wot* using charcoal, kerosene and electricity fuels.

Metal type	Charcoal	Kerosene	Electricity
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
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
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
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
Ni	0.006±0.004	0.025±0.001	0.004±0.005
Co	0.003±0.002	0.003±0.003	0.001±0.003

The patterns of each elements concentration in PM_{10} sampled during the cooking of *Wot* using charcoal, kerosene and electricity fuels are shown in Figure 17. As it has been seen from the Figure 17, the patterns of the elements in PM_{10} sampled during charcoal, kerosene and electricity fuels used 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.

Most of the toxic trace elements including Cd, Mn, Sn, Cr, As, Cu were found high in the kerosene used as fuel use. B was found highest during charcoal use.

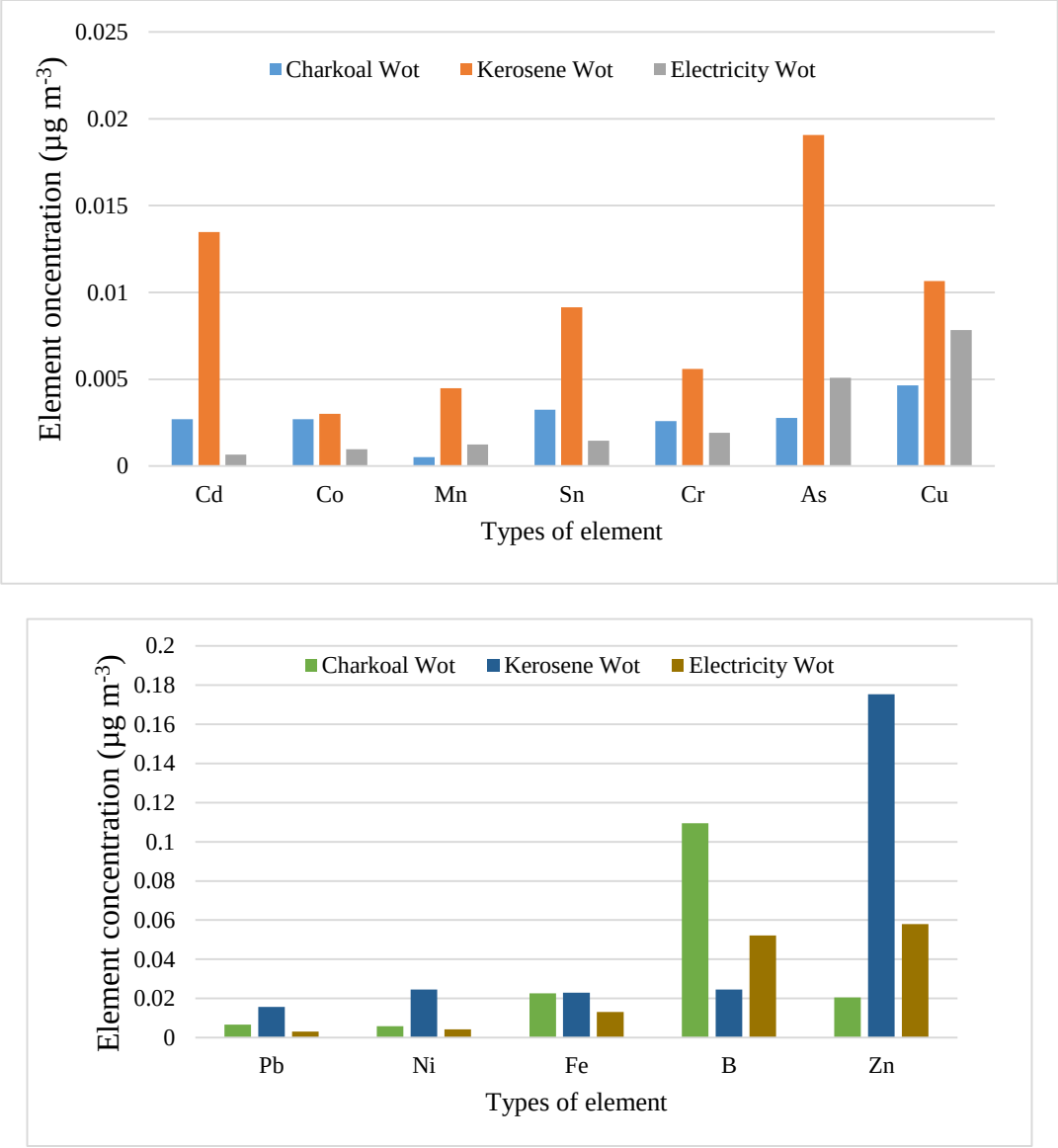


Figure 17. The patterns of Fe, Mn, B, Zn, Cu, Pb, Cr, Cd, Sn, As, Ni and Co across the fuel types.

4.5.4 Trace element concentration determination in PM_{10} at the living room ME

The elemental contamination of indoor particle can depend on outdoor particle penetration, indoor emission source (such as smoking and cooking) and emission from building materials (Estokova, et al, 2010). However, the level of indoor particulate matter at the living rooms are mainly due to outdoor polluted air, movement of occupants, furnishing and ventilation system of the house (Sidra

et al., 2015). There is no smoking and cooking practice while sampling carried out at ME used in this study.

The concentration of elements found in PM_{10} sampled at the living room was found in the range of 0.001-0.026 µg m^{-3}, where the highest and the lowest concentration was obtained for Fe and Pb, respectively. The details of the result are given in Table 38.

Table 38. PM_{10} bound elemental composition (mean ± SD, in µg m^{-3}) at the living room.

Metal type	Fe	Cu	Mn	B	Zn	Pb
Concentration	0.026±0.012	0.005±0.002	0.008±0.004	0.010±0.007	0.010±0.009	0.001±0.001
Metal type	Cr	Cd	Sn	As	Ni	Co
Concentration	0.003±0.001	0.004±0.001	0.003±0.002	0.003±0.002	0.003±0.002	0.002±0.001

The patterns of element concentration bound in PM_{10} at living room is given in Figure 18. Based on the elemental concentration, the patterns of the element in PM_{10} sampled at living room was: Pb < Co < Ni < Sn < As < Cr < Cd < Cu < Mn < B < Fe, respectively.

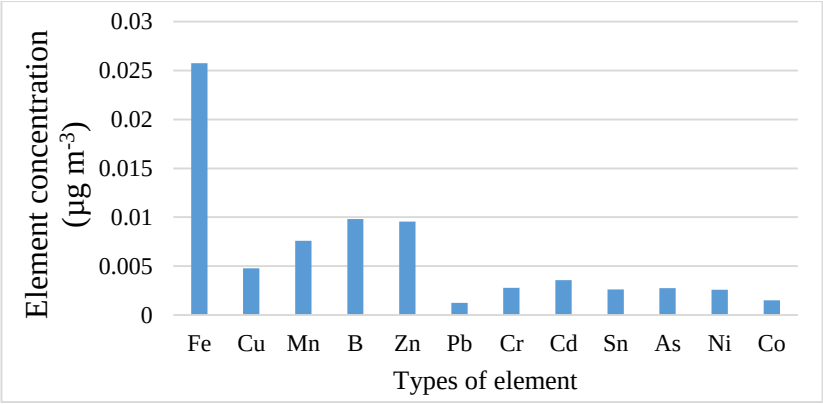


Figure 18. The patterns of Fe, Mn, B, Zn, Cu, Pb, Cr, Cd, Sn, As, Ni and Co in the living room ME.

4.6 Health Risk Assessment due to Elements in PM_{10} at different MEs

According to International Agency for Research on Cancer (IARC) report in 2010, 223, 000 peoples were died due to lung cancer caused by air pollution. Since different element species have different toxicity, concentrations and mobility behavior, their health risk also varies. Hence, determination of their cancer and non-cancer risk have a vital role in the prioritizing of individual metal species to the total risk contributions and to take a remediation and emission control at the individual level (Izhar *et al.*, 2016).

Cancer and noncancer risk will develop due to the exposure to elements bound to particulate matter (Benson *et al.*, 2017; Liu *et al.*, 2017; Liu *et al.*, 2018). Cancer risk also called lifetime cancer risk is a method of estimating of the probability of a person developing cancer over his/her lifetime as a result of exposure to the identified carcinogens, whereas noncarcinogenic effects means a probability of a person developing health problems other than cancer effect during his exposure time to contaminants (Benson *et al.*, 2017). Exposure of trace elements found in the particulate matters can occur through inhalation, ingestion and dermal absorption routes (Sidhu, 2017). The elements under consideration in this study can be classified as carcinogenic and noncarcinogenic metals. According to Integrated Risk Information System (IRIS) Cu, Fe, Zn and Mn are classified as noncarcinogenic, meanwhile Cd, As, Pb, Cr and Ni are carcinogenic metals (Kushwaha *et al.*, 2012; Liu *et al.*, 2017; Liu *et al.*, 2018).

Moreover, in this study evaluating of threats to the health (the carcinogenic and non-carcinogenic risks) of the inhabitants due to elements in PM_{10} for both children and adults via direct inhalation, ingestion, and dermal contact were assessed at different microenvironment. Thus, this assessment helps to understand the severity of the health risks and to take a remedial action at individual

microenvironments. So that the health risk assessment due to the particulate matter bound elements exposure were calculated using US EPA's methodology as expressed in equation 13-18 (Liu *et al.*, 2018).

$$D_{inh} = \frac{C\ x\ InhR\ x\ ED\ x\ EF}{BW\ x\ AT} \quad (13)$$

$$D_{ing} = \frac{C\ x\ IngR\ x\ ED\ x\ EF}{BW\ x\ AT}\ x\ 10^{6} \quad (14)$$

$$D_{der} = \frac{C\ x\ AF\ x\ SA\ x\ ABS\ x\ ED\ x\ EF}{BW\ x\ AT}\ x\ 10^{6} \quad (15)$$

$$HQ = \frac{D}{RfD} \quad (16)$$

$$HI = \sum HQ \quad (17)$$

$$LCR\ or\ CR = D_{inh}\ x\ IUR = D_{ing}\ x\ SF = D_{der}\ x\ (\frac{SF}{G}) \quad (18)$$

where C is concentration of elements (µg m^{-3} or mg kg^{-1}), D_{inh}, D_{inge} and D_{der} is 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 inhalation rate (m^3 day^{-1}), ED is exposure duration (years), EF is exposure frequency (day $year^{-1}$), BW is body weight (Kg), AT is averaging time (years), LCR is lifetime cancer; IUR is 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 parameter considered for health risk assessments due to trace element concentration at all the microenvironments in this study are given in Table 39 and Table 40.

Table 39. The constant values used in risk calculation (Kushwaha *et al.*, 2012; Benson *et al.*, 2017; 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 40. The exposure parameters for health risk assessments (Walpole *et al.*, 2012; Benson *et al.*, 2017; Liu *et al.*, 2018)

Parameters	Values	
	Children	Adults
InhR (m^3 day^{-1})	7.6	20
ED (year)	6	30
EF (days $year^{-1}$)	(6/6/5; 50/50/43; 32 and 122)*	(6/6/5; 50/50/43; 32 and 122)*
	(202/209/203/210)**	(202/209/203/210)**
AT (days): (for non-carcinogenic)	ED x 365	ED x 365
:(for carcinogenic)	70 x 365	70 x365
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

*** indicate the exposure of frequency in using improved stove/traditional stove/clean stove; charcoal fuel/kerosene fuel/electricity; at living room and at an outdoor roadside MEs; ** is the exposure frequency for a person in combined MEs of A/B and C/ D and G/E, F, H and I, respectively.**

According to US EPA total cancer risks associated with exposure to contaminants over a lifetime is greater than $1x10^{-4}$ are generally considered unacceptable. However, the US EPA's threshold range indicated for tolerable risk is between $1x10^{-4}$ and $1x10^{-6}$ (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 *et al.*, 2018). Therefore, these values were used as threshold values throughout this study.

4.6.1 Carcinogenic and non-carcinogenic risk assessment at the roadside ME

As it is can be seen in Table 41, the carcinogenic risk of inhabitants at the roadside due to elements in PM_{10} were predominantly caused by direct ingestion pathways followed by inhalation and then dermal contact for adults. Direct ingestion also the main pathway for children, followed by inhalation pathways and dermal contact. In addition, all the values of carcinogenic risks are found in a tolerable range and below given by US EPA (Benson *et al.*, 2017). The carcinogenic risk posed by Pb and As through ingestion were higher than posed by inhalation and dermal contact for children. Such similar trend was seen in adult, only by As.

The non-carcinogenic risks posed by individual elements were determined by using HQ of each element which indicates that Mn via inhalation is high for both children and adults. Mn metal is the only element which poses the non-carcinogenic risk for both children and adults through inhalation pathway. In addition, all elements did not pose a non-carcinogenic health risk through dermal contacts. On the other hand, the total non-carcinogenic risk due to all elements at each exposure pathways showed, HI > 1 for both children and adults though through inhalation only. Furthermore, the total non-carcinogenic health risk due to elemental exposure through the three

pathways were calculated by taking the HQ sum of each element obtained at each pathway. The result (total HI = 3.39) confirmed that children could have a likelihood to affect by non-carcinogenic health problems. Besides, the percent contribution of each exposure pathway for the total risk values (total HI) were calculated that inhalation, ingestion and dermal contact exposure pathways for children account 75.00, 24.99 and 0.01%, respectively. Similarly, total HI for adults (total HI = 1.76) also confirmed that the likely to have non-carcinogenic health problems. The percent contribution of inhalation, ingestion and dermal contact exposure pathways to the total HI was found in the order of 94.04, 5.955 and 0.005%, respectively.

Table 41. Carcinogenic and non-carcinogenic risks of each element for children and adults via inhalation, ingestion, and dermal exposure at the roadside microenvironment.

	LCR	HQ	LCR	HQ
Type of metal	Adults		Children	
		Inhalation exposure		
Cu		$1.5x10^{-4}$		$2.41x10^{-4}$
Mn		0.978		**1.504**
Zn		$1.22x10^{-4}$		$1.89x10^{-4}$
Pb	$4.43x10^{-07}$	0.0034	$1.36x10^{-07}$	0.0052
Cr	$7.93x10^{-06}$	0.0143	$2.44x10^{-06}$	0.022
Cd	$2.47x10^{-06}$	0.297	$7.60x10^{-07}$	0.457
As	$7.87x10^{-06}$	0.264	$2.42x10^{-06}$	0.406
Ni	$5.37x10^{-07}$	0.097	$1.65x10^{-07}$	0.149
Sum (HI)	$1.92x10^{-05}$	**1.650**	$5.78x10^{-06}$	**2.544**
		Ingestion exposure		
Fe		$7.32x10^{-05}$		$5.92x10^{-4}$
Cu		$7.85x10^{-4}$		0.006
Mn		0.0017		0.014
B		$5.48x10^{-4}$		0.004
Zn		$6.17x10^{-4}$		0.005
Pb	$7.20x10^{-06}$	0.017	$1.17x10^{-05}$	0.139
Cr	$1.53x10^{-06}$	0.002	$2.48x10^{-06}$	0.019
Cd	$4.08x10^{-06}$	0.015	$6.60x10^{-06}$	0.120
As	$1.27x10^{-05}$	0.066	$2.06x10^{-05}$	0.534
Ni	$8.72x10^{-07}$	$4.84x10^{-4}$	$1.41x10^{-06}$	0.004
Sum (HI)	$2.64x10^{-05}$	0.105	$4.28x10^{-05}$	0.847
		Dermal exposure		
Cu		$4.42x10^{-07}$		$7.85x10^{-07}$
Mn		$3.44x10^{-06}$		$6.12x10^{-06}$
Zn		$2.60x10^{-06}$		$4.63x10^{-06}$
Pb	$1.09x10^{-07}$	$8.45x10^{-07}$	$7.89x10^{-07}$	$1.50x10^{-06}$
Cr	$9.30x10^{-07}$	$4.03x10^{-06}$	$6.72x10^{-06}$	$7.16x10^{-06}$
Cd	$2.47x10^{-07}$	$8.37x10^{-07}$	$1.79x10^{-06}$	$1.49x10^{-06}$
As	$5.80x10^{-07}$	$8.37x10^{-07}$	$4.19x10^{-06}$	$1.49x10^{-06}$
Ni	$3.31x10^{-07}$	$8.53x10^{-06}$	$2.39x10^{-06}$	$1.51x10^{-05}$
Sum (HI)	$2.20x10^{-06}$	$2.16x10^{-05}$	$1.59x10^{-05}$	$3.83x10^{-05}$

Bolds indicate higher from threshold values

4.6.2 Carcinogenic and non-carcinogenic risk assessment at kitchen ME during the baking of *Injera*

The carcinogenic and non-carcinogenic risks were calculated for inhabitants who bake *Injera* using different types of stove and stay at bake area, the results are given in Table 42. Metals including Pb, Cr, Cd, As and Ni inhalation and ingestion exposures pathway for children during the baking of *Injera* using improved stoves showed a cancer risk values below tolerable range. Similarly, inhalation and ingestion exposure of Cr, Cd, As, Ni and Pb for adult showed carcinogenic risk values below tolerable range. All the elements also showed below tolerable range in dermal contact exposure pathway for both children and adults. In addition, metals including Pb, Cd, As, Cr and Ni exposure through inhalation, ingestion and dermal contact pathways for both children and adults during baking of *Injera* using traditional stoves showed a cancer risk values below tolerable range. Similarly, the trend was seen using the clean stove for the baking of *Injera*.

As it can be seen in Table 42 while using clean stove the carcinogenic risk, predominantly caused by ingestion exposure pathway followed by dermal contact and inhalation pathways for children, whereas inhalation is followed by ingestion and dermal contact pathway for adults.

Furthermore, non-carcinogenic risk caused by inhalation exposure pathway is the predominant path followed by ingestion and dermal contact paths for both children and adults during the baking of *Injera* across all types of stove. 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. Thus, the result 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 affect by non-carcinogenic health problems. Besides, the percent contribution of each exposure pathway for the total risk values (total HI) at the improved stove was calculated that inhalation, ingestion and dermal contact exposure pathways for children account 63.2, 36.7 and 0.04%, respectively. Similarly, inhalation, ingestion and dermal contact exposure pathways for children at traditional and clean stoves were: 61.5, 30.8, 7.7% and 58.8, 35.3, 5.9%, respectively.

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

Table 42. Carcinogenic and non-carcinogenic risks of each element for children and adults via inhalation, ingestion, and dermal exposure during baking *Injera* using clean, improved and traditional stoves.

	Improved				Traditional				Clean stove			
	Adult		Children		Adult		Children		Adult		Children	
Type of metal	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Inhalation exposure												
Mn		$5.42x10^{-4}$		$8.33x10^{-4}$		$4.33x10^{-4}$		$6.66x10^{-4}$		$6.32x10^{-4}$		$9.72x10^{-4}$
Zn		$6.32x10^{-06}$		$9.71x10^{-06}$		$1.91x10^{-06}$		$2.93x10^{-06}$		$9.60x10^{-07}$		$1.48x10^{-06}$
Pb	$3.00x10^{-09}$	$1.38x10^{-05}$	$5.54x10^{-10}$	$2.13x10^{-05}$	$2.67x10^{-09}$	1.2310^{-05}	$4.92x10^{-10}$	$1.89x10^{-05}$	$3.06x10^{-09}$	$1.41x10^{-05}$	$5.64x10^{-10}$	$2.17x10^{-05}$
Cr	$5.50x10^{-07}$	$6.00x10^{-4}$	$1.01x10^{-07}$	$9.12x10^{-4}$	$5.0x10^{-07}$	$5.41x10^{-4}$	$9.23x10^{-08}$	$8.3x10^{-4}$	$4.17x10^{-07}$	$4.53x10^{-4}$	$7.69x10^{-08}$	$6.94x10^{-4}$
Cd	$6.75x10^{-08}$	0.005	$1.25x10^{-08}$	0.007	$3.75x10^{-08}$	0.003	$6.92x10^{-09}$	0.004	$4.37x10^{-08}$	0.0031549	$8.07x10^{-09}$	0.005
As	$5.37x10^{-08}$	0.001	$9.92x10^{-09}$	0.002	$3.58x10^{-08}$	$7.21x10^{-4}$	$6.61x10^{-09}$	0.001	$8.96x10^{-08}$	0.0018	$1.65x10^{-08}$	0.003
Ni	$7.00x10^{-09}$	$7.58x10^{-4}$	$1.29x10^{-09}$	0.001	$9.00x10^{-09}$	$9.75x10^{-4}$	$1.66x10^{-09}$	0.001	$5.83x10^{-09}$	$6.32x10^{-4}$	$1.08x10^{-09}$	$9.72x10^{-4}$
Sum (HI)	$6.81x10^{-07}$	0.008	$1.26x10^{-07}$	0.012	$5.85x10^{-07}$	0.005	$1.08x10^{-07}$	0.008	$5.59x10^{-07}$	0.007	$1.03x10^{-07}$	0.01
Ingestion exposure												
Fe		9.83^{-06}		$7.95x10^{-05}$		$3.17x10^{-06}$		$2.57x10^{-05}$		$2.51x10^{-06}$		$2.04x10^{-05}$
Mn		9.67^{-07}		7.83^{-06}		$7.74x10^{-07}$		$6.26x10^{-06}$		$1.13x10^{-06}$		$9.13x10^{-06}$
B		8.56^{-05}		$6.93x10^{-4}$		$6.76x10^{-05}$		$5.47x10^{-4}$		$4.74x10^{-06}$		$3.84x10^{-05}$
Zn		3.17^{-05}		2.5644		$9.57x10^{-06}$		$7.74x10^{-05}$		$4.81x10^{-06}$		$3.90x10^{-05}$
Pb	$4.87x10^{-08}$	6.96^{-05}	$4.73x10^{-08}$	5.636	$4.33x10^{-08}$	$6.19x10^{-05}$	$4.21x10^{-08}$	$5.00x10^{-4}$	$4.96x10^{-08}$	$7.09x10^{-05}$	$4.82x10^{-08}$	$5.74x10^{-4}$
Cr	$1.06x10^{-07}$	9.93^{-05}	$1.03x10^{-07}$	$8.04x10^{-4}$	$9.67x10^{-08}$	$9.03x10^{-05}$	$9.39x10^{-08}$	$7.31x10^{-4}$	$8.06x10^{-08}$	$7.52x10^{-05}$	$7.83x10^{-08}$	$6.09x10^{-4}$
Cd	$1.11x10^{-07}$	$2.44x10^{-4}$	$1.08x10^{-07}$	0.002	$6.19x10^{-08}$	$1.35x10^{-4}$	$6.01x10^{-08}$	0.001	$7.22x10^{-08}$	$1.58x10^{-4}$	$7.01x10^{-08}$	0.001
As	$8.70x10^{-08}$	$2.71x10^{-4}$	$8.45x10^{-08}$	0.002	$5.80x10^{-08}$	$1.81x10^{-4}$	$5.64x10^{-08}$	0.001	$1.45x10^{-07}$	$4.51x10^{-4}$	$1.41x10^{-07}$	0.004
Ni	$1.14x10^{-08}$	$3.79x10^{-06}$	$1.10x10^{-08}$	$3.07x10^{-05}$	$1.46x10^{-08}$	$4.87x10^{-06}$	$1.42x10^{-08}$	3.95^{-05}	$9.48x10^{-09}$	$3.16x10^{-06}$	$9.21x10^{-09}$	$2.56x10^{-05}$
Sum (HI)	$3.65x10^{-07}$	$8.15x10^{-4}$	$3.54x10^{-07}$	0.007	$2.75x10^{-07}$	$5.54x10^{-4}$	$2.67x10^{-07}$	0.004	$3.57x10^{-07}$	$7.72x10^{-4}$	$3.47x10^{-07}$	0.006
Dermal contact exposure												
Mn		$1.91x10^{-09}$		$1.42x10^{-10}$		$1.53x10^{-09}$		$9.45x10^{-10}$		$9.53x10^{-10}$		$4.13x10^{-08}$

Zn		$1.34x10^{-07}$		$9.95x10^{-09}$		$4.04x10^{-08}$		$2.50x10^{-08}$		$2.22x10^{-09}$		$9.64x10^{-08}$
Pb	$7.39x10^{-10}$	$3.43x10^{-09}$	$5.49x10^{-11}$	$2.55x10^{-10}$	$6.57x10^{-10}$	$3.05x10^{-09}$	$4.88x10^{-11}$	$1.89x10^{-09}$	$7.53x10^{-10}$	$3.50x10^{-09}$	$3.92x10^{-09}$	$1.52x10^{-07}$
Cr	$6.45x10^{-08}$	$4.13x10^{-08}$	$4.80x10^{-09}$	$3.12x10^{-09}$	$5.87x10^{-08}$	$3.81x10^{-08}$	$4.36x10^{-09}$	$2.36x10^{-08}$	$4.89x10^{-08}$	$3.18x10^{-08}$	$2.54x10^{-07}$	$1.38x10^{-06}$
Cd	$6.76x10^{-09}$	$1.37x10^{-08}$	$5.02x10^{-10}$	$1.02x10^{-09}$	$3.75x10^{-09}$	$7.66x10^{-09}$	$2.79x10^{-10}$	$4.72x10^{-09}$	$4.38x10^{-09}$	$8.90x10^{-09}$	$2.28x10^{-08}$	$3.86x10-^{07}$
As	$3.96x10^{-09}$	$3.43x10^{-09}$	$2.94x10^{-10}$	$2.55x10^{-10}$	$2.64x10^{-09}$	$2.29x10^{-09}$	$1.96x10^{-10}$	$1.42x10-^{09}$	$6.60x10^{-09}$	$5.72x10^{-09}$	$3.43x10^{-08}$	$2.48x10^{-07}$
Ni	$4.31x10^{-09}$	$6.67x10^{-08}$	$3.20x10^{-10}$	$4.96x10^{-09}$	$5.54x10^{-09}$	$8.58x10^{-08}$	$4.12x10^{-10}$	$5.31x10^{-08}$	$3.59x10^{-09}$	$5.56x10^{-08}$	$1.87x10^{-08}$	$2.41x10^{-06}$
Sum (HI)	$8.03x10^{-08}$	$2.65x10^{-07}$	$5.97x10^{-09}$	$1.97x10^{-08}$	$7.13x10^{-08}$	$1.79x10^{-07}$	$5.30x10^{-09}$	$1.11x10^{-07}$	$6.42x10^{-08}$	$1.09x10^{-07}$	$3.34x10^{-07}$	$4.71x10^{-06}$

4.6.3 Carcinogenic and non-carcinogenic risk assessment at kitchen ME during the cooking of *Wot*

The carcinogenic and non-carcinogenic risk were calculated for inhabitants who spent some of his/her time during cooking *Wot* using different fuel types and the results are given in Table 43. As it can see in Table 43 while using charcoal fuel the carcinogenic risk is predominantly caused by inhalation pathway followed by ingestion exposure and dermal contact pathways for adults, whereas ingestion is followed by inhalation and dermal contact pathway for children. All metals including Pb, Cr, Cd, As and Ni exposure through inhalation, ingestion and dermal contact for both children and adults while using charcoal fuel showed a cancer risk values below tolerable range. However, the LCR values for the element Cr, As and Cd for adult; Cd and As for children during using kerosene fuel and As during using electricity were found within the tolerable range.

On the other hand, while using kerosene fuel the carcinogenic risk is predominantly caused by ingestion exposure pathway followed by inhalation and dermal contact pathways for both children and adult. Hence, metals including Cd, 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 inhalation and ingestion pathways. Regarding dermal contact exposure pathway, all the metals (Pb, Cd, Cr, As and Ni) cancer risk values showed below tolerable range for both children and adults.

Furthermore, while using electricity fuel during cooking *Wot*, the carcinogenic risk 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. In inhalation, ingestion and dermal contact exposure pathways, the cancer risk value for Cd, Pb, As and Ni were found below the tolerable range, except As metal which is found within the tolerable range in ingestion exposure for both children and adults.

In addition, non-carcinogenic risk caused by inhalation exposure pathway is the predominant path followed by ingestion and dermal contact paths for both children and adults during cooking *Wot* across all fuel type. Besides, both HQ and HI values of the measured elements through inhalation, ingestion and dermal contact during cooking *Wot* using charcoal, kerosene and electricity fuels were found below 1 for both children and adults. Therefore, from this result, it can be concluded that both individual and cumulate elemental exposure will not induce non-carcinogenic health problems during cooking *Wot* by using any of the three types of fuels.

The total non-carcinogenic health risk due to elemental exposure through the three pathway during cooking *Wot* using charcoal, kerosene and electricity fuels were also calculated by considering the HQ sum of each element obtained at each pathway in each fuel type. Thus, the results of total HI for children using charcoal, kerosene and electricity fuels found were: 0.08, 0.38 and 0.06, respectively. The result for children using any of the three types of fuels could not be induced any non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI) at charcoal fuel was calculated that inhalation, ingestion and dermal contact exposure pathways for children account 62.4, 37.5 and 0.01%, respectively. Similarly, inhalation, ingestion and dermal contact exposure pathways for children at kerosene and electricity fuels were: 58.3, 40.8, 0.9% and 51.2, 48.4 0.4%, respectively.

The similar calculation was made for adults, and the results of total HI using charcoal, kerosene and electricity fuels found were: 0.034, 0.164 and 0.025, respectively which showed adult person stay in the cooking of *Wot* using all the three fuel type could not have a likelihood to affect by non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI) at charcoal fuel was calculated that inhalation, ingestion and dermal contact exposure pathways account 88.2, 11.7 and 0.1%, respectively. Inhalation, ingestion and dermal contact exposure pathways for adults during kerosene and electricity fuels used were: 85.3, 12.2, 2.5% and 80.0, 16.0, 4%, respectively.

Table 43. 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 fuel				Kerosene fuel				Electricity fuel			
Types of element	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
	Adults		Children		Adults		Children		Adults		Children	
					Inhalation exposure							
Cu		$5.64x10^{-06}$		$8.68x10^{-06}$		$1.12x10^{-05}$		$1.73x10^{-05}$		$7.76x10^{-06}$		$1.19x10^{-05}$
Mn		$4.51x10^{-04}$		$6.94x10^{-04}$		0.004		0.006		$7.76x10^{-04}$		0.001
Zn		$3.00x10^{-06}$		$4.61x10^{-06}$		$2.62x10^{-05}$		$4.04x10^{-05}$		$7.48x10^{-06}$		$1.15x10^{-05}$
Pb	$1.94x10^{-08}$	$8.98x10^{-05}$	$3.59x10^{-09}$	$1.38x10^{-04}$	$4.44x10^{-08}$	$2.05x10^{-04}$	$8.20x10^{-09}$	$3.15x10^{-04}$	$7.17x10^{-09}$	$3.31x10^{-05}$	$1.32x10^{-09}$	5.0910^{-05}
Cr	$1.25x10^{-6}$	0.001	$2.31x10^{-07}$	0.002	$2.50x10^{-06}$	0.003	$4.61x10^{-07}$	0.004	$7.17x10^{-07}$	$7.76x10^{-04}$	$1.32x10^{-07}$	0.001
Cd	$1.87x10^{-07}$	0.01	$3.46x10^{-08}$	0.021	$8.12x10^{-07}$	0.059	$1.50x10^{-07}$	0.090	$5.37x10^{-08}$	0.004	$9.92x10^{-09}$	0.006
As	$4.48x10^{-07}$	0.009	$8.26x10^{-08}$	0.014	$2.84x10^{-06}$	0.057	$5.23x10^{-07}$	0.088	$6.42x10^{-07}$	0.013	$1.18x10^{-07}$	0.020
Ni	$5.00x10^{-08}$	0.005	$9.23x10^{-09}$	0.008	$2.08x10^{-07}$	0.023	$3.84x10^{-08}$	0.035	$2.87x10^{-08}$	0.003	$5.29x10^{-09}$	0.005
Sum (HI)	$1.95x10^{-06}$	0.030	$3.61x10^{-07}$	0.046	$6.40x10^{-06}$	0.145	$1.18x10^{-06}$	0.223	$1.45x10^{-06}$	0.022	$2.67x10^{-07}$	0.033
					Ingestion exposure							
Fe		$7.42x10^{-06}$		$6.00x10^{-05}$		$7.42x10^{-06}$		$6.00x10^{-05}$		$3.60x10^{-06}$		2.92x10-05
Cu		$2.82x10^{-05}$		$2.28x10^{-04}$		$5.64x10^{-05}$		$4.57x10^{-04}$		$3.88x10^{-05}$		$3.14 x10^{-04}$
Mn		$8.06x10^{-07}$		$6.52x10^{-06}$		$6.45x10^{-06}$		$5.21x10^{-05}$		$1.38x10^{-06}$		1.12x10-05
B		$1.22x10^{-04}$		$9.95x10^{-04}$		$2.82x10^{-05}$		$2.28x10^{-04}$		$5.04x10^{-05}$		$4.08 x10^{-04}$
Zn		$1.50x10^{-05}$		$1.22x10^{-04}$		$1.32x10^{-04}$		$1.07x10^{-04}$		$3.75x10^{-05}$		$3.04 x10^{-04}$
Pb	$3.16x10^{-07}$	$4.50x10^{-04}$	$3.07x10^{-07}$	0.004	$7.22x10^{-07}$	0.001	$7.01x10^{-07}$	0.008	$1.16x10^{-07}$	$1.66 x10^{-04}$	$1.13x10^{-07}$	0.001
Cr	$2.42x10^{-07}$	$2.26x10^{-04}$	$2.35x10^{-07}$	0.002	$4.84x10^{-07}$	$4.51x10^{-04}$	$4.70x10^{-07}$	0.004	$1.39x10^{-07}$	$1.29x10^{-04}$	$1.35x10^{-07}$	0.001
Cd	$3.10x10^{-07}$	$6.77x10^{-04}$	$3.01x10^{-07}$	0.005	$1.34x10^{-06}$	0.003	$1.30x10^{-06}$	0.024	$8.88x10^{-08}$	$1.94x10^{-04}$	$8.62x10^{-08}$	0.002
As	$7.25x10^{-07}$	0.002	$7.05x10^{-07}$	0.020	$4.59x10^{-06}$	0.014	$4.46x10^{-06}$	0.116	$1.04x10^{-06}$	0.003	$1.01x10^{-06}$	0.026
Ni	$8.12x10^{-08}$	$2.70x10^{-05}$	$7.89x10^{-08}$	$2.19x10^{-04}$	$3.39x10^{-07}$	$1.13 x10^{-04}$	3.28x10-^{07}	$9.13 x10^{-04}$	$4.66x10^{-08}$	$1.56x10^{-05}$	$4.52x10^{-08}$	$1.26 x10^{-04}$
Sum (HI)	$1.67x10^{-06}$	0.004	$1.63x10^{-06}$	0.031	$7.48x10^{-06}$	0.019	$7.26x10^{-06}$	0.154	$1.43x10^{-06}$	0.004	$1.39x10^{-06}$	0.031

Dermal contact exposure												
Cu		$1.58x10^{-08}$		$9.84x10^{-09}$		$3.17x10^{-08}$		$1.97x10^{-08}$		$2.19x10^{-08}$		$1.48x10^{-08}$
Mn		$1.59x10^{-09}$		$9.84x10^{-10}$		$1.27x10^{-08}$		$7.87x10^{-09}$		$2.73x10^{-09}$		$1.85x10^{-09}$
Zn		$6.35x10^{-08}$		$3.94x10^{-08}$		$5.56x10^{-07}$		$3.44x10^{-07}$		$1.58x10^{-07}$		$1.07x10^{-07}$
Pb	4.79x10-09	$2.22x10^{-08}$	$3.56x10^{-10}$	$1.38x10^{-08}$	$1.09x10^{-08}$	$5.08x10^{-08}$	$8.14x10^{-10}$	$3.15x10^{-08}$	$1.77x10^{-09}$	$8.19x10^{-09}$	$1.43x10^{-10}$	$5.55x10^{-09}$
Cr	1.47x10-07	$9.53x10^{-08}$	$1.09x10^{-08}$	$5.90x10^{-08}$	$2.93x10^{-07}$	$1.91x10^{-07}$	$2.18x10^{-08}$	$1.18x10^{-07}$	$8.41x10^{-08}$	$5.46x10^{-08}$	$6.83x10^{-09}$	$3.69x10^{-08}$
Cd	1.89x10-08	$3.81x10^{-08}$	$1.40x10^{-09}$	$2.36x10^{-08}$	$8.13x10^{-08}$	$1.65x10^{-07}$	$6.05x10^{-09}$	$1.02x10^{-07}$	$5.38x10^{-09}$	$1.09x10^{-08}$	$4.37x10^{-10}$	$7.40x10^{-09}$
As	3.30x10-08	$2.85x10^{-08}$	$2.45x10^{-09}$	$1.77x10^{-08}$	$2.09x10^{-07}$	$1.81x10^{-07}$	$1.55x10^{-08}$	$1.12x10^{-07}$	$4.73x10^{-08}$	$4.10x10^{-08}$	$3.84x10^{-09}$	$2.77x10^{-08}$
Ni	3.08x10-08	$4.76x10^{-07}$	$2.29x10^{-09}$	$2.95x10^{-07}$	$1.28x10^{-07}$	$1.98x10^{-06}$	$9.53x10^{-09}$	$1.23x10^{-06}$	$1.77x10^{-08}$	$2.73x10^{-07}$	$1.43x10^{-09}$	$1.85x10^{-07}$
Sum (HI)	2.34x10-07	$7.41x10^{-07}$	$1.74x10^{-08}$	$4.60x10^{-07}$	$7.23x10^{-07}$	$3.17x10^{-06}$	$5.37x10^{-08}$	$1.96x10^{-06}$	$1.56x10^{-07}$	$5.71x10^{-07}$	$1.27x10^{-08}$	$3.86x10^{-07}$

4.6.4 Carcinogenic and non-carcinogenic risk assessment at the living room ME

The carcinogenic and non-carcinogenic risks were calculated for inhabitants who spent 2 h per day in the living room and the results are given in Table 44. As it is seen in Table 44 carcinogenic risk 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. All the metals (Pb, Cd, As, Cr and Ni) exposure through inhalation, ingestion and dermal contact for both children and adults showed a cancer risk values below tolerable range.

In addition, non-carcinogenic risk caused by inhalation exposure pathway is the predominant path followed by ingestion and dermal contact paths for both children and adults. Besides, both HQ and HI values of the measured elements (Fe, Cu, B, Pb, Mn, Zn, Cr, Cd, As and Ni) through inhalation, ingestion and dermal contact were found below 1 for both children and adults which indicates that the individual elements and sum of all elements exposure will not induce non-carcinogenic health problems to the exposed person.

Furthermore, the total non-carcinogenic health risk due to elemental exposure through the three pathways were calculated by taking the HQ sum of each element obtained at each pathway. The result (total HI = 0.06) confirmed that children could not have a likelihood to affect by non-carcinogenic health problems. The percent contribution of each exposure pathway for the total risk values (total HI for children) were calculated that inhalation, ingestion and dermal contact exposure pathways for children account 67.8, 32.1 and 0.1%, respectively. Similarly, total HI for adults (total HI = 0.03) also confirmed that no likelihood to have non-carcinogenic health problems. The percent contribution of inhalation, ingestion and dermal contact exposure pathways to the total HI was found in the order of 92.3, 7.6 and 0.11%, respectively.

Table 44. Carcinogenic and non-carcinogenic risks of each element for children and adults via inhalation, ingestion, and dermal exposure at the living room microenvironment.

Type of elements	LCR	HQ	LCR	HQ
	Adult		Children	
Inhalation exposure				
Cu		$3.61x10^{-06}$		$5.55x10^{-06}$
Mn		0.004		0.007
Zn		$9.60x10^{-07}$		$1.47x10^{-06}$
Pb	$1.78x10^{-09}$	$8.21x10^{-06}$	$3.28x10^{-10}$	$1.26x10^{-05}$
Cr	$7.99x10^{-07}$	$8.67x10^{-04}$	$1.48x10^{-07}$	0.001
Cd	$1.60x10^{-07}$	0.012	$2.95x10^{-08}$	0.018
As	$2.87x10^{-07}$	0.006	$5.29x10^{-08}$	0.009
Ni	$1.60x10^{-08}$	0.002	$2.95x10^{-09}$	0.003
Sum (HI)	$1.26x10^{-06}$	0.025	$2.33x10^{-07}$	0.038
Ingestion exposure				
Fe		$5.36x10^{-06}$		$4.34x10^{-05}$
Cu		$1.81x10^{-05}$		$1.46x10^{-04}$
Mn		$8.25x10^{-06}$		$6.68x10^{-05}$
B		$7.22x10^{-06}$		$5.84x10^{-05}$
Zn		$4.81x10^{-06}$		$3.90x10^{-05}$
Pb	$2.89x10^{-08}$	$4.13x10^{-05}$	$2.81x10^{-08}$	$3.34x10^{-04}$
Cr	$1.55x10^{-07}$	$1.44x10^{-04}$	$1.50x10^{-07}$	$1.16x10^{-04}$
Cd	$2.64x10^{-07}$	5.7710^{-04}	$2.57x10^{-07}$	0.005
As	$4.64x10^{-07}$	0.001	$4.51x10^{-07}$	0.012
Ni	$2.60x10^{-08}$	$8.67x10^{-06}$	$2.52x10^{-08}$	$7.01x10^{-05}$
Sum (HI)	$9.38x10^{-07}$	0.002	$9.11x10^{-07}$	0.018
Dermal contact exposure				
Cu		$1.01x10^{-08}$		$6.30x10^{-09}$
Mn		$1.63x10^{-08}$		$1.01x10^{-08}$
Zn		$2.03x10^{-08}$		$1.26x10^{-08}$
Pb	$4.38x10^{-10}$	$2.03x10^{-09}$	$3.26x10^{-11}$	$1.26x10^{-09}$
Cr	$9.39x10^{-08}$	$6.10x10^{-08}$	$6.98x10^{-09}$	$3.78x10^{-08}$
Cd	$1.60x10^{-08}$	$3.25x10^{-08}$	$1.19x10^{-09}$	$2.02x10^{-08}$
As	$2.11x10^{-08}$	$1.83x10^{-08}$	$1.57x10^{-09}$	$1.13x10^{-08}$
Ni	$9.85x10^{-09}$	$1.52x10^{-07}$	$7.32x10^{-10}$	$9.45x10^{-08}$
Sum (HI)	$1.41x10^{-07}$	$3.13x10^{-07}$	$1.05x10^{-08}$	$1.94x10^{-07}$

4.6.6 The comparison and integrated total exposure risk assessment of elements in PM_{10} for the selected MEs

As it is discussed in section 4.4.5, the exposure risk of the person depends on the time spent and the concentration of pollutants at each MEs. So, the total exposure risk assessment of a person was performed by overall mean exposure concentration which is calculated by the using equation 10. In this study, we have measured the concentration of selected elements in 8 MEs (baking *Injera* using the clean stove, baking *Injera* using the improved stove, baking *Injera* using the traditional stove, cooking *Wot* using electricity, cooking *Wot* using kerosene, cooking *Wot* using charcoal, the living room and outdoor at the roadside). Among these MEs, peoples can spend some fraction of their daily time in different combination MEs. Knowing of which combination of these microenvironments less polluted is vital to protect the health problems due to exposure of toxic elements in particulate matter.

Accordingly, we can classified nine possible combination based on real practice (A ME (clean stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside), B ME (clean stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside), C ME (clean stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside), D ME (Improved stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside), E ME (Improved stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside), F ME (Improved stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside), G ME (Traditional stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside), H ME (Traditional stove for *Injera* + kerosene for *Wot* + living room + outdoor at roadside) and I ME (Traditional stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside)). The exposure concentration

of analysed elements at A, B, C, D, E, F, G, H and I MEs were found in the range 0.007-0.180, 0.007-0.182, 0.008-0.197, 0.007-179, 0.007-175, 0.008-0.172, 0.008-0.180, 0.007-0.176 and 0.008-172 μg m^{-3}, respectively. Cr was the lowest concentration of the metal found in all combined MEs, whereas Zn is the highest concentration for ME A, B, C and Mn for E, F, G, H, I MEs. The details of total exposure concentration were summarized in Table 45.

Table 45. The total exposure concentration of Fe, Cu, Mn, B, Zn, Pb, Cr, Cd, Sn, As, Ni and Co at nine possible combinations MEs.

Types of element	A	B	C	D	E	F	G	H	I
Fe	0.075	0.073	0.073	0.055	0.053	0.053	0.055	0.052	0.044
Cu	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.033
Mn	0.179	0.176	0.172	0.179	0.175	0.172	0.180	0.176	0.172
B	0.170	0.160	0.153	0.155	0.144	0.137	0.102	0.092	0.083
Zn	0.180	0.182	0.197	0.151	0.154	0.169	0.146	0.149	0.162
Pb	0.046	0.044	0.045	0.046	0.044	0.045	0.046	0.045	0.052
Cr	0.007	0.007	0.008	0.007	0.007	0.008	0.007	0.007	0.008
Cd	0.013	0.012	0.014	0.013	0.012	0.014	0.013	0.012	0.014
Sn	0.050	0.049	0.049	0.050	0.049	0.048	0.050	0.048	0.049
As	0.016	0.016	0.018	0.016	0.016	0.017	0.016	0.016	0.018
Ni	0.019	0.019	0.022	0.020	0.019	0.022	0.020	0.019	0.022
Co	0.018	0.017	0.017	0.018	0.017	0.017	0.017	0.017	0.017

Furthermore, the carcinogenic and non-carcinogenic health risk assessment for selected elements for adults and children of these combined MEs were performed, and the results are given in Table

46 and 47, respectively. The HQ values of all in each ME through inhalation, ingestion and dermal contact exposure were less than one, except HQ of Mn metal for children is greater than one in all MEs. Thus, all the determined elements could not induce a health problem to a person spent in these MEs, except Mn element could induce non-carcinogenic health problems to the exposed children. Moreover, the cumulative effect of the determined elements was assessed by calculating HI values for children and adults. Hence, HI for adults from all exposure pathways at A, B, C, D, E, F, G, H and I MEs were 1.24, 1.26, 1.32, 1.24, 126, 132, 125, 132 and 134, respectively. Similarly, HI for children from all exposure pathways at A, B, C, D, E, F, G, H and I MEs found were 2.41, 2.45, 2.60, 2.41, 2.44, 2.60, 2.44, 2.60 and 2.65, respectively.

Consequently, the values of HI for both children and adults at all MEs were greater one that one can be concluded a person who spent 604, 615, 629, 601, 615, 628, 601, 615 and 628 min in A, B, C, D, E, F, G, H and I MEs, respectively, could face with non-carcinogenic health problems. Inhalation exposure pathway is the major exposure pathway in all the MEs, followed by ingestion and dermal contacts for both children and adults. Based on the values of HI, the patterns of MEs followed were in increasing order of A = D < G < B = E < C = F = H < I for adults and A = D < E = G < C = F = H < I for children. Besides, the LCR for both adults and children at all MEs were found within tolerable range.

Table 46. Carcinogenic and non-carcinogenic risks of each element for adults via inhalation, ingestion, and dermal exposure who spent at four different MEs

Clean stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside (A)							Clean stove for *Injera* + Kerosene fuel for *Wot* + living room + outdoor at roadside (B)					
	Inhalation exposure		Dermal contact exposure		Ingestion exposure		Inhalation exposure		Dermal contact exposure		Ingestion exposure	
Type of element	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Fe						$9.79x10^{-05}$						$9.80x10^{-05}$
Cu		$1.10x10^{-04}$		$3.10x10^{-07}$		$5.51\ x10^{-04}$		$1.14x10^{-04}$		$3.22x10^{-07}$		$5.73x10^{-04}$
Mn		0.652		$2.29x10^{-06}$				0.662		$2.33x10^{-06}$		0.001
B						$1.16x10^{-04}$ $7.77\ x10^{-04}$						$7.55x10^{-04}$
Zn		$1.08x10^{-04}$		$2.31x10^{-06}$		$5.46\ x10^{-04}$		$1.14x10^{-04}$		$2.42x10^{-06}$		$5.73x10^{-04}$
Pb	$5.13x10^{-07}$	0.002	$1.26x10^{-07}$	$5.87x10^{-07}$	$8.34x10^{-06}$	0.012	$5.16x10^{-07}$	0.002	$1.27x10^{-07}$	$5.90x10^{-07}$	$8.38x10^{-06}$	0.01
Cr	$1.26x10^{-05}$	0.014	$1.48x10^{-06}$	$9.59x10^{-07}$	$2.43x10^{-06}$	0.002	$1.27x10^{-05}$	0.014	$1.49x10^{-06}$	$9.65x10^{-07}$	$2.45x10^{-06}$	0.002
Cd	$3.25x10^{-06}$	0.234	$3.25x10^{-07}$	$6.60x10^{-07}$	$5.36x10^{-06}$	0.012	$3.23x10^{-06}$	0.233	$3.23x10^{-07}$	$6.57x10^{-07}$	$5.33x10^{-06}$	0.01
As	$9.42x10^{-06}$	0.190	$6.94x10^{-07}$	$6.01x10^{-07}$	$1.53x10^{-05}$	0.047	$9.81x10^{-06}$	0.198	$7.22x10^{-07}$	$6.26x10^{-07}$	$1.59x10^{-05}$	0.049
Ni	$6.53x10^{-07}$	0.071	$4.02x10^{-07}$	$6.23x10^{-06}$	$1.06x10^{-06}$	3.54	$6.58x10^{-07}$	0.071	$4.05x10^{-07}$	$6.27x10^{-06}$	$1.07x10^{-06}$	$3.56x10^{-04}$
Sum (HI)	$2.64x10^{-05}$	1.162	$3.02x10^{-06}$	$1.39x10^{-05}$	$3.24x10^{-05}$	0.077	$2.69x10^{-05}$	1.181	$3.06x10^{-06}$	$1.42x10^{-05}$	$3.31x10^{-05}$	0.079
Clean stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (C)							Improved stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside (D)					
Fe						$9.80x10^{-05}$						$7.20x10^{-05}$
Cu		$1.14x10^{-04}$		$3.22x10^{-07}$		$5.72x10^{-04}$		$1.11x10^{-04}$		$3.13x10^{-07}$		$5.57x10^{-04}$
Mn		0.650		$2.29x10^{-06}$		0.001		0.657		$2.31x10^{-06}$		0.001
B						$7.21x10^{-04}$						$7.08x10^{-04}$
Zn		$1.23x10^{-04}$		$2.62x10^{-06}$		$6.20x10^{-04}$		$9.22x10^{-05}$		$1.95x10^{-06}$		$4.62x10^{-04}$
Pb	$5.27x10^{-07}$	0.002	$1.30x10^{-07}$	$6.03x10^{-07}$	$8.57x10^{-06}$	0.012	$5.17x10^{-07}$	0.002	$1.27x10^{-07}$	$5.91x10^{-07}$	$8.40x10^{-06}$	0.012
Cr	$1.34x10^{-05}$	0.015	$1.57x10^{-06}$	$1.02x10^{-06}$	$2.59x10^{-06}$	0.002	$1.25x10^{-05}$	0.014	$1.47x10^{-06}$	$9.55x10^{-07}$	$2.42x10^{-06}$	0.002
Cd	$3.68x10^{-06}$	0.266	$3.68x10^{-07}$	$7.48x10^{-07}$	$6.07x10^{-06}$	0.013	$3.18x10^{-06}$	0.229	$3.18x10^{-07}$	$6.45x10^{-07}$	$5.24x10^{-06}$	0.011
As	$1.09x10^{-05}$	0.221	$8.09x10^{-07}$	$7.01x10^{-07}$	$1.78x10^{-05}$	0.055	$9.41x10^{-06}$	0.190	$6.94x10^{-07}$	$6.01x10^{-07}$	$1.52x10^{-05}$	0.0474

Ni	$7.55x10^{-07}$	0.082	$4.65x10^{-07}$	$7.20x10^{-06}$	$1.23x10^{-06}$	$4.09x10^{-04}$	$6.70x10^{-07}$	0.073	$4.13x10^{-07}$	$6.39x10^{-0}6$	$1.09x10^{-06}$	$3.63x10^{-04}$
Sum (HI)	$2.93x10^{-05}$	1.26	$3.34x10^{-06}$	$1.55x10^{-05}$	$3.62x10^{-05}$	0.087	$2.63x10^{-05}$	1.165	$3.02x10^{-06}$	$1.38x10^{-05}$	$3.24x10^{-05}$	0.077
Improved stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside (E)							Improved stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (F)					
Fe						$7.13x10^{-05}$						$7.20x10^{-05}$
Cu		$1.15x10^{-04}$		$3.24x10^{-07}$		$5.75x10^{-04}$		$1.15x10^{-04}$		$3.24x10^{-07}$		$5.75x10^{-04}$
Mn		0.665		$2.34x10^{-06}$		0.001		0.653		$2.30x10^{-06}$		$1.17x10^{-04}$
B						$6.82x10^{-04}$						$6.50x10^{-04}$
Zn		$9.68x10^{-05}$		$2.05x10^{-06}$		$4.86x10^{-04}$		$1.07x10^{-04}$		$2.26x10^{-06}$		$5.35x10^{-04}$
Pb	$5.17x10^{-07}$	0.0023	$1.27x10^{-07}$	$5.91x10^{-07}$	$8.40x10^{-06}$	0.012	$5.29x10^{-07}$	0.002	$1.30x10^{-07}$	$6.06x10^{-07}$	$8.60x10^{-06}$	0.012
Cr	$1.25x10^{-05}$	0.014	$1.47x10^{-06}$	$9.56x10^{-07}$	$2.43x10^{-06}$	0.002	$1.33x10^{-05}$	0.014	$1.56x10^{-06}$	$1.02x10^{-06}$	$2.58x10^{-06}$	0.002
Cd	$3.14x10^{-06}$	0.227	$3.14x10^{-07}$	$6.39x10^{-07}$	$5.18x10^{-06}$	0.011	$3.60x10^{-06}$	0.260	$3.60x10^{-07}$	$7.32x10^{-07}$	$5.94x10^{-06}$	0.013
As	$9.75x10^{-06}$	0.197	$7.18x10^{-07}$	$6.23x10^{-07}$	$1.58x10^{-05}$	0.049	$1.09x10^{-05}$	0.221	$8.07x10^{-07}$	$6.99x10^{-07}$	$1.77x10^{-05}$	0.055
Ni	$6.72x10^{-07}$	0.073	$4.14x10^{-07}$	$6.41x10^{-06}$	$1.09x10^{-06}$	$3.64x10^{-04}$	$7.71x10^{-07}$	0.083	$4.75x10^{-07}$	$7.35x10^{-06}$	$1.25x10^{-06}$	$4.17x10^{-04}$
Sum (HI)	$2.66x10^{-05}$	1.177	$3.05x10^{-06}$	$1.39x10^{-05}$	$3.29x10^{-05}$	0.078	$2.92x10^{-05}$	1.234	$3.33x10^{-06}$	$1.53x10^{-05}$	$3.61x10^{-05}$	0.086
Traditional stove for *Injera* +electricity fuel for *Wot* + living room + outdoor at roadside (G)							Traditional stove for *Injera* + Kerosene fuel for *Wot* + living room + outdoor at roadside (H)					
Fe						$7.14x10^{-05}$						$7.05x10^{-05}$
Cu		$1.11x10^{-04}$		$3.14x10^{-07}$		$5.56x10^{-04}$		$1.15x10^{-04}$		$3.24x10^{-07}$		$5.75x10^{-04}$
Mn		0.659		$2.32x10^{-06}$		0.001		0.667		$2.35x10^{-06}$		0.0012
B						$4.66x10^{-04}$						$4.36\ x10^{-04}$
Zn		$8.92x10^{-05}$		$1.89x10^{-06}$		$4.47x10^{-04}$		$9.38x10^{-05}$		$1.99x10^{-06}$		$4.71\ x10^{-04}$
Pb	$5.20x10^{-07}$	0.002	$1.28x10^{-07}$	$5.95x10^{-07}$	$8.45x10^{-06}$	0.012	$5.20x10^{-07}$	0.002	$1.28x10^{-07}$	$5.95x10^{-07}$	$8.46x10^{-06}$	0.012
Cr	$1.25x10^{-05}$	0.014	$1.47x10^{-06}$	$9.55x10^{-07}$	$2.42x10^{-06}$	0.002	$1.30x10^{-05}$	0.014	$1.47x10^{-06}$	$9.57x10^{-07}$	$2.43x10^{-06}$	0.002
Cd	$3.23x10^{-06}$	0.233	$3.24x10^{-07}$	$6.57x10^{-07}$	$5.33x10^{-06}$	0.012	$3.20x10^{-06}$	0.231	$3.20x10^{-07}$	$6.50x10^{-07}$	$5.28x10^{-06}$	0.012
As	$9.72x10^{-06}$	0.196	$7.16x10^{-07}$	$6.20x10^{-07}$	$1.57x10^{-05}$	0.049	$1.01x10^{-05}$	0.203	$7.41x10^{-07}$	$6.42x10^{-07}$	$1.63x10^{-05}$	0.051
Ni	$6.62x10^{-07}$	0.072	$4.08x10^{-07}$	$6.31x10^{-06}$	$1.08x10^{-06}$	$3.58x10^{-04}$	$6.63x10^{-07}$	0.072	$4.08x10^{-07}$	$6.32x10^{-06}$	$1.08x10^{-06}$	$3.59x10^{-04}$
Sum (HI)	$2.67x10^{-05}$	1.175	$3.04x10^{-06}$	$1.37x10^{-05}$	$3.30x10^{-05}$	0.078	$2.70x10^{-05}$	1.188	$3.07x10^{-06}$	$1.38x10^{-05}$	$3.35x10^{-05}$	0.080
Traditional stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (I)												
Cu		$1.56x10^{-04}$		$4.39x10^{-07}$		$7.79x10^{-04}$						
Mn		0.652		$2.29x10^{-06}$		0.001						

Zn		$1.02x10^{-04}$		$2.17x10^{-06}$		$5.13x10^{-04}$
Pb	$6.01x10^{-07}$	0.003	$1.48x10^{-07}$	$6.88x10^{-07}$	$9.77x10^{-06}$	0.014
Cr	$1.35x10^{-05}$	0.015	$1.58x10^{-06}$	$1.03x10^{-06}$	$2.61x10^{-06}$	0.002
Cd	$3.74x10^{-06}$	0.270	$3.74x10^{-07}$	$7.60x10^{-07}$	$6.17x10^{-06}$	0.013
As	$1.13x10^{-05}$	0.228	$8.34x10^{-07}$	$7.23x10^{-07}$	$1.83x10^{-05}$	0.057
Ni	$7.58x10^{-07}$	0.082	$4.67x10^{-07}$	$7.22x10^{-06}$	$1.23x10^{-06}$	$4.10x10^{-04}$
Sum (HI)	$2.99x10^{-05}$	1.249	$3.40x10^{-06}$	$1.53x10^{-05}$	$3.81x10^{-05}$	0.0899

Table 47. Carcinogenic and non-carcinogenic risks of each element for children via inhalation, ingestion, and dermal exposure who spent at four selected MEs

Clean stove for *Injera* + Electricity fuel for *Wot* + living room + outdoor at roadside (A)							Clean stove for *Injera* + Kerosene fuel for *Wot* + living room + outdoor at roadside (B)					
	Inhalation exposure		Dermal contact exposure		Ingestion exposure		Inhalation exposure		Dermal contact exposure		Ingestion exposure	
Types of elements	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Fe						$7.92x10^{-04}$						$7.92x10^{-04}$
Cu		$1.69x10^{-04}$		$1.92x10^{-07}$		0.004		$1.76x10^{-04}$		$2.00x10^{-07}$		0.005
Mn		1.00		$1.42x10^{-06}$		0.009		1.020		$1.44x10^{-06}$		0.010
B						0.006						0.006
Zn		$1.67x10^{-04}$		$1.43x10^{-06}$		0.004		$1.76x10^{-04}$		$1.50x10^{-06}$		0.005
Pb	$9.47x10^{-08}$	0.004	$9.39x10^{-09}$	$3.63x10^{-07}$	$8.10x10^{-06}$	0.096	$9.52x10^{-08}$	$3.66x10^{-04}$	$9.45x10^{-09}$	$3.66x10^{-07}$	$8.14x10^{-06}$	0.097
Cr	$2.32x10^{-06}$	0.021	$1.10x10^{-07}$	$5.94x10^{-07}$	$2.36x10^{-06}$	0.018	$2.34x10^{-06}$	0.021	$1.10x10^{-07}$	$5.98x10^{-07}$	$2.38x10^{-06}$	0.018
Cd	$5.99x10^{-07}$	0.361	$2.42x10^{-08}$	$4.09x10^{-07}$	$5.21x10^{-06}$	0.095	$5.96x10^{-07}$	0.359	$2.40x10^{-08}$	$4.07x10^{-07}$	$5.18x10^{-06}$	0.094
As	$1.74x10^{-06}$	0.292	$5.16x10^{-08}$	$3.73x10^{-07}$	$1.48x10^{-05}$	0.384	$1.81x10^{-06}$	0.304	$5.37x10^{-08}$	$3.88x10^{-07}$	$1.54x10^{-05}$	0.399
Ni	$1.20x10^{-07}$	0.109	$2.99x10^{-08}$	$3.86x10^{-06}$	$1.03x10^{-06}$	0.003	$1.21x10^{-07}$	0.110	$3.01x10^{-08}$	$3.89x10^{-06}$	$1.04x10^{-06}$	0.003
Sum (HI)	$4.87x10^{-06}$	1.790	$2.25x10^{-07}$	$8.64x10^{-06}$	$3.15x10^{-05}$	0.622	$4.96x10^{-06}$	1.82	$2.28x10^{-07}$	$8.79x10^{-06}$	$3.22x10^{-05}$	0.638
Clean stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (C)							Improved stove for *Injera* + electricity fuel for *Wot* + living room + outdoor at roadside (D)					
Fe						$7.93x10^{-04}$						$5.83x10^{-04}$

Cu		$1.76x10^{-04}$		$1.99x10^{-07}$		0.005		$1.71x10^{-04}$		$1.94x10^{-07}$		0.005
Mn		1.00		$1.42x10^{-06}$		0.009		1.01		$1.43x10^{-06}$		0.010
B						0.006						0.006
Zn		$1.9\ x10^{-04}$		$1.62x10^{-06}$		0.005		$1.41x10^{-04}$		$1.21x10^{-06}$		0.004
Pb	$9.73x10^{-08}$	0.004	$9.66x10^{-09}$	$3.74x10^{-07}$	$8.32x10^{-06}$	0.099	$9.53x10^{-08}$	0.004	$9.46x10^{-09}$	$3.66x10^{-07}$	$8.15x10^{-06}$	0.097
Cr	$2.47x10^{-06}$	0.022	$1.17x10^{-07}$	$6.33x10^{-07}$	$2.52x10^{-06}$	0.020	$2.31x10^{-06}$	0.021	$1.09x10^{-07}$	$5.92x10^{-07}$	$2.35x10^{-06}$	0.018
Cd	$6.79x10^{-07}$	0.409	$2.78x10^{-08}$	$4.63x10^{-07}$	$5.90x10^{-06}$	0.108	$5.86x10^{-07}$	0.353	$2.36x10^{-08}$	$4.00x10^{-07}$	$5.09x10^{-06}$	0.093
As	$2.03x10^{-06}$	0.340	$6.01x10^{-08}$	$4.34x10^{-07}$	$1.73x10^{-05}$	0.448	$1.74x10^{-06}$	0.292	$5.16x10^{-08}$	$3.72x10^{-07}$	$1.48x10^{-05}$	0.384
Ni	$1.39x10^{-07}$	0.126	$3.46x10^{-08}$	$4.46x10^{-06}$	$1.19x10^{-06}$	0.003	$1.24x10^{-07}$	0.112	$3.07x10^{-08}$	$3.96x10^{-06}$	$1.06x10^{-06}$	0.003
Sum (HI)	$5.41x10^{-06}$	1.90	$2.47x10^{-07}$	$9.60x10^{-06}$	$3.52x10^{-05}$	0.703	$4.85x10^{-06}$	1.79	$2.25x10^{-07}$	$8.53x10^{-06}$	$3.15x10^{-05}$	0.619
Improved stove for *Injera* + kerosene fuel for *Wot* + living room + outdoor at roadside (E)							Improved stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (F)					
Fe						$5.77x10^{-04}$						$5.82x10^{-04}$
Cu		$1.77x10^{-04}$		$2.01x10^{-07}$		0.005		$1.77x10^{-04}$		$2.01x10^{-07}$		0.005
Mn		1.02		$1.45x10^{-06}$		0.010		1.00		$1.42x10^{-06}$		0.009
B						0.006						0.005
Zn		$1.49x10^{-04}$		$1.27x10^{-06}$		0.004		$1.64x10^{-04}$		$1.40x10^{-06}$		0.004
Pb	$9.54x10^{-08}$	$3.67x10^{-04}$	$9.47x10^{-09}$	$3.66x10^{-07}$	$8.16x10^{-06}$	0.097	$9.77x10^{-08}$	0.004	$9.70x10^{-09}$	$3.75x10^{-07}$	$8.36x10^{-06}$	0.099
Cr	$2.31x10^{-06}$	0.021	$1.09x10^{-07}$	$5.92x10^{-07}$	$2.36x10^{-06}$	0.018	$2.46x10^{-06}$	0.022	$1.16x10^{-07}$	$6.29x10^{-07}$	$2.50x10^{-06}$	0.019
Cd	$5.79x10^{-07}$	0.349	$2.36x10^{-08}$	$3.96x10^{-07}$	$5.03x10^{-06}$	0.092	$6.64x10^{-07}$	0.400	$2.68x10^{-08}$	$4.53x10^{-07}$	$5.77x10^{-06}$	0.105
As	$1.80x10^{-06}$	0.302	$5.34x10^{-08}$	$3.86x10^{-07}$	$1.54x10^{-05}$	0.398	$2.02x10^{-06}$	0.339	$6.00x10^{-08}$	$4.33x10^{-07}$	$1.72x10^{-05}$	0.445
Ni	$1.24x10^{-07}$	0.112	$3.08x10^{-08}$	$3.97x10^{-06}$	$1.06x10^{-06}$	0.003	$1.42x10^{-07}$	0.128	$3.53x10^{-08}$	$4.55x10^{-06}$	$1.21x10^{-06}$	0.003
Sum (HI)	$4.91x10^{-06}$	1.81	$2.26x10^{-07}$	$8.63x10^{-06}$	$3.19x10^{-05}$	0.632	$5.38x10^{-06}$	1.90	$2.48x10^{-07}$	$9.47x10^{-06}$	$3.51x10^{-05}$	0.698
Traditional stove for *Injera* +electricity fuel for *Wot* + living room + outdoor at roadside (G)							Traditional stove for *Injera* + Kerosene fuel for *Wot* + living room + outdoor at roadside (H)					
Fe						$5.76x10^{-04}$						$5.71x10^{-04}$
Cu		$1.71x10^{-04}$		$1.94x10^{-07}$		0.005		$1.77x10^{-04}$		$2.01x10^{-07}$		0.005
Mn		1.01		$1.44x10^{-06}$		0.010		1.03		$1.45x10^{-06}$		0.010
B						0.004						0.004
Zn		$1.37x10^{-04}$		$1.17x10^{-06}$		0.004		$1.44x10^{-04}$		$1.23x10^{-06}$		0.004
Pb	$9.60x10^{-08}$	0.004	$9.52x10^{-09}$	$3.69x10^{-07}$	$8.21x10^{-06}$	0.098	$9.60x10^{-08}$	0.004	$9.53x10^{-09}$	$3.69x10^{-07}$	$8.21x10^{-06}$	0.098
Cr	$2.31x10^{-06}$	0.021	$1.09x10^{-07}$	$5.92x10^{-07}$	$2.35x10^{-06}$	0.018	$2.31x10^{-06}$	0.021	$1.09x10^{-07}$	$5.92x10^{-07}$	$2.36x10^{-06}$	0.018

Cd	$5.96x10^{-07}$	0.359	$2.40x10^{-08}$	$4.07x10^{-07}$	$5.18x10^{-06}$	0.094	$5.90x10^{-07}$	0.354	$2.38x10^{-08}$	$4.03x10^{-07}$	$5.12x10^{-06}$	0.093
As	$1.79x10^{-06}$	0.301	$5.32x10^{-08}$	$3.84x10^{-07}$	$1.52x10^{-05}$	0.396	$1.86x10^{-06}$	0.312	$5.51x10^{-08}$	$3.98x10^{-07}$	$1.58x10^{-05}$	0.410
Ni	$1.22x10^{-07}$	0.110	$3.029x10^{-08}$	$3.91x10^{-06}$	$1.04x10^{-06}$	0.003	$1.22x10^{-07}$	0.110	$3.04x10^{-08}$	$3.92x10^{-06}$	$1.05x10^{-06}$	0.003
Sum (HI)	$4.92x10^{-06}$	1.810	$2.26x10^{-07}$	$8.46x10^{-06}$	$3.21x10^{-05}$	0.632	$4.98x10^{-06}$	1.83	$2.28x10^{-07}$	$8.56x10^{-06}$	$3.26x10^{-05}$	0.645
Traditional stove for *Injera* + charcoal fuel for *Wot* + living room + outdoor at roadside (I)												
Fe						$4.83x10^{-04}$						
Cu		$2.40x10^{-04}$		$2.72x10^{-07}$		0.006						
Mn		1.00		$1.42x10^{-06}$		0.009						
B						0.003						
Zn		$1.57x10^{-04}$		$1.34x10^{-06}$		0.004						
Pb	$1.11x10^{-07}$	0.004	$1.10x10^{-08}$	$4.26x10^{-07}$	$9.49x10^{-06}$	0.113						
Cr	$2.49x10^{-06}$	0.022	$1.17x10^{-07}$	$6.36x10^{-07}$	$2.53x10^{-06}$	0.020						
Cd	$6.90x10^{-07}$	0.415	$2.78x10^{-08}$	$4.71x10^{-07}$	$5.99x10^{-06}$	0.109						
As	$2.09x10^{-06}$	0.351	$6.20x10^{-08}$	$4.48x10^{-07}$	$1.78x10^{-05}$	0.462						
Ni	$1.40x10^{-07}$	0.126	$3.46x10^{-08}$	$4.47x10^{-06}$	$1.20x10^{-06}$	0.003						
Sum (HI)	$5.52x10^{-06}$	1.920	$2.53x10^{-07}$	$9.49x10^{-06}$	$3.70x10^{-05}$	0.730						

Since cooking *Wot*, sitting in the living room and commuting to work are the daily practice, there is need to assess the health risk due to spending in these combined MEs. Hence the combined MEs are symbolized as: AA (a person cooking *Wot* using an electric stove, sitting in the living room for 123 min and spent 4 h per day at the roadside) BB (if a person cook *Wot* using kerosene fuel, sitting in the living room for 123 min and spent 4 h per day at the roadside) and CC (a person cooking *Wot* using charcoal fuel, sitting in the living room for 123 min and spent 4 h per day at the roadside). Accordingly, the exposure frequency (days $year^{-1}$) for a person spend in AA, BB and CC MEs are 135, 142 and 138, respectively. The LCR, HQ and HI for both adults and children were calculated using similar equation used in A, B, C, D, E, F, G, H and I MEs, and the results are given in Table 18 and 49, respectively.

As it is seen in Table 48 and 49, ingestion exposure is a predominant LCR exposure pathway in AA, BB and CC MEs, followed by inhalation and dermal contact exposure pathways for both adults and children. The total LCR values calculated from individual metal LCR values were found within the tolerable range for both children and adults. On the other hand, non-carcinogenic risk in each of the MEs were also investigated using HQ and HI values. Hence, the HQ values of all elements for any of the three exposure pathway were below one, except Mn which is greater than one for children through inhalation exposure pathway at CC ME. Thus, Mn metal is the only metal that a likely cause for children at CC ME. However, the cumulative health impact of the determined elements was estimated by HI values. All HI values for both children and adults were below one in three exposure ways at AA, BB and CC MEs, except in inhalation exposure for children were greater than one for children.

Generally, it can conclude children who are in ME CC might have health problems due to exposure to PM_{10}.

Table 48. Carcinogenic and non-carcinogenic risks of each element for adults via inhalation, ingestion, and dermal exposure who spent at four selected MEs for Adults

AA (a person cook *Wot* using electricity fuel, sitting at living room + spent 4 h per day at roadside)							BB(a person cook *Wot* using kerosene fuel, sitting at living room + spent 4 h per day at roadside)					
Types of elements	Inhalation exposure		Dermal contact exposure		Ingestion exposure		Inhalation exposure		Dermal contact exposure		Ingestion exposure	
	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Fe						$4.48x10^{-05}$						$4.38x10^{-05}$
Cu		$8.38x10^{-05}$		$2.36x10^{-07}$		$4.19x10^{-04}$		$8.58x10^{-05}$		$2.41x10^{-07}$		$4.29x10^{-04}$
Mn		0.494		$1.74x10^{-06}$		$8.81\ x10^{-04}$		0.494		$1.74x10^{-06}$		$8.82x10^{-04}$
B						$3.33\ x10^{-04}$						$3.08x10^{-04}$
Zn		$6.38x10^{-05}$		$1.35x10^{-06}$		$3.20\ x10^{-04}$		$6.65x10^{-05}$		$1.41x10^{-06}$		$3.33x10^{-04}$
Pb	$3.81x10^{-07}$	0.002	$9.38x10^{-08}$	$4.36x10^{-07}$	$6.19x10^{-06}$	0.009	$3.77x10^{-07}$	0.002	$9.29x10^{-08}$	$4.31x10^{-07}$	$6.13x10^{-06}$	0.009
Cr	$7.95x10^{-06}$	0.009	$9.32x10^{-07}$	$6.06x10^{-07}$	$1.54x10^{-06}$	0.001	$7.86x10^{-06}$	0.009	$9.23x10^{-07}$	$6.00x10^{-07}$	$1.52x10^{-06}$	0.001
Cd	$2.27x10^{-06}$	0.164	$2.28x10^{-07}$	$4.62x10^{-07}$	$3.75x10^{-06}$	0.008	$2.22x10^{-06}$	0.160	$2.22x10^{-07}$	$4.52x10^{-07}$	$3.67x10^{-06}$	0.008
As	$7.00x10^{-06}$	0.141	$5.15x10^{-07}$	$4.47x10^{-07}$	$1.13x10^{-05}$	0.035	$7.18x10^{-06}$	0.145	$5.29x10^{-07}$	$4.58x10^{-07}$	$1.16x10^{-05}$	0.036
Ni	$4.77x10^{-07}$	0.052	$2.93x10^{-07}$	$4.55x10^{-06}$	$7.75x10^{-07}$	$2.58\ x10^{-04}$	$4.73x10^{-07}$	0.051	$2.91x10^{-07}$	$4.51x10^{-06}$	$7.69x10^{-07}$	$2.56x10^{-04}$
Sum (HI)	$1.81x10^{-05}$	0.861	$2.06x10^{-06}$	$9.82x10^{-06}$	$2.36x10^{-05}$	0.056	$1.81x10^{-05}$	0.861	$2.06x10^{-06}$	$9.84x10^{-06}$	$2.38x10^{-05}$	0.057
CC (a person cooks *Wot* using charcoal fuel, sitting at living room + spent 4 h per day at roadside)												
Fe						$4.52x10^{-05}$						
Cu		$8.72x10^{-05}$		$2.46x10^{-07}$		$4.35x10^{-04}$						
Mn		0.493		$1.74x10^{-06}$		$8.81x10^{-04}$						
B						$2.93x10^{-04}$						
Zn		$7.52x10^{-05}$		$1.59x10^{-06}$		$3.77x10^{-04}$						
Pb	$3.93x10^{-07}$	0.002	$9.68x10^{-08}$	$4.49x10^{-07}$	$6.38x10^{-06}$	0.009						
Cr	$8.60x10^{-06}$	0.009	$1.02x10^{-06}$	$6.57x10^{-07}$	$1.67x10^{-06}$	0.002						
Cd	$2.61x10^{-06}$	0.188	$2.61x10^{-07}$	$5.30x10^{-07}$	$4.31x10^{-06}$	0.009						
As	$8.20x10^{-06}$	0.165	$6.04x10^{-07}$	$5.24x10^{-07}$	$1.33x10^{-05}$	0.041						
Ni	$5.56x10^{-07}$	0.060	$3.43x10^{-07}$	$5.30x10^{-06}$	$9.04x10^{-07}$	$3.01x10^{-04}$						
Sum (HI)	$2.04x10^{-05}$	0.918	$2.31x10^{-06}$	$1.10x10^{-05}$	$2.65x10^{-05}$	0.064						

Table 49. Carcinogenic and non-carcinogenic risks of each element for children via inhalation, ingestion, and dermal exposure who spent at four selected MEs for children

AA (a person cooks *Wot* using electricity fuel, sitting at living room + spent 4 h per day at roadside)							BB (a person cook *Wot* using kerosene fuel, sitting at living room + spent 4 h per day at roadside)					
	Inhalation exposure		Dermal contact exposure		Ingestion exposure		Inhalation exposure		Dermal contact exposure		Ingestion exposure	
Types of element	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ	LCR	HQ
Fe						3.63×10^{-04}						3.54×10^{-04}
Cu		1.29×10^{-04}		1.46×10^{-07}		0.003		1.32×10^{-04}		1.50×10^{-07}		0.003
Mn		0.759		1.08×10^{-06}		0.007		0.760		1.08×10^{-06}		0.007
B						0.003						0.002
Zn		9.80×10^{-05}		8.37×10^{-07}		0.003		1.02×10^{-04}		8.73×10^{-07}		0.003
Pb	7.03×10^{-08}	0.003	6.97×10^{-09}	2.69×10^{-07}	6.01×10^{-06}	0.071	7.00×10^{-08}	0.003	6.91×10^{-09}	2.67×10^{-07}	5.95×10^{-06}	0.071
Cr	1.47×10^{-06}	0.013	6.93×10^{-08}	3.75×10^{-07}	1.49×10^{-06}	0.012	1.45×10^{-06}	0.013	6.86×10^{-08}	3.71×10^{-07}	1.48×10^{-06}	0.011
Cd	4.19×10^{-07}	0.252	1.69×10^{-08}	2.86×10^{-07}	3.64×10^{-06}	0.066	4.10×10^{-07}	0.247	1.65×10^{-08}	2.80×10^{-07}	3.56×10^{-06}	0.065
As	1.29×10^{-06}	0.217	3.83×10^{-08}	2.77×10^{-07}	1.10×10^{-05}	0.285	1.32×10^{-06}	0.225	3.93×10^{-08}	2.84×10^{-07}	1.13×10^{-05}	0.293
Ni	8.80×10^{-08}	0.079	2.18×10^{-08}	2.82×10^{-06}	7.53×10^{-07}	0.002	8.74×10^{-08}	0.079	2.17×10^{-08}	2.79×10^{-06}	7.47×10^{-07}	0.002
Sum (HI)	3.34×10^{-06}	1.323	1.53×10^{-07}	6.08×10^{-06}	2.30×10^{-05}	0.453	3.34×10^{-06}	1.324	1.53×10^{-07}	6.10×10^{-06}	2.30×10^{-05}	0.458
CC (a person cook *Wot* using charcoal fuel, sitting at living room + spent 4 h per day at roadside)												
Fe						5.38×10^{-04}						
Cu		1.97×10^{-04}		2.24×10^{-07}		0.005						
Mn		1.116		1.58×10^{-06}		0.010						
B						0.003						
Zn		1.70×10^{-04}		1.45×10^{-06}		0.004						
Pb	1.07×10^{-07}	0.004	1.06×10^{-08}	4.09×10^{-07}	9.12×10^{-06}	0.109						
Cr	2.33×10^{-06}	0.021	1.10×10^{-07}	5.98×10^{-07}	2.38×10^{-06}	0.019						
Cd	7.08×10^{-07}	0.426	2.86×10^{-08}	4.83×10^{-07}	6.15×10^{-06}	0.112						
As	2.22×10^{-06}	0.374	6.61×10^{-08}	4.77×10^{-07}	1.90×10^{-05}	0.492						
Ni	1.51×10^{-07}	0.136	3.75×10^{-08}	4.83×10^{-06}	1.29×10^{-06}	0.004						
Sum (HI)	5.52×10^{-06}	2.078	2.53×10^{-07}	1.01×10^{-05}	3.79×10^{-05}	0.759						

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

The present study has assessed the level of PMs and TVOCs at different microenvironments during the baking of *Injera* (using clean, improved and traditional stoves), cooking of *Wot* (using electricity, kerosene and charcoal fuels), at the living room and outdoor at the roadsides. The amounts of PMs and TVOCs pollutants measured in the baking of *Injera* during wet season were relatively higher than that measured in the dry seasons using clean, improved and traditional stoves. Furthermore, the levels of TVOCs were much higher than the levels of PMs emissions from each type of stove in both the wet and dry seasons. Generally, the level of PMs emissions found in this study using the clean stove was lower than the levels found using the traditional stoves. Thus, the *Injera* baker is subjected to lower degree of pollutants exposure by using clean stove and hence less susceptible to the health risk. This study showed hazard quotient value not greater than one in all types of pollutants and stove types used which confirmed that only the baking of *Injera* could not induce any health problems. Although the health risk assessment due to the exposure to $PM_{2.5}$, PM_{10} and TSP showed no health problems, its contribution to the total chronic intake is very high. Hence, the long-term consequence of these exposures to women, who do most of the *Injera* baking could be significant. Particularly, a person who uses the traditional stove for baking for a long period of time might take a higher amount particulate matter and TVOCs. Therefore, there is need to give awareness about the health benefits of using the clean-stove instead of the traditional and improved-stove.

On the other hand, cooking *Wot* is the most widely, and almost the daily practice for most Ethiopian. It can increase the individual long-term exposure to PMs and TVOCs. Mainly, a person who uses charcoal and kerosene fuels for an extended period could face various health-related problems due to long-term exposure to the higher amount of particulate matter. Using electricity fuel is much better in the reduction of exposure so that one can reduce the exposure by using electricity fuel as an alternative manner with kerosene and charcoal fuels. Although studies reported kerosene is more clean fuel than charcoal, the elemental non-carcinogenic health risk assessment showed the user of kerosene were more likely affected by non-cancer health problems than charcoal users.

Concentration of PMs and TVOCs has been investigated in 10 different sub cities at the roadside of Addis Ababa. The pollution level of PMs and TVOCs in Addis Ketema, Kolfe Keranio and Akaki Kality sub cites were relatively higher than from other sub cities that might need intervention action in order to prevent further increments. Generally, the level of PMs and TVOCs emissions found in this study during afternoon was lower than the levels found in the morning. Thus, the commuter is subjected to lower degree of pollutants exposure during afternoon and hence less susceptible to the health risk. Furthermore, the health risk assessment has been evaluated using the overall GOM regardless of sampling sites. The hazard quotient value for TSP pollutant was not greater than one, which confirmed that only TSP exposure could not induce any health problems. However, the hazard quotients for PM_{10} and $PM_{2.5}$ were greater than one, which revealed that PM_{10} and $PM_{2.5}$ will induce the health problems. Therefore, there is need to give awareness to the public and the stakeholders about the health impacts due to exposure to PM_{10} and $PM_{2.5}$ during commuting time so that they can look for the alternative solutions for the reduction of the roadside air pollution.

5.2 Recommendations

Since the level of PMs at the roadside found was high which might be predominantly comes from transport-related facilities, there is a need to installing selective catalytic reduction trap combined with continuously regenerating particulate trap that can reduce the level of particulate matter in the air. In addition, since the level of exposure to ambient air pollutants depends on the mode of commuting (car, buses, tram, bicycling, walking), further work should be done to suggest the better mode of commuting.

Improving both indoor and outdoor air quality can be carried out through changes in fuels use (such as reduction of using biomass fuel), using improved combustion technology, and improving public transportation, formulating of regulations regarding the age of cars. For instance, the government can give the level for the cars depending on their emission level and ban them from the center of the city, and the government can promote the people to buy less pollutant emission cars by increasing the taxation of the old car. In addition, gasoline powered cars emitted less amounts of pollutants as compared to diesel powered cars. So that the government should promote the people to buy such types of cars.

Furthermore, although this study has provided the information related to the exposure level due to the PMs and TVOCs during the baking of *Injera* and cooking *Wot* and estimated the health impacts of the baker or cooker due to exposure to $PM_{2.5}$, PM_{10}, TSP and trace elements bound in PM_{10} during their lifetime, it has some shortcomings. First, although measuring the pollutant levels along with examining of different health issue is more realistic to estimate the health impacts of the exposed person, this work were estimating the health impacts based on the concentration measurement of $PM_{2.5}$, PM_{10}, TSP and trace elements bound in PM_{10} only. Second, the amount

and the type of chemical substance present in the smoke of biomass fuel (charcoal, wood, leaves, sawdust, tree branch) depends on the moisture content of the fuel, the species of plant that the fuel is originated and amount of fuel used. However, this study did not go in these aspects, these shortcomings will be addressed in future work. Third, biomass smoke can be emit different pollutants other than PMs and TVOCs, further work should be done on the health aspects of chronic exposure to the Ethiopian traditional cooking practices along with the measurement of other pollutants levels. Fourth, there are other traditional cooking activities other than baking *Injera* and cooking *Wot* (such as traditional coffee ceremony, distillation and making processes of traditional alcoholic beverages including *Tela, Areki Keribo* and others) which might have high indoor air pollution contribution, so further work should be done on the measurement different pollutants along with different health examination during such cooking activities.

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Appendix I

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

Site code	Fuel type		Ventilation type	Kitchen position	Family size	Volume 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 found in living room; NLR = kitchen found in separate from living room.

Appendix II

Some characteristic of kitchens for selected households.

Sites code	Fuel type	Ventilation type/area of ventilation (m^2)/position	Kitchen position	Family size	Type of sauce/*Wot*		Volume of kitchen (m^3)
					Dry	Wet	
ar1A	Electricity	Door, 1.62, open	LR	5	Shiro	Shiro	34.8
ar1B	Electricity	Door, 1.43, open	NLR	5	Shiro	Shiro	11.1
ar1C	Electricity	Door, 1.44, open	LR	2	Shiro	Shiro	8.28
ar1D	Electricity	Door, 1.52, open	LR	5	Shiro	Shiro	20.0
ar1E	Electricity	Door, 1.62, open	NLR	4	Shiro	Misir	16.8
ar2A	Charcoal	Door, 1.2, open	LR	3	Potato	Potato	16.0
ar2B	Charcoal	Door,1.28, open	NLR	5	Shiro	Shiro	11.5
ar2C	Charcoal	Door, 1.71, open	NLR	5	Misir	Misir	4.36
ar2D	Charcoal	Door,1.71, open	LR	4	Shiro	Shiro	14.04
ar2E	Charcoal	Door, 1.48, open	NLR	4	Shiro	Shiro	9.01
ar3A	Kerosene	Door, 1.4, open	NLR	2	Shiro	Shiro	8.28
ar3B	Kerosene	Door, 1.57, open	LR	1	Shiro	Shiro	19.0
ar3C	Kerosene	Door, 1.67, open	LR	1	Shiro	Shiro	21.5
ar3D	Kerosene	Door, 1.67, open	LR	1	Misir	Misir	18.8
ar3E	Kerosene	Door, 1.2, open	NLR	3	Potato	Potato	14.5
gu1A	Electricity	Door, 1.6, partially open	LR	5	Shiro	Shiro	18.7
gu1B	Electricity	Door, 1.81, closed	LR	2	Shiro	Shiro	17.5

gu1C	Electricity	Door, 1.85, open	NLR	6	Shiro	Shiro	16.6
gu1D	Electricity	Door, 1.66, open	LR	1	Shiro	Shiro	8.34
gu1E	Electricity	Door, 1.2, open	LR	3	Shiro	Misir	16.0
gu2A	Charcoal	Door, 1.81, open	LR	6	Shiro	Misir	13.7
gu2B	Charcoal	Door, 1.86, open	LR	4	Shiro	Potato	22.9
gu2C	Charcoal	Door, 1.00, open	NLR	4	Shiro	Shiro	15.8
Gu2D	Charcoal	Door, 1.95, open	NLR	4	Misir	Shiro	12.0
gu2E	Charcoal	Door, 1.57, open	LR	3	Misir	Shiro	16.4
gu3A	Kerosene	Door, 1.71, open	LR	3	Misir	Shiro	17.4
gu3B	Kerosene	Door, 1.76, open	LR	4	Shiro	Misir	21.0
gu3C	Kerosene	Door, 1.31, partially open	LR	5	Potato	Shiro	14.8
gu3D	Kerosene	Door, 1.71, open	LR	2	Shiro	Shiro	9.61
gu3E	Kerosene	Door, 1.57, partially open and window, 0.26, open	LR	5	Shiro	Shiro	12.4
ak1A	Electricity	Door, 1.2, open	LR	3	Shiro	Shiro	16.0
ak1B	Electricity	Door, 1.94, open	LR	2	Shiro	Shiro	9.26
ak1C	Electricity	Door, 1.76, open	LR	5	Shiro	Misir	44.8
ak1D	Electricity	Door, 1.95, open	LR	4	Potato	Potato	12.5
ak1E	Electricity	Door, 1.67, partially open and window, 0.3, open	LR	2	Shiro	Misir	5.32
ak2A	Charcoal	Door, 1.76, open	LR	2	Shiro	Shiro	18.7
ak2B	Charcoal	Door,1.11, open	LR	6	Shiro	Shiro	5.00

ak2C	Charcoal	Door, 1.85, open	LR	3	Shiro	Shiro	21.0
ak2D	Charcoal	Door, 1.95, open	LR	5	Misir	Shiro	32.1
ak2E	Charcoal	Door, 2.4, open	NLR	4	Misir	Misir	42.0
ak3A	Kerosene	Door, 1.76, open	LR	3	Shiro	Shiro	7.98
ak3B	Kerosene	Door, 1.67, open	LR	4	Misir	Misir	15.6
ak3C	Kerosene	Door, 1.71, open	LR	6	Misir	Shiro	35.9
Ak3D	Kerosene	Door, 1.71, open	LR	4	Shiro	Shiro	46.9
ak3E	Kerosene	Door, 1.62, open	NLR	2	Shiro	Shiro	4.00

Site code: ar = Arada sub-city; gu = Gulelle sub-city; ak = Akaki Kality sub-city; 1,2 and 3 = indicates fuel types electricity, charcoal and kerosene, respectively; A, B, C, D and E represent different households in each sub-city; LR = kitchen found in living room; NLR = kitchen found in separate from living room.

Appendix III

The location of PMs and TVOCs monitoring sites at Addis Ababa.

Sampling sites	Sampling points	Geographical location of Sampling sites	Altitude (m)	Distance from the road (m)	Description of sampling sites
AA	A1	9º03′34.884″N; 38º44′14.610E	2606	3	Retail shops, street food sellers and various other businesses, relatively low vehicle and pedestrian traffic, bus stop and near a roadside, pickup point for passengers, serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of northern parts
	A2	9º03′40.380″N; 38º45′42.982″E	2581	3.5	Retail shops, street food sellers and various other businesses, relatively low vehicle and pedestrian traffic, minibuses stop and near a roadside, pickup point for passengers,
	A3	9º03′20.862″N; 38º46′26.274″E	2524	4	Retail shops, shoeshine boys and some restaurants, and relatively low vehicle and pedestrian traffic, minibuses stop and near a roadside, pickup point for passengers
BB	B1	8º58′59.172″N; 38º41′49.001″E	2528	4	Street fast food, tea and coffee sellers, and minibuses stop near a roadside and pickup point for passengers and has high vehicle and pedestrian traffic hours
	B2	9º03′55.916″N; 38º41′37.272″E	2657	3.5	Retail shops, street vendors and various other businesses, and has high vehicle, pedestrian traffic major, minibus stop and near a congested, pickup point for passengers and rural bus station and one soap factory, it is also serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of western parts
	B3	9º02′00.000″N; 38º42′53.544″E	2400	3.5	Commercial cooking smoke exhaust from roadside buildings, Café and restaurants, street vendors and various other businesses, heavy pedestrian and vehicle

					traffic at the commuting times, major minibus and bus stops and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of northwestern parts
CC	C1	8°53′43.458″N; 38°46′21.132″E	2146	6	Retail shops, street vendors and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus stop and near a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of southern parts
	C2	8°54′40.446″N; 38°45′49.674″E	2168	3	Few café and restaurants, many industries, some retail shops and various other businesses, and has high vehicle and pedestrian traffic at most of the days, the road at the sampling point is paved, and the road served for all types of vehicle (bot heavy trucks and automobiles) serves as an important commuter route into and out of Addis Ababa and southern parts of Ethiopia
	C3	8°55′56.724″N; 38°46′00.000″E	2259	3	Street vendors, very few cafes and various other businesses, and has the high vehicle and pedestrian traffic at most of the days, most of the road at the sampling point is paved, and presence of highway approximately 200 m far from the sampling point which allows heavy trucks
DD	D1	9°00′39.318″N; 38°43′16.692″E	2407	5	Street vendors, supermarkets, and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus stop and pickup point for passengers, relatively low traffic congestions
	D2	9°00′40.002″N; 38°44′55.486″E	2373	3.7	Bookshops, government institutions, café and restaurants, street vendors and various other businesses, and heavy pedestrian and vehicle traffic at the commuting time
	D3	9°01′13.800″N; 38°44′02.124″E	2408	4	Retail shops, café and restaurants, street vendors and various other businesses, and has relatively low vehicle

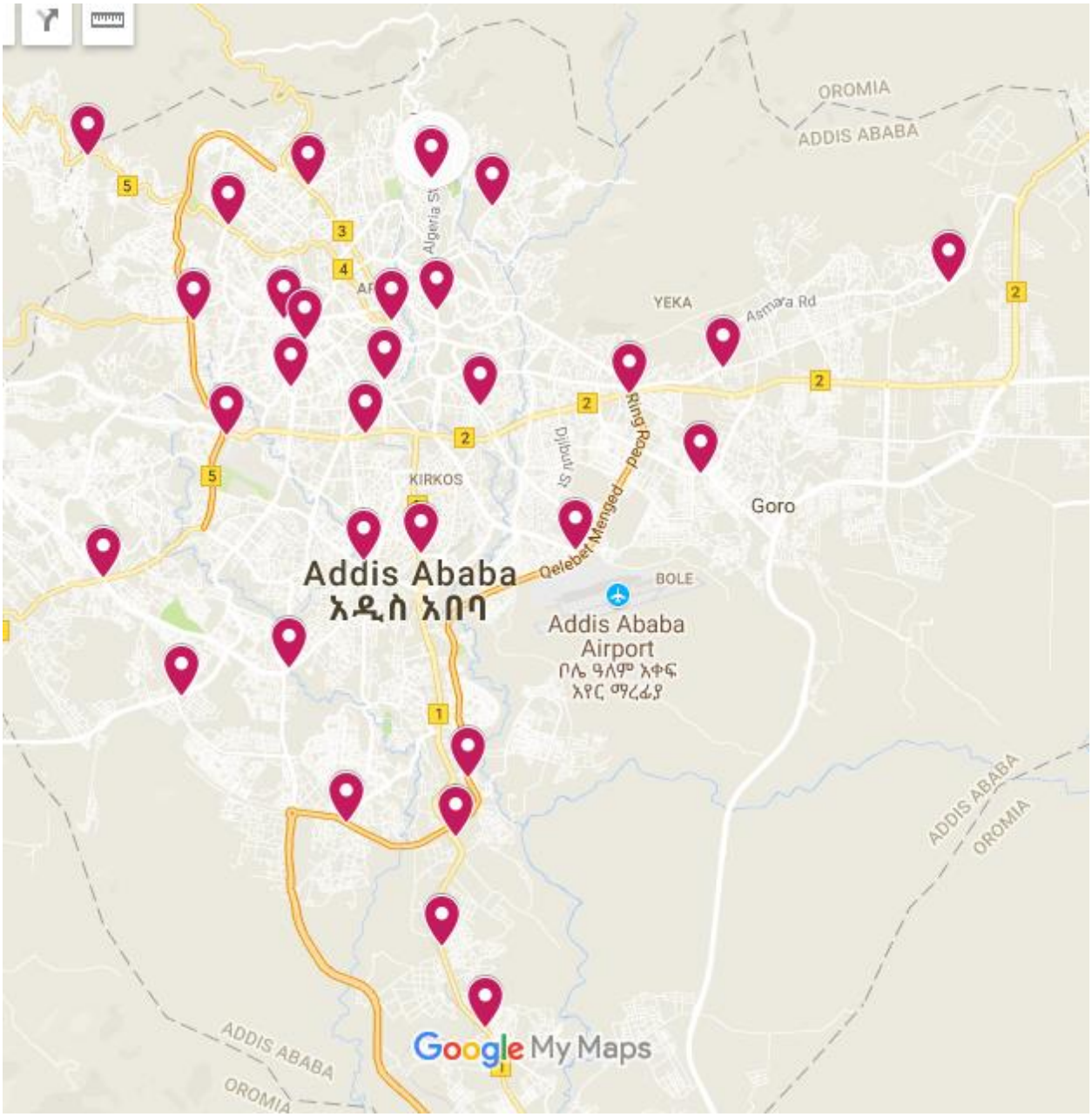
					and pedestrian traffic, the availability of heavy truck is almost negligible during sampling
EE	E1	9º00′12.198″N; 38º48′53.652″E	2344	3.3	Retail shops, café and restaurants, street vendors and various other businesses, and has the high vehicle and pedestrian traffic, the availability of heavy truck is during sampling, congested pickup point for passengers
	E2	8º59′18.402″N; 38º47′24.930″E	2357	4	Ethiopia international airport, hotels, supermarkets, street vendors and various other businesses, and has the high vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling, compacted buildings building
	E3	8º56′38.610″N; 38º46′09.102″E	2252	4	Retail shops, café and restaurants, and various other businesses, and has highways which allows heavy truck and pedestrian traffic at commuter's time, during sampling, there was highly Wendy
FF	F1	8º56′07.350″N; 38º44′41.568″E	2365	2.5	Retail shops, café and restaurants, and various other businesses, and has the high vehicle and pedestrian traffic at most of the days, the roadside is paved, and presence of highway which allows heavy trucks
	F2	8º57′36.228″N; 38º42′44.454″E	2246	5	Street vendors, heavy pedestrian and vehicle traffic most of the day, major minibus and bus stop, nearly a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of southwest parts
	F3	8º57′55.386″N; 38º44′01.806″E	2234	3.2	Retail shops, café and restaurant, and various other businesses, relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers, the presence of highway approximately 250 m far from the sampling point which allows heavy trucks
GG	G1	9º01′08.844″N; 38º48′03.126″E	2413	6	Near a major minibus stop, nearly a congested pickup point for passengers, many street vendors, street food

					sellers, many retail shops and other business center availability of heavy tuck ways, has the high vehicle and pedestrian traffic at most of the days
	G2	9º02′26.436″N; 38º51′50.940″E	2587	2.5	Retail shops, street vendors and various other businesses, low pedestrian and vehicle traffic most of the day, major minibus stop and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of northeast parts
	G3	9º01′27.318″N; 38º49′10.434″E	2453	3.4	Retail shops, supermarkets, and various other businesses, and has the high vehicle and pedestrian traffic
HH	H1	9º03′06.666″N; 38º43′18.120″E	2536	5	Retail shops, schools, hospitals, street vendors and various other businesses, and has relatively low vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling
	H2	9º01′46.212″N; 38º44′12.930″E	2445	4	In general it the largest and compacted market center in the country which many peoples were available (general and retail shops, supermarkets, street vendors and various other businesses), and has a very high vehicle and worker traffic at most of the days, many buildings under construction, some of the road is paved
	H3	9º02′01.458″N; 38º43′58.004″E	2506	5	Retail shops, street vendors and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus and bus stops and near a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban and rural destinations of northern parts
II	I1	8º59′10.830″N; 38º44′53.830″E	2223	2.7	Many general and retail shops, café and restaurants, street vendors and various other businesses, and has the high vehicle and pedestrian traffic, the heavy truck has seen during sampling, street sweepers

	I2	8°59′16.408″N; 38°45′34.680″E	2298	4.5	Retail shops, street food sellers, café and restaurant, and various other businesses, relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers
	I3	9°01′00.000″N; 38°46′16.590″E	2363	3.2	Retail shops, Hotels, street vendors and various other businesses, and has relatively low vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling
JJ	J1	9°01′18.612″N; 38°45′09.150″E	2313	2.5	Retail shops, supermarkets, some governmental origination where many peoples are visiting per day (Black lion hospital, immigration office and others) and various other businesses, and relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers,
	J2	9°02′07.518″N; 38°45′46.549″E	2458	7.6	Café and restaurants, street vendors, supermarkets, both primary and secondary schools, Addis Ababa University, particularly college of natural science, and various other businesses, and has high vehicle and pedestrian traffic in most of the days (especially at the commuter time)
	J3	9°01′59.382″N; 38°45′13.794″E	2464	4	General and retail shops, Hotels, street vendors and various other businesses, and has relatively medium vehicle traffics, high pedestrian traffic, the availability of heavy truck is almost negligible during sampling (except public buses)

A1 = Addisu Gebiya; A2= Shiromeda, A3 = Arband- Iyesus, B1 = Ayertena, B2 = Asiko Bus Station, B3 = Lukanda 18, C1 = Kality C2 = Kality Gebrieal, C3 = Maselitegna D1 = Maselitegna D2 = Mexico D3 = Abenet, E1 = Jakrose Square, E2 = Bole Bridge, E3 = Saris Abo F1= Hana Mariam, F2 = Jemo, F3 = Jermene Square, G1 = Megenagna, G2 = Kara Kotebie, G3 = Lambert bus station H1= Medehaniyalem School around pastor, H2 = Merkato, H3 = Merkato Bus Station, I1 = Kera round, I2 = Agona, I3 = Kasachis, J1 = Black Lion, J2 = Arat Kilo, J3 = Piyassa (Minlk square); AA = Gulelle sub-city, BB = Kolfe Keranio sub-city, CC = Akaki Kality sub-city, DD = Lideta sub-city, EE = Bole sub-city, FF = Nefas Silk-Lafto sub-city, GG = Yeka sub-city, HH = Addis Ketema sub-city, II = Kerkos sub-city and JJ = Arada sub-city

Appendix IV



Sampling point location for outdoor air pollution measurement