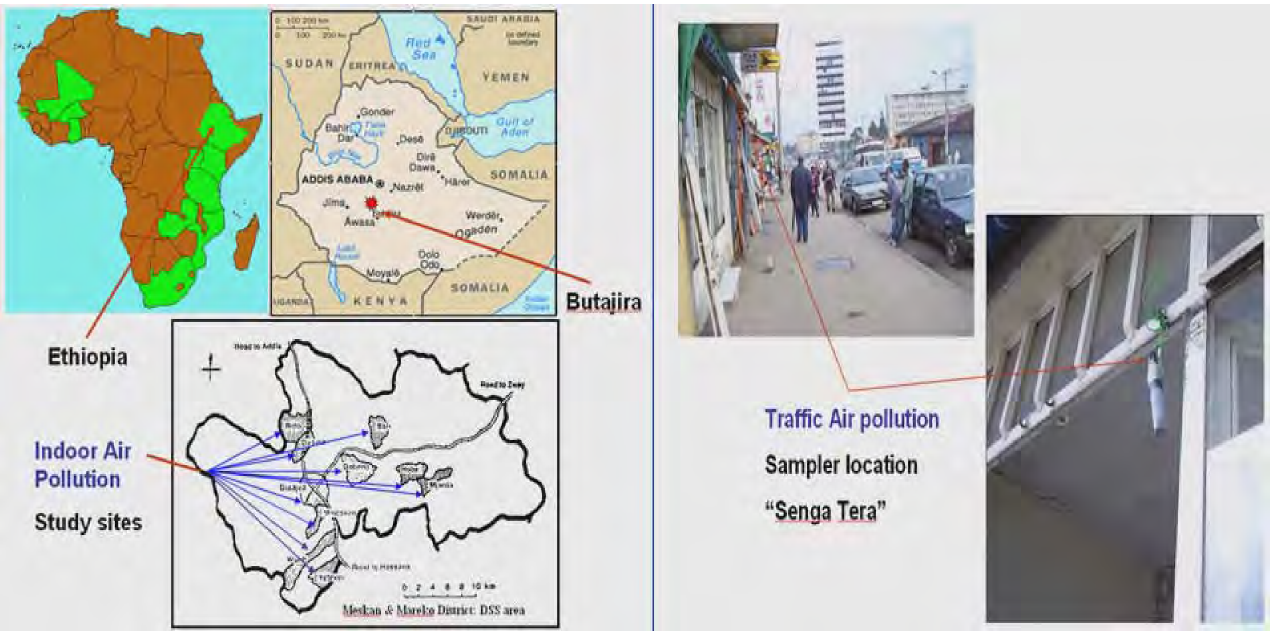
AIR POLLUTION IN ETHIOPIA:
Indoor Air Pollution in a rural Butajira and Traffic Air Pollution in Addis Ababa

Abera Kumie



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School of Public Health
Medical Faculty
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Abera Kumie

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Advisors:

Professor Yemane Berhane
and
Professor Ahmed Ali

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ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Indoor Air Pollution in a Rural Setting of Ethiopia and Traffic Air Pollution in Addis Ababa

BY: - Abera Kumie

SCHOOL OF PUBLIC HEALTH, ADDIS ABABA UNIVERSITY

APPROVED BY THE EXAMINING BOARD

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Chairman, School of Graduate Committee

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Advisor (Primary)

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Advisor (Secondary)

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Examiner

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Examiner

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Examiner

Dedication

To my wife Zewde Belay and our daughter Achame Abera

List of ORIGINAL PAPERS

This thesis is based on the following papers which will be referred to in the text by respective Roman numbers.

I. *Kumie A. Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, Brandstrom D.* **Magnitude of indoor NO_2 from biomass fuels in rural settings of Ethiopia.** Indoor Air 2009 19(1):14-21

II. K*umie A Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonen E, Worku A.* D. Brandstrom. **Sources of variation for indoor nitrogen dioxide in rural residences of Ethiopia.** (Under review Environmental Health Journal, BMC series)

III. *Kumie A, Chris Ckei, Berhane Y, Ali. Kumie A, Chris Ckeil, Berhane Y, Ali A.* **Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia** (Under review by Journal of Environmental and Public Health)

Abbreviations

AAU	Addis Ababa University
ALRI	Acute Lower Respiratory Infection
ARI	Acute Respiratory Infection
AURI	Acute Upper Respiratory Infection
BLH	Black Lion Hospital
bln	Billion
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
DHS	Demographic and Health Survey
DHSE	Demographic and Health Survey Ethiopia
DSS	Demographic Surveillance System
EPA/USA	Environmental Protection Agency of USA
ETS	Environmental Tobacco Smoke
GM	Geometric Mean
GSD	Geometric Standard Deviation
IAP	Indoor Air Pollution
LPG	Liquefied Petroleum Gas
masl	Meters above sea level
$\mu g/m^3$	Microgram per cubic meter
NOx	Nitrogen dioxides, including NO, NO_2
PAH	Polyaromatic Hydro Carbons
PASDEP	Plan for Accelerated Development to End up Poverty
Ppm	Parts per million
ppb	Parts per billion; (1ppm= 1000ppb)
PM	Particulate Matter
ppm	Parts per million
RPM	Respirable Particulate Matter
RSP	Respirable Suspended Particulates
RSPM	Respirable Suspended Particulate Matter
SD	Standard Deviation
SPH	School of Public Health
SSA	Sub-Sahara Africa
TSAP	Total Suspended Airborne Particles
TSP	Total Suspended Particulates
VOC	Volatile Organic Compound
WHO	World Health Organization

Glossary and definitions

ARI	Acute respiratory infection referring both to upper respiratory tract and lower respiratory infections
ALRI	Serious form of ARI, resulting in pneumonia or bronchopneumonia.
AURI	Infection of the upper respiratory tract involving larynx, pharynx, tonsillar glands, Eustachian tube, nasal cavities and sinuses
Ecology	Ecology in the thesis reflects the altitudinal set-up in reference to the rural study sites for indoor air pollution. Study sites with 2000 masl and higher are categorized as highland (*Dega*), and those with lower than 2000 masl are categorized as lowland (*Kolla*).
PM	Particulate matter.
PM_{10}	Particulate matter with aerodynamic diameter of < 10 microns. PM_{10} is also called inhalable particulate matter.
$PM_{2.5}$	Particulate matter with aerodynamic diameter of < 2.5 microns. They are also called fine particles or respirable particulates
RSPM	Particulate matter with aerodynamic diameter of < 7 microns.
TSAP	A generic term for all airborne particulates. It may contain soil particles, organic matter, compounds of sulfur, nitrogen, hydrocarbons, metals, etc.

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ABSTRACT

Background

About half of the global population and over 70% of countries in the Sub-Saharan Africa rely on biomass fuel as a source of household energy. Over 95% of households in Ethiopia use biomass fuel for cooking. Despite the prevailing major concerns among policy makers and professionals on air pollution, the magnitude of air pollution from domestic and traffic sources in Ethiopia is not well established.

Objectives

This thesis attempted to examine the magnitude of air pollution by measuring 24-hr concentrations of indoor nitrogen dioxide in rural Butajira and daily measurement of ambient carbon monoxide in traffic congested areas of Addis Ababa.

Materials and Methods

A longitudinal study was conducted to assess the indoor air pollution component between March 2000 and April 2002. Concentrations of NO_2 were measured cross-sectionally at about three-month interval using a modified Willems badge air samplers. Mothers of children in households were interviewed within 24 hours of air sampling about characteristics of fire use, type of fuel and cooking pattern. A Saltzman colorimetric method using a spectrometer calibrated at 540 nm was used to analyze the mass of NO_2 in field samples.

Roadside traffic air pollution was assessed using portable CO USB data loggers. CO monitor is small electronic equipment installed along 40 roadside sampling points to continuously measure and record CO concentrations at an average interval of 10 seconds for about 10 hours in the daytime. Four on-road traffic light posts were also included to explore the association with the results of roadside CO concentrations. Data were entered and analyzed using EPI INFO version 6.02 statistical software. SPSS version 15.0 was further used to run regression analysis. Data from CO logger were downloaded in Excel format. Summary statistics, graphs, charts, and tables were the main tools used to present findings. One-way ANOVA, multiple regression analysis and linear mixed model analysis were also used to sort out any non-random differences in NO_2 and factors affecting the levels of NO_2.

Results

Wood, crop residues and animal dung were the main fuels in rural households in the study area. The mean 24-hr concentration of NO_2 was 97.3 µg/m^3 (95% CI: 95.9, 98.6). The median (IQR) was 68.4 (98.7) µg/m^3. Ecology and season have shown differences in the mean concentration of NO_2. Households in the highland areas and during wet season had higher indoor NO_2 concentration. Biomass fuel type, ecology, purpose of fire use, cooking of at least one type of food in a day, and frequency of fire use were important household variables to explain the variations in the daily NO_2 concentration. While ecology was the major predictor, housing physical structures showed little influence on the variation of indoor NO_2.

In Addis Ababa, the 15-minute mean (±SD) CO concentrations were 2.03 (1.94) and 2.64 (2.53) ppm respectively observed during the wet and dry seasons of 2007 and 2008. The two means did not vary significantly. There were variations in average CO by time and location of sampling. CO tended to be high in early mornings and in the afternoon rash hours. The CO profiles between roadside and on-traffic post light were, however, not different from each other.

Conclusions and Recommendations

About 70% of NO_2 indoor measurements were more than double the currently proposed annual mean of WHO air quality guideline. Ecology and fire-fuel use household characteristics were important determinants of indoor air pollution. Although average CO concentrations were below the US-EPA and WHO ambient air quality guidelines, there is a strong indication that CO concentrations will exceed or approach these guidelines shortly.

Further studies in the description of burden of diseases attributed to indoor air pollution are highly recommended. Interventions targeting at improving the design and utilization of fuel-stove efficiency and ventilation are essential. The measurement of traffic particulate matter in high traffic areas is suggested given the high proportion of on-road diesel-engined vehicles in Addis Ababa.

Key words: magnitude, NO_2, indoor air pollution, agro-ecology, sources, biomass fuel, variation, Addis Ababa, CO, traffic air pollution, Ethiopia.

1. INTRODUCTION

More than 50% of the global population heavily relies on biomass fuel as a source of household energy (1). Exposure to indoor air pollution (IAP) from the combustion of biomass fuel is affecting the lives of 3 billion people worldwide (2-7). Furthermore, diseases of the respiratory system, mainly acute respiratory infections and chronic obstructive lung diseases are known to have a link with indoor air pollution (8-10). The fact that IAP is associated with ARI was also demonstrated in African countries (11-16). These studies consistently showed that proxies of IAP such as the use of biomass fuels and traditional unvented stoves are related with ARI. However, quantifying the exposure to IAP was highly limited in those studies.

Traffic air pollution is more specific to ambient air pollution. The major cause of air pollution in urban settings originates from vehicles. An increased level of traffic air pollution was observed in most urban settings in developing countries. The average concentrations of respirable suspended particles and particulate matters (aerodynamic size of 2.5 and 10 microns) were found to be 10-30 times greater than that set by the World Health Organization (15, 17-22). The current ambient air pollution level in urban settings of developed nations is 10-20 times less than that of developing countries (23). This gap will continue to exist unless the use of improved energy is possible in the latter.

Ethiopia is not an exception to the above air pollution reality. Over 95% of households in the country use biomass fuel (24, 25). However, the status of both indoor air pollution and ambient air pollution has not been studied sufficiently. This thesis thus attempted to make an in-depth investigation into the status of indoor air pollution in a rural setting and traffic air pollution in an urban setting of Ethiopia.

2. LITERATURE REVIEW

2.1 Indoor Air Pollution

Indoor air pollution caused by the use of solid fuel for cooking and heating in households is a major problem in developing countries, particularly in the Sub-Saharan Africa, Asia and South America. In contrast, IAP is not as such a major problem in the developed countries as they currently use cleaner energy sources.

The magnitude of indoor air pollution is commonly assessed indirectly by measuring proximate factors such as fuel and stove type or directly by measuring the level of indoor air pollutants. In developing countries, where the possibility of measuring the concentration of indoor air pollutant is very limited, the use of proxy factors is very useful (26). Generally, any fuel with complete combustion generates heat (energy), CO_2 and water vapour. Unfortunately, due to stove-fuel use inefficiency, complete combustion is not at all possible under any circumstance where fuel is commonly used. The principal products of combustion include carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter and volatile organics. All of these can be categorized into three types: gaseous, particulate matter, and volatile substances (27).

The use of particulate matter in assessing exposure to air pollution is a common practice. PM_{10} is an inhalable particle with aerodynamic diameter of 10 microns and less, which has the capability of reaching the bronchioles. $PM_{2.5}$ is a fine respirable particle size with aerodynamic of 2.5 microns and less, with the capability of further entering the alveoli tissue. Further, there is a third category which is PM less than 0.1 microns, known as ultra fine particles. It behaves like an air mass reaching and leaving the lung. PM_{10} and $PM_{2.5}$ together make the total suspended particles. PM is generally unburned hydrocarbons containing many types of “air toxic” chemicals and unburned carbon which include benzene, polyaromatic hydrocarbons (PAHs), formaldehyde, Acetaldehyde, Acrolein, and benzoapyrene. Secondary pollutants such as sulfates and nitrates are also part of PM. Nickel, chromium, and manganese can also be found because of the emissions from metal processing factories and incineration sources (28-30).

The intensity and amount of air pollutants from the combustion process mainly depend on the conditions of fuel use. The amount of emission is directly proportional to the type and quality of fuel. Because crude solid fuels produce relatively more pollutants than that of cleaner fuels (Figures 1 and 2), the adverse health effects are more serious in households using these fuels in poorly ventilated cooking places in developing countries. Wood stoves are known to release 50 times more pollution than gas stoves (5). The intensity of air pollution is much dependent on the energy ladder. The cleaner the fuel, the less is the emission of air pollutants. The use of clean fuel is often associated with prosperity and development (Figure 3).

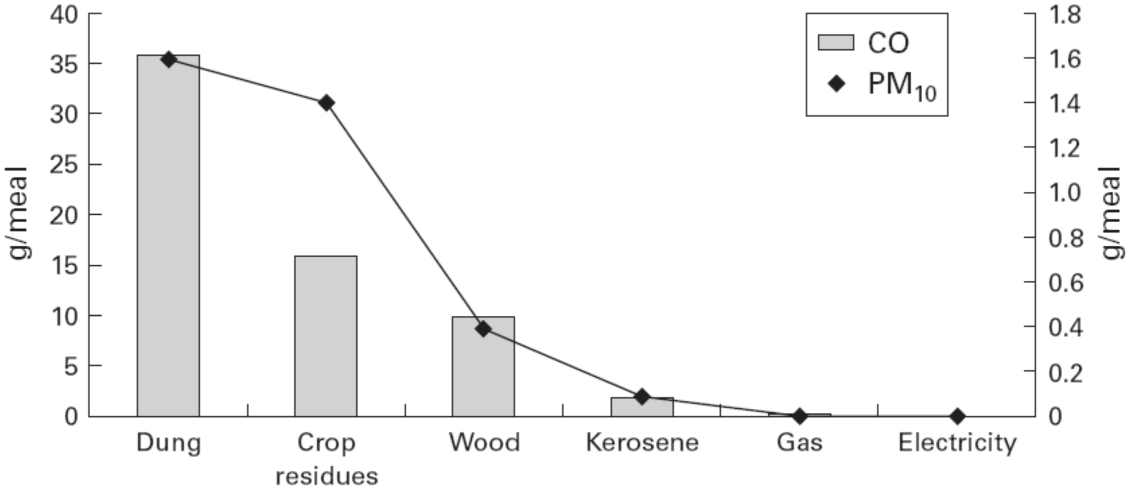


Figure 1: Emissions along the household fuel ladder

Source*: Smith KR, Samet JM, Romieu IBruce N. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 2000b; 55:518–532* (9).

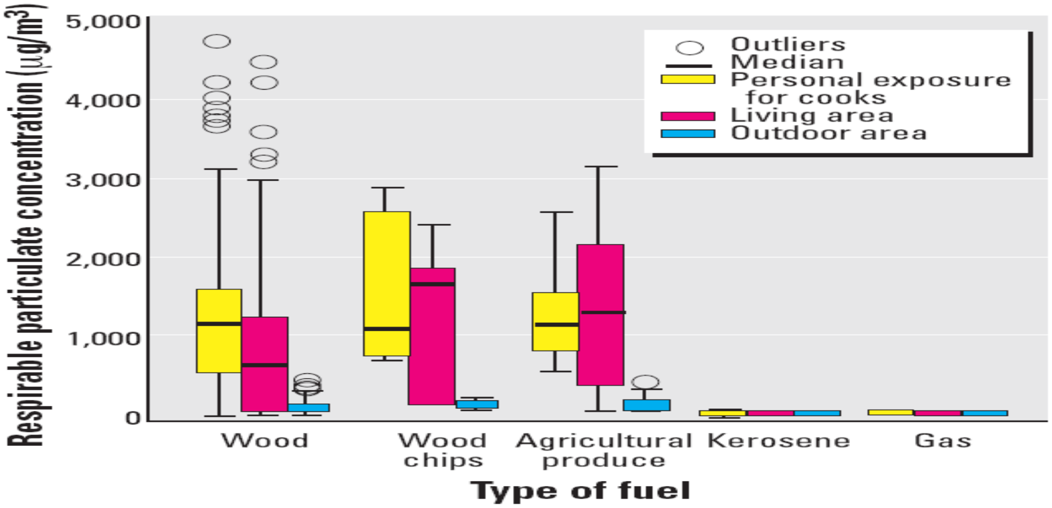


Figure 2: Distribution of personal exposure of respirable particulate matter during cooking by type of fuel and exposure profiles

Source: Balakrishnan K, Parikh mJ, Sankar S, Padmavathi R, Srividya K, Venugopal V, Prasad S, Pandey VL. *Daily Average Exposures to Respirable Particulate Matter from Combustion of Biomass Fuels in Rural Households of Southern India. Environ Health Perspect* 2002; 110:1069–10 (17).

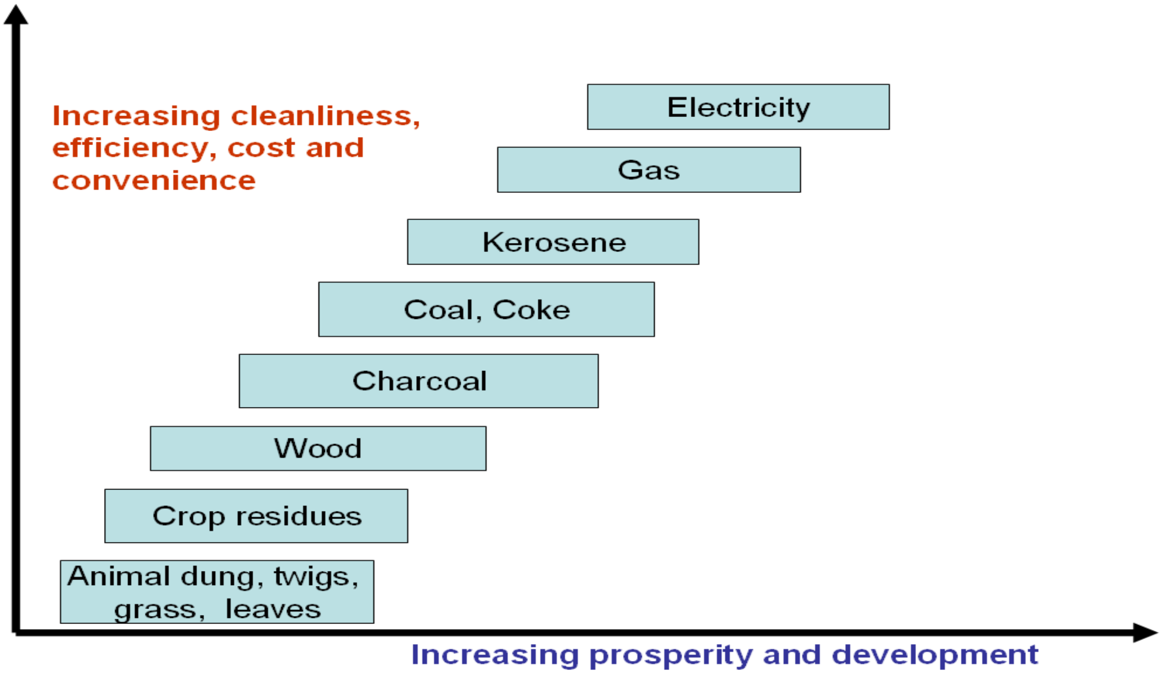


Figure 3: Energy ladder

Source: http://www.unep.org/geo/yearbook/yb2006/056.asp (31)

The level of air pollution in developing countries

The level of indoor air pollution through the measurement of gases such as CO and NO_2 in developing countries is a very rare event. There is limited access to literature on NO_2 measurements of recent times in developed countries as well. In a Mongolian study conducted in the city of Ulaanbaatar, the 24-hr mean (±SD) level of CO from the use of wood and coal using improved stoves was 9.5 (6.2) ppm (range 8.9-11.6 ppm) which did not exceed international standard (32). Another study in three cities - Lusaka, Maputo, and Hanoi - revealed that the 1-hr mean (±SD) level of CO during cooking with the principal use of biomass fuel ranged from 35 to 48 ppm (33).

A study in an effort to associate the relationship between respiratory illness and indoor levels of nitrogen dioxide showed that the average concentrations of NO_2 were 112.2 ppb and 87 ppb in kitchens using gas and electric cookers respectively while the corresponding concentrations in bedrooms using gas cookers and electric cookers were 30.5 ppb and 13.9 ppb respectively (34). The level of NO_2 in kitchens and bedrooms using gas stoves was much greater than outdoor NO_2 level observed at the time of the study (14-24 ppb) and greater than the present WHO guideline of 21 ppb (35). In 77 low-income homes in the USA, the average mean (±SD) NO_2 concentrations in kitchen, living room, and outdoor were 43 (20)ppb, 36 (17) ppb, and 19 (6) ppb respectively (36). A NO_2 mean (±SD) concentration of 30.0 (33.7) ppb was found in low-income homes (37). In 23 homes of Umea, Sweden, the level of 24-hr average concentration was 28 $\mu g/m^3$, much less than the Swedish 75 $\mu g/m^3$ standard (38). In the USA, a 24 hr NO_2 concentration mean (±SD) was 8.6 (9.1) ppb and 25.9 (18.11) ppb in homes with electric and gas stoves respectively (39). In a study involving 1421 homes in three European cities, the average concentrations of NO_2 in living rooms were 5.79 ppb, 6.06 ppb, and 23.87 ppb for Ashford, Minorca, and Barcelona respectively (40). NO_2 was found to vary with gas stoves and gas fire.

Given the limitation of finding articles on CO and NO_2 researches undertaken in developing countries, there was a need to research indicators of IAP other than CO and NO_2 with reference to assessing recent research developments. Respirable suspended particles (RSP), PM_{10} and $PM_{2.5}$, are commonly used to evaluate the degree of air pollution. The summary of the review is indicated in Table 1.

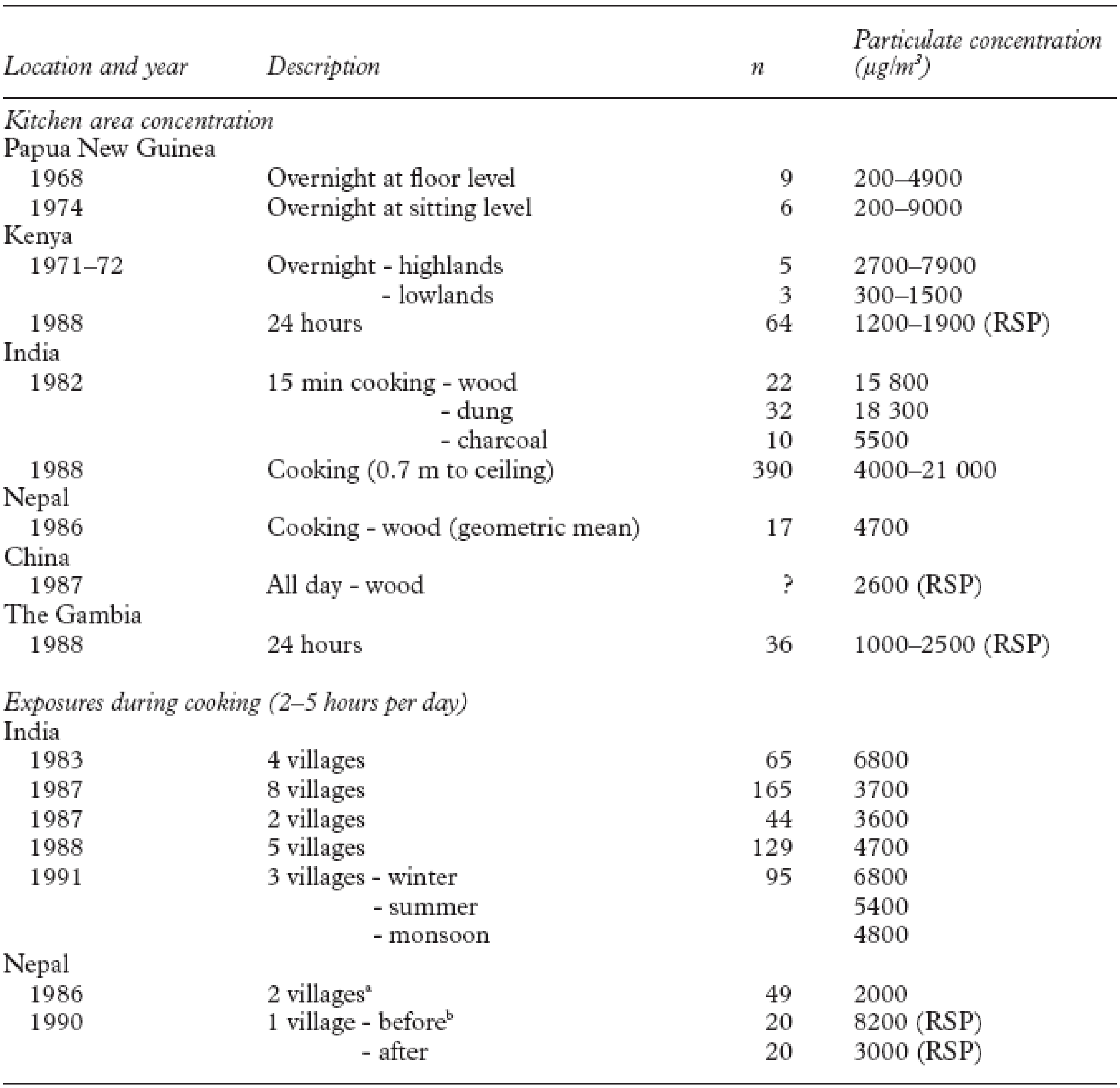
Table 1: Review summary of PM air pollution levels

Study place/country	Measurement description	Sample size	Pollutant concentration
Kenya, 1990 (12)	24-hrs of RSP	36	• Average: 1400 mg/m^3; • Peak: up to 3600 mg/m^3 using traditional stoves
Ghana, 2005 (41)	Aerial: 24-hrs of PM$_{2.5}$	36	650 µg/m^3, traditional stove
Nicaragua, 2003 (18)	Aerial: 24-hrs of PM$_{2.5}$	60	• **514-639** µg/m^3 traditional stoves; • **53-121** µg/m^3 improved stoves;
Guatemala, 2001 (42)	Aerial: 24-hrs of PM$_{3.5}$	58	1560 µg/m^3, traditional open fire cook stove
Zimbabwe, 1991 (43)	Comparing ARI and URI by IAP exposure	18 15	Mean PM$_{10}$: 1998 µg/m^3 , traditional stove Mean PM$_{10}$: 546 µg/m^3
Uganda, 2003 (22)	4 hrs during cooking at breathing zone	60	Mean PM$_{10}$: 11,400-128,600 µg/m^3 traditional stove
Mozambique, 1995 (15)	Descriptive study to relate IAP with symptoms of ARI	**218**	Mean RSP: 1200 µg/m^3 , wood stove Mean RSP: 540, µg/m^3 charcoal stove Mean RSP: 200-380 µg/m^3, modern fuel
Bangladesh,, 2003-2004 (20)	Arial: 24 hr		Mean PM$_{10}$: • 291, use of dung • 263 µg/m^3 firewood • 237 µg/m^3, sawdust • 101 µg/m^3, natural gas stove • 134 µg/m^3, kerosene stove
India, 2002 (17)	Aerial 24-hr	436	RPM: range 500-2000 µg/m^3 in kitchens
India , 2004 (19)	Aerial 24-hr	450	RPM mean: • 500 wood stove µg/m^3 • 203 kerosene stove µg/m^3
China, 2005 (21)	Aeraial 24-hr	457	Mean RPM: 351-719 µg/m^3, biomass fuel

Smith (9) in his review compiled a range of measured indoor air pollutants in various countries (Table 2). Although the mean values are variable because of the methodological differences in assessing the PM concentrations, it is understood from the findings that the levels of indoor pollutant are very much unacceptable by the standards set for outdoor air in developed countries. The author further critically reviewed the analog in pollutant components of cigarette smoking, ambient air pollution and indoor air pollution and made judgment about the presence of similarities in health outcomes as well. He drew evidence from the literature that the established effect of cigarette smoking on health situations including birth weight can be further extended to air pollution as well.

In summary, the available literature suggested that indoor air pollution tended to exceed the international and national air pollution standards.

Table 2: Measured PM in different contexts of developing countries



Location and year	*Description*	*n*	*Particulate concentration (µg/m³)*
Kitchen area concentration			
Papua New Guinea			
1968	Overnight at floor level	9	200–4900
1974	Overnight at sitting level	6	200–9000
Kenya			
1971–72	Overnight - highlands	5	2700–7900
	- lowlands	3	300–1500
1988	24 hours	64	1200–1900 (RSP)
India			
1982	15 min cooking - wood	22	15 800
	- dung	32	18 300
	- charcoal	10	5500
1988	Cooking (0.7 m to ceiling)	390	4000–21 000
Nepal			
1986	Cooking - wood (geometric mean)	17	4700
China			
1987	All day - wood	?	2600 (RSP)
The Gambia			
1988	24 hours	36	1000–2500 (RSP)
Exposures during cooking (2–5 hours per day)			
India			
1983	4 villages	65	6800
1987	8 villages	165	3700
1987	2 villages	44	3600
1988	5 villages	129	4700
1991	3 villages - winter	95	6800
	- summer		5400
	- monsoon		4800
Nepal			
1986	2 villages[a]	49	2000
1990	1 village - before[b]	20	8200 (RSP)
	- after	20	3000 (RSP)

Source: Smith KR, Samet JM, Romieu IBruce N. *Indoor air pollution in developing countries and acute lower respiratory infections in children.* Thorax 2000b; 55:518–532 (9)

Recommended level of air pollution

Pollutants that have health importance on the basis of epidemiological research are regulated and monitored. Guidelines provide an average exposure that is required to protect the general public from short and long term health effects. National Ambient Air Quality Standards developed by the Environmental Protection Agency of USA (EPA-USA) is widely cited and used by many researchers. EPA-USA uses two types of air quality guidelines: primary ambient air quality standards which are required to safeguard the health of population, and secondary ambient air quality standards required to protect the public welfare such as buildings, soil, water, visibility, and vegetation (Table 3). World Health Organization provides international air quality guidelines that can be adopted or modified by each member country based on socio-economic conditions (Table 4). Individual countries, depending on their resource and technological feasibilities, have their own standards adopted or modified from the international practice (Table 5).

Table 3: Primary and secondary standards for the criteria pollutants, Environmental Protection Agency, USA

Pollutant	Primary Standard (Health-Based)		Secondary Standard (Welfare-Based)	
	Type of Average	Standard Level Concentration	Type of Average	Standard Level Concentration
PM_{10}	Annual Arithmetic mean	50 µg/m^3		Same as primary standard
	24-hr average not to be exceeded more than once per year on average over 3 years	150 µg/m^3		Same as primary standard
$PM_{2.5}$	Spatial and annual arithmetic mean in area	15 µg/m^3		Same as primary standard
	98th percentile of the 24-hr average	65 µg/m^3		Same as primary standard
O_3	Maximum daily 1-hr average to be exceeded no more than once per year averaged over 3 consecutive years	µg/m^3 0.12		Same as primary standard
	3-yr average of the annual fourth highest daily 8-hr average	0.08 ppm		Same as primary standard
NO_2	Annual arithmetic mean	0.053 ppm		Same as primary standard
SO_2	Annual arithmetic mean	0.03 ppm	3-hr	0.50 ppm
	24-hr average	0.14 ppm		
CO	8-hr (not to be exceeded more than once per year)	9 ppm		No secondary standard
	1-hr (not to be exceeded more than once per year)	35 ppm		No secondary standard
Lead	Maximum quarterly average	1.5 µg/m^3		Same as primary standard

Source: U.S Environmental Protection Agency. National Ambient Air Quality Standards (NAAQS). Available: http://www.epa.gov/air/criteria.html **(44)**

Table 4: WHO Air Quality Guideline adopted in 2000 and 2005

Pollutant	**Averaging time**	**Concentration**
PM_{10}[1]	Annual mean	20 µg/m^3
	24-hour mean	50 µg/m^3
$PM_{2.5}$[1]	Annual mean	10 µg/m^3
	24-hour mean	25 µg/m^3
O_3[1]	8-hour mean	100 µg/m^3
NO_2	Annual mean	40 µg/m^3
	1-hour mean	200 µg/m^3
SO_2[1]	24-hour mean	20 µg/m^3
	10-minute mean	500 µg/m^3
CO[2]	15 minutes mean	90 ppm
	30 minutes mean	50 ppm
	1-hour mean	25 ppm
	8-hour mean	10 ppm
Lead[2]	Annual mean	0.50 µg/m^3

Source: *1 WHO aid quality guidelines, Global updates 2005 (23)
*2 WHO Air Quality Guidelines 2000 (28)

Table 5: National ambient air quality standard for traffic zones in India

Pollutants	Time weighted average	Traffic, Residential, Rural and other area
Sulphur Dioxide	Annual average	60 µg/m^3
	24 hours	80 µg/m^3
Oxides of Nitrogen as NO_2	Annual average	60 µg/m^3
	24 hours	80 µg/m^3
Suspended particulate matter (SPM)	Annual average	140 µg/m^3
	24 hours	200 µg/m^3
Respirable particulate matter (RSPM) (mg/m³) size less than 10mm	Annual average	60 µg/m^3
	24 hours	100 µg/m^3
Carbon Monoxide (CO)	8 hrs	2000 µg/m^3
	1 hr	4000 µg/m^3

Source: Ministry of Environment and Forests, Government of India notification,1994, ambient air quality standards at http://cpcbenvis.nic.in/airpollution/standard.htm (45)

Measuring level of indoor air pollution

The measurement of pollutants is very complex and requires human skill and advanced technology in the design of measuring equipments. Generally, the selection for the methods of sampling and measuring air pollutants depends on precision, accuracy, and validity of instrumentation (46, 47). Cost and portability are also other concerns.

The level of air pollution is usually determined by the concentrations of black smoke (carbon particles), suspended particulate matter of diameter less than 2.5 and 10 microns ($PM_{2.5}$, PM_{10}), hydrocarbons, lead oxide, NO_2, SO_2, CO, photo-chemical oxidants, and ozone. There are different methods of measuring air pollutants. These methods could be classified as traditional and emerging ones. In older times, air samples were taken to the laboratory using air bags, flask or cylinder. In the 1970's the use of portable pumps was introduced to pump air sample into a sampling filter (Figure 4). This is used for both aerial and personal exposure assessment and is known as active sampler. Its wider application in the field was very much limited due to the high cost and time limitations. Passive samplers in the early 1980's were introduced for industrial exposure assessments and then adopted for field surveys (46). Passive (diffusion) air samplers or air monitors are portable, relatively cheap, and can be used in rural areas where electricity is limited. Air monitoring data loggers are now available as products of improved technology of passive sampling. They are small electronic devices with memories for data storages and are highly specific to certain measurements such as relative humidity, temperature, and CO. Data loggers can be used for 24 hours or more continuous sampling depending on the average time interval needed. Such instruments are also known as real time monitors.

In recent times, the use of active sampling or passive sampling in combination with time budget inventory is widely used to estimate the personal exposure to IAP (13, 47, 48). This method was useful for a mass survey (17).

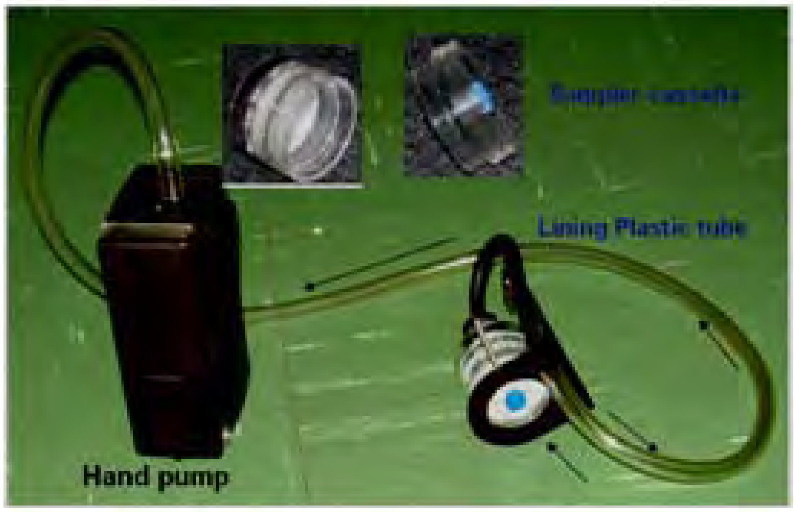


Figure 4: Active air sampling devices and assembling

Determinants of exposure to indoor air pollution

Many studies used proxies of IAP as **distal factors** such as environmental factors (availability of fuel, ecology, accessibility of fuels); **housing characteristics** (e.g., the size of the house and the material it is built from, the number of windows, and the arrangement of rooms); **socio-economic variables** such as income, education; the **proximal factors** such as type of fuel, type of stove, kitchen location, ventilation efficiency, housing construction materials, number of rooms, household size, number and location of windows; and the **more proximal** ones: cooking personalities and time spent near a fire, (13, 48). Distance between the subject and fire sources is a unique identifier for indoor air pollution, which can be modified by those who are involved in cooking and heating (10, 13, 40-51).

The type of fuel was related to respiratory symptoms and diseases (52). Wood, dung, and straw in this study were classified as high pollution fuel while liquefied petroleum gas (LPG), natural gas and electricity were categorized as low pollution fuel. Kerosene and charcoal played an intermediate role. The type of stove, stove-fuel combination, and the cooking phase are most proxies affecting the intensity of exposure to smoke from cooking. In a study involving 55 different households stratified by five different types of stoves, the median emission concentration of PM_{10} measured near stoves during burning phase significantly varied, ranging from 207 for charcoal (Loketto) stove to 2394 $\mu g/m^3$ for 3-stoned wood fuel. Ceramic wood stove, Metal charcoal stove, and Ceramic charcoal stove had emission concentration of 1922, 807, and 316 $\mu g/m^3$ respectively (13). About 31-61% of the total exposure of household members who took part in cooking was accounted for by exposure during high-intensity emission episodes (53). High intensity of emission occurred when fuel was added, or removed, the stove was lit, the cooking pot was placed on or removed from the fire, or food was stirred or removed. Increased exposure to indoor smoke during increased activity of cooking was consistent in the Nicaraguan study (50, 54).

In an effort to evaluate the benefits of improved stoves in Nicaragua, it was found out that the level of $PM_{2.5}$ was reduced on the average by 86% compared to traditional type of stoves (17). Similar results were observed in rural Guatemala in an intervention study using improved stove (3, 55). In a study in the USA involving a cohort of 242 children, the presence of gas stoves as proxy to NO_2 exposure and type of housing (multifamily or single family) were associated with symptoms of asthma (39). The housing variable was related to the number of rooms, presence of gas stoves, and ventilation factor. The household size that determined the amount of food, hence the time needed for cooking, might have increased the exposure to NO_2.

A 24-hr PM_{10} in kitchen and living areas was monitored in a stratified 236 households (rural, urban and peri-urban) in Dhaka Region of Bangladesh. Type of fuel, stove location, ventilation practices (opening doors and windows), structural characteristics and building materials of the household significantly affected the average levels of PM_{10}, ventilation factor being the most relevant compared to others (20). This study suggested that income and education were strongly related to exposure to biomass smoke. The same study found a spatial and temporal variation in the level of PM_{10} as demonstrated by day-to-day and household variations (inter-household and intra-household) which was explained by the difference in socio-economic factors and type of fuel-stove. The findings implied that a reasonable clean indoor air could be maintained using those determining factors (mainly ventilation and behavior) until such times when clean fuels become accessible. Behavior in this study was understood as actions taken by someone to protect her/himself from being exposed to indoor smoke while cooking. A similar study conducted at a different location demonstrated the presence of intra-household and inter-household variations reflected in day-to-day and seasonal differences of PM_{10} concentrations. The variation was explained by differences in the type of fuel, time-activity budget, ventilation factor, and kind of cooked food (13, 53). The benefit of ventilation efficiency as measured by the air exchange rate between the indoor kitchen and outdoor ambient air was a factor for the significant reduction of the measured 24-hr mean of $PM_{2.5}$ and PM_1 in Costa Rica. The air exchange rate using CO decay was 12.2/hr (54).

The above review summarizes the following:

- The combination of type of energy source, type of stove and kitchen, and the behavior of cooks are decisive to determine the level of indoor air pollution.
- The type of housing structures in reference to ventilation efficiency through chimneys, windows and doors are major factors to affect the level of emissions from the source.
- Socio cultural context such as education, income level and housing structures are also important determinants that could modify the level of exposure during cooking.

Health effects due to indoor air pollution

The health effect of air pollution is generally dependent on the type of pollutant (PM, gas or vapor), concentration of these pollutants in the breathing zone, duration of exposure, and demographic characteristics of the recipients. There are two suggested mechanisms by which IAP causes diseases such as ARI (9).

Non-specific mechanisms: air pollutants passing through the air ways adversely affect the mucosal epithelial lining thereby affecting the host mucociliary defensive mechanism against foreign bodies which include filtration and removal of particles by the upper air way. These effects include paralysis of cilia, hyper secretion of bronchial mucous glands, and mucous gland hypertrophy and extension into smaller air ways. The irritation of respiratory linings further causes inflammation that could be entry point for viral and bacterial infection.

Specific mechanisms: suppression of immunoglobulin promoted phagocytosis and cell-mediated immunity required to kill organisms capable of living within alveolar macrophages.

Smith cited a number of epidemiological and animal studies that have indicated nitrogen dioxide, sulfur dioxide, PM, and ozone adversely affecting the mucociliary apparatus, humoral and immune defenses (9).

Most of the health effects are related to a variety of respiratory diseases, primarily ARI including (acute lower respiratory infection) and chronic obstructive lung diseases (bronchitis, asthma). Indoor air pollution was associated with high risk of ARI in developing countries where over 70% of households use biomass fuel. Prevalence of ARI was higher among children under 5 years and women aged 15-60 years in households using traditional 3-stoned stoves than in those with improved stoves in a rural community of Kenya (56). In a case control study in India, the use of solid fuel as source of household energy was associated with pneumonia among children (57). That study demonstrated that solid fuel (OR, 95%CI: 3.97, (2.00-7.88), history of asthma (OR: 95%CI: 5.49, 2.37-12.74), poor economic status (OR: 95%CI: 4.95, 2.38-10.28), and keeping large animals indoor (OR: 95%CI: 6.03: 1.13-32.27) were associated with high risk of pneumonia after controlling for confounding factors in a logistic regression analysis. The population-attributable risk of pneumonia is high in India because 80% of its population uses biomass fuel. Mishra in his review of ARI and associated factors discussed the link between the uses of animal dung as primary cooking fuel and the risk of ARI. ARI was by one-third higher among under-five children in households using animal dung than children in households using cleaner type of fuel (16).

Descriptive studies in African countries (Kenya, South Africa, Uganda, Mozambique, and Ethiopia) have indicated the presence of high prevalence of ARI associated with the use of fire wood (10-15, 58). Smith following critical reviews of 15 published articles that had rigorous study designs came to a conclusion that there is sufficient evidence that indoor air pollution is strongly associated with ARI among children. However, there is still a need to explore a dose-response relationship using a randomized trial (9). Because children in developing countries spend much of their time with their mothers while cooking using biomass fuel and because their physiological functions are immature, intervention in indoor air pollution could impact on childhood morbidity and mortality caused by ARI.

Chronic bronchitis and chronic air flow lung obstruction was commonly observed among mothers who spend more than two-third of their time indoor cooking and doing other household activities. In a case-control study, women exposed to wood smoke had five fold risk of those COPD as compared to those not exposed (59). In Turkey, chronic bronchitis as defined by the presence of cough and phlegm in most days of 3 months per year for at least the two previous years was much higher among people who use biomass fuel (60). The overall contribution of biomass fuel to the country’s burden of diseases was minimal given that 11% of the Turkish population uses solid fuel for household cooking (52). In earlier times in Nepal, domestic smoke pollution as measured by the time spent near a fire was identified as a contributing factor in the development of chronic bronchitis (61). The prevalence of chronic bronchitis among adult Bolivians was associated with the location of cooking, whether it was exclusively either indoor or outdoor (42). The use of biomass fuel affects the ventilation capacity of the lung of an exposed person. In other studies, decreased lung functions were found to be associated with the use of cooking stoves using biomass fuel (62, 63).

IAP is associated with health outcomes other than ARI and COPD. There is compelling evidence that the use of coal as household energy was associated with lung cancer (27, 64). Low birth weight and otitis media were documented due to exposure to indoor air pollution (65, 66). The presence of PM, other eye irritants, and heating effect due to cooking cause cataract and thus blindness (67, 68). The physical comfort while cooking was investigated. In a study which investigated the physical comfort, tears while cooking was strongly related to high level of PM (33). Other than ARI, TB was also associated with IAP due to the use of solid fuels (69, 70).

Burden of diseases in recent times is used to evaluate and compare health situation across countries. Burden of diseases combines morbidity and mortality by measuring lost healthy life years due to death and lost days due to illness by using disability adjusted life years (DALY). Globally, about 2.5-3 billion people are exposed to excessive concentrations of indoor air pollutants (7). In 1990, 8.5% of global deaths were attributed to lower respiratory infections (2). Globally, 80% of all deaths occurred in developing countries. Of these 21% were in Sub-Sahara Africa (SSA) and 46% were in India and China. Indoor air pollution, through its effect of causing ARI, is estimated to cause 1.6-2 million deaths per year (50% of deaths are children), accounting for 4-5% of global deaths (9).

IAP was the 4th leading cause of burden of diseases (next to underweight, unsafe sex, and water and sanitation problems) in 2000, accounting for 3.6% of DALYs in developing countries with high child and adult mortalities (Figure 5) (5). Bruce in his review of published articles in areas of IAP and ARI had similar conclusions that indoor air pollution due to biomass fuel is a global challenge accounting for 4% of the global burden of diseases and two million excess deaths in developing countries (26, 71).

The World Health Organization is updating the trend of global burden of diseases due to indoor air pollution. More than 1.6 million annual deaths, mainly women and children, and 2.7% of DALY were attributed to indoor air pollution from the use of solid fuels. This kind of pollution ranked 2nd to sanitation in contributing to ill health in 2002. Attributable DALY to IAP was disproportionate by level of economy (Figure 6). IAP caused 3.7% and <0.5% of DALY in developing and industrialized countries respectively (7). Indoor air pollution in developing countries was highly politicized as being a silent killer of mothers and children (71).

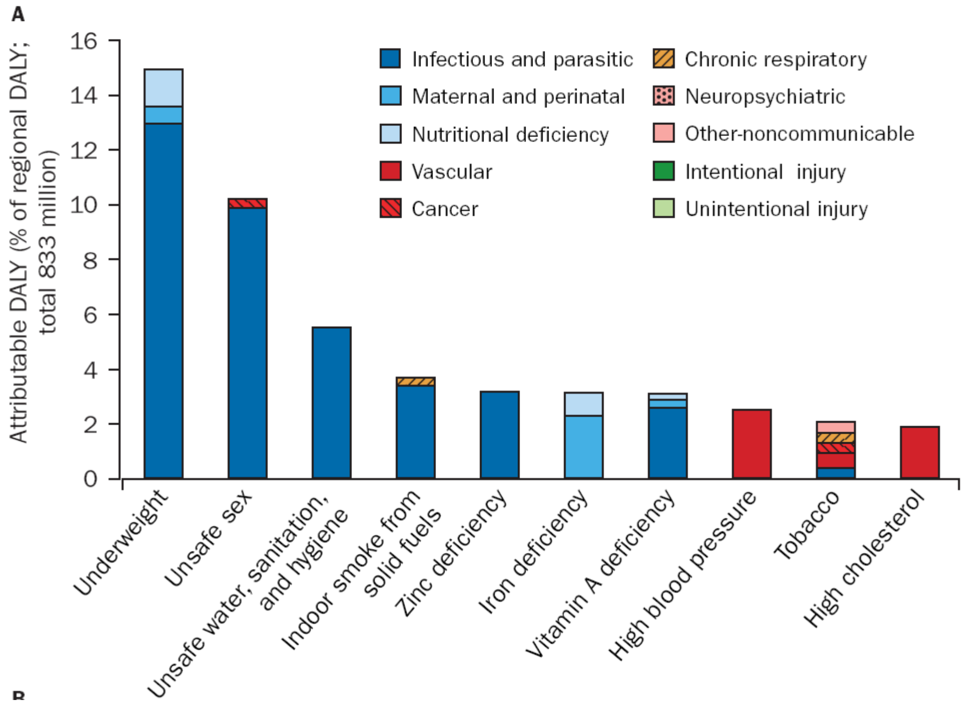


Figure 5: Burden of disease due to leading regional risk factors in high-mortality developing regions for 2000

Source: Ezzati M, Alan Lopez D, Rodgers A, Hoorn SV, Murray CJ. Selected major risk factors and global and regional burden of disease. The LANCET 2002; 360(9343):1347-1360 (5).

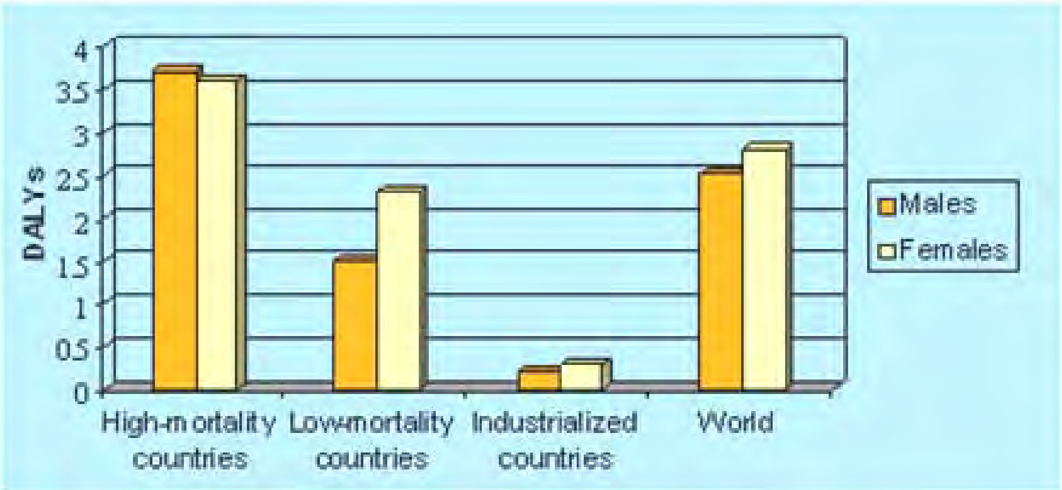


Figure 6: Disease burden (DALYs) due to indoor pollution by level of development

Source: World Health organization (WHO). Indoor air pollution: National burden of disease estimates. WHO 2007. (http://www.who.int/indoorair/health_impacts/burden_global/en/index.html) (7)

2.2 Traffic Air Pollution

Ambient air pollution

The World Health Organization evaluated the magnitude of urban air pollution using four main indicators: PM_{10}, NO_2, SO_2, and troposphere ozone in 24 mega cities of the world. The study showed the presence of increased level of urban air pollution in larger cities of developing countries compared to those of the developed nations (28) (Figure 7). Annual particulate matter was the single most important pollutant of ambient air, often exceeding 4-5 times the WHO guideline (20 µg /m^3) (28), in Asian mega cities. Cairo had the highest PM_{10}, nearly 150 µg/m^3. Johannesburg and Cape Town had less than 40 µg/m^3. The continued use of coal and biomass fuel in Beijing was a factor that contributed to the annual PM_{10} level of 140 µg/m^3 that labeled the city as the most polluted in the World. Developing countries must learn from previous experiences in Europe and America where increased hospital admissions and deaths occurred due to ambient air pollution in the 1950's and 1960's. The 1952 two-week crisis of excess 4000 deaths in London was due to coal burning and traffic pollution that resulted in high level of ambient air pollution including on the traffic lines (28). There is good reason why this could not happen in African cities like Cairo where biomass fuel is used in over 77% (1) of households and where there is increasing use of low standard vehicles.

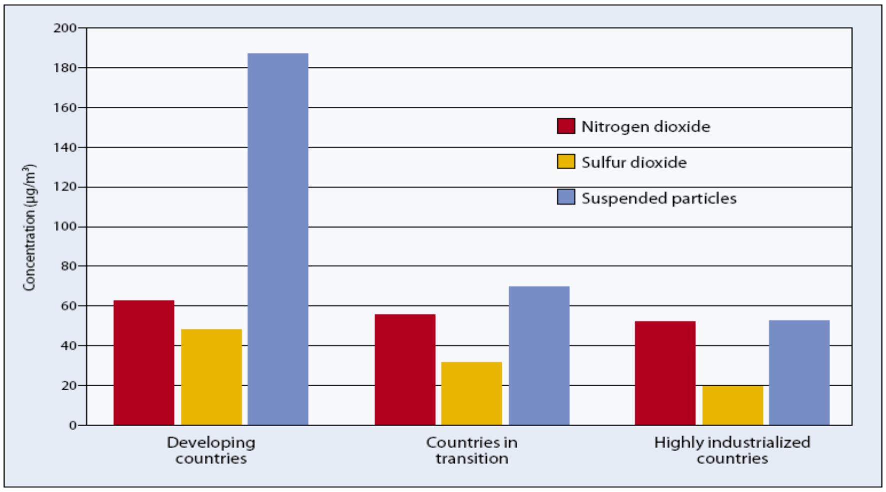


Figure 7: Typical annual average concentrations of nitrogen dioxide, sulfur dioxide and suspended particles in different parts of the world

Source: World Health Organization (WHO). WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide. Global Update 2005 Summary of Risk Assessment, Available online at http://www.euro.who.int/Document/E87950.pdf (28)

There is spatial variation of ambient air pollutants in Europe where concentrations of pollutant are monitored regularly. There was an increased level of NO_2 and PM_{10} in traffic sampling points compared to other non-traffic sampling points, and the level of ozone was higher in rural air monitoring stations. However, overall air pollution level is generally greater in urban areas than in the rural (28) due to the relatively increased emissions from vehicles and factories.

The annual average concentration of sulphur dioxide was high, exceeding 20 µg/m^3 for the years 2000-2005, although a declining trend is observed. Typical annual average concentration of sulfur dioxide for developing countries and developed nations was 40-80 µg/m^3, and 10-30 µg/m^3 respectively. In African nations, annual sulfur dioxide was also high, 100 µg/m^3 in Harare, 40 µg/m^3 in Cairo, and less than 20 µg/m^3 in South African cities (Johannesburg, Gaborone, Durban and Cape town). Sulfur dioxide emission is due to the use of sulfur containing coal, typical of 1-5%. US-EPA's annual average concentration for sulfur dioxide is 80 µg/m^3. The annual average concentration of nitrogen dioxide varied from city to city for the 2000-2005 data. Typical annual figure was 23-74 µg/m^3 for Asian cities, 13-44 µg/m^3 for European cities and 36 µg/m^3 for 125 cities in the USA. For African cities it ranged from 65 in Cairo µg/m^3 to 33 µg/m^3

in Cape Town. The annual WHO guideline for the average concentration of NO_2 is 40 μg/m^3. The dominant source of nitrogen dioxide was traffic emissions (28).

Generally, Asian and African cities have about 4 times higher concentrations of ambient air pollutants than cities in developed countries. It will take far longer time for the developing countries to reach the current level that developed nations have attained.

The level of traffic air pollution

Vehicle-related air pollution predominates in urban centers of developing countries. Criteria pollutants are often used to evaluate the level of traffic air pollution along road sides and in the nearby zones. Explicit data that could describe the situation of traffic air pollution are limited. Only the available ones are presented below.

The level of SPM, RSPM, and CO measured from a site called Gate in New Delhi, representing a traffic zone, was much more than the national Indian air quality standards. The annual average concentrations varied between 275 and 470 μg/m^3, 220 and 390 and 470 μg/m^3, and 2490 and 4200 μg/m^3, for SPM, RSPM, and CO respectively for the years 1999-2003 (72). Although there was a gradual declining trend for the five-year study duration, the presence of increasing rates for the respirable particulate matters, which was 3.6-6.5 times greater than the Indian standard, showed high concern (45). The concentration of CO was 1-2 times more than the Indian 8-hr standard. Indian cities are considered to be among the most polluted Asian cities (28).

The concentration of particulate matter was measured in Greater Cairo with the purpose to identify the sources of emission (73). The 24 hour average concentration was found to be 216 μg/m^3 for $PM_{2.5}$ in industrial monitoring sites. Vehicular emissions displayed by non-methane hydrocarbons were higher there than in other sites. Highest level of lead was found in traffic sites, 26.8 μg/m^3. In another study of Greater Cairo involving air sampling stratified by type of sites (background, residential, urban, and industrial), 24-hr weighted means of PM_{10} and $Pm_{2.5}$ were 170 μg/m^3 and 85 μg/m^3 respectively (74). Spatial variation was observed: highest concentrations of air pollutants were observed in industrial and urban (traffic) sites showing an increase rate by a factor of 1.0-1.4. The background 24-hr mean ($\underline{+}$SD) levels for PM_{10} and

$PM_{2.5}$ were 140 (40) μg/m^3 and 77 (21) μg/m^3 respectively. The weighted ratio $PM_{2.5}/PM_{10}$ was 0.50 indicating that PM by large had a diameter of 10 microns.

CO and NO_2 as proxy of exposure to traffic air pollution are rarely monitored in developing countries. The daily concentration of NO_2 and CO in 21 traffic line sites in Kuwait was above 50 ppb and 8 ppm respectively, the peak traffic level reaching 500 ppb (75). The WHO recommended guideline for the annual mean of NO_2 and 8-hr mean of CO is 0.021 ppm (40 mg/m^3) and 10 ppm (10 mg/m^3) respectively. The concentration of CO and factors contributing to this exposure were studied in 16 kiosks near heavy traffics in Venezuela. In seven of them the average concentration of CO exceeded the permissible CO-air limits (76).

The concentration profiles of PM_{10}, CO and NO_2 in Bangkok on high traffic density locations showed significant correlations with the measurements made in the indoors of roadside shops. The indoor to outdoor ratios were 0.33, 0.51, and 0.47, for PM_{10}, CO and NO_2 respectively (77). The one-hourly average of CO during the day time (7:00-19:00) in highly traffic congested locations ranged between 8 and 10 ppm. The corresponding PM_{10} and NO_2 were above 80 μg/m^3 and 40 μg/m^3 respectively. The researchers concluded that the indoor concentrations were due to infiltration of emissions from the traffic sources, given the absence of other indoor sources and prevailing poor ventilation.

In Pakistan traffic-related CO, NO_2, SO_2, and PM_{10}were measured in public sites of nearby National Highway. The concentrations of PM_{10}, ranging between 123 and 434 μg/m^3, were found to exceed the US-EPA limits of 150 μg/m^3 (78). The increased volume of vehicles, absence of vegetation around the highway, and high content of soil particles in the PM explained these high concentrations.

Generally, the traffic pollution in major cities of developing countries exceeds the WHO recommended guidelines. Extensive data on ambient air pollution status of the global major cities is found in WHO references (28).

Factors affecting the level of traffic emissions

Many factors interplay to affect the amount of emissions of vehicular sources. The type of fuel (petrol or diesel), the efficiency of internal combustions, the driving velocity (idle, fast or slow), the topography of road (uphill, downhill or plain), the age of the vehicle, temperature changes on the surface of the earth and weather conditions such as wind velocity, its strength and direction are some of the factors.

Diesel engines are known to produce emissions that are low in hydrocarbons, CO, NO, and CO_2 compared to gasoline engines. However, the former produce more PM (in a form of soot) that contains hundreds of chemical compounds, many known to be toxic and some known or suspected to be carcinogenic. These include benzene, polycyclic aromatic hydrocarbons, arsenic, aldehydes and formaldehyde. Much of the PM fraction is small enough to be inhaled into human lung tissues. Diesel engines generate PM in a form of smoke or black smoke or soot, often 60-80% more than do the vehicles using petrol. The quantity and composition of diesel fumes depends on many factors involved during driving: the quality of diesel fuel used, the type of engine, (standard, turbo or injector), the state of engine tuning, the fuel pump setting, the workload demand on the engine, the engine temperature, and whether the engine has been regularly maintained. Typical tailgate emissions from diesel and petrol engines are indicated in Table 6. Petrol engines produce more CO than diesel, while diesel engines have more PM than petrol (28, 79)

Table 6: Estimates of tail gate emissions

Pollutant	Diesel engine	LPG engines
CO, ppmv	5-1500	0.2-2 (vol %)
Hydro Carbon , ppmv	20-400	50-70 ppm
Diesel PM g/m3	0.1-0.25	Negligible
NOx ppmv	50-2500	250-2000
$S0_2$ ppmv	10-150	None

vppm: ppm by volume; NOx: nitrogen oxides, mostly represented by nitric oxides.

Source: What are the diesel emissions? http://www.nett.ca/faq/diesel-1.html (79)

The modes of transportation were found to affect the level of personal exposure. Commuter's exposure to CO was measured concurrently with its monitoring at fixed stations in Mexico City. The in-vehicle CO concentration was always greater than the concurrent ambient concentrations: 5.2 times more for automobile, 5.2 for minivan, 4.3 for mini bus, 3.1 for bus, 3.0 for trolleybus, and 2.2 for metro (80). The ambient mean CO levels during the study time were more than the Mexican standard of 13 ppm. The implication of this study is that drivers are at higher risk of traffic air pollution. They are also likely to shoulder health impacts because of their profession making them always on the road.

Distance between motorway and home, traffic density as measured by cars and lorries as proxies of traffic air pollution were associated with reduced lung functions and increased respiratory diseases among children living near major motorways (81). Spending at least one year in schools located closer to a road with high traffic density was associated with asthma among schoolchildren (82). Traffic density within distance of 90 to 150 meters was associated with increased respiratory illness (83-86).

In an air sampling assessment in the road sides of Canada, there was an increased concentration of PM_{10} and $PM_{2.5}$ above the background ambient air quality measured in the same area. $PM_{2.5}$ tended to increase with distance, while larger particles tended to decrease with distance (87). The increased levels over the background were 6 to 8 $\mu g/m^3$ for TSPs and 2 $\mu g/m^3$ for PM_{10}, during normal traffic flows. The increase rates were high during high traffic congestions: 10-25, 2-69, 2-14 times for TSP, PM_{10}, and $PM_{2.5}$ respectively.

The average concentrations of traffic air pollutants had spatial variation due to the effect of either horizontal or vertical pollutants' dispersion in air. The concentrations of smoke, lead and benzypyrene measured at the middle of the traffic were 1.7-4 times greater than those at the control sites located at 150 ft (45 m) away from the streets of London (88). This study indicated that on road traffic vehicles independently contributed to the increased level of air pollutants affecting the overall urban ambient air quality. In a study in Greater Cairo using PM_{10} and $PM_{2.5}$, high level of these ambient pollutants were observed during spring season due to the dessert storm in addition to the increased urban and industrial activity. Marked increase was also observed at the time of rice harvesting due to the burning of wastages of harvested rice stocks (74).

The age of the vehicles has increased relevance to the case of developing countries. Because of the tendency of developing countries to import low priced used vehicles from the developed countries, the effect of traffic pollution is assumed to be high. The average Pakistani vehicle emits 20 times more hydrocarbon, 25 times more Carbon Monoxide (CO) and 3.6 times more nitrous oxide of grams per kilometer than the average vehicle in the United States (78).

The poor road infrastructure facility is also of great importance. High traffic congestion and slow driving due to limited road ways leads to energy inefficiency, causing the rise of travel time per each traveled distance resulting in an increase of emissions per each kilometer. The reduction of speed by half doubles emission of carbon monoxide and volatile organic compounds (89, 90).

Health effects of traffic pollution

The health effect of traffic air pollution is a cross-cutting issue with indoor air pollution and cigarette smoking. Respiratory symptoms, chronic respiratory diseases such as asthma and chronic bronchitis have been shown to be related to traffic air pollution. The physical and chemical characteristics of air pollutants determine their disposition in air and in the breathing apparatus often ending with chronic illnesses. Traffic-related air pollutions were associated with respiratory symptoms, asthma and allergic rhinitis among school children (83-86, 91, 92). Other studies had also shown associations between traffic air pollution levels and respiratory symptoms, ear and throat infections (93-96).

Work-related exposure to vehicle emissions was strongly associated with respiratory diseases. Occupations such as truck and taxi driving were related to an increased risk of cancer (97, 98). Such workers had long latency to develop the disease. Professional bus and taxi drivers had increased rates of throat pain, phlegm, chronic rhinitis, and chronic pharyngitis (99). High exposure to traffic emissions was observed among street cleaners (100), asphalt workers (101) and traffic officers (102). It is also logical to expect that shoe shiners usually working along the main roadsides, street children, and frequent commuters could be highly exposed to traffic emissions.

Geographical information system is used to evaluate the difference in exposure to traffic air pollution by residency. Distance from major roads as a proxy for exposure to traffic air pollution, residence close to high traffic roads and traffic density (traffic count or intensity) were common factors that were used to study related health outcomes (28). Residence within 50 meters of highways was associated with increased risk of birth outcomes as measured by small for gestational period and low birth weight among large sample size of cohort children in Vancouver (103). Otitis media was related to proximity of traffic corridors (65). Eczema was associated with traffic related air pollutants (CO, NO_2) after adjusting for possible confounding factors (104).

Traffic air pollution is also known to affect mortality other than morbidities. BBC, based on research published in the Lancet Medical Journal, announced that 6% of deaths per year in Austria, France and Switzerland are due to air pollution. Half of those deaths, some 20,000, were linked to traffic pollution (105).

3. ETHIOPIA: BACKGROUND REVIEW

Geography and Climate

Ethiopia is located in East Africa with an area of 1.12 million square kilometers. It is a land-locked country bordered by Kenya in the South, Eritrea in the North, Sudan in the West, and Djibouti in the East. Ethiopia possesses three agro-climatic zones: low land (*kola*) located below 1500 meters above sea level (masl), temperate or middle land areas (*woyina dega*) extending between 1500-2400 masl, and highland (*dega*) above 2500 masl. There are extreme sub categories known as desert below 500 masl and *wurch* or alpine zone above 4000 masl. Rainfall, temperature, and humidity are strongly related to altitude. Low land has often a mean annual rainfall and temperature of 300-1000 mm, and 30-33^{o}C respectively. The mean annual rainfall and temperature for the highlands constitute 1000-1400 mm and 10-16^{o}C, respectively. *Woyina dega* has mean annual temperature of 16-29^{o}C (105). The distribution of population density differs by these zones: highland is most inhabited, has 37% of the national population, temperate land has 45% and low land has 18% of the national population (107).

Population

The 2007 census preliminary report indicated that Ethiopia has a total population of 73.92 million with 84% rural and 16% urban distribution. Male to female ratio was 1.02:1 (108). Ethiopia has an annual population growth of 2.7% and total fertility rate of 5.4 (6.0 in rural and 2.4 in urban areas). The age structure of Ethiopian population has a pyramid shape with a broad base. About 45% of the population is under 15 years of age; elders above 65 years of age comprise only less than 4%. Under-five children comprise about 15% of the population.

Ethiopia is a country of more than 80 diverse ethnic groups. Oromo, *Amhara* and *Tigr*e are the predominant ethnic groups, comprising more than 65% of the total population. Amharic is the official language of the country, but some Regional States such as *Oromia*, *Tigray* and *Somali* use their own languages for their day to day communication and State affairs. Orthodox Christianity and Islam are the two major religious denominations in the country.

Political and Administrative structure

The country is governed by a parliamentary Federal Government composed of nine National Regional States (NRSs) and two city administrative councils (Addis Ababa and Dire Dawa). The NRSs and the city councils are further sub-divided into 611 *woredas* (districts). A *woreda* at present is a basic unit of socio-economic development. *Kebele*s are the lowest government administrative units. Each *woreda* has about 100,000 population. There are about 15000 *kebele*s in the country (109).

Economy

Ethiopia is one of the poorest nations in the world with per capita gross national income (GNI) of about US$110 in 2004. The agriculture sector predominates the economy sector making about 50% of the gross domestic product (GDP). Coffee, animal skin and hide, and oil seeds are the main export products, while *tef (Eragrostis tef)*, in the form of *injera*, is the staple food for the majority of the people. The main occupation of the population is subsistence farming. Agriculture is the main source of livelihood for about 85% of households in Ethiopia.

Ethiopia has placed itself under a rapid socio-economic transformation. It has realized a free market economy that encourages local and international investments. The economy grew at a rate of 10-11% for the 2005-2008 period (110). GDP per capita based on purchasing power parity for the 2008 (in May) was 868 Ethiopian Birr (approximately 1000 US$) (110). However, sustained economic growth for a period of 20-30 years is needed to transform Ethiopia from a low income to a middle-income country.

Health services and health indicators

Ethiopia follows a sector-wide development approach under the context of Plan for Accelerated Development to End up Poverty (PASDEP) (109). Health Sector Development Program (HSDP) is one sector among others that plans and executes the health sector activities. Ethiopia is now on the HSDP III (2005/06-2009/10) aiming at accomplishing the national and international MDG goals. It has committed itself to attain UN declarations of MDG by 2015, including Target 9 of Goal 7 to ensure the transition from biomass fuel use to modern household energy uses. Health Services Extension Program (HSEP) is integrated with HSDP III as a vehicle to carry out the implementation of PHC components at household level, greatly focusing on behavioral changes towards sanitation, disease prevention, and child and maternal health promotion (111).

The potential health service coverage is about 89.6% with the provision of health posts and health centers. Ethiopia follows 4-tier health delivery system. Primary Health Care units, composed of one health center with 5 satellite health posts, are found at the grassroots. District, Zonal and specialized referral hospitals are the subsequent health facilities serving the nation (112). The Ethiopian Health Policy focuses on the provisions of comprehensive and integrated Primary Health Care (PHC) services using a decentralized approach. Major PHC activities include prevention and control of communicable diseases, promotion of environmental health and hygiene, promotion of nutrition, and child and maternal health (104, 113). About 1.8 billion ET Birr was consumed for the health expenditure in the 1999 Ethiopian fiscal year, of which 72% was on recurrent expenditure. The share of the health expenditure (recurrent and capital) in the national economy was about 13%. The per capita expenditure on health was 23.1 Birr for the same year (111). The total outpatient utilization of government health facilities in the country was 0.32 per person per year in 2006/07. Only 10% of persons reporting illness had treatment for their conditions from any health institution, government or private, in 1997 (111). Acute respiratory and helminthic infections were the leading causes of outpatient visits, while malaria, maternal conditions, pneumonia, and TB were the leading causes of hospital admissions and deaths. Prevalence of HIV/AIDS has stabilized at 2.1% nationally (112). Analysis of burden of diseases in Ethiopia indicated that about 71-72% of the DALY is caused by communicable, maternal, perinatal and nutritional causes which are greatly preventable (114, 115). Basic health indicators are provided in Table 7.

Table 7: Vital health indicators of Ethiopia

Health indicators	Value
Crude death rate, per 1000 pop.	15.0
Crude birth rate, per 1000 pop.	35.7
Infant mortality rate, per 1000 live births	77
Child mortality rate, per 1000 live births	50
Under five mortality rate, per 1000 live births	123
Maternal mortality ratio, per 100000 live births	673
Total fertility rate	5.4
Health service coverage (by health center and health posts)	89.6
HIV prevalence, %	2.1
Adult HIV incidence, %	0.27
Access to sanitation, %	37.0
Access to safe water, %	59.5
Life expectancy at birth, years	54

Source: Central Statistical Agency (CSA Ethiopia) and ORC Macro. *Ethiopia Demographic and Health Survey 2005*. Addis Ababa, Ethiopia and Calverton, Maryland, USA: Central Statistical Authority and ORC Macro 2006 (25)

Federal Ministry of Health, Ethiopia. *Health Sector development Programme (HSDP*) III, 2005/06-2009/10. June 2005 (112)

4. INDOOR AND TRAFFIC AIR POLLLUTION STATUS IN ETHIOPIA

Studies assessing indoor air pollution in households of Ethiopia are strictly limited. Only assessing proxies are available in addition to few quantitative attempts with IAP measurements using small samples of households.

Over 99% of the Ethiopian rural population relies on biomass fuel as source of household energy (24). Wood and leaves with animal dung are primary sources of fuel for cooking each contributing 81% and 11.5% respectively. The use of cleaner type of cooking fuel is very much limited. Kerosene is only used in about 3%, while electricity with LPG and natural gas is very negligible, <1% (112). DHS of Ethiopia has indicated slightly different figures at national level: about 88% and 7.4% of households use wood and animal dung respectively (25).

The crowding status in housing units is very high. About 90% of the Ethiopian rural households use the same room for cooking as that used for daily and night activities (116, 117). Over 90% of households in rural areas use a three stoned traditional stove which is open and poorly ventilated resulting in high emission of pollutants. The absence of windows in the majority of households (>85%) to ventilate homes is inherent in rural villages of Ethiopia as well (118, 119).

In the Amhara Region of Ethiopia, 15% of DALY was due to respiratory infections that affected 87% of under-five children (120). The two-week prevalence of ARI (cough and rapid breathing symptoms) was 13% among under-five children. WHO estimated that 4.9% of the national burden of diseases (DALY) was attributed to the use of solid fuels in Ethiopia (114) implying that the continued sufferings of children and mothers with acute and chronic respiratory diseases will not end until there is a major change in energy technology and conditions of their use in households.

A rapid assessment using grab sampling of indoor air in rural villages of Ethiopia suggested an excess level of CO, total respirable particulate matter and smoke (118). Pilot samples in urban and rural settings had also indicated increased concentrations of indoor CO, $PM_{2.5}$ and PM_{10}

(121-125). The mean concentrations of these pollutants ranged from 640 to 2170 µg/m^3 for $PM_{2.5}$, and from 22.1 to 70.5 ppm for CO, which by large exceeded the international guideline.

Household energy sources

Households both in rural and urban areas need energy for two basic reasons: cooking and lighting as shown in Table 8 (116). Overall, wood and combination of leaves with dung and crop residues were the predominant types of biomass fuel used for cooking while kerosene and fire wood were used for indoor lighting. Households in urban areas are largely dependent on kerosene for cooking. Indoor air pollution from the use of biomass fuel is expected to be high. Wood-fueled traditional stoves were 5 to 10% energy efficient while the figure for electric stoves was 80-90% (125).

Table 8: Distribution of households by type of fuel used for cooking and lighting, Ethiopia, 2007

Type of fuel	**% of households for Cooking**			**% of households for lighting**		
	Urban	**Rural**	**Country level**	**Urban**	**Rural**	**Country level**
Fire wood	65.4	84.4	81.4	0.3	18.5	15.7
Charcoal	7.7	0.2	1.3			
Leaves/dung/crop residues	5.3	12.7	11.5			
Kerosene	13.8	0.2	2.4	23.2	80.1	71.1
Butane gas	2.7	0.1	0.5			
Electricity	2.4	0.1	2.1	75.3	1.2	12.9

Generally, biomass fuel and petroleum products meet 94% and 5% of the country’s energy needs respectively. Of the total energy demand in Ethiopia, households consumed about 89%, while a mere 4.6% was used by industry. These patterns are expected to continue with a growth rate of 2.6% for biomass, 8% for electricity, and 8.7% for petroleum between the years 2001 and 2010 (126).

The transport sector and traffic air pollution

Ethiopia is currently undertaking huge investments to improve its urban and rural road networks. The country's road network has been estimated (end 2006) at 39,477 km, of which about 19,313 km are federal roads and 20,164 regional roads (127). According to PASDEP, the Ethiopian Government is planning to construct about 2,715 kms of new federal roads and 8,226 kms of new regional roads, upgrade 4890 federal roads, and maintain 4152 kms of federal and regional roads (109).

Addis Ababa is currently undergoing rapid urbanization with huge investment in transport sectors with the purpose of increasing the road network and quality of service. The Ethiopian Road Authority report for the 1990-2002 years indicated that 60% of all national vehicles were automobiles. The overall annual vehicles increase rate was 7.7%, giving about 4700 new on-road vehicles every year (128). Of the total 116,415 vehicles in the country in 2002, only 20.5% had less than ten years of service, while nearly 40% were more than 30 years old. Vehicles with 15 years old produce five times more hydrocarbons and four times nitrogen oxides than those of new ones (129). The number of vehicles retired each year in Addis Ababa is very low, as vehicles serve long period of time.

By the end of 2007 there were 184,249 vehicles nationwide, of which 76% were found in Addis Ababa. Petrol engine users were 56% and 60% in the country sides and Addis Ababa, respectively. The on-road vehicle increase rate in Addis Ababa varied from 4 to 6% per year (about 4000-5000 annually). The traffic volume along major roads is increasing at 20% per year, well above the forecasted level (109).

The increasing street venders, road side shoppers, drivers, commuters, pedestrians, traffic police, and residents within the vicinity of road networks are at the greatest risk to traffic air pollution exposure. According to urban mobility study, 70%, 21%, 8%, and 1% of the total population walk on foot, use public buses, taxis, and private cars, respectively (128). Nowadays, many streets are over-crowded with pedestrians either waiting for taxis and buses or walking along the foot paths or crossing these streets. Pedestrians sharing the streets are increasing from time to time due to influxes of large population to the city in search of work.

Ambient air pollution assessment on the streets of Addis Ababa is very limited. It was possible to access only one study. This study had ambient air sampling on 12 different sites and concluded that the 24-hourly PM_{10} and 8-hr average of CO were below US-EPA permissible levels, while the annual PM_{10} concentrations could exceed the guideline. The study found that the level of PM_{10} ranged from 35 to 97µg/m^3 and peak 1-hr average CO concentrations were less than 7 ppm. The hourly average concentration of CO was less than 2 ppm. The study had limitations in that the samples were limited and were taken at a distance of 50-100 meters away from streets, many of them representing low traffic densities (130).

The urban infrastructure of Ethiopia is inadequate to accommodate the large and growing number of vehicles. According to the Addis Ababa Road Authority, the city possesses one-laned streets of 3.5 to 4.0 meters wide, with an average of 3.5-meter width. The average speed of vehicles in Addis Ababa is about 20-30 km per hour on many roads, especially at peak hours during 7.50-9:00 am and 14:00-19:00 pm (128). The topography in Addis Ababa has a slope varying between 0.5 and 12.0% which also affects the speed and use of fuel. Frequent stopping, repeated accelerations and decelerations reduce engine efficiency, and therefore, increase emissions on the road.

5. GENESIS OF THE THESIS WORK

The investigation of determinants of under-five mortality in Butajira DSS showed that the absence of window in a house had significant association both in the bivariate and multivariate logistics regression analysis (131). Lack of window was associated with 2.7 fold relative risk of infant mortality. The same study concluded that lack of window in a traditional hut had a five-fold ARI mortality risk among infants. ARI and diarrhea were isolated as the chief causes of under-five mortality in Butajira DSS. Project idea looking at factors explaining increased mortality risk due to lack of window was generated in the early 1990's, and subsequently came out with a research project entitled *Indoor air pollution and acute respiratory infections among children in the Butajira area in Ethiopia*. Pilot studies were run in 1995 to establish the feasibility of this epidemiological study (132). ARI is known to be associated with indoor air pollution (2, 3, 5, 7, 9, 10, 26). *Indoor air pollution and ARI* project is a collaborative research between the Umea University and School of Public Health of Addis Ababa University. The two key research tasks were to define the household exposure to indoor air pollution by measuring NO_2, and to link this exposure with ARI. Both tasks were accomplished, and this thesis reflects the first task. The second task is underway.

6. THE RATIONALE OF THE THESIS

There is a growing demand for energy in Ethiopia due to population growth and rapid industrialization. On the other hand, the use of improved energy technology is very much limited especially in rural settings. The increased demand in energy implies the generation of wastes in a form of indoor air pollutants that could affect users. Living in crowded and poorly ventilated housing, and limited access to separate cooking and living areas in rural and urban homes are visible features of living conditions in Ethiopia. The use of biomass fuel for cooking by the majority of families in poorly designed houses is another major cause of exposure to IAP. These socio-economic factors play a major role in substantiating exposure to IAP. The knowledge of the magnitude of IAP problem is important for understanding the link between IAP and burden of diseases. Previous studies indicated that IAP is the chief determining factor of infant and child morbidity and mortality.

The urban setting in Ethiopia has its own inherent characteristics as demonstrated by the conditions in Addis Ababa. The number of vehicles is growing at 4000-5000 per year. The traffic volume along major road is also growing by 20% every year (109). The increasing demand to vehicles is not coping with the road network expansion, although in recent times visible effort is well progressing to alleviate the problem. The road development is often accompanied with the increasing of traffic side activities such as shops, markets, and entertainments. The assessment of traffic side air pollution is vital given those conditions.

Limited attempts were made to explore the level of both indoor and ambient air pollution. These studies, with their own methodological limitations, however, are just snap shots often not useful for generalizing. The absence of epidemiological and exposure data on air pollution makes the magnitude of the problem totally unknown implying the need for base line data. A continuous ambient air monitoring may represent a course of future action based on the assessed background air pollutant concentrations. This is believed to enhance the development of air pollution epidemiological studies and air quality surveillance system in the long run. Experience from the developed countries indicates that air pollution is a sensitive matter that could end up with handling of undesired emergencies (4, 46, 133).

Given favorable conditions for the presence of indoor air pollution in rural settings of Ethiopia and traffic air pollution in Addis Ababa, this thesis attempted to fill the gap in assessing of the magnitude and factors affecting both indoor air pollution and urban traffic pollution using appropriate and feasible study methods. The thesis was initiated on the background of unknown or limited knowledge of the extent of pollution. The rationale for the selection of NO2 proxy for the IAP and CO for traffic air pollution is indicated in the respective methodology sections.

7. THEORETICAL FRAMEWORK FOR THE INDOOR AIR POLLUTION

The above reviewed papers and reports can be condensed into the following framework (Figure 8). Assessing the magnitude of indoor air pollution and its variations in rural areas where the primary use of household energy is represented by solid biomass fuel is the focus of this study. The thesis assessed the exposure covariates in terms of describing the concentration of nitrogen dioxide from the use of solid fuels and environmental factors that could explain the variation in NO_2 concentration across the households observed during the two-year study period. Fuel use characteristics, housing and ecology were also assessed. The measurement of personal exposure could not be done without the overall knowledge of the level of indoor air pollution.

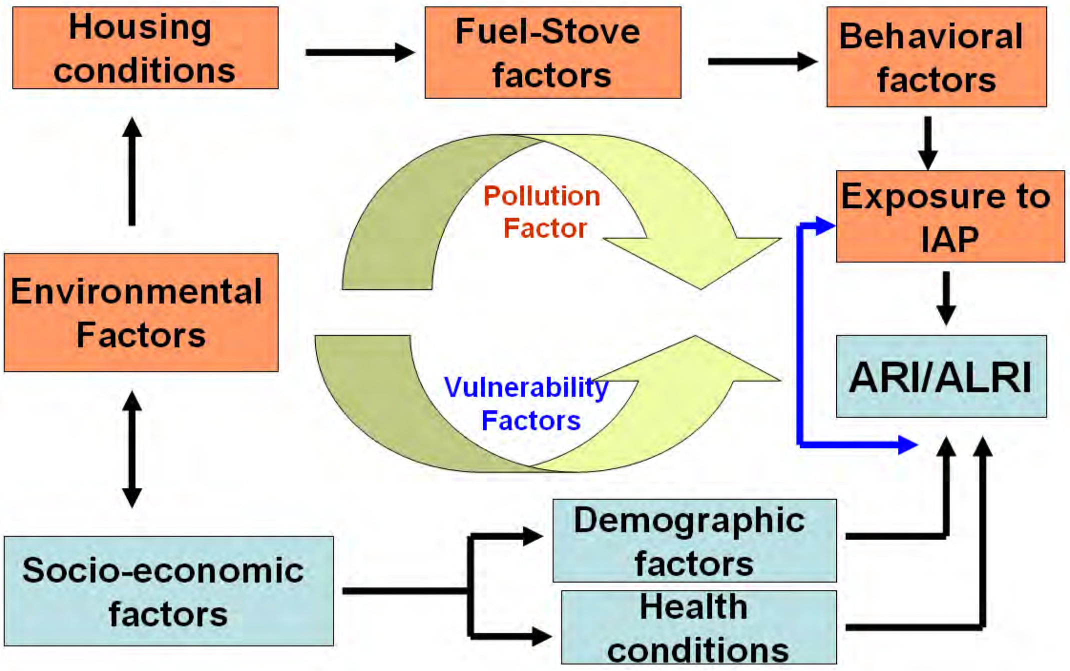


Figure 8: Conceptual framework of the indoor air pollution for Butajira study area, Ethiopia.

8. OBJECTIVES OF THE THESIS

8.1 General Objective

This thesis assesses the situation of indoor air pollution in rural areas of Ethiopia and urban traffic-related air pollution in Addis Ababa.

8.2 Specific Objectives

1. To assess the magnitude of indoor air pollution in a rural area of Butajira, South West Ethiopia, using nitrogen dioxide as an indicator of pollution (**Paper I**).
2. To describe sources of variation of indoor air pollution, and its temporality and spatiality (**Paper II**).
3. To examine the level of traffic air pollution and its variation in Addis Ababa using CO continuous measurement (**Paper III**).

9. SUBJECTS AND METHODS

9.1 Study Areas and Population

This dissertation generated two data sets, one from Butajira rural setting for the indoor air pollution, and the other from Addis Ababa for the traffic air pollution. The two study areas are described separately below.

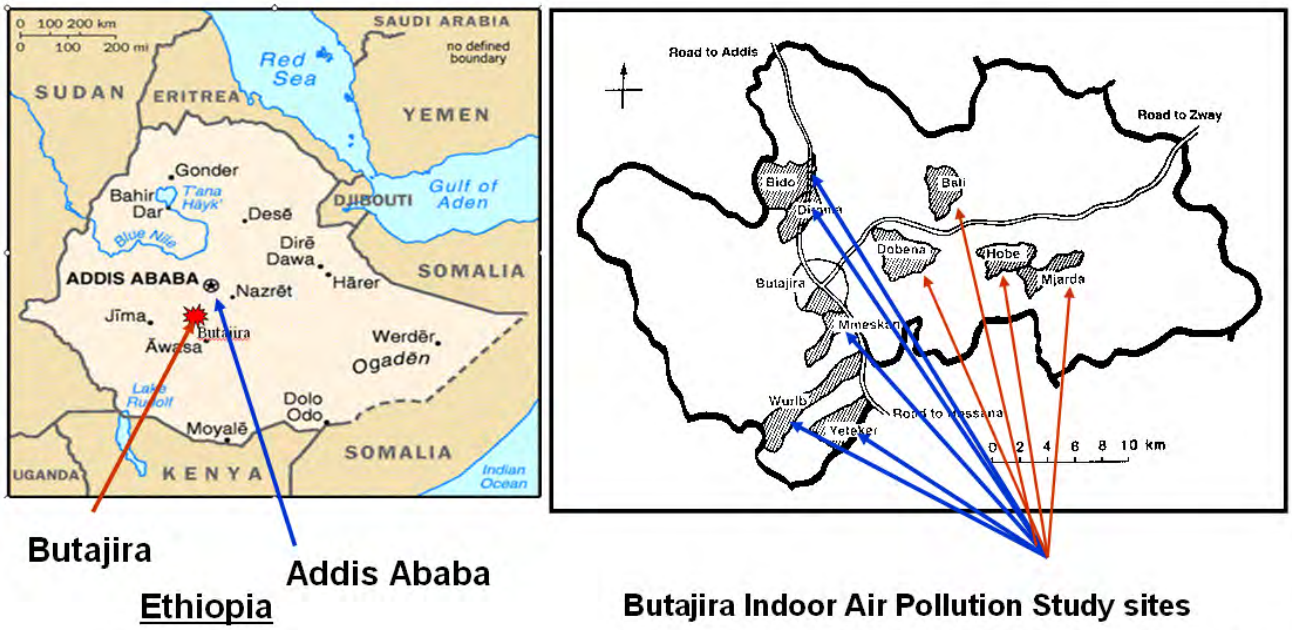
9.1.1 *Meskanen* and *Mareko* District: Population and health

Butajira is located 130 Kms away south of Addis Ababa (Figure 9). The district represents all the three agro-ecology sites of Ethiopia: *kola* which is warm, *woyina dega* which is temperate, and *dega,* which is cold, respectively. Population of the study site in 2007 was about 48,000 with annual growth rate of 2.7%. The area is mainly inhabited by ethnic *Gurage* population speaking varying dialects of *Guragigna*. Majority of the population follows Islamic Religion. About 77% of the District population is illiterate. More than 95% of the rural population lives in traditional housing units designated as *tukul* with thatched roof and circular wall shape (Figure 10). The wall is mud plastered wooden structure that occasionally has very small opening for ventilation. Agriculture is the only source of income in the district though petty trades are widely practiced.

Butajira District has one rural public hospital, one private hospital, two government health centers, two government clinics, nine functional health posts in the BRHP sites, and a few private clinics and rural drug shops (personal communication March 2009). Health posts serve as the first entry point to the health referral system, linking the health centers and the district hospital. Malaria, ARI, diarrhea and intestinal infections are the major causes of morbidity. An average of 1.13 (0.16 episode was on ALRI) and 1.17 episodes of ARI and acute diarrhea, respectively, were observed among under-five children in a one-year community based study (134). Under-five mortalities were 80, 160 and 219 deaths per 1000 person-years in urban, rural high land, and low land areas respectively. Life expectancy at birth is about 51 years, which is not very different from the national figure. Infant mortality varied from 80 to 110 deaths for rural highland and lowland areas (132).

The Demographic Surveillance System (DSS) in Butajira has been operational since the mid of 1980's for the purpose of generating continuous demographic surveillance data of deaths, births, and migration as epidemiological population events. The DSS site has 10 clusters called *kebele*s of which nine (5 in the highland and 4 in the lowland) are in the rural sites and one is in an urban community. Ecology in the Butajira DSS sites is defined by altitude. Sites with 2000 masl and above are categorized as highland (*dega*) and those with less than 2000 masl are lowlands (*kolla*) (135). The established surveillance system with its demographic data, the appropriateness of different climate representation and socio-economic profiles of the area were reasons for the selection of Butajira for the indoor air pollution. The indoor air pollution exposure assessment was undertaken in all nine villages of the Butajira Rural Health Project (BRHP). The study on *Indoor air pollution and acute respiratory infections among children in the Butajira area, Ethiopia* has been actively underway since 2000 with the approval of the concerned local and national institutions. The study was initiated with collaboration between the School of community Health of Addis Ababa University and the Department of Public Health and Epidemiology of the Umea University, Sweden. The collaboration was a result of the long standing and productive cooperation between the two institutions. Data collection on IAP was accomplished in late March 2002.

DSS of Butajira follows an open cohort prospective design for the surveillance of vital statistics since 1986 (Figure 11). The cohort individual enters (birth and in-migration) and leaves (death and out-migration) the system any time. Individual’s stay in the DSS is well tracked and his contributed person-time is calculated based on records of movement. The IAP study followed this system for the selection and inclusion of study subjects.



Butajira Indoor Air Pollution Study sites

(Blue lines: Highland sites; red lines: lowland sites)

Figure 9: Map of study area: Rural Butajira and Urban Addis Ababa.

Figure 10: Typical *tukul* in Butajira and interior floor with traditional stove and axis pole at the center

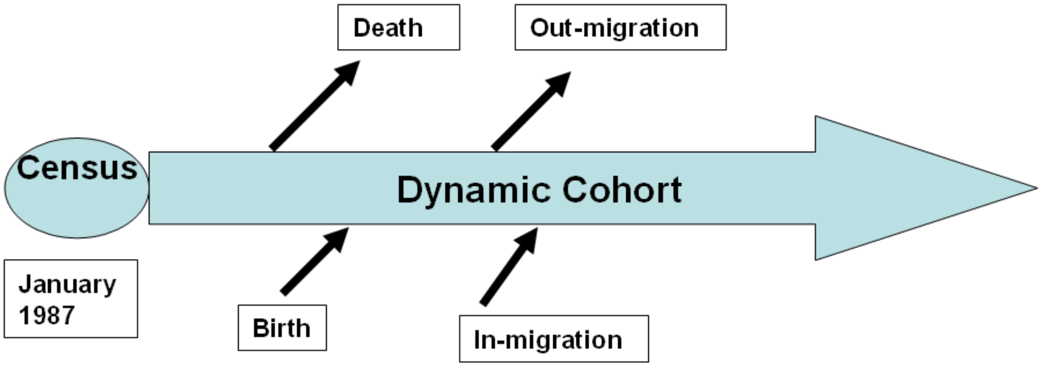


Figure 11: Study design-prospective-surveillance of vital events, DSS Butajira

Source: Berhane Y, Stig Wall, Derege Kebede, et al. *Establishing an epidemiological field laboratory in rural areas - potentials for public health research and interventions, the Butajira rural health programme.* Ethiopian Journal of Health Development 1999;13: 1-13 **(132)**

Addis Ababa population and administration

Addis Ababa is the capital city of Ethiopia with 2.74 million inhabitants in 2007 (108) and with a population density of 5070 persons per sq km. Male to female ratio is about 1.0 to 1.0. The annual population growth is 1.5%, and is largely contributed by in-migrants from other parts of the country. Total fertility rate (TFR) in the city is 1.4. Under-15 years of age population are 24%. Life expectancy at birth is 62 years, which seemed to be 8 years higher than the national average of Ethiopia (112).

The city is administratively divided into 10 sub-zones with 100 *kebele*s, the smallest administrative units having approximately 15,000-20,000 population. *Kebele*s are also the basic units for socio-economic infrastructural developments. A City Council with its branches of local councils at the periphery leads the political and socio-economic life of the city.

Health services in Addis Ababa

The situation of health service coverage and access to preferred health institution is much better in the city than in other parts of the country, despite the negligible difference in disease distribution and mortality patterns compared to the rural population. Privates and NGOs are also involved in the health infrastructure management. There were 11 public hospitals, 28 private hospitals, 29 public health centers (24 are public), 442 private clinics, 236 pharmacies and drug shops in 2008 (data by courtesy of Addis Ababa Health Bureau, March 2009). About 168 million Birr was spent in the form of recurrent expenditures on health (112).

Geography and climate of Addis Ababa

Addis Ababa is located in the center of the country at an altitude of 2200-2800 meters above the sea level (masl), spreading between 9 degrees North latitude and 18 degrees East longitude, with a rising slope from South to the North, North East and North West. The average maximum and minimum temperature were 23.2^{o}C and 10.8^{o}C, respectively, with a total mean monthly rainfall of 78.5 mm in 2007 (23). It has three months of moist season (June-August) and nine months of dry season. A cold season prevails between October and January when a relatively humid air forms dew at nights and sometimes with fog observed occasionally in early mornings (personal observation).

The city of Addis Ababa, with an area of 54 000 hectares, is located at the foot of Mountain Intoto with a number of low-lying pockets. The area with its present expansion approximates a circular shape with a diameter of about 30-40 kms. Its elevation of 2800 to 2200 meters above sea level with a varying degree of vegetation is a factor for the facilitation of natural ventilation system of the air mass in the city. Cold wind flows unevenly from the mountain sides to lower sides in early mornings and throughout the nights, leaving some pockets with stagnated air density. Such localities are found in valleys that follow the basins of streams crossing the city. Sites of low lying places that are found behind hills like the land mass below *Terara Hotel* located on the way to Kotebe could not be effectively ventilated by the air mass around it. This implies that the residence time for air pollutants is sustained for some times in local air mass. The relative rapid cooling effect of the land mass makes the air around it condense and form fog, usually in the early mornings. This is usually observed in wet season (July-August, had few personal observations) and during the months of October-January. The fog is sustained until the land gets relatively warmer than the surrounding air. This is the reason that fog collects traffic pollutants and makes visibility very difficult. It is known that peak exposures to air pollutants can happen during the times of fog formation.

The present city's vegetation coverage is about 11%, which is much lower than the master plan of 41% coverage (data by courtesy of Addis Ababa Regional Government). This is an indication that the natural cleaning capacity of an inner urban environment in which vegetation is involved is minimal.

Street conditions in Addis Ababa

The City Administration estimated the existence of 436-km asphalted and 1725-km gravel roads in 2001, satisfying only 70% of the assumed needs. More than 70% of the roads are below standard with respect to width, which contributes to the congestion of vehicle traffics. Another data source indicated that 48%, and 52% of the asphalted roads have width of 6-8 meters, and 8-12 meters respectively (128). A 14-km travel (from home in Kotebe to work place in Black Lion Hospital) took about 25 minutes in 2000, while in 2004-2008 the travel time reached 40-60 minutes on the average using the same departure time of 7-8 am from home (personal observation). Such an observation has become common at present, an indication that vehicular emissions per traveled unit distance is increasing from time to time. The increase in the number of vehicles without the corresponding expansion of road infrastructures is a possible factor for traffic congestion, and therefore, enhancing the increase of traffic pollution level.

9.2 Materials and Methods

9.2.1 Indoor air pollution assessment

Study design

The research involved a longitudinal design with community-based series of cross-sectional quantitative study to measure NO_2 in all households with under-five children for the period of March 2000 to April 2002 in the rural settings of Butajira. Background data were collected prior the measurement of NO_2. NO_2 measurement was made quarterly. In consistent with Butajira DSS cohort design, households with new births and under-five in-migrants occurring during the study period were included, while households with children above 5 years of age and out-migrants were excluded from this study. In this manner, changes in exposure to indoor air pollution and in the characteristics of fuel use were tracked over two years using repeated cross-sectional surveys.

Study subjects

The study units were households with under-five children. Only households with refusals were planned to be excluded, although this was not found to be a concern. A household in this study was a family living independently and sharing the same roof and food. Respondents were mothers of under-five children and caregivers in the absence of mothers.

Sample size

All households with under-five children in Butajira DSS site were included in the study for a quarterly surveillance of the concentrations of NO_2 and household socio-economic factors. The consideration of involving all households with under-five children was made on the basis of getting about 1000-1500 cases of acute lower respiratory infections (ALRI) for a nested case referent study whose data is linked to NO_2 exposure assessment. The ALRI study considered detection of an odd ratio of 1.5 over the background incidence of ALRI with an exposure of moderate exposure of 80% and in order to detect 1500 new cases of ALRI over two years time which required the involvement of all households with under-five children. ALRI episode per child was 0.16 (134). These two studies, exposure assessment and the case-referent study, were run simultaneously. The number of such households at the beginning of the study was 3,300. Considering the 3,300 households was not changed over time (this is not actually true due to the dynamic nature of the cohort), then there could be about 26,400 records in two years time involving on the average four times per household.

Sampling method

No sampling method was employed for the choice of study subjects as all households with under-five children were considered.

Nitrogen dioxide sampling and equipment

NO_2 was used to measure the aerial concentrations of indoor air pollution in the study area. NO_2 is released as a by-product of any combustions process. The selection of households with children aged less than 5 years was purposely made in order to estimate the level of environmental burden to ARI among children in one of the forthcoming papers.

A 24-hour structured indoor sampling was taken by an air monitor called Willems badge which was developed at the University of Wageningen in the Netherlands (136-138). Willems badge was used for measuring NO_2 as an indicator of air pollution in European Union countries (38, 139). The sampler has a glass fiber impregnated with triethanolamine to absorb the indoor NO_2. The air sampling dates, badge ID, name of PA, starting and completing times were recorded in a separate sheet that was later used for analysis. All field Willems badges in a cold box reached the central laboratory located in Addis Ababa in less than a week after sampling. Different parts of the Willems badge are indicated in Figure 12.

The use of NO_2 for the indoor air pollution assessment has many justifications. The ability to handle large sample size, portability, cheapness, ease of handling in a field that does not require high human skill, absence of frequent calibration, and usability in remote rural areas where electricity is limited are the features of Willems badge (136-138).

Figure 12: Passive air sampler device and assembling (Willems badge or diffusive sampler)

Laboratory method to measure NO_2 concentration

A modified Saltzmann colorimetric method was used to estimate NO_2 concentrations using standard laboratory methods. The glass fiber after sampling was extracted by Saltzmann solution which provides a pink color after the mix because of the NO_2^- ions. A spectrometer at 540 nm wave length was used to determine the absorbance of the colored solutions. A standard curve using nitrite solution was used to estimate the concentration of indoor nitrogen dioxide. The following equation was used.

$$C = 10^6 * Mass / (exposure\ minutes * 40),$$

where 'C' is indoor air concentration of NO_2 in µg/m3; 'Mass' is mass of NO_2 on the glass fiber used for air sampling after subtracting mass of NO_2 of the blank glass fiber; 'expmin' is indoor air sampling duration in minutes ('exposure in minutes'), and 40 is a constant of air sampling rate for the diffusive sampler, 40 ml/min (137). The detection limit of Willems badge depends on the mass of absorbed NO_2 of exposed badges and mass of NO_2 on the blank badge. The aggregated data for standard calibration curves (n=642) were used to sort out the detection limit through the analysis of lowest value of absorbance of the blank and the respective lowest mass of NO_2 on the blank. In this way, it was possible to fix the above equation to provide the minimum NO_2 concentration equivalent to 0.

The use of Willems badge using Saltzman modified colorimetric method for NO_2 measurement was well validated in Sweden (137, 138). Those sources showed recommended the use of Willems badge for the indoor NO2 assessment and personal exposure assessment in factories.

All chemicals used for the preparation of standard NO_2^- and Saltzman solution came from Sweden. The collaborating partner from the University of Umea purchased all necessary chemicals from approved sources. The quality of chemicals was checked before shipping to Ethiopia. The use of chemicals (99% of ethanol, double distilled water, acetone) that were locally purchased were of analytical type.

Household data collection

A structured and pre-tested questionnaire was used to collect data related to socio-economic and demographic characteristics of each eligible household. The questionnaire was administered to mothers immediately after 24-hrs indoor air sampling. Cooking habits characterized by type of fuels, purpose and timing for using the fuel, and type of food cooked on the same day of indoor air sampling, a week and 3 months before that were included in the questionnaire. These data were used to check variations in NO_2 over the study duration.

The physical dimensions (radius, axis, and wall height) of the study homes were taken from the 1999 Butajira DSS census, which was launched just before the beginning of the study.

Data quality

The laboratory data quality was maintained using various methods. Laboratory technicians were properly trained and supervised on each day of laboratory analysis. The internal validity of the laboratory procedures were checked by analysis of standard solution, blank absorbance, and control chart for NO_2. The inter laboratory variation was also checked by the analysis of exposed badges in the indoor and outdoor situations and looking at NO_2 concentration variations between morning and afternoon sessions of laboratory analysis. All data quality activities were properly recorded for follow up evaluations.

Data management and analysis

Indoor air pollution data were entered and cleaned using the Epi Info version 6.04d statistical package (version 6.04; Center for Diseases Control and Prevention, Atlanta, GA, USA and World Health Organization, Geneva, Switzerland). The Butajira DSS database was used for cross checks of IDs of respondents and household numbers. The data base was also used to identify new households entering and leaving the study. Consistency and completeness of each questionnaire was checked both at the field and during data entry. Data were analyzed using EPI INFO, and SPSS (version 15; SPSS Inc., Chicago, IL, USA). STATA (version 9.0; STATA Corp LP, College Station, TX, USA) was used to adjust the effect of clustering of NO_2 on the same household. The data set was exported first to dbf and then to SPSS sav files for advanced statistical analysis. Mean values and 95% CI of NO_2 concentrations were calculated to compare with relevant data. NO_2 concentration was transformed into log10 to meet the assumptions of normality in assessing the difference in mean NO_2 concentrations by selected variables. Box plots and stem plots were intensively used to identify outliers when comparing mean values of NO_2 concentrations.

Analysis of variance (one way ANOVA and one way repeated measures of ANOVA) was employed for the detection of any difference and change in NO_2 concentrations in the presence of fuel-use characteristics. A multiple linear regression (Enter method) was run to find out the relative importance and predicting power of household physical characteristics after checking assumption of normality and multicollinearity. Linear mixed model was used to evaluate fire-use determinants related to NO_2 concentrations. This analysis was useful to adjust the effects of repeated measurements. Descriptive statistics, tables, and charts were used to present major findings.

Ethical Considerations

The study had ethical approval from both countries, Sweden and Ethiopia. The local ethical clearance was obtained from the Faculty of Medicine, Addis Ababa University, and the then Science and Technology Agency of Ethiopia. The purpose of the study was verbally communicated to each respondent and verbal consent was secured once agreement on the interview was obtained. Inconveniences for the provision of air sampling and refusals were very much respected, although the study did not face any serious problem in this regard. Results of the study are planned to be communicated to the local authorities and community after publication.

9.2.2 Traffic air pollution assessment

Study design

An urban based cross-sectional study for the traffic air pollution assessment was taken in the months of July 2007 and January 2008 in Addis Ababa. July and January represented the wet and dry seasons of the Ethiopian calendar, respectively.

Study subjects

Roadside shops and kiosks were selected to host the sampler for about 10 hours of sampling duration in order to avoid loss of samplers.

Sample size

A literature based purposive judgment was used to involve 80 traffic air samples, 40 samples each for the moist and dry months. A sample size of 40 was assumed to be adequate for the exploration of CO real time concentration in the two time series. CO monitor availability was the main limiting factor to this optimum sample size

Sampling method

Addis Ababa traffic count was consulted for the selection of traffic density. Roadside sampling sites were selected purposely in high traffic density areas in order to detect the maximum possible traffic pollution. All sampling sites were located on the road side with 2-10 meters from the nearest road edge. The absence of any barrier between the traffic line and the sampling site was ensured at the time of sampling. Once the traffic line is identified, a transient walk was made to identify the presence of kiosks and shops that could satisfy the selection criteria. Exact locations were identified using GPS taking (GPS 12 XL, Garmin 12 channel). The estimated traffic density of sampling points and GPS locations are indicated in Table 9.

Table 9: Traffic counts per 24 hours along sampling points, Addis Ababa 2005

SN	Sampling sites	Traffic count	UTM X Coordinate	UTM Y Coordinate
1	Legehar Megenagna Mini bus stop	17,752	472863	995952
2	Churchil, Pepsi Kiosk infront of Post Office	10,184	472660	996938
3	Autobus Tera-Andnet shop near Mesgid	12,332	471416	998417
4	Black Lion Hospital gate, in front of SIM	17,877	472315	996962
5	Autobus Tera shop, next to Z music	12,332	470463	998360
6	Autobus Tera Ismael shop near Z Music	12,332	470454	998362
7	Piassa Awash Stationary	14,239	473090	999061
8	Paissa infront of Commercial Bank	8,714	472939	998309
9	Gotera intersection, bread retailer	13,889	473522	992078
10	Gotera, infront of 3F, General shop	14,311	473971	989923
11	Bole road near Flamingo, Electronic shop	14,465	474051	995592
12	Bole Printing Press Coka Cola Kiosk	12,670	474814	994357
13	Kazanchis, Grocery, near Awash Bank	21,655	474463	996479
14	Kazanchis, ceramic shop, Urael direction	17,752	474999	995958
15	Megenagna, Yaekob Mobile center	16,362	477855	996793
16	Haya Hulet Mazoria, general shop	14,875	476560	996417
17	Kotebe College infront, dairy kiosk	12,722	482325	998813
18	Gofa intersection, Kokeb Fashion	13,662	472508	992968
19	Gofa intersection, Mebrat Hail	13,662	472387	992681
20	Saris, Blue Nile shoes, infront of Red Cross	14,997	473939	989571
21	Harer Fruit shop named Harer, Saris Chimad	17,992	474207	988558
22	Mesalemia Mimi Bakery shop	13,815	469548	998515
23	Autobus Tera, Alfa public book	12,332	470177	998354
24	Giorgis intersection Pepsi kiosk	10,583	472680	998838
25	Giorgis, Ato Teklu Barber Verandah	10,583	472742	998557
26	Giorgis Church translation and PC service	10,583	472680	998709
27	Dej. Bela Road, Marvlous PC center	8,010	472124	999803
28	Sidist kilo total, Hiwot stationary	3673	473900	999419
29	Medhanialem School, MN shoe repair shop	13815	469057	1000341
30	Kotebe College end of fence, Harer shop	12,722	482647	998872
31	Teklehamanot, Kurtu Tyre shop	12,877	472066	997242
32	Teklehaimanot, Tsion Spare parts	13,255	471800	997712
33	Leghar, Watch and eye glass kiosk	21,384	472518	995950
34	Sengatera, electric shop	19,344	472182	996227
35	Lideta, Tele Center	6,192	470724	996089
36	Lideta, Temesgen shop, infront of Balcha	24,738	471192	995863
37	Lideta, near Desse Hotel Pepsi kiosk	20,630	470633	995927
38	Mexico Square Pepsi kiosk	21,384	471880	995830
39	Kera Discovery shop near Genet Hotel	10,391	472099	994742
40	Kera, Teka shop near Bulgaria Mazoria	10,391	472180	994047
41	Olympia Traffic Post light	19672	474431	995099
42	Legehar Traffic Post light	17752	472746	995958
43	Urael Traffic Post light	17122	475133	995861
44	Post Office Traffic post light	17877	472676	997004

Source: Addis Ababa Roads Authority, 2005.

Data collection and Instruments

A structured check list was used to collect basic data such as starting and ending time, date, sampler code, and location. Two portable CO USB data loggers (Figure 13) were used to measure the level of CO in each sampling site. The USB CO monitor had a detection limit of 0 to 1000 ppm, storing capacity of 32510 measurements with an operating temperature range of -10-40^{o}C and humidity of 15-90% . The CO logger had an internal resolution of 0.5 ppm and accuracy of ±6%of reading (140). The CO monitor operated based on electro-chemical reaction, in which the CO was oxidized internally by a sensor into CO_2 and registered at a given time interval. The CO monitor had many features which included portability, inexpensiveness, easy manageability during data collection, not requiring frequent calibration, and ease of getting CO data using an inbuilt software (133). In addition, there was a preference to look first on the more toxic emission agent, which is CO, and then look for alternatives. Theses advantages are reasons for selecting this equipment. The use of Willems badges was not indicated as NO_2 measurements is affected by the outdoor wind (137-138).

Two samples were collected daily using the two CO monitors. A user-friendly CO monitor with inbuilt software was used to stop the data logging, download the data, and fix the logging rate, starting time and date. Sampling interval of 10 seconds (10s) was set in order to pick any varying level of CO. A data sheet was used to record the date, USB ID code, name of site of sampling, and the time at which the air sampling in the office and sampling site was set and stopped.

CO monitors were set at 2-meter height in a visible location of the selected local roadside sampling point after ensuring the free flowing of air from the immediate traffic towards the sampler. Sampling duration for the actual analysis in all sites was set between 7:00 am and 18:00 pm in order to get maximum possible CO concentration from vehicular activities.

Sampling was done from Monday to Saturday for each on-traffic line sampling site between March 31 and April 12/2008. The on-line traffic was similarly done by placing the CO monitor at 2-meter height just under the traffic light post (Figure14 and 15), which was located at the center of the road serving vehicles in both directions.

Figure 13: EL-USB-CO (carbon monoxide data logger)

Figure 14: Field location of CO monitor in road side sampling sites, Addis Ababa, Ethiopia, July 2007

27-28 Mar 08:

Pre-testing sampler;
Post Office Traffic light

CO sampler
location

Figure 15: Field location of CO monitors on a traffic light stand, Addis Ababa, Ethiopia, April 2008

Data quality assurance

A factory-calibrated two CO-data loggers were used to measure CO. These CO loggers were checked for validity in a gas chamber with known CO concentration at Bowling Green State University, Ohio, USA. In addition, a quality control protocol was used to evaluate the performance of the two CO loggers during the study time. The protocol was to check the consistency and reliability of measurement of the two loggers by placing them in the same location and same sampling characteristics (timing, height). The consistency and reliability of CO measurements were checked for the time fraction between the monitor login setting and the actual sampling. The second time fraction was between completion of actual sampling and downloading of the data. All these time fractions were on the road while traveling to the sampling sites. There were 17 different tests, each having duration of about 1.5-3 hours of sampling.

The third quality control protocol involved the traffic air sampling for all day along roadside sites that were selected based on medium and high traffic density. There were 12 such measurements, each taken for 10-11 hours sampling duration. The data quality control chart is indicated in Figure 16.

The 4th method involved the use of CO monitor variant called Hobo, which was used for the measurement of CO in a project evaluating stove efficiency. Hobo and USB CO logger were placed at the same conditions to measure CO for 24 hrs. Hobo was assumed to validate the CO USB logger as it had better calibration procedures.

The level of agreement between the two monitors was evaluated by the correlation coefficient. A scatter plot and linear regression analysis were employed to evaluate the pattern and direction of the relationship. The correlation coefficients were more than 0.90 and beta coefficients for the regression were closer to unity. Details of summary statistics are indicated in Paper III.

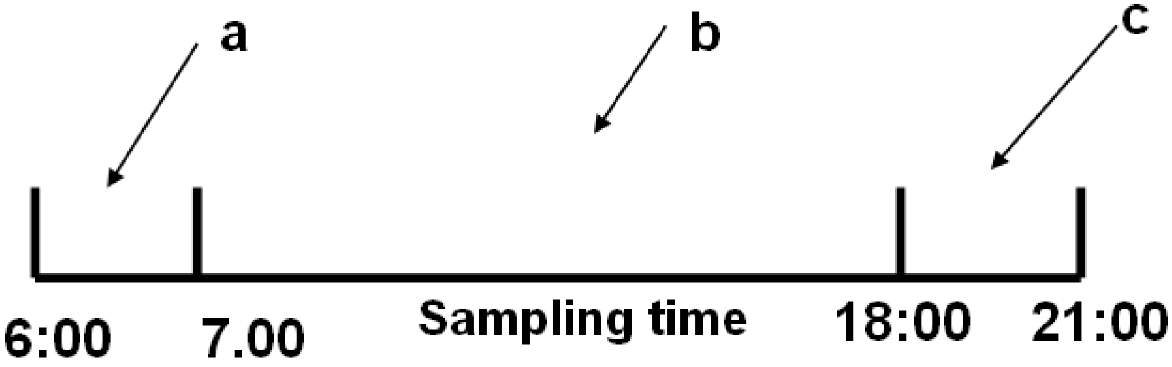


Figure 16: CO-monitor data quality control protocol: (a) and (c) had 17 sampling tests for a duration of 1-3 hours; (b) had 12 sampling tests for a duration of 11 hours

Data management and analysis

Traffic air data from the CO data logger was immediately downloaded using Excel format after each episode of sampling using El-USB-CO software. The 10 seconds original averaging time was transformed into 15 minutes averaging time in order to manage the data with better resolution. Excel line charts were mainly used to evaluate CO pattern by time and characterize sampling sites. Summary statistics were calculated using Excel software (Microsoft Office Excel 2003), while SPSS (version 15; SPSS Inc., Chicago, IL, US) was used to evaluate the data quality performance using correlation coefficients and beta values of linear regressions. Graphs and tables were used to summarize the data. Weighted mean, maximum averages, tables and graphs were used to describe the data. US-EPA and WHO ambient air quality guidelines were used to compare the research findings.

Ethical Considerations

Willingness of road side shop owners to host the traffic air sampler was requested after explaining the purpose, the reason for selection, and demonstrating how the instrument operates. The air sampling was arranged only after getting their verbal agreement. Addis Ababa Traffic Police Department was formally consulted for the selection of appropriate traffic light posts. The Department had communication with branch traffic offices about the study after securing permission. Preliminary results were communicated to the Traffic Police Department in September 2009.

10. MAJOR FINDINGS

Main findings of this thesis are outlined in Table 10. Important major findings for both indoor and traffic air pollution are presented in some depth.

Table 10: Major findings of the Thesis

Research questions	Major findings
Paper I 1. What is the magnitude of indoor air pollution using NO_2 as an indicator? 2. Is there a variation in NO_2 by type of ecology? (Spatial variation?) 3. Is there a variation in NO2 by time? (temporal variation)	o The overall 24-hour mean NO_2 ($97 \mu g/m^3$) concentration was about 2.5 times more than the 2005 WHO proposed air quality guideline for NO_2 o There is a spatial and temporal variation in NO_2. Increased concentration was found in "Dega" areas during wet season.
Paper II 1. What are sources of NO_2 variation in households using biomass fuel? 2. Is there a defined relationship between sources of variation and NO_2 concentrations?	o Biomass fuels of wood and crop residues are the dominant source of household energy in the study area. o Household use fuel characteristics, ecology, and season were important household variables to explain the variations in the daily NO_2 concentration o Highland ecology is a major predictor of NO_2 concentrations. o Physical structure of housing unit, its volume and the presence of separate kitchen, have weak association with indoor NO_2 concentrations. o Repeated measurements of 24 hr averaged NO_2 concentrations varied over time (within household to household variation)
Paper III 1. What is the level of traffic air pollution using CO as an indicator in road side shops and kiosks? 2. Does road side CO vary by season? 3. What is the level of CO under the traffic light post? 4. Is there a link between the road side and on-road CO concentration?	o The 15 minutes, 1-hr and 8-hr average CO concentration did not exceed the WHO guideline for the roadside sampling points. o Six in 40 road side sampling sites and 3 in 4 on-road sampling sites had exceeded 50% of the 2005 WHO 8-hr guideline. o The weighted mean (±SD) of CO in wet season (July 2007) and dry season (January 2008) were 2.03 (1.94) and 2.64 (2.53) ppm. The mean CO concentrations did not vary by season. o The overall daily mean of CO concentration measured under the center of the traffic light post (5.7 ppm) did not exceed the WHO 8-hr guideline of 10 ppm. Average CO concentrations of Monday through Friday were similar, but 50% more than Saturday's. "Olympia" traffic site had increased CO concentrations compared to other there sites involved in the study o Similarity in the daily pattern of CO concentration is an indication that on-line traffic sources are related to road side CO concentrations.

Main findings of Papers I-III

10.1 Paper I: Magnitude of Indoor NO2 from Biomass Fuels in Rural Settings of Ethiopia[1]

The magnitude of indoor air pollution can be measured using various indicators. The use of proxy indicators to measure the exposure were popular until the mid of the 20th century. Such proxy indicators were widely used because of their simplicity. The technology of air pollutant measurement is now available to explore both environmental and personal exposures. NO_2 was used as an indicator of biomass smoke components.

Magnitude of NO_2

A 24-hr weighted mean (±SD) was 97.0 µg/m^3 (91.41) involving 17,215 NO_2 measurements. The distribution of the mean NO_2 concentration was highly positively skewed, making the median (inter quartile range) 68.4 (97.7) µg/m^3. NO_2 concentrations varied significantly from one sampled household to another. The variation was so wide including as low as 0 and as high as 978 µg/m^3 among all measurements (Figure 17). This between-household variations is acceptable as no smoke provided no measurement and intense smoking provided very high concentration. This is a characteristic of findings by many environmental sampling.

Variation in NO_2

Comparing average level of NO_2 meaningfully was important for this study. Data was aggregated and initially compared by agro-ecology after adjusting the dependency of measurements. Highland villages had adjusted mean (95%CI) 76.48 (73.9,79.1) µg/m^3, while low land villages had 49.9 (47.8,51.4). A difference of 26.6 µg/m^3 was big enough to conclude for the presence of significant difference. Figure 18 indicates the arithmetic mean distribution of NO_2 by ecology. A reflection of this difference is found in variation in NO_2 between wet and dry seasons, which had mean (95%CI) 66.4 (64.54, 68.3) µg/m^3 and 58.58 (56.87,60.34) µg/m^3, respectively, although the magnitude of the difference was a bit lower in the extent compared to

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[1] **Publication: Submitted 15 December 2008; accepted 8 June 2008; on line published 6 Oct 2008; Published as "Volume 19 Issue 1, pages 14-21'; PubMed Indexed Feb 2009 as "Indoor Air 2009 19(1):14-21"**

the ecology. However, the magnitude of variation as measured by variance in all cases was too big, has almost similar magnitude with the corresponding mean indicating the presence of high variability in NO_2 concentrations.

Temporal variation in NO_2 concentration by month was visible. January, May, June, July, and August had showed increased NO_2 concentrations over the yearly average. The increasing rate ranged from 1% to 13%, the highest being for July. The months of June-August are wet seasons for the Ethiopian climate. The difference in NO_2 average concentrations between dry and wet months is an indicative of that the use of biomass fire is related to climatic condition, temperature and moisture in particular.

Monthly rainfall and minimum and maximum temperature were sought for the town of Butajira during the study period (2000-2002) to relate with the monthly average NO_2 concentrations. Assuming these data work for the rural settings with minimal variation, maximum temperature and rainfall had good correlation (r=0.61, r=0.82, respectively) with NO_2 concentration (Figure 19 and 20). Correlation between 0.50 and 0.69 is moderate, and between 0.70-0.89 is high (141).

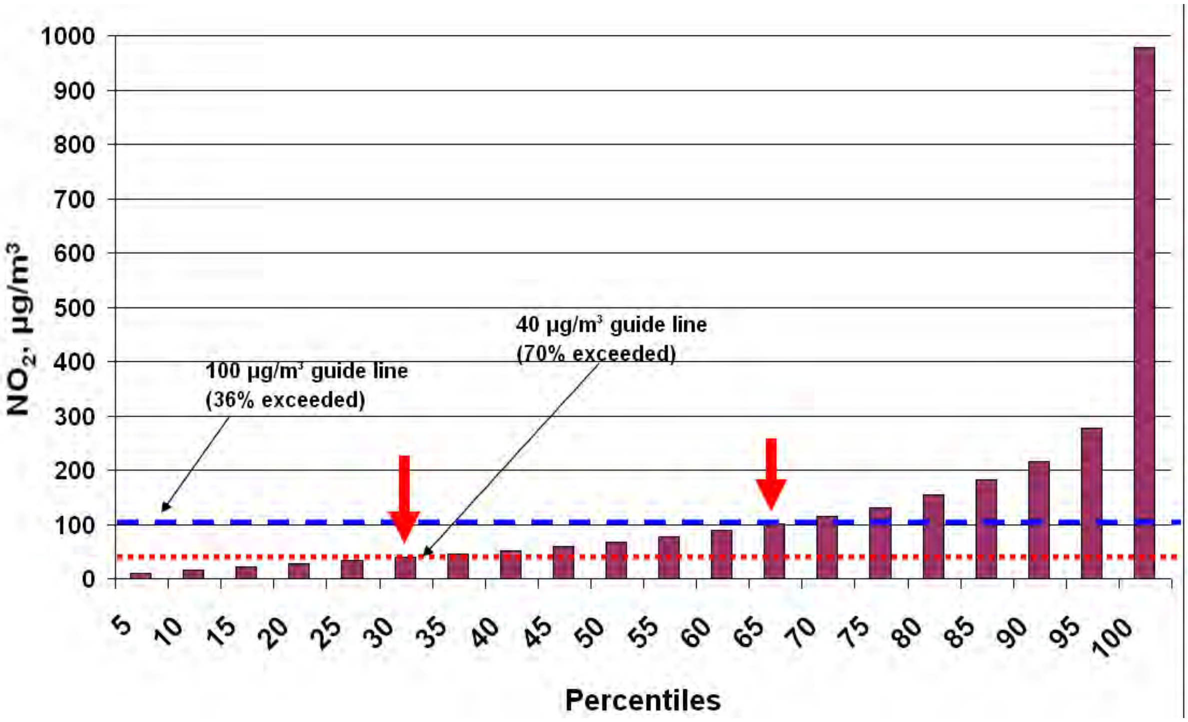

Figure 17: Distribution of NO_2 concentration by percentiles, Butajira, Ethiopia, 2000-02

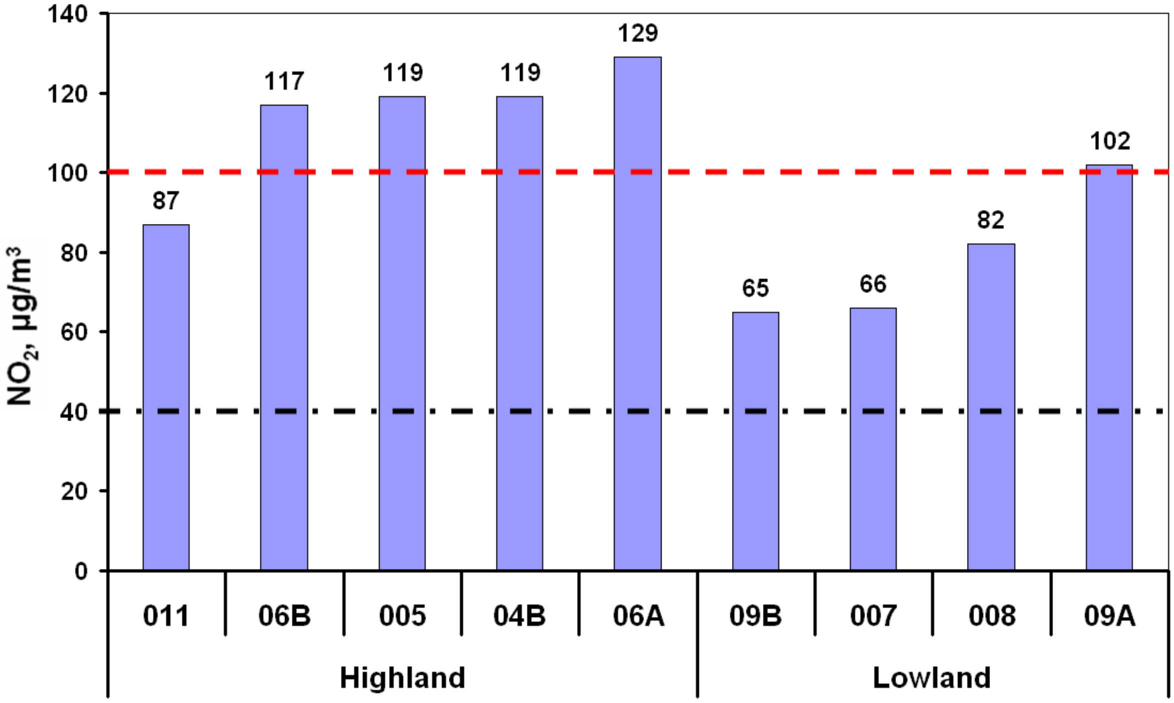

Figure 18: Indoor NO_2 concentrations by village and ecology, *Butajira*, Ethiopia, 2000-2002

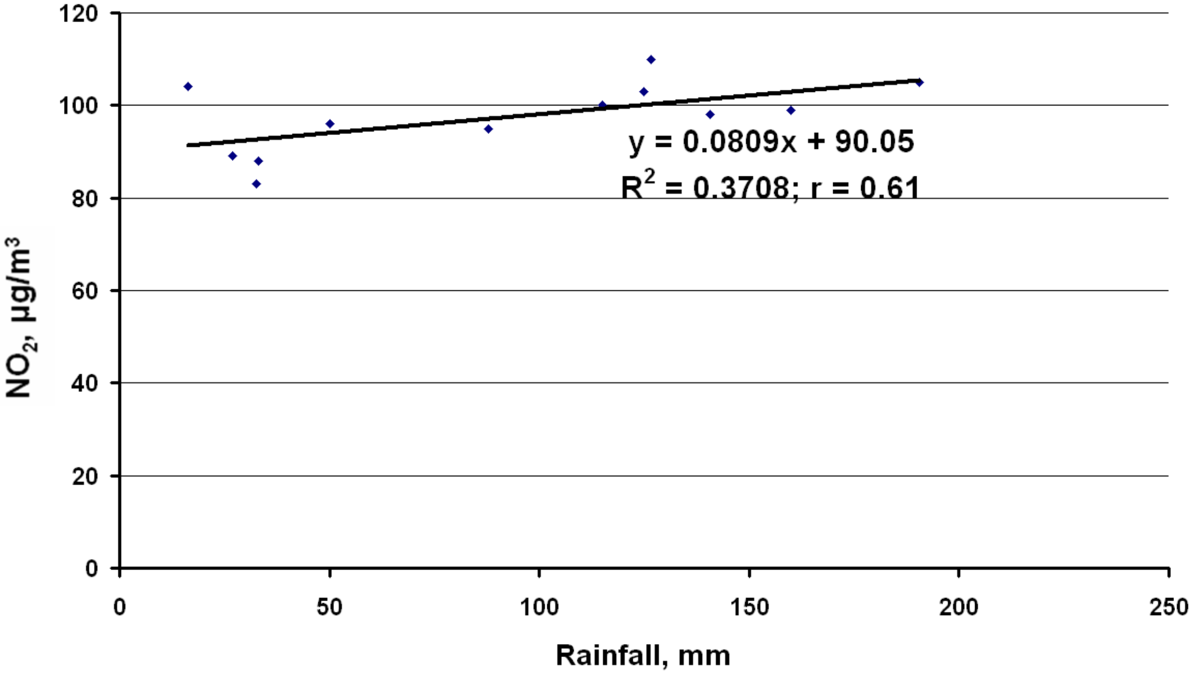

Figure 19: Monthly rainfall related to monthly NO_2 concentrations, Butajira, Ethiopia, 2000-2002

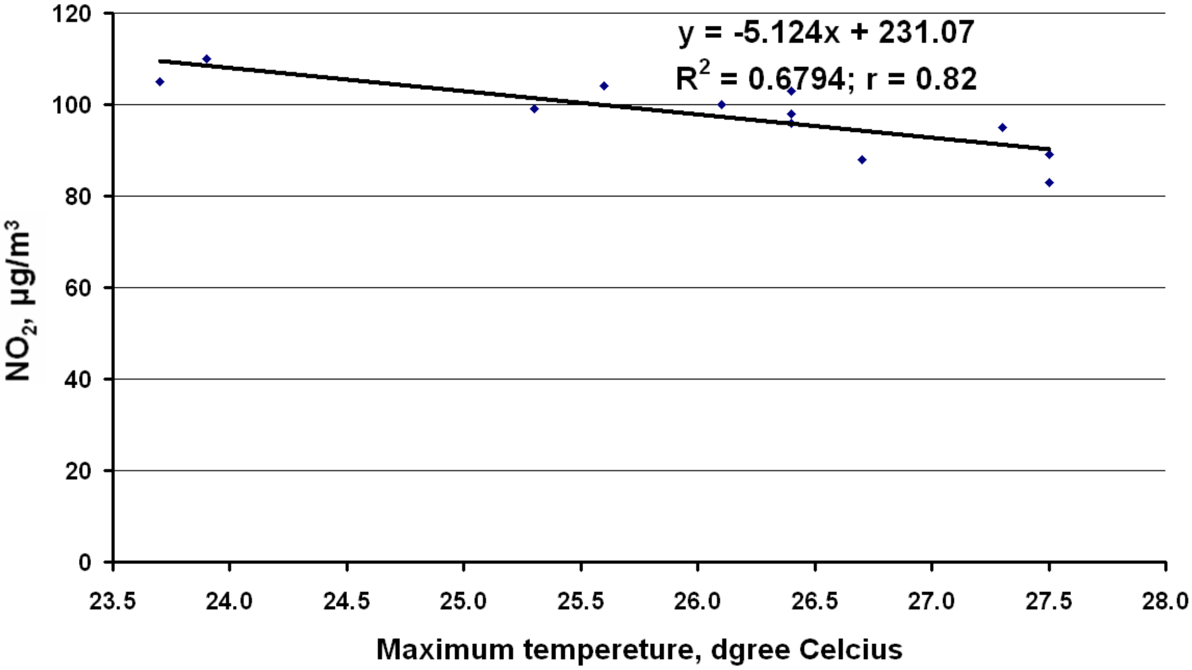

Figure 20: Monthly maximum temperature related to monthly NO_2 concentrations, Butajira, Ethiopia, 2000-2002

10.2 Paper II: Sources of Variation for Indoor NO_2 in Rural Residences of Ethiopia[2]

Household energy sources

The dominant source of household energy was biomass fuel. Firewood and crop residues were largely used. The distribution of biomass fuel (as defined by used "only" or "mostly") was 51%, 45%, and 2.4% of the observations (n=16899) for fire wood, crop residues, and cow dung, while 29%, 16%, and 0.4% had exclusive use, respectively. Kerosene was used only in the majority of households to illuminate the lamp for the interior. There was a difference in the types of biomass fuel used: the use of wood predominated in the *dega* ecology (74%), while crop residues and animal dung were mostly used in the *kolla* ecology (71% and 79%, respectively).

Purpose of fire use

Among the quarterly interviewed households asked for a multiple response (n=16899 interviews), cooking, heating, and insect repelling were found to be the main purposes of biomass fuel use in 98%, 35%, and 13% of the samples, respectively. Cooking one type of food per day was an uncommon practice, only 4% of the interviewed cases practiced it. More common was cooking two and three types of food per day, 16% and 77%, respectively. Types of food frequently cooked included *gomen*, coffee (for traditional ceremony), bread and *kocho*. Three times a day use of fire was common: morning, midday and evening. The use of fire at night and once a day was uncommon.

Sources of variation: Bivariate and multivariate analysis (Biomass fuel use related variables)

24-hr averaged NO_2 concentrations varied by type of biomass fuel used. In a one-way ANOVA, higher concentrations were observed with wood and cow dung users compared to those that employ crop residues, accounting for 21 $\mu g/m^3$ difference (arithmetic mean: 107 Vs 86 $\mu g/m^3$) (Figure 21). In addition, the purpose of fire use, frequency of food, and timing for use showed increased NO_2 concentrations in a one-way ANNOVA.

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[2] Status: Submitted to BMC on 27 November 2008, Environmental health Journal type; Reviewers comment received on 4 April 2009; Under review.

A linear mixed model was employed in order to isolate relevant variables affecting indoor air pollution. In addition to the above indicated variables, ecology and season were included as distinct parameters following the findings of Paper I. Almost all t-variables were found to significantly contribute to the differences in NO_2 average concentrations. Higher concentrations were found in highlands (by ecology) and during wet season in households that use crop residues, use fire at least once a day, and cook any number of food items in a day. The purpose of fire use (cooking, heating, or repelling insects) did not come out as main effect to impact NO_2. Figure 22 indicates the relationship between the number of food items cooked and NO_2 concentration demonstrating the gradient of NO_2.

Sources of variation (housing physical structures)

There was an initial null hypothesis that the physical structure of *tukul* affects the NO_2 concentration: the larger the volume it has, the less likely would be NO_2 concentrations and vice versa. Measurements of radius, axis, and wall height were extracted from *Butajira* census data of 1999, which was conducted just before the present study. The same data source was also used to extract the presence of window and type of kitchen. These housing variables were considered to explore their effect on indoor air pollution. When the relationship of these variables with weighted mean of NO_2 was subjected in a hierarchical multiple linear regression Model, “volume” and presence of separate kitchen had significant association with NO_2 concentration. However, only volume factor was found to be a strong predictor as it, compared to the kitchen variable, contributed to larger explainable variation in the outcome variable.

Repeated measurements of NO_2

About 3,300 households at the beginning and 3,924 households with under-five children at the end of the 26^{th} month of study were contained in the research. The mean ($\underline{+}$SD) number of NO_2 measurements was 4.37 (1.90) per household, while the median was closer to 5. Measured five NO_2 concentrations at different times were compared using repeated ANOVA to explore the presence of any difference over a series of time. The compared five NO_2 measurements in order of time 1 to time 5 were GM ($\underline{+}$GSD): 68.6 (2.58), 70.3 (2.54), 69.1 (2.47), 70.1 (2.49), 65.2 (2.62) $\mu g/m^3$ (n=2051). Post hoc pair-wise comparison showed that the difference was accounted between time 2 and time 5, time 4 and time 5. mparison showed the difference was accounted between time 2 and time 5, time 4 and time 5. There was a significant difference in the repeated measurements of NO_2 concentrations over time, Wilk's Lambda=0.993, (F(4,2047)=3.46, $p<0.05$ with multivariate eta squared=0.007 and observed power of 89%. The repeated NO_2 measurements also differed by ecology, (F(1,2049)=260.5, $p<0.05$) and by location of households ("peasant associations"), F(8,2042)=48.9, $p<0.05$).

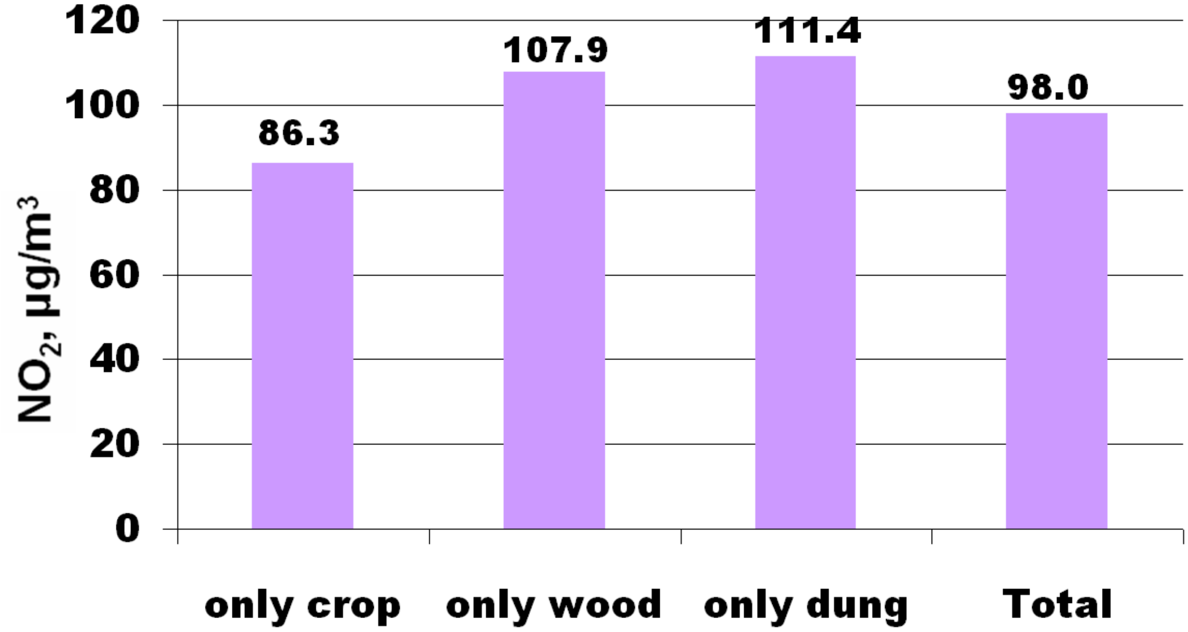

Figure 21: 24-hr averaged NO_2 concentration by type of biomass fuel, *Butajira,* Ethiopia, 2000-2002

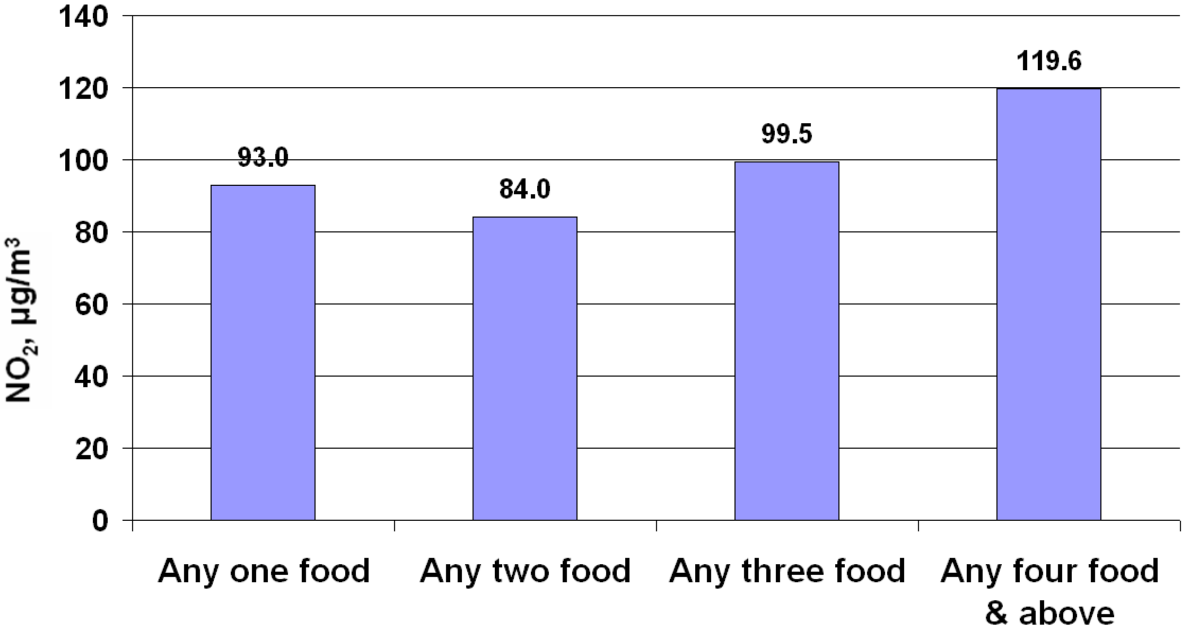

Figure 22: 24-hr averaged NO_2 concentration by frequency of cooked food items, *Butajira*, Ethiopia, 2000-2002

10.3 Paper III: The Level of Traffic Air Pollution as Measured by CO in the City of Addis Ababa, Ethiopia[3]

Magnitude of CO on roadside sampling sites

The 10 seconds averaging used for original sampling was converted to 15 minutes to meet two advantages: smoothening the data for better time trend analysis, and comparing the averages with international guidelines. In the majority cases of roadside air sampling, the CO measurement duration was between 7:00 am and 18:00 pm. This was purposely made in order to maximize the presence of high vehicles activity on the road.

The 15-minute mean of (±SD) 2.03 (1.94) ppm for the wet month of July 2007 and the 2.53 (2.53) ppm mean for the dry month of January 2008 did not show any difference. The daily CO profile for both sampling times was similar. Temporal variation in CO concentrations was observed. There was increased CO concentration above the average during increased on-road vehicular activities which was commonly observed between 8:30-9:00 am and between early and late afternoon (14:30-18:00 pm) for July 2007, and 7:30-8:30 am and 14:20-16:30 pm for January 2008. The month of January had a third component of exceeding the daily average: lunch time between 12:30-13:20 pm. Excess of CO concentrations during lunch time was uncommon.

The spatial variation of CO concentration was visible in that the study sites had as low as 0 ppm (CO monitor could not detect any concentrations) and as high mean as 7.75 ppm. The maximum reached as high as 18 ppm in one of the sampling sites. There were six pocket roadside sites where increased CO concentrations were consistently observed during both sampling months. The sites were located on Kera Road, Gofa intersection, Bole Road (two sites), Haya Hulet Mazoria on Megenagna Road, and Legehar mini bus stop sampling sites (Figure 23). They had between 5.1 and 6.4 ppm average for the two months, representing about 60% of the WHO 8-hr limit. Roadside sampling aerial location by the weighed mean of CO is indicated in Figure 24.

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[3] **Submitted to Journal of Environmental and Public Health, Hindawi Publishing Corporation, 20 April 2009, under review by Editor in Chief.**

The 15 minutes, 30 minutes, 1 hr and 8 hrs of WHO guidelines for CO were not exceeded. However, 15% of the roadside samples and 3 in 4 of the on-road side samples had exceeded 50% of the 8-hrs WHO guideline.

Four on-traffic line samplings were included to evaluate the average and time trend of CO concentrations. The four sites, namely, Main Post Office, *Legehar, Urael*, and *Olympia* traffic light posts, were included after physical observation by counting traffic densities for a brief time and consulting the on-duty traffic police. The mean (±SD) 15-minute averaged CO concentrations are indicated in Table 11. The overall 15-minute average for each day looked similar, except for Saturday, which was about 50% less, implying the presence of higher rate of traffic air pollution during Monday through Friday. However, the spatial variation was significant: Olympia traffic post had visible increased CO concentration (Figure 25).

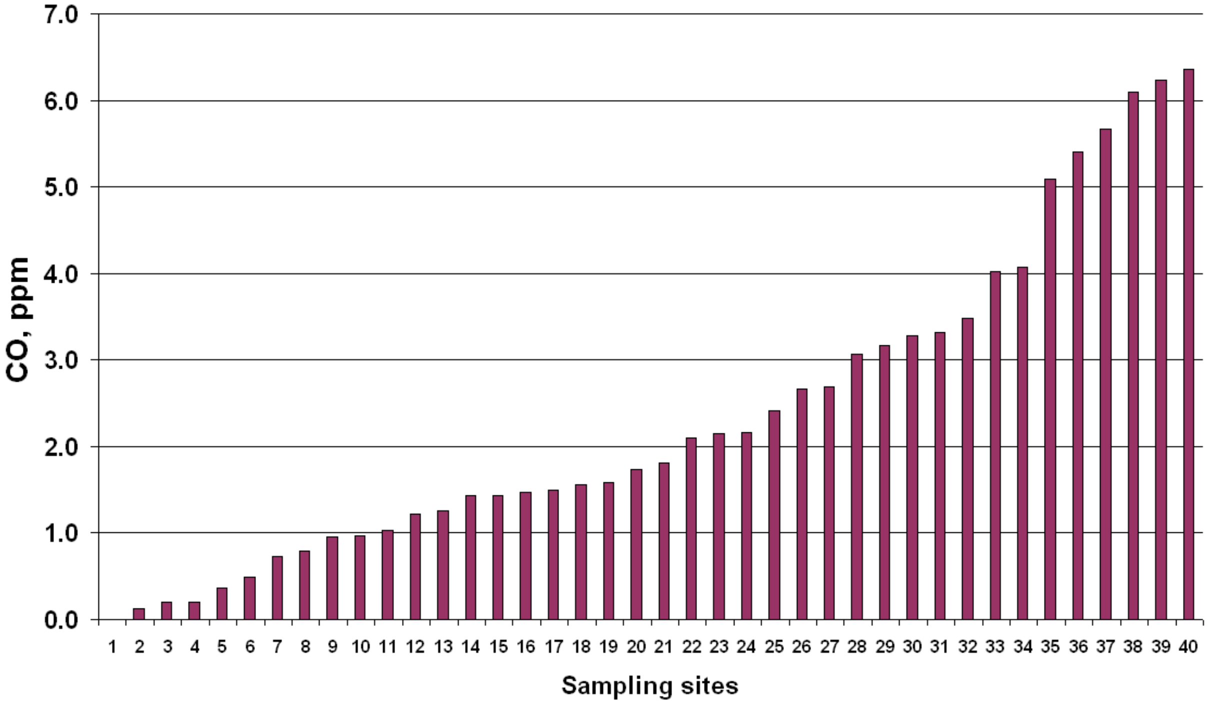
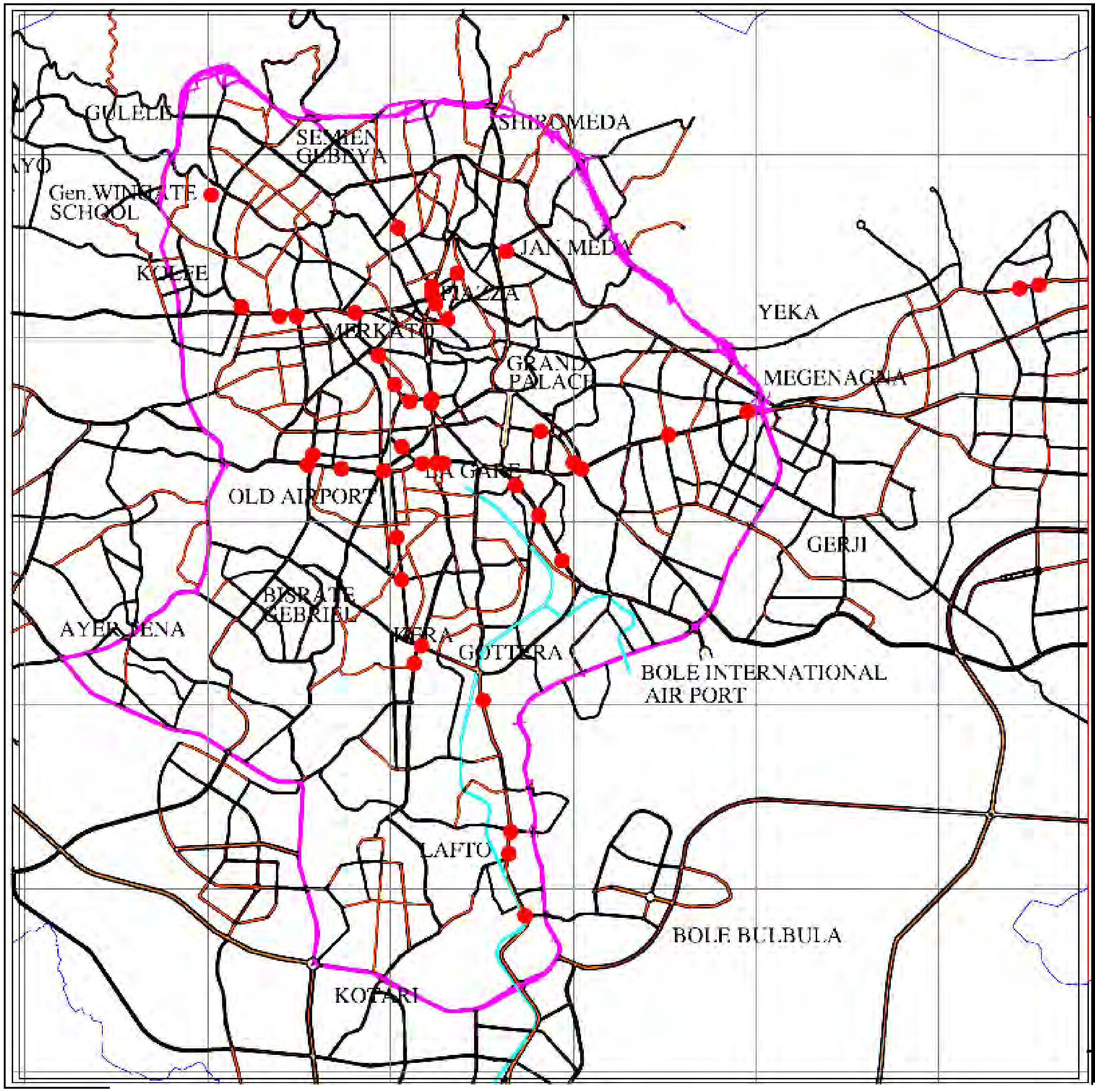


Figure 23: Averaged CO concentrations for the two sampling periods, Addis Ababa, Ethiopia (July 2007 and January 2008) (35-“Discovery Kera road”, 36-Kokeb Fashion Gofa intersection”, “37-Bole Printing Press Bole road”, “38-Legehar mini bus stop” , 39-“Haya Hulet Mazoria Megenagna road”, , 40-‘Bole Flamingo Bole road”).



SN	Sampling site	UTM X	UTM Y
1	Legehar Megenagna Mini bus stop	472863	995952
2	Churchil, Pepsi Kiosk infront of Post Office	472660	996938
3	Autobus Tera-Andnet shop near Mesgid	471416	998417
4	Black Lion Hospital gate, in front of SIM	472315	996962
5	Autobus Tera shop, next to Z music	470463	998360
6	Autobus Tera Ismael shop near Z Music	470454	998362
7	Piassa Awash Stationary	473090	999061
8	Paissa infront of Commercial Bank	472939	998309
9	Gotera intersection, bread retailer	473522	992078
10	Gotera, infront of 3F, General shop	473971	989923
11	Bole road near Flamingo, Electronic shop	474051	995592
12	Near Bole Printing press Coka Cola Kiosk	474814	994357
13	Kazanchis, Grocery, near Awash Bank	474463	996479
14	Kazanchis, ceramic shop, Urael direction	474999	995958
15	Megenagna, Yaekob Mobile center	477855	996793
16	Haya Hulet Mazoria, general shop	476560	996417
17	Kotebe College infront, dairy kiosk	482325	998813
18	Gofa intersection, Kokeb Fashion	472508	992968
19	Gofa intersection, Mebrat Hail	472387	992681
20	Saris, Blue Nile shoes, infront of Red Cross	473939	989571
21	Harer Fruit shop Saris Chimad	474207	988558
22	Mesalemia Mimi Bakery shop	469548	998515
23	Autobus Tera, Alfa public book	470177	998354
24	Giorgis intersection Pepsi kiosk	472680	998838
25	Giorgis,Ato Teklu Barber Verandah	472742	998557
26	Giorgis church translation and PC service	472680	998709
27	Dej. Bela Road, Marvlous PC center	472124	999803
28	Sidist kilo total, Hiwot stationary	473900	999419
29	Medhanialem School, MN shoe repair shop	469057	1000341
30	Kotebe College, end of fence, Harer shop	482647	998872
31	Teklehamanot, Kurtu Tyre shop	472066	997242
32	Teklehaimanot, Tsion Spare parts	471800	997712
33	Leghar, Watch and eye glass kiosk	472518	995950
34	Sengatera, electric shop	472182	996227
35	Lideta, Tele Center	470724	996089
36	Lideta, Temesgen shop, infront of Balcha	471192	995863
37	Lideta, near Desse Hotel Pepsi kiosk	470633	995927
38	Mexico Square Pepsi kiosk	471880	995830
39	Kera Discovery shop near Genet Hotel	472099	994742
40	Kera, Teka shop near Bulgaria Mazoria	472180	994047
41	Olympia Traffic posslight	474431	995099
42	Legehar Traffic Post light	472746	995958
43	Urael Traffic Post light	475133	995861
44	Post Offic Traffic post light	472676	997004

Figure 24: Location of CO monitoring sites, Addis Ababa, July 2007 and January 2008, Ethiopia

Table 11: Daily minutes averaged CO concentration by traffic light posts, Addis Ababa, Ethiopia, March 2008, Ethiopia

	Post Office		Legehar		Urael		Olympia		Total	
Day	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**
Monday	4.25	2.04	5.34	2.01	6.25	1.67	7.54	1.89	5.85	1.9
Tuesday	3.19	1.9	5.22	1.35	6.31	2	9.5	2.32	6.06	1.89
Wednesday	3.25	2.49	6.05	1.6	5.42	1.48	7.97	2.16	5.67	1.93
Thursday	2	1.17	5.42	1.33	5.02	1.55	9.73	2.32	5.54	1.59
Friday	3.03	1.82	5.02	1.54	4.75	1.45	9.03	2.06	5.47	1.72
Saturday	1.31	0.97	4.53	1.15	3.63	1.07	5.42	1.67	3.72	1.22
Total	**2.84**	**1.73**	**5.26**	**1.5**	**5.23**	**1.54**	**8.2**	**2.07**	**5.38**	**1.71**

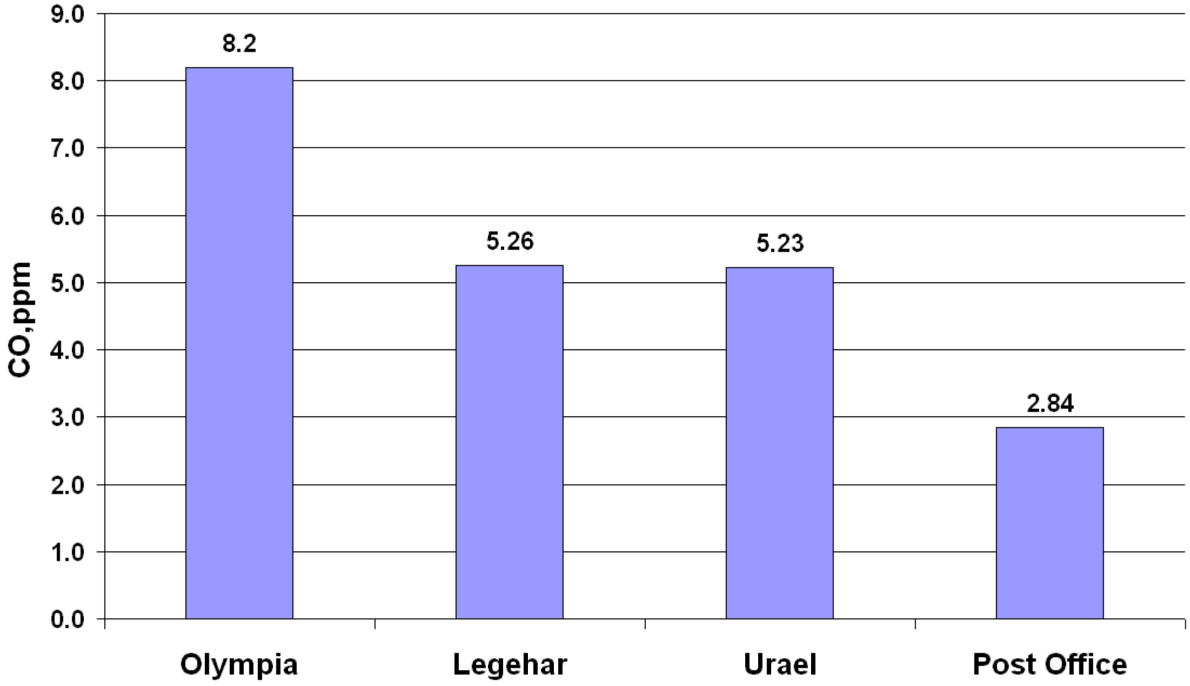


Figure 25: Weekly averaged CO concentration in four traffic light posts, Addis Ababa, Ethiopia (Sampling dates: 31 March - 5 April in the Main Post Office and *Legehar*; April 7-12 in *Urael* and *Olympia* areas)

30 Jan 08

“Hidar” 12/ 2008, 7:05 am
BLH inner site

Figure 26: Temperature inversion: The road to *Legehar*: Smoky early morning and clear road in the day time

17 Dec 2008; 7:29am

11:15am

Figure 27: Temperature inversion: One of the Addis site: Smoky early morning and clear road in the day time

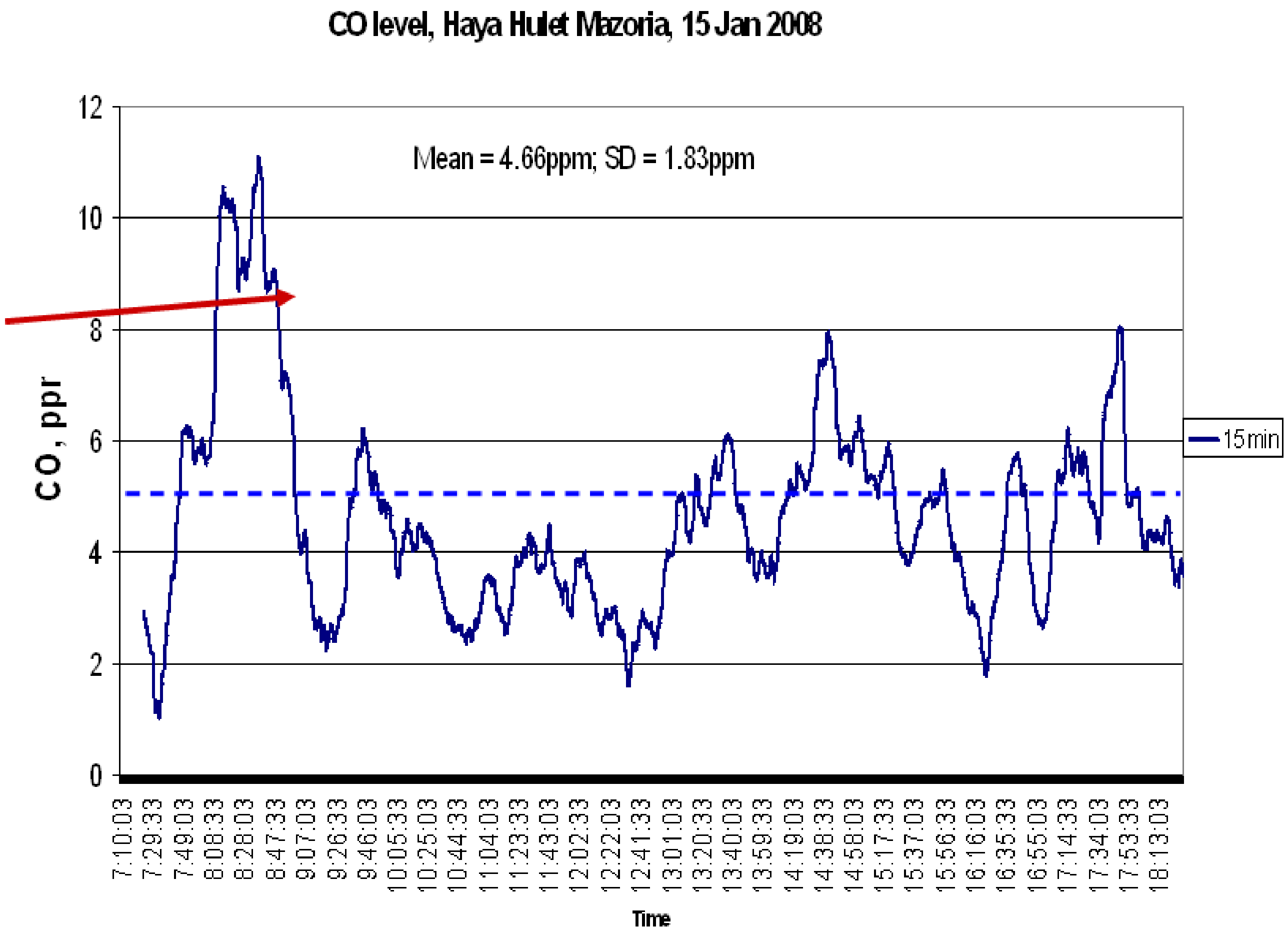


Figure 28: CO peaks in early morning, Addis Ababa, 30 January 2008

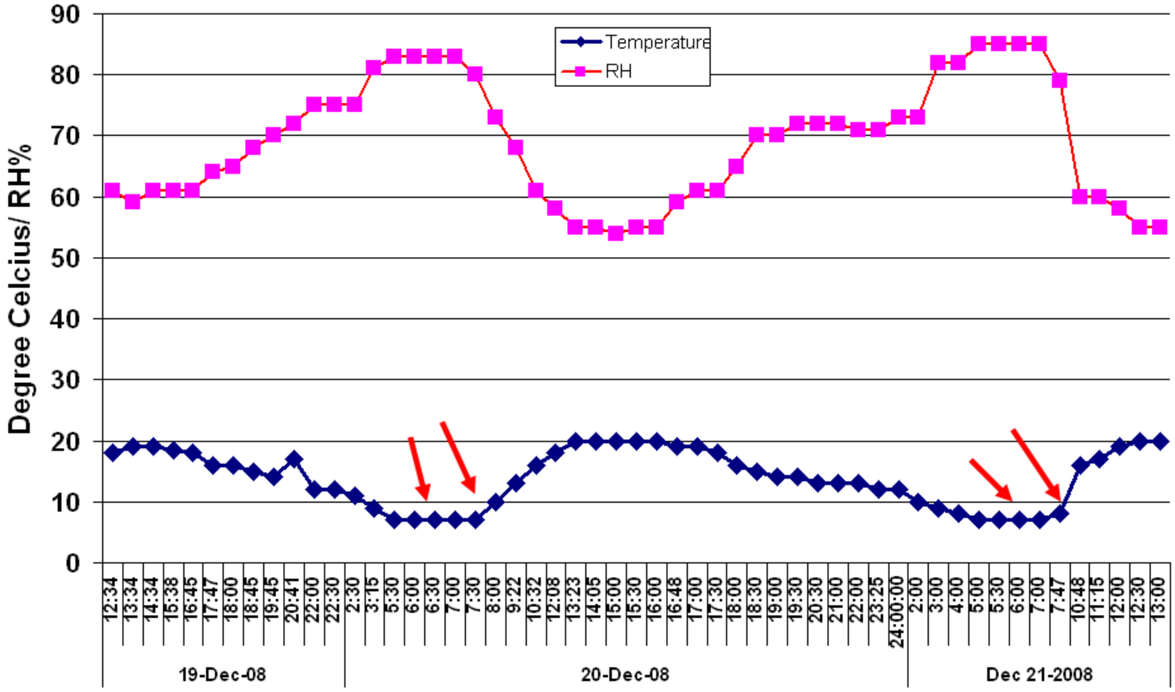


Figure 29: Daily temperature and relative humidity changes, December 19-21/2008, *Kotebe*, Addis Ababa

11. DISCUSSION

The predominant source of rural household energy in the study area was biomass fuel, which was largely represented by wood fuel and crop residues. This was not surprising given the national dependency on this type of fuel serving over 98% of households (25, 116). Crop residues such as stalks of corn, barley, wheat, etc, are abundant just after harvest, often following December. The use of cow dung was relatively less in magnitude, and was only used in one third of the households. Ethiopia, an agrarian country as it is, the use of crop residues and cow dung is common in all rural areas. Biomass fuel has larger intensity of emissions compared to cleaner fuels such as kerosene and natural gas. PM emissions from the use of dung, crop residues and wood are 4-15 times more than that of kerosene. Gas stoves emit indoor air pollutants 50 times less than the traditional stoves (4). Because of this intensity, personal exposure due to these fuel types is also high. In an Indian study, the calculated average personal daily exposure in the kitchen to respirable particulate matter was more than 1000 µg/m^3 (18*)* compared to negligible amount by kerosene users. World Health Organization was generous in the comparison of rate of outdoor air pollution of developed countries and the indoor air pollution levels in developing countries. It concluded that there existed a difference of 10-20 times (23). The implication of this conclusion is very relevant to appreciate the very poor conditions of living in developing countries like Ethiopia. Generally, biomass fuel is rich in emissions of pollutants in a greater degree than cleaner type of fuels, hence enhancing higher rate of exposures to indoor air pollutants. The national burden of diseases attributable to biomass fuel in Ethiopia is 2.5 more than the global average (28). Many African countries share similar experiences. There is truth in this burden given the high extent use of biomass fuel in households for various activities requiring heat energy. However, this subjective assumption does not concretely guarantee the presence of exposure to indoor air pollution unless measurements are taken.

Assessing the level of indoor air pollutants in this thesis was conducted using NO_2 air monitors. The overall 24-hour mean (±SD) concentration of NO_2, 97 (91.41) µg/m^3 was high in the study settings. The study found that about 36% and 70% of NO_2 measurements exceeded the US-EPA standard of 100 µg/m^3 and WHO guideline of 40µg/m^3, respectively (28, 44). Given only the 70% measurements exceeding 40µg/m^3, the mean (±SD) NO_2 was 130.3 (101.9) µg/m^3, which is a lot worse taken the WHO guideline into consideration. NO_2 concentration for the assessment of indoor air pollution is not commonly used in developing countries. Very few available data in developed countries indicated that average NO_2 concentrations are within the limit of international and local standards (34, 38, 39)**.** Such achievement was possible due to the use of cleaner type of fuels such as gas and electricity. Developing countries including Ethiopia probably need many decades to reach the level that developed nations have currently attained. The study population average of NO_2 exceeded 2.4 times that of the WHO standard. The difference in the rate of violations could only be explained by the prevailing use of biomass fuel in Ethiopia. Indoor nitrogen with the presence of oxygen and high temperature is first oxidized into nitric oxide, and then into a more harmful NO_2. The formation of NO_2 depends on the quality of fuel, and duration and intensity of combustion. It is not possible to say that the source of measured indoor NO2 could be other things than biomass fuel during combustion. The possibility of photochemical reaction is very unlikely in the study traditional homes where the penetration of direct sunlight is very limited.

This thesis found out a difference in average NO_2 concentrations by ecology type and season, higher concentration being observed in *dega* ecology and during wet seasons compared to *kolla* and dry months. This is due to temperature and moisture difference between the two ecological categories. The average minimum and maximum temperature and rainfall for *Butajira* ranged between 11.8-13.3^{o}C, 23.7-27.5^{o}C, and 16.4-159.0 mm respectively (Ethiopian Meteorology Agency, 2000-2002, personal communication). It is believed that rainfall and cold days provide opportunities to stay longer in the house (indoor) and this enhances the use of fire for heating and cooking. Residents are likely to continue heating once cooking started at these times. Extended cooking and heating implies the use of more fuel, hence more emissions of pollutants. The altitude from sea level and monsoon based rainfall are major factors for climate characteristics in Ethiopia (106). Given the study’s hypothetical assumption of other unknown variables, ambient temperature explains the temporal variations in NO_2 and hence determines the amount of biomass fuel used for cooking and heating. The *dega* areas are colder in wet seasons.

In air pollution epidemiology, the identification of factors affecting the level of environmental insults is very important. One of the research questions of this study was related to what condition (s) is making a difference in the level of NO_2 concentrations other than ecology and season. Household variables related to the use of biomass fuel were used to characterize the variation in NO_2 levels for the study period. Such variables were type of fuel, purpose of fire use, type and number of food items cooked, and frequency of fire use in addition to ecology and season variables as described above. The contribution of physical characteristics of the traditional housing was also evaluated. The thesis was then able to relate the immediate, intermediate, and remote factors affecting the level of indoor air pollution as measured by NO_2 concentrations. The type of stove was not included, as it was homogenously represented by traditional stove in all households. Immediate factors in the study were type of fuel, purpose of fire events, frequency of fire events, and type and loads of cooked food. The intermediate factors were housing variables, while the remote factors were those represented by ecological and seasonal variables.

The tendency of using one type of fuel for fire per given day is common in the study area. The type of biomass fuel data was strongly related to log transformed NO_2 concentrations. The use of “only wood” and “only cow dung” were accompanied with increased NO_2 by a factor of 1.25 over NO_2 of crop residue households. The use of cow dung had smaller contribution to the overall NO_2 concentration as its use was generally less than 3%, compared to wood use of 51%. The gradient of change seemed not be consistent with PM whose emission is higher in cow dung and crop residues than in wood fuels *(*9, 17). In Bangladesh the emission of PM_{10} was higher for dung and fire wood than for straws by a factor of 1.3-1.5 times (20). Studies conducted in the USA showed income, ventilation, occupant density, stove type, cooking time, housing factors, and type of stove were closely related to measured NO_2 concentrations (36, 37, 142, 143). The rate of pollutant’s emission varies by type and physical conditions of biomass fuel. Biomass fuels with low moisture content burn relatively easier than those with high moisture content. Generally, low grade fuels emit more pollutant than the relatively cleaner ones. In the case of NO_2, it is the atmospheric nitrogen which is trapped by the combustion process and oxidized into nitrogen dioxide. The higher the temperature of the combustion, the more NO_2 is generated. Wood fuel is in higher energy ladder compared to dung and crop residues, and therefore has better energy potential capable of oxidizing atmospheric nitrogen. Crop residue, considering its use in the homes of 45% of the interviewees, is the next important fuel type to affect NO_2 concentrations. The multivariate analysis, however, showed that the use of crop residues was a factor to affect NO_2 concentrations after controlling other factors.

The purpose of fire use for cooking, heating, or insect repellent was also associated with NO_2 concentration. Many homes were unlikely to initiate only one type of fire use activity. The cooking activity often was linked with heating the home and insect repelling at the same time. The cost and availability of fuel might encourage getting a combined type of service per any fuel used. The multiple nature of this combination was taken into consideration for the analysis as well. In a bivariate analysis, either a single use or combined ones were important factors. In a linear mixed model regression analysis, this relationship was lost, and only heating activity was on the borderline for the association with NO_2 concentration. However, when the combination of any one purpose was observed, 98% of responses were on cooking. The contribution of cooking even in the "any two" activity was dominant representing 99% of the responses, implying cooking was the major determining factor for the increased level of NO_2 concentration compared to heating

The time and food load were also important factors to affect the level of indoor NO_2. The general trend is that the more the frequency of timing to initiate fire use (single or in combination with two or three involving the times in reference to morning, midday, afternoon or night), the more NO_2 was in the indoor. Likewise, the frequency of cooked food items per day showed positive relationship with NO_2 concentrations. These two variables are indicators of the burden of work load measured by the frequency of fire events (time) and frequency of cooking. The gradient of the association was obvious: the frequent use of fire and cooking naturally increases indoor NO_2 concentration. However, any one time of fire use and any frequency of food were determinants in a mixed linear model analysis in the presence of other factors in the Model.

The other dimensions of looking at associations were to evaluate the role of housing structures, such as volume of *tukul* and the presence of window and kitchen. Volume and kitchen were found to affect NO_2, while window did not. The research hypothesis was that volume has a reciprocal association with NO_2 concentration. This hypothesis was statistically refuted. There was 1.27 mg/m^3 increase for each 10m^3 of *tukul* volume. It is difficult to tell the impact of this relationship on exposure to IAP, as the multiple correlations between the two factors and NO_2 concentration is very weak, presenting only 0.078. In addition, the explainable variation on the dependent variable was less than 1%, which implied that other factors might be important to look other than the physical dimensions of “Tukul”. The statistical association might just be explained by large sample size. A smaller magnitude of built up NO_2 concentration can be explained by ventilation inefficiency that is facilitated by the structure of the local housing (*tukul*). The walls of many *tukul*s were not air tight. The presence of open space under the eve is another air outlet. At the time of biomass combustion in *tukul*s, the chance of building up of smoke is minimal as the smoke continuously escapes through these outlets. In addition, emitted pollutants are absorbed by the thatched roof, which serves as a good smoke cleaner. The roof also acts as home heater as it absorbs and reradiates the smoke heat.

A study in Bangladesh has demonstrated the presence of inter-household (between households) differences in PM_{10} concentrations due the difference in location of stoves, structural differences of housing, and efficiency of ventilation while cooking (20). Some households using dirty fuels such as firewood, dung, and jute had PM_{10} exposures resembling those for natural gas. The presence of windows, opened doors, open spaces on mud walls and thatch roofs that were active at the time of cooking was responsible for the reduced PM_{10} concentration at a range of 16-55% for different types of fuel. The lower reduction rate was for biomass fuel, while the higher extreme was for cleaner fuels. However, the comparison of PM_{10} reduction by the type of fuel was just relative, which otherwise could not rule out the excess PM_{10} above the international guideline.

One of the purposes of quarterly measurement was to observe the presence of any difference among the averaged values of NO_2 concentrations by time. This assessment found an overall difference among the five repeated NO_2 measurements. This implies that the major factors affecting the level of indoor air pollution, such as type of fuel, purpose of fire use, timing, frequency of food items and the type of housing structural factors were different by time. This research confirmed that increased NO_2 concentrations above an international guideline occurred in the traditional home settings of Ethiopia.

At the inception of this thesis plan, there was a similar idea to explore the status of urban air pollution through the assessment of traffic air pollution. The presence of old on-road cars, the ever increasing number of vehicles and the limited road infrastructures in Addis Ababa were the motives to undertake traffic air pollution assessment. The assessment was made using CO measurement due to resource limitations to other methods such as PM measurement. The use of NO_2 employing Willems badge was not possible due to the systematic influence of outdoor wind on the diffusion constant (138). Sampling of CO was preferred because of its short-term toxicity and the need for exploring the level of air pollutants given the availability and simplicity of the instrumentation.

July and January were represented in this thesis research to explore the gradient of difference of air pollution in wet and dry seasons. In addition, the increased rainfall in July is likely to affect the CO on road concentration, either washing it down or becoming an obstacle for the rapid dispersion of CO into air because of the poor ambient ventilation. The provision of CO sampling during the day time (for 10-11 hours) in both sampling periods is justified to maximize the trapping of CO during high traffic activity.

An overall 15 minutes mean (±SD) CO concentrations were 2.03 (1.94) ppm and 2.64 (2.53) ppm for the months of July and January respectively. The difference between these means was not statistically significant. Only speculation was possible to explain this difference. The traffic density in July was understood to be less than that in January. The majority of schools in July were closed which implied less demand for vehicles. However, the presence of rainfall could be the major factor to affect the dispersion of vehicular CO emissions in July (29). The traffic density in January was higher than in July (communication with the Addis Ababa Traffic Police Office). The on-road wind might be a factor to explain the quick vertical and horizontal CO dispersion. This might reduce the built up CO on the roadside, hence contributing to the low level at respective sampling points.

The photochemical reaction that takes place in the daytime might be another factor to explain the low level of CO in January. The sunlight energy under bright radiation has the capacity to transform CO into CO_2 in the presence of emitted hydrocarbons, thereby limiting the detection of CO by the air sampler. However, identifying whether or not a photochemical process contributed to the low level is beyond the scope of this research.

Calculated 15 minutes, 30 minutes, 1 hour, and 8 hr averaged CO concentrations measured at the roadsides did not exceed the WHO proposed guidelines (23). However, this should not be considered as a healthy condition of traffic air, as vehicular emission is a complex mix containing a number of toxic gases, vapors, and particulate matter in addition to CO (28-30). Moreover, there were pocket sites demonstrating high level of CO concentrations exceeding 50% of the WHO guideline.

The profiles of 15 minutes averaged CO concentrations had similar pattern of fluctuations for both episodes of CO sampling. The presence of increased CO concentrations in early mornings and afternoons was characteristics for both sampling periods, although there was a difference in the timings. Frequent peaks of CO concentration were common in January during early afternoons, while this was not a major event in July. However, late afternoon elevated CO concentration was seen in July which was not characteristics for January. The peaks of CO concentrations by time could probably be explained by three major factors: temperature inversion, traffic density, and photochemical oxidation process. The phenomenon of low temperature inversion is inherent in Addis Ababa in the early mornings of many days and that might perhaps start after mid night. The inversion occurs when the land cools more rapidly than the next layer of air mass affecting the vertical movement or slowing it down. Then , air pollutants emitted from the ground surface do not go upwards and in horizontal direction. The phenomenon of this inversion is usually reversible when the sun heats the ground surface. One can observe a kind of dim or smog and visible air mass in early mornings near bridges, around the horizon of Intoto mountain, and along side of the roads (Figures 26-28) (personal observations on many occasions). The low temperature inversion type in Addis Ababa is likely to be related to daily temperature variations, when there is a shift from low to high temperature (Figure 29). Smoke and dust plumes are visible when dispersing horizontally and not vertically in early mornings. Temperature inversion was known to affect the urban air pollution in Canada (144).

The traffic density is another obvious factor to make a difference in the levels of CO. Traffic activity was assumed high during the month of January. Rush hours in mornings, lunch time, and early to late afternoons explain the peak of CO at these hours. However, high level of CO concentration was sustained even without the presence of the assumed high traffic activity in early mornings as observed in January due to the sustained and frequent occurrence of temperature inversion. The CO source in this condition could be individual households at night time.

The other question this thesis attempted to answer was the relationship between the roadside and on-traffic line CO concentrations. The measurement of CO concentration in 4 selected traffic light standing posts was assumed to explore this relationship. Although, these sites may not be representative of all the sampled spots (n=40), the study covered few roadside samplings around these traffic lights during the two-month study period. The sample size for the on-traffic line sampling was 24 which is a reasonable figure to be related to the 40 sites. The overall 15-minute mean (±SD) of CO concentrations on the four sites was 5.38 (1.71) ppm which is 2 times greater than the July and January averages taken together. The research also found out the presence of spatial and weekly variations for the on-traffic CO measurements. Saturdays tend to have less concentration than Monday through Friday, on the average 50% less, while Olympia site had shown increased concentration, almost closer to the 8-hr USA-EPA standard and 3 times greater than the Main Post Office traffic post level. High traffic volume and ventilation differences are factors to explain this difference. The ventilation condition in the sampling site of the Main Post Office traffic light was much better than that of the Olympia site. In addition, the Olympia traffic post lies on the way to Bole Air Port, which is under intensive vehicular movement all day. The Main Post Office traffic light post lies in a wider intersection area inhabited by few construction densities along the roadsides.

The profile of 15-minute averaged on-road CO concentrations mimicked exactly the profile of the roadside based CO samplings. Increased CO concentrations in early mornings and from early to late afternoon were the characteristics for both conditions. Peaks of CO concentrations during lunch time were not visible. This perhaps explains the close linkage between the roadside and on-road CO concentration by having the same source as designated by vehicular emissions.

The assessment of both indoor and ambient air pollution through traffic air pollution has an important contribution to Goal 7 of the international MDG to which Ethiopia has committed. The findings could be used as baseline data for future directions. The methods used for the assessment of air pollution in the rural and urban study settings are assumed to be scientific that followed adequate sample size and valid methodology. In addition, strict data quality assessment was performed in order to closely estimate the extent of air pollution while minimizing systematic errors. The size and type of variables explored in parallel with IAP measurement were also adequate to explain the variation in the dependent variable.

Large sample size coverage over adequate study duration involving different ecological settings and rigorous data quality were well addressed to make the findings more useful. The findings of indoor air pollution can be generalized to other rural settings as the socio-economic conditions in many ways are very similar (25, 108, 116, 119). The CO data, which were gathered in Addis Ababa, may be difficult to generalize to other major cities of Ethiopia. Addis Ababa is found in a highland ecology characterized by various slopes of topography. Moreover, about 70% of the country’s vehicles are found in Addis Ababa and this contributes to the high traffic volume in the roads of the city.

12. Public health significance

The exposure time patterns of children were studied in 120 households having under-5 children just before the initiation of NO_2 assessment. A significant variation was observed. The number of hours the fire kept burning per day varied between 1 and 23, the median being 9 hours, while the duration children were kept near the stove varied between 1 and 15 hours a day, the median being 5 hours. The exposure time of children, 5 hours out of 9 per day, is significant combined with the measured high concentrations of NO_2. Given these exposure profiles, there really is no reason why indoor air pollution could not be a factor to ARI and mortality among children in *Butajira*. In addition to these pilot findings, the thesis has found the presence of increased indoor NO_2 concentrations in 70% of sample measurements. However, the link between ARI among under-5 children and NO_2 exposure needs to be further researched in *Butajira* DSS.

13. Validity and Generalizability

This section tries to discuss validity and generalizability of the findings. Validity is concerned whether the findings are the reflection of the truth in the study settings while generalizability is concerned whether the findings can be inferred to other settings, if found valid.

The extent to which the research findings were a true reflection of population parameters depends largely on the data quality at all stages of the study and the relevance of the study design. The involvement of well-experienced data collectors, field testing of the methodology for nearly three months before the start of the main survey, and strict field supervisions enforced during data collection were some of the measures taken to increase the quality of the data. Thus, there is very little room for generating poor quality data at the field level.

Laboratory works that measure the concentration of nitrogen dioxide were another area that was aggressively monitored. Unless properly monitored errors due to inter-observers, intra-observers, and variations in the instruments could be a potential sources of biases. The provisions of training, repeated daily supervisions, and the implementation and management of lab quality control protocols were important tools that were used to maintain laboratory data quality. The use of known and validated method in reference to the application of Willems air monitor (136,137) makes the procedure comparable with other similar studies.

The studies were conducted in all households with under-five children in the study area; the Butajira Demographic Surveillance sites. The database is supervised and updated on a regular basis. Thus, selection bias that could arise from non-response and omission of households during field work is unlikely to happen in this study because of the repeated visits. There is no total refusal to participate in the study.

The potential confounding effects of some selected variables were handled in this thesis in a number of ways. This thesis used advanced statistical analysis, such as stratified analysis, multiple regression, and linear mixed model in order to determine the relative importance of each independent variable on the main outcome variables of the study.

It is important to recognize some the drawbacks of this thesis. The use of NO_2 as proxy indicator to measure indoor air pollution level is not the best choice. Other indicators such as PM could determine indoor air pollution in a much better way. However, the cost of measuring PM in the field was prohibitive; especially for the large sample needed for this study. The use of NO_2 in the study was preferred because the technology was simple and affordable. It is however important to note the need for further exploration of affordable technology for measuring PM in rural settings of Ethiopia. Personal air pollutants exposure assessment is a critical epidemiological indicator to determine exposure dose and isolate the most exposed. This thesis could not address this issue because of the different methods involved.

The exposure assessment of using Willems badge has also another drawback. Because of the inherent air sampling strategies attached to Willems badge air monitor, it was not possible to observe the exposure profile by time. As a result, the peak intensity of NO_2 and the usual time for the use of fire events were not established. The study had only weighted mean values all the time during the quarterly NO_2 survey.

Researches on the measurement of indoor NO_2 and traffic CO were somehow limited in the literature of developing countries. A number of studies were primarily on particulate matter, both PM_{10} and $PM_{2.5}$, with the focus on the latter. This has limited comparison with the thesis findings.

Lack of complete traffic counts at the time of the study is another area of concern of limitations. Only very limited efforts were made to record the traffic count at the beginning of each sampling, just for 3-5 minutes duration. This cannot represent the needs of the sampling duration. Available routine data on traffic volume is hardly available in Addis Ababa.

The establishment of *Butajira* DSS site is a unique opportunity to undertake public health researches like the one in this thesis. The database setting, the availability of trained enumerators and supervisors, and the rural infrastructure are real incentives to handle data quality and sustain data collection. Despite the overwhelming evidence of possible high exposure to indoor air pollution using proxy indicators, little attention was given to a large sample size. This thesis undertook a quantitative study for nearly two years in the rural settings of Butajira. The NO_2

measurements could be maintained in the DSS data base in order to relate them with some other health outcomes like cases of ARI and infant mortality. This is planned to be undertaken after this thesis defense.

The study area resembles many parts of rural Ethiopia in its use of fire. Although studies on indoor air pollution are rare in Ethiopia from personal observations the type of biomass fire fuel used and the purpose of fire appear to be similar to many parts of the country. The pattern of biomass use, the housing design, the absence of separate kitchen, and lack of openable window are also similar to other parts of the country (117-119, 131). Thus, the findings of this study can be reasonably generalized to many setting in Ethiopia.

Traffic air pollution in particular and ambient air pollution in general are untouched territories of public health in Ethiopia. This study has attempted to look into the level of CO at two different time intervals involving forty major roads of Addis Ababa. The CO data undertaken in Addis Ababa may be difficult to infer to other major cities of Ethiopia. Addis Ababa is found in a highland ecology characterized by various slopes of topography. About 70% of the country’s vehicles are found in Addis Ababa, making the major roads entertain high traffic volume. Thus, the finding of this thesis with regard to traffic air population cannot be generalized to other major regional urban centers.

14. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions in reference to the three studies are as follows.

1. There is strong evidence that indicates the presence of increased exposure to indoor air pollution. The use of biomass fuel in over 98% of the households, and the increased NO_2 concentrations in over 70% of the study samples, both indicating higher value than the international practice, suggest that household members are highly exposed to indoor air pollution in the rural settings of Ethiopia.

2. Household fuel use characteristics such as the type of fuel, purpose and frequency of fire events, and type and food load are important determinants of indoor air pollution other than ecological and seasonal variables. These factors concluded the temporal and spatial NO_2 concentrations. Housing physical factors like the volume of *tukul*, and the presence of window and separate kitchen were not important factors in this research to explain the variation in NO_2 concentration. The homogeneity of these factors should have hidden the apparent association with NO_2 concentrations. Ecology among other factors was the dominant factor impacting NO_2 concentration.

3. The assessment of CO on the road-sides and on-road lines was explorative in nature. Although the overall averaged concentrations of CO in both sampling periods were within US-EPA and WHO limits, there is a reasonable indication that these guidelines might be exceeded in the long run. The sites in concern are located in major roads of Addis Ababa and the traffic light posts at Olympia. Traffic volume and temperature inversions in Addis Ababa are assumed to determine the levels of traffic air pollution along the roadsides. The link between the roadside and on-road CO concentrations was obvious from the observation of CO concentrations profiles.

The following operational and policy recommendations are suggested based on the above major findings.

1. The current knowledge generated by this research on the magnitude of indoor air pollution as measured by NO_2 concentrations is not acceptable by any air pollution standard. However, the use of additional air pollutants measurement like PM_{10} and $PM_{2.5}$ are most useful to further validate the research findings. PM_{10} and $PM_{2.5}$ are the common pollutants that have attention in recent times.

2. Exposure assessment using proxies and NO_2 measurements indicated strong association with ARI. The study involved a fairly large size of household measurement of NO_2 for nearly two years. There is possibility that the data can be linked with ARI incidence that has already been collected in parallel with the NO_2 exposure assessment.

3. Given the high contribution of IAP to increased level morbidity and mortality among under-5 children and adult women, the introduction of interventions would be highly relevant. Changing the type of fuel is unlikely either in the short or medium term plan. Improving the stove-fuel efficiency is an important aspect to bring positive results in the reduction of indoor air pollution to an acceptable level. Such efforts as improving stoves, modifying the cooking area to have chimneys and good ventilation, and placing kitchen separately from main housing rooms are most possible interventions that can be intensified and harmonized in the field practice. There is known intervention effort made by the health extension program and similar activities run by NGOs. The findings of the thesis can be used to direct this effort.

4. Given the high proportion of old cars and on-road diesel engine vehicles, the use of PM in traffic air pollution assessment is highly commendable. The emission of PM on the road has fine aerodynamic size, in many cases less than 2.5 μm that are mainly characteristics of a diesel exhaust. It is understood that CO emissions quickly dissipate after generation.

15. ACKNOWLEDGEMENTS

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17. Original Papers (I-III)

Paper I

Kumie A. Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, Brandstrom D.

Magnitude of indoor NO2 from biomass fuels in rural settings of Ethiopia.

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Paper II

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Sources of variation for indoor nitrogen dioxide in rural residences of Ethiopia.

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Paper III

Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia

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Magnitude of indoor NO_2 from biomass fuels in rural settings of Ethiopia

Abstract Half of the world's population and about 80% of households in Sub-Saharan Africa depend on biomass fuels. Indoor air pollution due to biomass fuel combustion may constitute a major public health threat affecting children and women. The purpose of this study was to measure levels of indoor NO_2 concentration in homes with under-five children in rural Ethiopia. The study was undertaken in the Butajira area in Ethiopia from March 2000 to April 2002. 24-h samples were taken regularly at about three month intervals in approximately 3300 homes. Indoor air sampling was done using a modified Willems badge. For each sample taken, an interview with the mother of the child was performed. A Saltzman colorimetric method using a spectrometer calibrated at 540 nm was employed to analyze the mass of NO_2 in field samples. Wood, crop residues and animal dung were the main household fuels. The mean (s.d.) 24-h concentration of NO_2 was 97 $\mu g/m^3$ (91.4). This is more than double the currently proposed annual mean of WHO air quality guideline. Highland households had significantly higher indoor NO_2 concentration. This study demonstrates high levels of indoor NO_2 in rural homes of Ethiopia.

A. Kumie[1], A. Emmelin[2], S. Wahlberg[2], Y. Berhane[3], A. Ali[1], E. Mekonnen[4], D. Brandstrom[2]

[1]School of Public Health, Medical Faculty, Addis Ababa University, Addis Ababa, Ethiopia, [2]Umeå International School of Public Health, Umeå University, Umeå, Sweden, [3]Addis Continental Institute of Public Health, Addis Ababa, Ethiopia, [4]Department of Pharmacology, Medical Faculty, Addis Ababa University, Addis Ababa, Ethiopia

Key words: Magnitude; NO_2; Indoor air pollution; Agro-ecology; Ethiopia.

A. Kumie
School of Public Health, Medical Faculty
Addis Ababa University
P.O. Box: 9086, Addis Ababa, Ethiopia
Tel.: +251-11-5157701
Fax: +251-11-5517701
e-mail: aberakumie2@yahoo.com

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Practical Implications
Respiratory infection is a major cause of morbidity and mortality, globally. Acute respiratory symptoms are also related to high levels of air pollution. Interventions aimed at reducing exposure to indoor air pollution should focus on cooking and heating practices in developing countries. This study is not undermining the role of other biomass smoke constituents in determining respiratory infections.

Introduction

Indoor air pollution in developing countries due to domestic biomass fuel has become the focus of increasing concern due to potential health and environmental impacts. About 50% of the population globally and 77% of the population in Sub-Saharan African countries rely on biomass fuels for cooking, heating, and lighting purposes (Rehfuess et al., 2006).

Respiratory infections together with chronic obstructive lung diseases caused 12.9% of all deaths, while lower respiratory infections were the leading cause of DALYs world wide in 1990 (Murray and Lopez, 1997a,b). Murray also found that respiratory infections are the third leading cause of mortality worldwide, accounting to 4.3 million deaths (8.5% of all deaths) in 1990, of which 91% of deaths occurred in developing countries (Murray and Lopez, 1997b). The World Health Organization acknowledged that indoor air pollution was associated to 1.6 million premature deaths annually and stands 4th in rank of risk factors (WHO, 2002). The burden of diseases due to respiratory infections in developing countries can be attributed to the level of indoor air pollution assuming ambient air pollution has relatively less importance. Acute lower respiratory tract infections (ALRI) have long been identified as one of the two major causes of death among children in low income countries.

Respiratory infections are major causes of morbidity among adults and children in Ethiopia, standing out as one of the top ten diseases (Planning and Programming Department, Ministry of Health, 1999). A 1-year weekly follow up study in the Butajira area showed that acute respiratory infections (ARI) predominated among under-five children (Muhe et al., 1997). ARI was also shown to be a major cause of under-five mortality in Butajira (Shamebo, 1994).

Among the more commonly suspected risk factors, exposure to smoke from unvented cooking fires indoor has ranked high, whether described as 'indoor air pollution' or as 'smoke from biomass fuels' (Chretien et al., 1984, 1984; Zhang and Smith, 2003). Several studies have addressed the question of exposure to biomass combustion products in relation to ALRI, using proxies of exposure such us the type and use of biomass fuel for cooking. However, there are few studies from developing countries using actual measurements of indoor air pollution (Emmelin and Wall, 2007; Smith, 2002).

Over 95% of the Ethiopian rural population is dependent on biomass fuel as a source of household energy (Central Statistical Agency, 2004, 2006). Wood and animal dung are primary sources of household energy in this country. In addition a majority of rural Ethiopian households live in traditional single-room houses. Over 95% of households in rural areas use the 'three stones' traditional fireplace on the floor. Few homes in rural villages have a window or other opening for ventilation and none have a smoke-vent in the roof (Faris, 2002; Shamebo, 1994).

Against the background of possible high levels of exposure to indoor air pollution and given high prevalence of respiratory infections among children accompanied, the assessment of the level of indoor air pollution in the context of Ethiopia is currently a necessity. This study was undertaken to show levels of concentration of NO_2 as an indicator of indoor air pollution in traditional homes in central Ethiopia.

Materials and methods

Study area and population

The study was done in the Butajira district in central Ethiopia, approximately 130 km south of the capital, Addis Ababa. Butajira has been the site of the Demographic Surveillance System, DSS, since 1987. Surveillance is done in one urban and nine rural communities (Peasants' Associations, PAs) as a cluster sample from a total of 88 such PAs at the time of sampling in 1987. The Peasants' Association is the lowest administrative unit in Ethiopia. The DSS generates a database of past and current population, to be used as a sampling frame for demographic and health research (Berhane et al., 1999).

The Butajira district lies on the western rim of the Great Africa's Rift Valley with the Gurage mountains rising to 3500 m in the westernmost PAs of the district, dropping eastwards to a plateau approximately 1700 m above sea level. Traditionally, two agro-ecological areas, highland and lowland, are used to categorize PAs using 2000 m above sea level as the dividing altitude (Berhane et al., 2000). Highland and lowland in our study have an average altitude of 2110 and 1860 m, respectively.

More than 95% of the rural population lives in traditional houses known as *Tukuls*. A *Tukul* is has a circular wall shaped and plastered with mud and a thatched roof (Figure 1). The wall only occasionally has a small opening, for natural ventilation and light. The roof is held up by a pole in the centre of the house. In some houses there is a partitioning wall connecting the pole and the outer wall up to 1–1.5 m. This provides storage space at the back of the house. Often the same space is also used to keep small livestock, calves, sheep, and goats during the night. Cooking is done indoors on a traditional open hearth. The fireplace is also used to provide light and heating.

The current study is a part of an ongoing epidemiological study of acute respiratory illness among under-five children in relation to indoor air pollution exposure. That study had to be limited to the nine rural PAs of the DSS in all homes with under five children. The choice of NO_2 as the indicator of indoor air pollution was necessitated by two factors: (i) the lack of electricity in the entire rural areas of the district and (ii) the need for large numbers of samples taken in a large number of homes during an extended period. Under the circumstances, passive sampling was the only feasible measurement method, technically and

Fig. 1 Traditional "Tukul" in Butajira, Ethiopia

economically. The availability of a validated method for passive sampling of NO_2, together with the fact that the substance in itself had been implicated in respiratory health studies in mobile homes in the USA made it a useful indicator (Petreas et al., 1988).

Indoor air pollution measurements

Sampling. Sampling was done by locally recruited data collectors, 'enumerators', according to a rotation scheme, where each home was visited at 3 months intervals (Figure 2). Samples were taken for approximately 24 h, with exact records of the date, start and finishing time (hh:mm) of each sample. Digital watch was provided to enumerators to accurately record the sampling time. At the time of terminating the sampling, the enumerator made an interview using a questionnaire concerning conditions relating to fire (fuels, times, purpose of having a fire) during the hours of sampling.

The air sampler was fixed in a standardized position by the field worker to the central post at 2 m above the floor. The sampler was positioned off the post, hung by a cord from a nail fixed at an angle of 90° to a line from the centre of the hearth to the center of the post, away from the partitioning wall (Figure 3). This position was chosen to avoid screening by the post itself and if possible avoid turbulence caused by the partition. The height 2 m was necessary in order to put the sampler out of reach of children, and for reasons to approximate breathing zone, which made the position on the post the only possibility. Samples were only taken if the family was at home.

For reasons of logistics, the closed and packaged samplers had to be stored in the house of the enumerator for few days before and after sampling. The field office of the DSS in Butajira town stored samplers in a refrigerator while waiting for transport to the laboratory in Addis Ababa.

Household interview. A structured and pre-tested questionnaire was used to collect data related household location, fire use and type of fuel. The questionnaire was administered immediately after indoor air sampling in each home. Fourteen enumerators were recruited and trained by project staff from Addis Ababa University to do air sampling and interview the head of household. The running of data collection was managed locally from the Butajira office by five supervisors working with quality control of interview data and overseeing the sampling. Informed consent was obtained from each interview, who signed a consent form.

Laboratory method

The sampler. NO_2 concentration was measured using Willems badge developed at the University of Wageningen in the Netherlands, originally developed for ammonia measurements, and later for measuring NO_2. Willems badge has been tested for both indoor and outdoor use in both laboratory and field experiments

Households inclusion scenarios	**Sampling time**								
	2000			**2001**				**2002**	
Family participated for the whole duration of the study	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Family present at the start of the study but left at any time	Δ	Δ							
Family moved in at any time during the study period				Δ	Δ	Δ	Δ	Δ	Δ
Family give birth during the study period and join the study						Δ	Δ	Δ	Δ
Child reached the 5th birthday and no more eligible for the study	Δ	Δ	Δ	Δ	Δ				

Δ indicates indoor air sampling in a quarter in homes with under 5 children with scenarios of inclusion into the study. The maximum number of sample collection point is nine.
Actual sampling duration between any two NO_2 subsequent measurements in a household on the average was: 3.83 ± 0.73 months.

Fig. 2 Household sampling framework for NO_2 measurement in homes with under-five children, Butajira, Ethiopia, 2000–2002

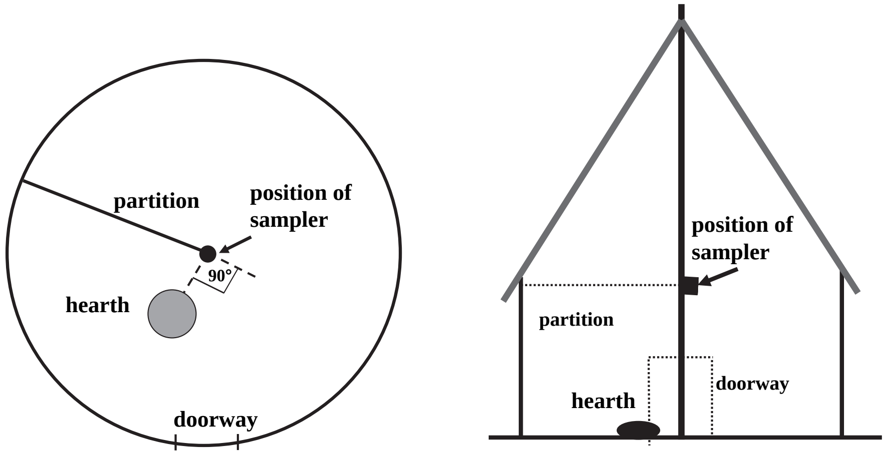

Fig. 3 Layout of a Tukul with standardized position of sampler

(Hagenbjork et al., 1996, 1999, 2002; Willems and Adema, 1992). The passive (diffusive) sampler used in this study, consists of a cylindrical 'cup' open in one end. Its inner diameter is 26 mm and its depth 6 mm. At the bottom of the sampler a fibreglass filter (Whatman GF-A) impregnated with triethanolamine as a collecting agent for NO_2 is inserted. The filter is held in place by a fixation ring. A distance ring is placed on top and Teflon filter (Schleicher & Schuell, TE 38, 5 μm), held in place by another fixation ring, is fitted at the opening. The role of the Teflon filter is to limit the influence of turbulent air movements. After assembling, the badge is closed with a lid made of polyethene. The badge and the fixation/distance rings are made of polyacetal (POM). Sampling is started by removing the lid from the sampler, and interrupted by putting the cap back in place after 24 h of sampling. The sampling rate for this badge has been found to be 40 ml/min (Hagenbjork et al., 1999).

Analysis. After exposure the absorption filter is extracted with an acid solution of sulphanilamide and N-(1-naphtyl) ethylenediammonium dichloride (NEDA). Absorbed nitrogen dioxide on the filter is converted to NO_2^- ions. If nitrite ions are present in the solution, a red colour will develop. The solution is centrifuged at 1790 RCF (relative centrifugal force, Beckman CPR centrifuge) and the absorbance of the solution is measured at 540 nm (Beckman DU^R .64 Spectrophotometer).

The nitrite concentration of the solution is determined by comparing it with a standard curve (absorbance against concentration) made with 0.00–0.25–0.50–1.00–1.50 mg/l NO_2^-. When a batch of samplers arrived at the laboratory in Black Lion Hospital, Addis Ababa University, it was immediately stored in a refrigerator awaiting analysis, which took place as soon as possible. For each batch a new standard curve was constructed resulting in a total of 610 standard curves. The agreement between the curves was very good and therefore the decision was taken to apply linear regression to the combined absorbance measurements of the standard solutions. The result was a straight line with the equation abs = 0.0070 + 0.9665*conc. A 99% confidence interval for the line was 0.97341 ± $7*10^{-4}$ (conc = 1.00 mg/l). The limit of detection based on the calibration line is 3 μg/m^3 for a 24-h sampling period. The indoor NO_2 concentration was then calculated using the equation:

$$C = (10^6 * \text{mass})/(\text{expmin} * 40),$$

where 'C' is indoor air concentration of NO_2 in micrograms per cubic meter, 'mass' is mass of NO_2 on the glass fibre used for air sampling after subtracting mass of NO_2 of the blank glass fibre, 'expmin' is indoor air sampling duration in minutes, and 40 is a constant of air sampling rate for the diffusive sampler, 40 ml/min.

Standard methods for quality control were applied using the following methods.

1. Four laboratory technicians were properly trained and supervised on each day of laboratory analysis. Procedure of standard laboratory work was fixed.
2. Instrumentation and standard calibration curve checking at each day of laboratory analysis were the main concerns. 99% CI for the regression coefficient of the standard curve was used as a guide to monitor the standard solution preparations. R^2 was set as 0.998 or greater corresponding to 99% CI of regression coefficient: 0.932–0.999 which were generated during pilot testing of the data collection tools. Laboratory procedures and instrumentation were checked in the event of $R^2 < 0.998$.
3. Ten blanks were prepared weekly during field sampler preparation in a laboratory setting. The mass of NO_2 on the blank was closely monitored not to exceed laboratory operating guideline value The 3s.d. of ten blanks of mean of NO_2 mass should not exceed 0.27 μg.

4. On monthly basis, a control chart was used to monitor the possible variations of control solution of $NaNO_2$ solution (0.8 mg/l, its 95% and 99% CI (called alarm and action limits) for the standard solution were set to monitor outliers. If unusual spread and outlier is observed, the laboratory session was stopped until the problem was sorted out and fixed.
5. Twenty field exposed air samplers were periodically exchanged between two laboratory settings (Addis Ababa, Ethiopia and Umeå, Sweden) to validate laboratory performances.
6. The intra-observers variation was also checked by the analysis of duplicate exposed badges in similar indoor and outdoor situations and looking at NO_2 concentration variations between morning and afternoon sessions of laboratory analysis. Only random variation should be possible.

In all cases of quality control, operating guidelines were monitored not to be violated.

Data management and analysis

Data were entered and cleaned using the EpiInfo version 6.04d statistical package. The Butajira DSS database was used for cross checks of IDs of respondents and household numbers and for adding new households entering during the project. In addition, consistency and completeness of each questionnaire was checked. Data were analyzed using EPI INFO (version 6.04; Center for Diseases Control and Prevention, Atlanta, GA, USA and World Health Organisation, Geneva, Switzerland), and SPSS (version 14; SPSS Inc., Chicago, IL, USA). STATA (version 9.0; STATA Corp LP, College Station, TX, USA) was used to adjust the effect of clustering of NO_2 on the same household. Mean values and 95% CI of NO_2 concentrations were calculated to compare data. NO_2 concentration was transformed into log10 to meet the assumptions of normality to assess if mean NO_2 concentrations differ by selected variables. Box plots and stem plots were used to identify outliers when comparing mean values of NO_2.

Results

A total of 17,995 samples in nine Peasant Associations (PA) were involved in this study. Seven hundred eighty (4.3%) households were excluded from the analysis due to incompleteness of data, leaving a total of 17,215 samples for analysis. Records beyond 60,000–108,000 s and below the detection absorbance limit were labeled as incomplete.

The average sampling duration was 24.5 h with a minimum of just over 18 h to a maximum of nearly 30 h. The mean interval between subsequent NO_2 samples was 3.8 months, which means that the intended quarterly sampling was not reached. However, 90% and 10% of all samples had duration between 3–4 months and 5–6 months, respectively. Median and mode sampling duration were 3.7 and 2.9 months, respectively.

Table 1 Indoor NO_2 concentrations ($\mu g/m^3$) by village, ecology and overall, Butajira, Ethiopia, 2000–2002 (n = 17,215)

Ecology	PA code	n	25%-ile	Median	75%-ile	Min	Max	Mean (s.d.)
Highland								
	005	1721	48	98	169	0	664	119 (93)
	04B	1264	40	88	175	0	608	119 (102)
	06A	1722	39	97	186	0	896	129 (119)
	06B	3155	48	85	156	0	978	117 (98)
	011	1338	25	64	121	0	629	87 (84)
	Mean highland	9500	40	86	161	0	978	116 (101)
Lowland								
	007	2621	25	47	84	0	553	66 (62)
	008	1824	32	62	113	0	671	82 (71)
	09A	1440	28	64	148	0	898	102 (103)
	09B	2130	24	45	88	0	623	65 (59)
	Mean lowland	8015	27	55	108	0	898	76 (74)
All	Overall means	17,215	33	68	131	0	978	97 (91)

Nearly all samples, 16,899 (98.2%), were accompanied with household firing activities for the last 24 h prior to indoor smoke sampling. Biomass fuel use in our study area was the dominant source of household energy that was used in all households mainly for cooking. Kerosene was the only fossil fuel used for lighting the night using a traditional lamp. The use of kerosene and charcoal as a fuel for cooking were insignificant, generally less than 0.5% of the households.

Concentrations vary between 0 and 978 $\mu g/m^3$, with an overall mean (s.d.) for the entire 26 months, all PAs, of 97 (91.41) $\mu g/m^3$. The median (IQR) of NO_2 was 68 (97.7) $\mu g/m^3$. NO_2 concentrations by agro-ecology differed significantly after adjusting the clustering effect of repeated measurements of NO_2 mean (95% CI): 76.48 $\mu g/m^3$ (73.93, 79.11) for the highland, mean (95% CI): 49.61 (47.85, 51.42) $\mu g/m^3$ for the lowland. The variation over the highland-lowland areas is shown in Table 1. The significance of NO_2 concentration by ecology and season was consistent even when outliers were included.

In the months of January, and May through August the annual average was exceeded (Figure 4). On the other hand, significantly lower than yearly average was observed in the month of February. Averaging the measures by 2 months help avoiding minor monthly variations. Significant variations between dry and wet months were observed; mean (95% CI) for dry season was 58.58 (56.87, 60.34) $\mu g/m^3$ and 66.4 (64.54, 68.3) $\mu g/m^3$ for wet season. The period from June to September is rainy season in Ethiopia.

Discussion

This study is the first to attempt relatively large scale, long term, measurements of an indoor air pollution

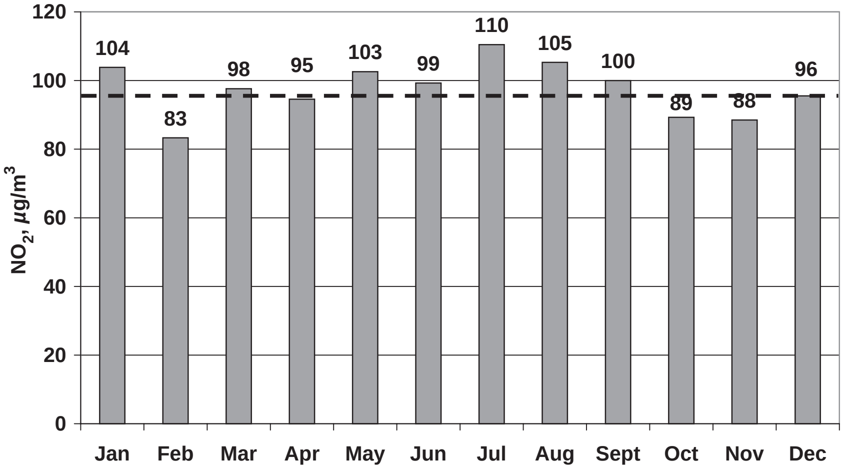

Fig. 4 Monthly mean level of NO_2, Butajira, Ethiopia, 2000–2002 ($n = 17{,}215$)

indicator in rural areas in a developing country. All the study households used biomass fuels, mainly firewood, but also crop residues and animal dung. The use of biomass fuel in the majority was consistent with other studies indicated for developing countries (Balakrishnan et al., 2002, 2004; Dasgupta et al., 2006; Faris, 2002; Rehfuess et al., 2006). Biomass fuels emit considerably more pollutants compared to fossil fuels (Smith, 2000a). The magnitude of the health risk due to biomass combustion may be as much as two- to three times greater compared to the risk associated with emissions from clean fuels (Chretien et al., 1984; Smith et al., 2000b; Zhang and Smith, 2003).

The mean level of 97 μg/m^3 exceeded the annual WHO air quality guideline of 40 μg/m^3 (WHO, 2005) by almost 2.5 times. The exceedance is consistent for all months of the survey. Close to 70% of the samples exhibited NO_2 levels over this guideline. This proportion goes down to 36% when compared to the National Ambient Quality Standard of USA annual mean of 100 μg/m^3 (EPA, 1990). The current EPA (USA) annual limit is twice more than that of WHO guideline. Studies in developing countries consistently indicated an increased level of measured indoor air pollution due to biomass fuel combustion (Balakrishnan et al., 2002, 2004; Ezzati and Kammen, 2002a; Shrestha and Shrestha, 2005; Smith, 2002; Wafula et al., 1990). The peak concentration at times of biofuel combustion in our study could be speculated to exceed the 1-h WHO guideline of 200 μg/m^3. Ezzati has demonstrated that the peak levels of PM_{10} were very high during brief high-intensity emission episodes (Ezzati and Kammen, 2002b; Ezzati et al., 2000).

The level of NO_2 differs between highlands and lowlands. To what extent this is an effect of altitude-based temperature gradients or of cultural differences giving rise to different practices is impossible to tell. Available rainfall and temperature data do not distinguish between local highland and lowland areas (Ethiopian Meteorology Service, unpublished). The seasonal variation in NO_2 concentration shown in Figure 4 is reasonably consistent with rainfall and temperature seasonality. Allowing for the fact that the study covers only 2 years, the pattern follows a pattern expected from rainy season patterns, with Small Rains expected within the period March-May and Big Rains in July–September. We believe that wet biomass fuels tend to take relatively longer time for cooking and heating and are less efficient, hence resulting in higher concentration of indoor air pollutants. The effect of season on indoor smoke further supports the evidence that relatively cooler PAs had higher concentration of indoor air pollution than those of in the lowland, which better have access to relatively drier type of biomass fuel. The efficiency of poor ventilation due to the absence of windows (Kumie and Berhane, 2002; Shamebo, 1994) in almost all homes is believed to have synergistic effect on indoor NO_2 concentrations. Locally, keeping smoke indoor is generally believed to maintain warmth. Wet season in the study area is accompanied with cooler daily temperature and steady rainfall at times. The gradient of temperature with wetting environment makes residents to stay longer and cook indoor, limiting the outdoor firing activities. This also explains the high level of NO_2 during wet season. The low level in February was consistent for the two years (2001 & 2002) that can be only explained by the high level of ambient temperature during this time. February in Ethiopia represents to be the end of the dry season. Households occasionally tend to smoke outside in the open air at the time when day time was difficult to undertake cooking indoor due to increased temperature.

The major limitation of this study is the use of NO_2 as the sole indicator of indoor air pollution from biomass fuels. Whether NO_2 is sufficient as an indicator for the epidemiological study of childhood ALRI remains to be shown, but for more general purposes, other pollutants should also be studied under empirical conditions in developing countries. Model calculations based on literature data on relations between the concentrations of NO_2 and of other pollutants such as particulate matter, whether measured as PM_{10} or as other fractions of suspended particles could be a possible approach.

However, the use of NO_2 as the indicator is what made a study of this size feasible. We can present data from approximately 3300 homes, visited six- to eight times over more than 2 years for 24 h sampling. The concentration levels shown indicate that large groups in the rural population of Ethiopia are exposed to NO_2 concentrations close to or above levels that are regarded as potentially harmful in the urban environments of more affluent countries.

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Original Research Article

Sources of variation for indoor nitrogen dioxide in rural residences of Ethiopia[1]

Kumie A[1] Emmelin A[2], Wahlberg S[2], Berhane Y[3], Ali A[1], Mekonen E[4], Worku A[1,]*

D. Brandstrom[2]

- [1]School of Public Health, College of Health Sciences, Addis Ababa University, Addis Ababa, Ethiopia
- [2]Umeå International School of Public Health, Umeå University, Umeå, Sweden
- [3]Addis Continental Institute of Public Health
- [4]Department of Pharmacology, Medical Faculty, Addis Ababa University, Addis Ababa, Ethiopia

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Corresponding Author
Abera Kumie
School of Public Health, Medical Faculty
Addis Ababa University
P.O.Box: 9086, Addis Ababa, Ethiopia
Tel: Mobile: +251-911-88-29-12
Office tel: +251-11-5157701
Fax: +251-11-5517701
Email: aberakumie2@yahoo.com

Email addresses of authors

1. Kumie A, aberakumie2@yahoo.com
2. Emmelin A, anders.emmelin@epiph.umu.se
3. Wahlberg S, s.b.wahlberg@gmail.com
4. Berhane Yemane, yemaneberhane@ethionet.et
5. Ahmed Ali, ahmedhb1950@yahoo.com
6. Mekonen E, eyassumakonnen@yahoo.com
7. Worku A, alemayehuwy@yahoo.com
8. D. Brandstrom, doris@coompanion.se

Abstract

Background: Unprocessed biomass fuel is the primary source of indoor air pollution in developing countries. The use of biomass fuel has been linked with acute respiratory infections. This study assesses sources of variations associated with the level of indoor NO_2.

Materials and Methods: This study assesses household factors affecting the level of indoor pollution by measuring nitrogen dioxide. Repeated measurements of indoor NO_2 were made using a passive diffusive sampler. A *Saltzman* colorimetric method using a spectrometer calibrated at 540 nm was employed to analyze the mass of NO_2 on the collection filter that was then subjected to a mass transfer equation to calculate the level of NO_2 for the 24 hours of sampling time. Structured questionnaire was used to collect data on fuel use characteristics. Data entry and cleaning was done in EPI INFO version 6.04, while data was analyzed using SPSS version 15.0. Analysis of variance, multiple linear regression analysis and linear mixed model were used to isolate determining factors contributing to the variation of NO_2 concentration.

Results

A total of 17,215 air samples were made during the study period. Wood and crop were principal source of household energy. Biomass fuel characteristics were strongly related to indoor NO_2 concentration in one-way ANOVA. There was variation in repeated measurements of indoor NO_2 over time. In a linear mixed model regression analysis, highland setting, wet season, cooking, use of fire events at least twice a day, frequency of cooked food items, and interaction between ecology and season were predictors of indoor NO_2 concentration. The volume of the housing unit and the presence of kitchen showed little relevance in the level of NO_2 concentration.

Conclusions

Agro-ecology, season, purpose of fire events, frequency of fire activities, frequency of cooking and physical conditions of housing are predictors of NO_2 concentration. Improved kitchen conditions and ventilation are highly recommended.

Background

Biomass fuel is the primary source of household energy in developing countries. Fifty two percent of the global population and more than 90% of rural homes in developing countries use solid biomass fuels for cooking, heating, and lighting purposes [1]. Biomass fuel, also designated as unprocessed or dirty solid biofuel, mainly includes firewood, animal dung, agricultural residues and plant leaves.

Indoor air pollution (IAP) is considered as one of the risk factors causing high burden of diseases and of premature deaths in developing countries [2-5]. IAP is recognized as a silent and unprotected killer among rural women and children who spend much of their time in the kitchen [6]. The burden of diseases due to IAP is high in developing nations using biomass fuel. Smith estimated that IAP in India accounted for 4.2-6.1% of the total national burden of disease, which is considered to be a major public health concern. This proportion was assumed to be equivalent to the saving of about half million premature annual deaths [7].

The health risk of direct exposure to biomass combustion is visible in the presence of the overwhelming practice of cooking in poorly ventilated and crowded single room in developing countries [4, 8, 9]. Proxy factors related to socio-economic status like income education, and use of biomass fuel were highly associated with the level of IAP [7, 4, 10, 11]. Despite the prevailing knowledge that exposure to biomass combustion products is high [4, 9, 12-19], quantitative studies on factors affecting the level of IAP are limited in developing countries [13].

Data on the measurement of indoor NO_2 is limited in developed countries. The mean concentration of NO_2 in kitchens using a gas stove varied between 26 ppb and 112 ppb [20, 21], while this was 18 ppb in kitchens using electric stoves [20]. Median NO_2 concentrations in living rooms were 5.8 ppb in Ashford (UK), 6.1 ppb in Minorca and 23.8 in Barcelona (Spain) [22] and 11 µg/m^3 (5.8 ppb) in Umea (Sweden) [23]. In low income homes of USA, mean concentrations of NO_2 were 43 ppb and 36 ppb in kitchens and living rooms, respectively [24] and 30 ppb in children's bedroom [25]. Increased level of NO_2 was related to the difference in fuel type and ventilation efficiency [26]. Those studies consistently demonstrated that the type of fuel, purpose of fuel use, and location of indoor activities are associated with increased NO_2. The use of gas stoves and heaters were often accompanied with the exceeding of the present World Health organization (WHO) Air Quality Guideline (AQG) of 21 ppb for 8 hours [27].

A particulate matter (PM) of various aerodynamic sizes is also used to measure the level of IAP. The mean concentration of respirable suspended particles (RSP) in homes using biomass fuel had variation depending on the type of kitchen and fuel used: 500-2000 μg/m^3 in kitchens of India [28], 1200 μg/m^3 in Mozambique [29], 850-1560 μg/m^3 in Guatemala [16], and 1400 μg/m^3 in Kenya [30]. The average concentration of PM of aerodynamic diameter of 10 microns (PM_{10}) in kitchens using biomass fuel varied between 237 and 291 in Bangladesh [10]. Smith showed that the concentration of PM_{10} commonly varied between 200-5000 μg/m^3 [4]. The average concentrations of $PM_{2.5}$ varied between 320-650 g/ m^3 in Ghana and Nicaragua [31, 32]. These studies indicated that the type of kitchen (whether inside or outside), the type of stove (traditional or improved), ventilation condition, place of measurement (kitchen or sleeping room), and type of biomass fuel (wood, dung, or residues) were major factors affecting the concentrations of indoor air pollutants. The above cited aerial concentrations related to RSP, PM_{10} and $PM_{2.5}$ exceeded by a factor of 2 to 40 times of the standards set by Environmental Protection Agency of USA (EPA-USA) for 24-hr and annual standards [33] and by a factor of 10 to 80 times of the present WHO 8hr AQG [27].

Biomass fuel in the form of firewood, agricultural residues and animal dung is the primary source of household energy in Ethiopia [34, 35]. The majority of rural homes have only one room serving all types of household activities [36]. Cooking takes place in the same room using traditional unvented stoves. Such rooms do not have functional ventilation outlets [3, 37]. Pocket studies in Ethiopia showed high level of exposure to indoor air pollution that exceeded the WHO one hour and eight hours AQG [27, 38-40]. However, the results of these studies could not be generalized to a larger population due to their methodological limitations.

Increased indoor NO_2 concentrations were revealed in our recent study [41]. That study also indicated ecology and season were affecting NO_2 concentrations. The present study was a continuation of an effort to further exploring other factors associated with indoor in the rural Ethiopian rural context. Considering that high exposure to IAP is likely in poorly ventilated housing units, it is possible that this contributes to increased burden of diseases and deaths due to ARI among the general population and under-five children [3, 42]. Therefore, the study will have great operational relevance for efforts to achieve the Millennium Development Goal 7 (MDG 7, target 9, indicators 27 & 29) in that it could generate important information on feasible interventions for the reduction of IAP in the Ethiopian rural homes.

Materials and Methods

Study setting, indoor air sampling and analysis for nitrogen dioxide

A longitudinal study was conducted to assess the level of indoor air pollution, by measuring NO_2 level, in rural households over a period of two years (March 2000-April 2002) in a rural district (*Meskan and Mareko)* in mid-southern Ethiopia. The presence of a Demographic Surveillance System that was instituted in the District since 1986 was an opportunity for the assessment of indoor NO_2 concentrations. Indoor air samples for nitrogen dioxide were taken in approximately 3,300 homes with under five children.

NO_2 was detected using a modified colorimetric *Saltzman* method. A 24 hours indoor air sampling was done by trained local enumerators at about three months interval to collect data on the date, start and finishing time (hh:mm) of each sample. A digital watch was used to record the time. NO_2 concentration was measured using *Willems Badge* that was developed at the University of *Wageningen* in the Netherlands [43-45]. The polyethylene passive sampler consists of a small cylindrical cup equipped with two rings, chemically impregnated fibreglass placed at the bottom of the cup and Teflon to serve as a wind barrier. The sampler was set in a central wooden post of the rural housing (locally called "*tukul*") after ensuring the room was used for sleeping. The samplers in a batch were sent to the field after proper assembly. Sampling in the house was started by opening of the lid of the diffusive sampler (*Willems Badge*) and finished by closing it back after 24 hours of sampling.

Samplers from the field sites were transported to Addis Ababa where the centrally located laboratory was used for analysis. The absorption filter from the sampler was extracted with an acid solution of sulphanilamide and N-(1-naphtyl) ethylenediammonium dichloride (NEDA) which converts the absorbed nitrogen dioxide into NO_2^- ions. The presence of these ions develops a red coloured solution whose absorbance was measured at 540 nm (Beckman DU^R .64 Spectrophotometer). A standard curve NO_2 solutions was developed to calculate the NO_2 concentrations using the equation:

C = ((10^6*mass)/(expmin*40), where:

'C' is indoor air concentration of NO_2 in micrograms per cubic meter, 'mass' is mass of NO_2 on the glass fibre used for air sampling after subtracting mass of NO_2 of the blank glass fibre, 'expmin' is indoor air sampling duration in minutes, and 40 is a constant of air sampling rate for the diffusive sampler, 40 mlmn^{-1} [45].

The laboratory data quality was maintained using various methods. Laboratory technicians were properly trained and supervised on each day of laboratory analysis. Laboratory protocols were structured and monitored by standard practices. internal validity was checked by the analysis of standard solution, blank absorbance, and control chart for NO_2. The inter-laboratory variation was controlled by comparing the variations of NO_2 concentrations of duplicate samples and exposed samples that were taken at different conditions.

Detail description of the study area, sampling procedures, air sample location, and the analytical method is available elsewhere [41].

Assessment of determinants of indoor nitrogen dioxide

A household structured questionnaire was administered immediately after the completion of the air sampling to collect fuel use related data and events that occurred at the time of NO_2 sampling. Type of household fuel, purpose of having fire, type of cooked food and its timing were main variables collected during data collection. Ecological and seasonal factors were also considered due to their importance to affect indoor NO_2 [41]. The physical dimensions (radius, axis, and wall height), the presence of window and separate kitchen in the study homes were extracted from the 1999 census data of the study setting.

Data management and analysis

Data were entered and cleaned using the EPI INFO (version 6.04; Center for Diseases Control and Prevention, Atlanta, GA, USA and World Health Organization, Geneva, Switzerland). Consistency and completeness of each questionnaire was checked during data collection, entry and analysis. The data set was exported first to data Base File (DBF) and then to Statistical Package for Social Sciences (SPSS) files (version 15.0; SPSS Inc., IL, USA) for advanced statistical analysis.

After data exploration, the original data set of indoor air NO_2 concentration was transformed into logarithmic base 10 (log10) to meet the assumptions of analysis of variance (ANOVA) and linear mixed model regression analysis. In addition, box plots and stem plots were used to observe the relevance of outliers when comparing mean values of NO_2 by categorical variables. Variables describing firing events were categorized in such a way to avoid multiple responses. These variables were type of fuel, purpose and time of fire events, and type of cooked food. One way ANOVA was employed for the detection of any differences and changes in the dependent variable represented by average indoor NO_2 concentration in the presence of categorical biomass fuel variables.

A mixed linear model was used to find out the relative importance of household characteristics on NO_2 after ensuring assumption of normality in the dependent variable, linearity between dependent and independent variables, and collinearity between variables. A unique identifier for each household and the time variable attached to each NO_2 measurement were created for this analysis. Ecology, season, type of biomass fuel, purpose and the time of the fire vents, and the frequency of food items were used for a fixed effect, while the quarterly measurements of NO_2 were considered for the repeated effect. The intercept model was only used for the random effect as all households with under-five children were involved in the study. The use of unstructured covariance structure was found to be the best fit for the linear mixed model.

One way repeated measures of ANOVA was employed to analyze the presence of any difference in NO_2 across time periods after structuring the data lay out. The effect of housing characteristics (calculated indoor volume of each home, presence of window and kitchen) on indoor NO_2 level was assessed using hierarchical model for a multiple linear regression analysis. Descriptive statistics, tables and inferential statistics were mainly used to present the findings. Further details on data management and data quality control are available elsewhere [41].

Results

Characteristics of fuel use

The study was conducted for 2 years period involving 17215 indoor air samples in 3300 households with no refusal of participation. About 98% of air samples were taken at times of fire events in households. Biomass fuel in a form of wood, crop residues, and cow dung were largely used in 71%, 65%, and 32% of samples, respectively. Other type of fuels that were seasonally used include eucalyptus dry leaves, corncobs, and leaves of false banana in 2.6% of households. The use of mixed type of fuel was a common pattern (Figure 1). All firing events, whether for cooking or not, took place mainly indoor.

Cooking, lighting, heating, and insect repellent were reported as the reasons for having fire events in households in the last 24 hours during the time of air sampling (Table 1). Cooking foods and heating the space, (in 98% and 34% of the samples, respectively), were the major activities for the fuel use. The use of biomass smoke for insect repellent was observed in about 13% of samples. Cooking and heating activities simultaneously took place in one third of the samples, while other activities in combination were rarely practiced representing less than 2% of the samples. Households had the practice of fire use three times a day. There were fewer activities at night that required the use of biomass fuel. Respondents in 73% of the samples perceived that firing at home took place relatively longer in the evenings than other times.

With regard to cooked food items, cabbage cooking, traditional coffee ceremony, bread and local staple diet (locally called "*kocho*") baking were the usual type of traditional foods that were prepared during the 24 hours of indoor NO_2 sampling. Traditional flat bread (locally called "*injera*") and its accompanying sausage (locally called "*wat*") were rarely cooked, and only observed in less than 10% of the samples. Over 90% of cooking activities took place in the mornings and evenings, while this was insignificant for the nights. Commonly cooked food items were cabbage ("*gomen*"), traditional coffee ceremony, and bread in 82%, 81% and 68% of samples, respectively. Other rarely cooked traditional food items were pea and bean roasting and boiling (locally called "kolo" and "*nifro*"), boiling of milk, cucumber cooking and maize boiling reported in 7.5% of the samples.

The association of fuel characteristics with ecological setting is presented in Table 2. There was a difference in the type of biomass fuel and its purpose of use. The use of wood predominated in the highland, while crop residues prevailed in the lowland. Heating of the housing space was more frequent in highland (40%) than the lowland (28%). Cooking of any three food items and having three fire events per indoor air sampling day were commonly practiced in 73% and 80% of samples, respectively. Ecology was strongly related to all fuel use characteristics ($p<0.05$).

Consistency of fire use events

There was not any difference in the time and frequency of fire use, type of fuel and type of cooked food items that occurred between the sampling time and one week recall period prior to that. It was only possible to identify that a religious holiday related to "*Romodan*" (the Moslem fasting month) was implicated to be a factor for additional cooking food items such as vegetable and meat soup, which took place relatively longer than the usual days of cooking.

The level of NO_2 by the characteristics of fuel use

The relative difference in NO_2 concentration by proxy fuel factors is indicated in Table 3. The concentration of NO_2 was found to significantly differ by type of fuel. On the average, households using wood had geometric mean (GM) and geometric standard deviation (GSD) of 71.2 (2.8) μg/m^3, for cow dung of 67.5 (2.9) µg/m^3, and for crop residues of 56.1 (2.7) µg/m^3. Any combination of biomass fuel use did not significantly impact NO_2 concentration.

The GM (GSD) concentration of NO_2 representing a single purpose of having a fire in a household was 69.2 (2.7) µg/m^3, any two purposes was 57.1(2.9) µg/m^3 and any three or more purposes was 55.6 (2.8) µg/m^3. Multiple comparisons indicated that high level of NO_2 was related to only single purpose compared to combination of them ($p<0.05$). The concentration of NO_2 had a declining linear trend from a single activity to combined activities (p-value for linear trend ($p < 0.05$).

Multiple food cooking was strongly related to NO_2 indoor level compared to any single food preparation ($p<0.05$). An increasing linear trend with the number of cooked food was also observed (p-value for linear trend ($p < 0.05$). Coffee drinking as well as bread and "Kocho" baking were the usual types of food that were frequently cooked.

Increased level of NO_2 was significant among households that frequently used firing ($p < 0.05$). One time of fire use per day was related to GM (GSD) NO_2 of 30.8 (3.34) µg/m^3, while this was 64.3 (2.79) µg/m^3 for any combination of timing of fire in reference to the morning, day time, evening or nighttime. NO_2 had an increasing trend with the frequency of cooking time (p-value for linear trend ($p < 0.05$).

In a mixed model linear regression, type of ecology, season, type of fuel, frequency of fire events and number of foods cooked per day were able to explain overall variations in NO_2 concentrations (Table 4). A household being in a highland, wet season, use of crop residues, any time of having a fire event, frequency of food items, and interaction between ecology and season emerged as predictors of indoor NO_2 concentration. The purpose of fire events did not make any effect.

Level of NO_2 by time of measurement and housing structure

The time for NO_2 measurement from our database and variables on housing (calculated volume, window, and kitchen) from Butajira Demographic Surveillance database were extracted for the analysis. The mean (SD) NO_2 measurements during our study period was 4.37 (1.90) per household, while the median was 5. Nearly 70% and 56 % of the households had at least 4 and 5 measurements of NO_2, respectively. There was a significant difference in the repeated measurements of NO_2 concentrations over time [Wilk's Lambda=0.993, (F(4,2047) =3.46, $p <0.05$ with multivariate eta squared=0.007 and observed power of 89%]. The compared five NO_2 measurements in order of time 1 to time 5 (n=2186) were GM (GSD): 68.6 (2.58), 70.3 (2.54), 69.1 (2.47), 70.1 (2.49), 65.2 (2.62) µg/m^3 (n=2051) Post hoc pair-wise comparison showed the overall difference was accounted to time 2 and time 5, and time 4 and time 5. The repeated NO_2 measurements also differed by ecology, (F(1,2049)=260.5, $p <0.05$) and by location of households ("*peasant associations*"), [F(8,2042)=48.9, $p<0.05$)].

The calculated volume of "*tukul*" was linearly related to NO_2 concentration [β (95% CI): 0.104 (0.055, 0.153]. The addition of window in the 2nd model did not show any association, while kitchen in the 3rd model showed a significant relationship with indoor NO_2. The indoor volume showed positive relationship, while kitchen was negatively related to indoor NO_2. Indoor volume alone indicated NO_2 to vary by about 1.0 µg/m^3 for every 10 m^3. Both volume and kitchen were able to explain less than 1% variations in NO_2 [adjusted R^2=0.008] (Table 5).

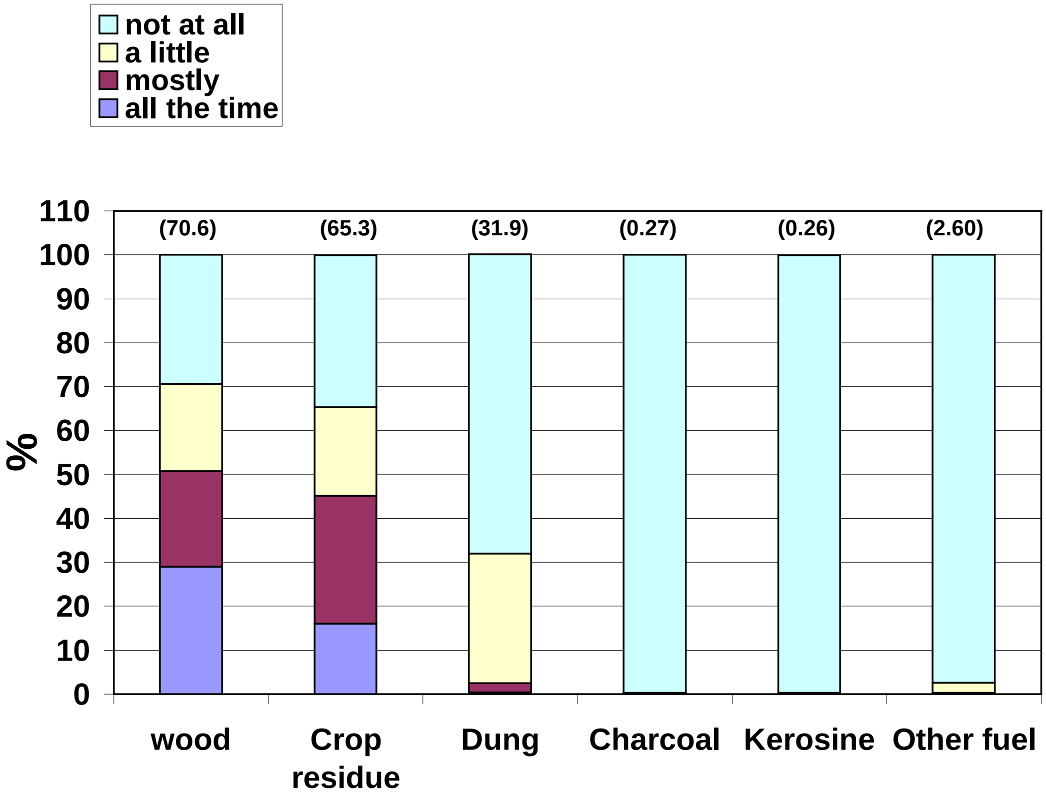

Figure 1: Type of fuel and its use pattern that was observed during 24 hours of indoor NO_2 sampling, Butajira, Ethiopia, 2000-2002 (n= 16899). For each type of fuel, the number in brackets indicates the proportion of type fuel used singly and in combination with others in reference to respondent's judgment comparing with the usual days.

Table 1: Distribution of purpose of having fire and its timing that were observed during the 24 hours indoor NO_2 sampling, Butajira, Ethiopia, 2000-2002 (n= 16899)

Purpose of having fire	**Morning** # **(%)***	**Mid day** # **(%)***	**Evening** #**(%)***	**Night** # (%)*	**Total** # (%)*
Cooking	15670 (98.9)	14583 (99.1)	16325 (98.8)	934(94.9)	16622 (98.4)
Lighting	668 (4.2)	615 (4.2)	684 (4.1)	95 (9.7)	703 (4.2)
Heating	5529 (34.9)	5185 (35.2)	5718 (34.6)	331 (33.6)	5838 (34.5)
Insect repellent	1945 (12.3)	1527 (10.4)	2009 (12.2)	212 (21.5)	2122 (12.6)
Total use of fire	15836 (93.7)	14714(87.1)	16520 (97.8)	984 (5.8)	16899

*Percentages did not add up 100% due to multiple responses

Table 2: The characteristics of fuel use by ecological setting, Butajira, Ethiopia, 2000-2002 (n=16899)

Characteristics	**Ecology type** **Highland,** **# (%)***	 **Lowland,** **# (%)***	**P value for X^2**	**Total** **# (%)***
Type of fuel				
Only wood	6209 (73.5)	2183 (8.5)	P<0.05	8392 (52.1)
Only Crop residue	2180 (25.8)	5231 (68.4)		7411 (46.0)
Only dung	63 (0.7)	234 (3.1)		297 (1.8)
Total	**8452 (52.5)**	**7648 (47.5)**		**16100**
Purpose of having fire				
Cooking	8905 (98.6)	7717 (98.1)		16622 (98.4)
Lighting	304 (3.4)	399 (5.1)	P<0.05	703 (4.2)
Heating	3609 (40.0)	2229 (28.3)		5838 (34.5)
Insect repellent	360 (4.0)	1762 (22.4)		2122 (12.6)
Total	**9031 (53.4)**	**7868 (46.7)**		**16899**
Food frequency				
Any one food item	318 (3.6)	331 (4.5)	P<0.05	649 (4.0)
Any two food items	1022 (11.6)	1423 919.2)		2445 (15.1)
Any three food items	6393 (72.9)	5433 (73.3)		11826 (73.1)
Any 4 & + food items	1040 (11.9)	224 (3.0)		1264 (7.8)
Total	**8773 (54.2)**	7411 (45.8)		**16184**
Frequency of having fire				
Any one time	147 (1.6)	175 (2.2)	P<0.05	322 (1.9)
Any two times	1088 (12.0)	1333 (16.9)		2421 (14.3)
Any three times	7386 (81.8)	6164 (78.3)		13550 (80.2)
Any four times	410 (4.5)	196 (2.5)		606 (3.6)
Total	**9031 (53.4)**	**7868 (46.6)**		**16899**

*Percentages did not add up 100% due to multiple responses.

Table 3: 24 hr indoor NO_2 concentrations related to household characteristics in a bivariate analysis, Butajira, Ethiopia, 2000-2002 (n=16899)

Characteristics	**n**	**log NO_2 mean(SD)** µg/m^3	**GM (GSD)** µg/m^3	**p-value**	**X^2 linear trend**
Ecology					
Highland	**9018**	**1.89 (0.45)**	**77.2 (2.82)**		
Lowland	**7857**	**1.70 (0.43)**	**50.5 (2.67)**	P<0.05	
	16875	**1.80 (0.45)**	**63.3 (2.81)**		
Biomass fuel type					
Only wood	8379	1.85 (0.45)	71.2 (2.8)		
Only cow dung	297	1.83 (0.47)	67.5 (2.9	P<0.05	
Only Crop residues	7400	1.75 (0.44)	56.1 (2.7)		P < 0.001
Total	**16076**	**1.80(0.45)**	**63.7 (2.8)**		
Purpose of having fire					
Any one activity	9256	1.84 (0.44)	69.2 (2.7)		
Any two activity	6657	1.76 (0.46)	57.1 (2.9)	P<0.05	
Any three and above	886	1.75 (0.45)	55.6(2.8)		P < 0.001
Total	16799	**1.80 (0.45)**	**63.4 (2.8)**		
Type of foods cooked					
Any one food item	649	1.76 (0.46)	58.1 (2.9)		
Any two food item	2442	1.74 (0.44)	54.7 (2.7)		
Any three food item	11806	1.81 (0.45)	65.3 (2.8)	P<0.05	
Any 4 food & above	1263	1.90 (0.43)	80.0 (2.7)		P<0.001
Total	16160	**1.81 (0.45)**	**64.3 (2.8)**		
Time of having fire					
Any one time	322	1.50 (0.52)	30.8 (3.3)		
Any two time	2418	1.75 (0.42)	56.2 (2.6)	P<0.05	
Any three time	13530	1.82 (0.45)	65.7 (2.8)		
Any four times	605	1.82 (0.42)	66.2 (2.6)		P<0.001
Total	16875	**1.80 (0.45**)	**63.3 (2.8)**		
Season					
Dry season	8160	1.78 (0.45)	59.64 (2.8)	P<0.05	
Wet season	8715	1.83 (0.45)	70.0 (2.8)		
	16875	1.80 (0.45)	63.3 (2.8)		

Table 4: Estimates of fixed effects of fire use characteristics in households having fire events during last 24 hours, Butajira, Ethiopia, 2000-2002 (n=3849)

Indoor Fire use characteristics	Parameter Estimate (Slope)	Std. Error	t	p-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	1.806	0.034	53.48	p<0.05	1.740	1.872
ECOLOGY						
Highland	0.189	0.012	15.75	p<0.05	0.165	0.212
Lowland	reference					
SEASON						
Dry	-0.030	0.009	-3.33	p<0.05	-0.048	-0.012
Wet	Reference					
BIOMASS FUEL TYPE						
Only wood	-0.019	0.025	-0.79	p>0.05	-0.067	0.029
Only Crop residues	-0.048	0.024	-1.98	P<0.05	-0.096	-0.001
Only dung	Reference					
PURPOSE OF FIRE EVENTS						
Cooking	0.026	0.016	1.65	p>0.05	-0.005	0.057
Heating	-0.029	0.016	-1.87	p>0.05	-0.060	0.001
Insect repellent	Reference					
FREQUENCY OF FIRE EVENTS						
One time per day	-0.146	0.032	-4.52	p<0.05	-0.209	-0.083
Two times per day	-0.00001	0.019	0.00	p>0.05	-0.038	0.038
Three times per day	0.020	0.017	1.16	p>0.05	-0.014	0.054
Four times per day	Reference					
FREQUENCY OF FOOD ITEMS						
One food item	-0.068	0.021	-3.32	p<0.05	-0.109	-0.028
Two food items	-0.093	0.015	-6.39	p<0.05	-0.122	-0.065
Three food items	-0.050	0.012	-4.09	p<0.05	-0.074	-0.026
Four food items	Reference					
Highland * Dry season	-0.066	0.012	-5.39	p<0.05	-0.090	-0.042
[Highland * wet season	Reference					

Dependent Variable: indoor concentration transformed to log 10

Table 5: A relationship between indoor NO_2 and housing physical structures, Butajira, Ethiopia, 2000-2002 (n= 2882)

Model	Variables	Regression Coefficients (Beta), (95%CI)	Std. Error of Beta	t-statistics	P value for beta	Model R^2 (adjusted)	Standardized beta
1	Volume	0.104 (0.055,0.153)	0.025	4.16	p<0.05	0.006	0.077
2	Volume	0.112 ((0.061,0.162)	0.026	4.35	p<0.05	0.006	0.083
	Window	-0.018 (-0.046,0.010)	0.014	-1.28	p>0.05		-0.024
3	Volume	0.102 (0.51,0.152)	0.026	3.93	p<0.05	0.008	0.076
	Window	-0.022 (-0.05,0.005)	0.014	-1.58	p>0.05		-0.030
	Kitchen	-0.5.3 (-0.89,-0.018)	0.018	-2.94	p<0.05		-0.055
Condensed	Volume	0.093 ((0.043,0.142)	0.025	3.66	p<0.05	0.008	0.069
	Kitchen	-0.050(-0.085,-0.015)	0.018	-2.79	p<0.05		-0.052

Discussion

Selected household characteristics affecting the level of indoor air pollution have their own role in changing the level of NO_2 in the context of our study area. Nearly all households in ther study area used biomass fuel in the form of firewood, crop residues, and animal dung among which the first two predominated. People in the study area are known for using wood most of the time throughout the year, crop residues such as stocks of maize and barley during harvest times, and animal dung during summer [46]. While biomass fuel sources are relatively cheap and easily available locally, fuels of fossil origin such as kerosene was only used to light local lamps for the interior of housing units at night. The cost of kerosene is less affordable for rural residents to use it for cooking purposes compared to residents of urban areas such as Addis Ababa [47]. The use of biomass fuel as a primary source of household energy is consistent with findings of studies in other developing countries [1, 10, 19, 28, 38, 48].

Biomass fuel was extensively used for cooking traditional foods compared to other purposes of having fire events. Cooking activity largely absorbed the largest share of household fuel use taking place in all times of the day. Heating ranked the 2nd purpose, while only about a tenth of the households used biomass fuel to repeal mosquitoes at night. The use of heating indoor space predominated in colder villages, mainly in the highlands, while repealing mosquitoes prevailed in the lowlands. It is evident from the data that home heating in the highland caused an additional fuel use burden, which possibly contributed to the increased concentration of indoor NO_2 compared to the relatively low fuel use burden required for repelling insects repellent in the lowlands. The extreme temperature difference [49] might have contributed to the variation in the use of fuel for heating between the two ecological settings. Low temperature in early mornings and nights is usual in the highlands of Ethiopia. Villages in the lowlands inherently possess a risk to malaria caused by mosquito bites and, therefore, there is a cultural practice in the study area for using indoor firing events to repel mosquitoes [42, 50].

Traditional foods that do not require a stock for more than a day were routinely cooked. The cooking time was equally important in all cases of cooking which involved commonly the mornings, middays and evenings. Traditional coffee and bread making are also among the daily practice of people in the study area. Coffee in each household was served for a group of neighborhoods nearly on daily basis, which is a cultural heritage of Ethiopia. The relative time and cost of preparing these food items are a bit less than that for "*injera*" and "*wat*" which are widely used in other parts of Ethiopia, especially in the temperate and highland areas. The practice of "*injera*" and "*wat*" is expensive and the raw material, locally called "*teff*" is considered as a cash crop for the rural residents in the study area. The linear relationship between the number of food items cooked and frequency of cooking with the level of IAP is obvious given the increased respective amount of biomass fuels and the corresponding higher emission of other pollutants in addition to nitrogen dioxide. This is just a reflection of "dose-response" relationship.

Cooking and heating activities are the main household factors that lead to the excess NO_2 concentration due to solid biomass fuel use in general, and in the highland areas in particular. In other studies, given the range of the purpose of biomass fuel use, cooking has been implicated as the main factor for the greater proportion of exposure to IAP in developing countries [4, 51]. Biomass fuel emits about 50 times more pollution during cooking compared to cleaner fuels [4], while the exposure magnitude of breathing in pollutants could be twice more for the same population [7]. Therefore, the magnitude of health risk due to biomass combustion can reach as much as 2-3 times greater than the risk among clean fuel users [4, 9]. Indoor smoke from biomass fuel is attributed to loss of healthy life in poor countries due to known health outcomes such as ARI, acute lower respiratory infections, and chronic obstructive lung diseases [52]. It is possible to speculate based on our findings that higher degree of exposure to indoor air smoke goes to mothers and children who often spend most of their time indoors. This implies that the attainment of Child Health MDGs would be a challenge in developing countries, like Ethiopia.

Assumption of the within-subjects (within a household over time) variation in indoor NO_2 concentration by time was certainly important given the possible differences in the exposure to various fuel characteristics within households.

This determined the presence of differences in exposure factors. The repeated between subject difference in NO_2 demonstrated by ecological factors and seasonality is an important effect that requires closer attention for designing an appropriate intervention, as well. The study revealed only an interaction between ecology and seasonality affecting the indoor NO_2 concentration by time. This was supported by our data that indicated variations of NO_2 to be dependent on the type of fuel in the bivaraite analysis, although this association remained significant for a crop residue in a linear mixed model.

Ecology, season, type of biomass fuel, the purpose and time of having fire events, and the frequency of cooked food items were all found to affect the level of indoor air in a bivariate analysis, while this association was consistent in a linear mixed model except for the type of biomass fuel for wood. In western countries, the type of fuel (gas or electricity), occupancy density, the number of cooked meals, frequency of cooking, season and income were found to significantly impact indoor NO_2 concentrations [20, 24-26, 53]. Those studies have indicated the presence of strong link among factors responsible for the increased level of indoor NO_2 both in the developed and developing countries. The new finding in our study is the presence of ecology as a factor that predominately affects the level of NO_2. The high level of NO_2 in the highland areas can also be explained by high proportion of wood fuel use. Wood is at least better than crop residues and animal dung in the energy ladder [54] and provides relatively better energy efficiency. When wood is used, it oxidizes relatively more indoor air nitrogen because of the relatively high combustion temperature.

The effect of housing volume was found to show little importance in affecting IAP as measured by NO_2, which was against our hypothesis. Together with the presence of window and kitchen in the multiple linear models, there was only very small proportion of explainable variance (less than 1%) in NO_2 concentration despite the statistical significance. The computed model was not able to indicate a practical relevance in explaining the direction and strength of the association between the magnitudes of indoor air pollution and the physical housing characteristics in our study area. The significant difference, however, could be only explained due to large sample size that could have picked up small differences for calculating p-value. Rural housing units, due to their nature of construction, allow the easily passage of indoor smoke through their thatched roof, open eves and unplastered or partially plastered wall, restricting the continued built up of indoor air pollutants. It is very usual to observe visually the penetration of intense smoke through such structures during active cooking times in early mornings when there is good visual contrast (personal observation). Windows in the majority of housing units in the area are represented by just small circular holes (usually < 5% of the floor area, which are often closed due to the fear of wind drafts). Furthermore, opening of windows is culturally believed to affect resident's heath in our study settings.

Lack of assessment for additional air pollutants such as PM and the absence of real time measurement for the indoor air pollution were major limitations of this study. Nevertheless, the present study has shown that ecology, season, purpose of fire events, the frequency of cooked food items and the frequency of fire events as being predictors of indoor NO_2 in a rural setting.

Based on these findings, further study on personal exposure assessment using NO_2 and PM is highly recommended. In addition, relating indoor NO_2 levels with commonly seen childhood diseases, such as respiratory symptoms, is another area of significant relevance for a research given the high level of IAP in our study settings. Finally, the provision of separate kitchen, improved stoves with hood, and presence of window in kitchens are highly advised to manage low level of IAP.

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Author's contributions: Kumie A and Emmelin A were involved in the study protocol design development, data collection, data quality monitoring, data analysis and preparation of the manuscript. Berhane Y and Ali A were involved in analysis and editing draft manuscripts. Wahlberg S and Brändström D designed and supervised NO_2 data collection and laboratory analysis; Mekonen E was involved in supervising and monitoring lab data analysis.

Worku A was involved mainly in data analysis and its data quality management. All authors contributed to revising the final manuscript.

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Research Article

Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia

Kumie A[1], Charles Keil[2], Berhane Y[3], Ali A[1], Emmelin A[4]

- [1]School of Public Health, College of Health Sciences, Addis Ababa University, Addis Ababa, Ethiopia
- [2]Bowling Green State University, Ohio, USA
- [3]Addis Continental Institute of Public Health, Addis Ababa, Ethiopia
- [4]Umeå International School of Public Health, Umeå University, Umeå, Sweden

Corresponding Author
Dr. Abera Kumie
School of Public Health, College of Health Sciences
Addis Ababa University
P.O.Box: 9086, Addis Ababa, Ethiopia
Tel: Mobile: +251-911-88-29-12
Office tel: +251-11-5157701
Fax: +251-11-5517701
Email: aberakumie2@yahoo.com

Email addresses of authors

1. Kumie Abera, aberakumie2@yahoo.com
2. Charles Keil, ckeil@bgnet.bgsu.edu
3. Berhane Yemane, yemaneberhane@ethionet.et
4. Ahmed Ali, ahmedhayat82@yahoo.com
5. Emmelin Anders. anders.emmelin@epiph.umu.se

Abstract

Background: Air pollution levels in urban centers of Ethiopia are presumed to be high due to the prevailing old vehicles and substandard road infrastructures. This study assesses CO concentration as surrogate for traffic air pollution along road sides and on-road of Addis Ababa.

Materials and Methods: A total of 80 road side and 24 on-road traffic air samples on the month of July/2007 and January 2008 were taken using CO data logger. Purposive criteria were set for the selection of these sites. On road CO assessment was used in order to evaluate the link with the road side CO concentrations. A structured checklist was used to document the sampling sites, starting and finishing sampling times, and the location from the edge of the road. Downloaded XLS CO data was used for the analysis of CO concentrations. Summary statistics and graphs were mainly used to present data. Data quality of CO measurement was ensured during data collection.

Results: The weighted mean (SD) for 15 minutes averaged CO concentrations were 2.03 ppm (1.94) and 2.64 ppm (2.53) for wet and dry seasons, respectively. The two means did not differ significantly. The CO profiles between the two months and on-road CO concentrations were similar. Generally, increased CO concentration in early mornings and late afternoons are characteristics of daily CO distribution. There was a very clear spatial and temporal variation among 40 samples after categorizing the sites by the level of CO concentration in reference to the 8hr CO concentrations guideline. One third of sites had indicated high level of CO concentration (>4ppm) for the two months. The temporal and spatial variation of CO concentration profiles between on the road and roadside air samples was similar. The overall mean (SD) on-road CO concentration was 5.38 (1.71) ppm. International CO guideline was not exceeded. 1hr and 8hr CO concentration did not exceed international standard.

Conclusions: There is a link between the roadsides and on-road measured CO concentrations. Vehicle density, atmospheric moisture, temperature inversion, and ventilation seemed to affect the level and variations in CO concentration. Some on-road sites might exceed the 8 hr WHO guideline for CO in future.

Key words: Addis Ababa, CO, traffic air pollution, temporal and spatial variation, July, January

Background

Increasing demand on transportation service and challenges of the prevailing poverty are basic problems in emerging cities of developing countries, like Addis Ababa. Markets in urban centers of third world countries are attractive for used vehicles to satisfy the growing needs of transportation. More than 50% of cities with increased level of ambient urban air pollution are found in developing countries [1]. Urban air pollutant related to Particulate Matter ($PM)_{10}$ mass concentration was found to exceed international limits in cities of developing countries [2-4]. The presence of old cars accompanied with poor handling in one hand, limited and slowly expanding urban road net works on the other hand, are present challenges that could not sustain cleaner urban air around traffic zones in many developing countries [5]. The measurement of either PM_{10} or Carbon Monoxide (CO) along the roadsides in developing countries exceeded often the local and international guidelines [6-9]. Data inventory among world wide mega cities made by the World Health Organization (WHO) indicated that urban air pollution due to vehicular emissions is visible in developing countries [4]. Vehicular sources are the dominant sources of CO emission contributing to urban air pollution. On-road transportation for 1970-1975 in the United States of America(USA) was about 70% of the total CO emissions [10]. Whereas, this was 57%

in European countries in 2000 [4].

Studies have indicated that distance between motorway and home, traffic density as measured by cars and lorries as proxies of traffic air pollution were associated with reduced lung functions and respiratory diseases among children living near major motorways [11]. Spending at least one year in schools located closer to a road with high traffic density was associated with asthma among schoolchildren [12]. Traffic density within distance of 90 to 150 metres was found to be related with increased respiratory illness [13-16]. Work related to an exposure to vehicle emissions was strongly associated with respiratory diseases. Occupations such as truck and taxi driving were related with an increased risk of cancer [17,18].

Addis Ababa is one of the emerging cities in Africa, which is currently under going rapid urbanization with huge investment in transport, buildings and road sectors. The Ethiopian Road Authority for the years 1990-2002 indicated that there were four categories of vehicles in the country: cars (automobiles), light duty trucks, heavy-duty trucks, and motor cycles. Automobiles contributed about 60% of the total vehicles. The annual growth rate of vehicles varied between 0.32% and 19.45%, with an annual mean increase rate of 7.7% in the 12 years duration [19]. The baseline of the estimation was 60,576 vehicles for 1990. Of the total 116,415 registered vehicles in 2002 by plate number, 39.4 % of them were above 30 years of age, 9.4% of the cars were between 20 and 30 years old, 25.7% of them were between 10 and 20 years; while only 20.5% of them being less than 10 years old. [19]. Nearly 50% of all vehicles had age of 20 years and above. The age of a vehicle is very important in the evaluation of traffic air pollution. Research has shown that vehicles with 15 years old produce five times more hydrocarbons and four times nitrogen oxides than that of new ones [5]. The number of vehicles in Addis Ababa that had annual vehicle inspection by Addis Ababa Road Authority in 2003 was 89,716, out of which about 80% had petrol engines and 90% were privately owned [20]. In 2007, this number had gone up to 105,246, showing an increase of 17% over 4 years period. If we assume United Nations (UN) and Federal plated vehicles are spending much of their time in Addis Ababa, the total number then is 139,535 with 40% diesel engined. Given the present age of vehicles and the growing traffic density that is not accompanied with the corresponding expansion of road infrastructure, traffic air pollution has become a major concern in Addis Ababa as 77% of the Country's vehicles are located in the City

The growing number of street venders, road side shoppers, drivers, commuters, pedestrians, traffic polices, and residents within the vicinity of road networks are at the greatest risk to traffic air pollution exposure. According to Addis Ababa City Administration, the urban mobility pattern was 70%, 21%, 8%, and 1% of the total population: walk on foot, use public buses, taxis, and private cars, respectively [20]. It has now become part of the city's life to observe pedestrians and vehicles sharing the same road in all times of the day.

There is limited body of evidence describing urban air pollution in Ethiopia. To our best knowledge, we are only aware one study that has undertaken the measurement of PM_{10}, CO, airborne lead, ozone, and SO_2 in the ambient environment [21]. That study concluded that the 24 hr PM_{10}, ranging from 35 to 97μg/m^3, in 12 sampled sites of the urban core, is likely to exceed the annual Environmental Protection Agency (EPA)-USA standard of 50 μg/m^3, while other pollutants were assumed to be reasonably lower than the respective standards. The authors also found the existence of site to site and temporal variations in the level of pollutant concentrations. The study, however, had air-sampling sites that were 50-100 meters away from the main arterial roads. The study had limitations to indicate the magnitude of those measured pollutants within the vicinity of the traffic zone.

The present study focused on the exploration of the level, temporal, spatial variations of traffic air pollution as measured by proxy CO in selected air sampling sites along the road side of the City of Addis Ababa. Addis Ababa is increasingly becoming an important City for Regional and International events.

Materials and Methods

Study setting

Addis Ababa is the capital City of Ethiopia and working center of African Union. Its population in 2007 was 2.74 million [22]. The City of Addis Ababa, with an area of 54 thousands hectares, is located at the foot of Mountain of "Intoto". The area approximates a circular shape with a diameter of about 30-40 kms. The varying elevation between 2,200 and 2,800 meters above sea level (masl) with an average of 2,400 masl is the characteristic of the topography. The city spreads between 9 degrees north latitude and 38 degrees longitude east, with a rising slope from south to the north. The average maximum and minimum temperatures were 23.2°C and 10.8°C, respectively, with monthly mean rainfall of 78.5 mm in 2007 [23]. The climate is characterized by three continuous months of moist season (June-August) and nine months of dry season. A relatively colder season of "Wurch" exists between October and January.

The City Administration estimated that there is 436 km asphalted (20%) and 1725 km non-asphalted road (80%). About 48% and 52% of the asphalted roads have width of 6-8 meters and 8-12meters, respectively. Gravel roads are often source of organic dust particles to the city's atmosphere [20]. Data on air emission inventory for each source is not available.

Sampling site description

A total of 20 major road networks were purposely selected to measure the daily level of carbon monoxide over 40 roadside sampling sites. The sites largely represented busy traffic lines lying mostly in the road side urban core and few in the periphery of the City. Each sampling site was selected using of the following purposely-designed criteria:

- Road side distance less than 10 meters from the edges of the road side: this criterion is used to approximate the immediate traffic zone. About 85% of our sampling site location had less or equal to 5 meters.
- Presence of shopping centers or kiosks

with substantial presence of pedestrians: this criterion is used to relate CO exposure with road side population. All 40 sampling sites were either shops or kiosks dealing with the sales of stationary, general items, and vehicle spare parts.
- Presence of adequate traffic density in order to detect CO adequately: these sites were decided after consulting City's traffic counts with the help of traffic polices and personal observations.
- Absence of visible barrier that could impair the air sampling process: consideration is given to a barrier standing between the sampler and the edge of the road so that the air sampler was in a free zone in all directions.
- Willingness of the owner of the sampling site to host the CO monitor for the sampling time: this was very relevant to secure the monitors for subsequent use and safeguarding against possible wetting by rain.

Figure 1 indicates Addis Ababa's road networks and locations of air sampling sites. Exact locations were identified using Global Positioning System (GPS) taking (GPS 12 X L, Garmin 12 channel).The road that goes from East to West (from "Megenagna" to "Lideta" and further to "Jimma" road) of the city intersects the ring road on both ends. This road is the major artery that divides the road network roughly into two parts. The Northern road net work is denser than the southern road network. We had 10 samples on the East-West main artery, 20 samples on the Northern network (represented by "Belay Zeleke" Road, " Teklehaimanot" to "Autobus Tera" road), and 10 samples on the southern road net work (represented by " Saris" road, "Kera" road, "Bole" road).

After looking at the preliminary results of CO concentration in 40 sites in July 2007, there was a need to relate the source of CO with the temporal and spatial pattern of the already measured CO. Four traffic lights ("Olympia", "Legehar", "Urael" , and Post office traffic light posts) were selected for this purpose. One of them takes to the international airport ("Bole'); two of them lie on the main artery running from East to West of the City, the fourth one entering to this artery. These sites have heavier traffic densities than other traffic line sites (judged by observation and interviewing traffic polices).

CO measuring

Road side CO measurements were performed at two different time lines: from July 7 to 27, 2007 representing the wettest month, and from January 1 to 26, 2008 represent the driest month of the year. On-road sampling was made from March 31 through April12, 2008. Sampling was done on six days of the week (i.e. Monday to Saturday). Sunday's was excluded after evaluating the relevance of traffic density during pre-testing.

Two portable CO USB real data loggers [24] were used to measure the level of CO in each sampling site. These CO monitors were made available by the Department of Environmental Health of State Green Bowling University(BGSU) . The monitors were factory calibrated and rechecked the calibration using of standard CO concentrations at the research laboratory of BGSU prior to their use. The present USB CO monitor has detection limit between 0 to 1000 ppm, storing capacity of 32510 measurements with an operating temperature range of -10-40°C and humidity of 15-90% . The CO logger has an internal resolution of 0.5 ppm and accuracy of ±6%of reading. The logger has a sensor that oxidizes CO into CO_2 electro-chemically. The measurement of CO_2 by the instrument is proportional to the amount of CO that is oxidized.

A user friendly CO monitor built in software was used to zeroed the CO monitor and fix the logging rate, starting time and date. Sampling intervals of 10 seconds (10s) were set in order to pick any varying levels of CO. A data sheet was used to record the date, USB ID code, name of site of sampling, and the time at which the air sampling in the field was set and stopped.

The CO monitors were set uniformly at 2 meters height in a visible location of the selected local sampling site after ensuring the free flowing of air from the immediate traffic towards the sampler. Permission for sampling was secured from the local traffic authorities. Consent for sampling was obtained after explaining the purpose of the survey to each owner of sampling sites. Sampling duration for the actual analysis in all sites was set between 7:00am and 18:00pm in order to get maximum possible CO concentration due to vehicular sources. The location of the sampler in one of the typical road side sites is indicated in Figure 2. The traffic light post is located at the center of the road serving vehicles in both directions (Figure 3)

Data management and Analysis

Stored data was immediately downloaded using XLS format after each sampling using the USB software. The data was then edited to fix the appropriate analysis time interval for CO concentrations. Three data sets were created, one for July of 2007, and others for January 2008 and on-road samplings. The 10s sampling interval was averaged by 15 minutes in order to smoothen short lived peaks of CO. This averaging time was also used to analyze the temporal and spatial variations.

Minimum, maximum, and weighted averages that were used to evaluate the profiles of CO concentrations were generated for both wet and dry months sampling periods. We had 90% of them having 30 and above measurements. Moving averaging time interval of 15 min, 30 min, 1 hr and 8 hr CO concentration was calculated for each sampling site in order to evaluate the concentrations in reference to the World Health guidelines, 90 ppm, 50 ppm, 25 ppm, and 10 ppm, respectively [25].

Line charts were mainly used to evaluate CO pattern by time and sampling sites. Summary statistics were calculated using XLS (Microsoft Office Excel 2003), while SPSS (version 15, SPSS Inc., Chicago, IL, US) was used to evaluate the data quality performance using correlation coefficients and beta value for linear regressions. Graphs and tables were used to summarize the data.

CO data quality evaluation

CO data logger has a calibration guarantee for two years when we started this study. However, frequently checking of the validity of measurements were important in order to track the quality of CO measurement through out the sampling duration. Three strategies of data quality assurance were used. These were:

1. Data quality checking based on daily CO measurements

The two monitors were subjected to CO measuring in actual road side sampling sites by setting the two monitors at similar height from the ground surface (2m) for sampling duration of 9-11 hrs. There were such 12 measurements from different sampling sites. Given the same starting and finishing time of CO sampling, we were able to project a regression line where "X" represents the CO level measured by one of the loggers, and "Y" represents CO level of the other logger. In this way, it was possible to calculate the correlation coefficients. ("r"). Overall average, using the 10 seconds interval of CO measurement "r" was 0.818 (95%CI: 0.807, 0.828), which demonstrated a very high correlation of CO measurements. If we were to smoothen the data using one minute or more logging rate, the overall correlation coefficient was greater than 0.90.

2. **Checking the performance during and after the actual air sampling episodes**

Purposeful CO data comparison between the two monitors was made on 17 occasions on the same dates through the exposure of these monitors on road side sites while the investigator was traveling to sampling site and when going home after routine sampling. The 10s sampling duration varied between 1-5 hrs. Correlation coefficients were about 0.906 (95%CI:0.893,0.918) indicating a good agreement in the measurement of CO. Data smoothening by 15 minutes interval had "r" more than 0.95.

3. Data comparison between two variants of CO loggers

A similar CO data logger (MicroDAQ.com, Ltd., Contoocook, NH 03 229, U.S.A) was used to evaluate the performance of USB EASY data logger. Hobo CO monitors are used by Gaia Association in Addis Ababa to evaluate the efficiency of clean ethanol stove project through the measurement of CO. A total of four data loggers (2 from each variant of CO monitors) were set at 2m height for 24 hours in a household using kerosene and charcoal for cooking on December 13-14/2008. Correlation coefficient between the two weighted data was 0.967 (95% CI: 0.965, 0.968). There was nearly a perfect match in concentrations between 0 and 45 ppm. The scatter plot for the two types of CO monitors is shown in Figure 4.

Our understanding was that both USB CO data loggers were reasonably measuring CO concentrations. Any technical failure was not accounted including battery life at all time of CO sampling.

Results

CO variation Characteristics

The average CO concentrations for 15 minutes during the wet and dry months are indicated in Table 1 and Figure 1. The profiles of weighted mean and averaged maximum CO concentration based on 15 minutes for the two multiple sampling periods (n=40) are indicated in Figure 5a and 5 b. Overall, the mean (SD) CO concentration for the dry season was2.64 ppm (2.53),. Similar amount was observed for the wet season(2.03 (1.94) ppm). The temporal variation observed for both sampling seasons was similar. The average CO levels during wet season were characterized by elevated peaks during rush hours in the morning (about 8:00-9:00 am local time), early afternoon (about 15:00 -16:00 pm), and late afternoon (17:15 -18:15 pm). Similar patterns were observed for the dry season although high levels were observed over wider range in afternoon times: from as early as 14:00 to the late hours of 18:24. Daily maxima for the month of July occurred at around 17:30-18:00pm, while this was around 8:00 am for the month of January. Early hours of CO measurements in July didn't happen as kiosks and shops selected for CO sampling were commonly closed due to the protracted seasonal rain. Shoppers were also restricted to come for shopping until rainwas subsidized.

The 15 minutes average maximum CO concentrations generally ranged between 3.30 and 31.46 ppm for the wet month, while these were, 9.78 ppm and 19.28 ppm, respectively, for the dry month. The maximum 15 minutes average CO mean (SD) concentration for July and January were, 15.58 (4.64) ppm and 13.42 (1.57) ppm, respectively. There was a statically significant difference between these two observations (p<0.01). The averaged minimum CO concentration level was not visible in Figure 5, as it was 0 ppm during all sampling time intervals.

Our study indicated a spatial variation in CO concentration. Of all 40 samples, 12 sites had more than 2-4 times of the aggregated mean of the 40 sites of CO concentrations compared to others. Five sampling sites ("a general shop Haya Hulet Mazoria", "Legehar" Minibus station, "Gofa" Mazoria Kokeb", "Bole Printing Press and "Kera Discovery") consistently showed high level of CO for both months, while four sites ("Bole Flamingo" , "Lideta Tele center", "Mexico Square Pepsi Kiosk", and "Mesalemia Mimi bread seller") exhibited higher level of CO in the dry month. All these sites were located in high traffic zones of Addis Ababa. Three sites ("Autobus Tera Z Music" shop and " Ismael" shop, and "Gofa MebratHail") had high level of CO during the wet month compared to the dry month . The horizontal sampling distance between the sampler and edge of the road did not correlate with the measured CO concentration in both months.

Characterizing CO concentrations by WHO guideline

CO concentrations by 15 minutes, 30 minutes, 1 hour, and 8 hours were generated using the ten seconds sampling interval data as shown in Tables 2-4. No data were found that exceeded the 2000 WHO standard guideline. The 50% guideline of 8 hr exceeded in 6 (15%) and 8 (20%) sampling sites for the month of July and January, respectively. This was also consistent for the 3 traffic posts out of the 4, excluding only the "Post Office" traffic post.

Concentration characterization in selected

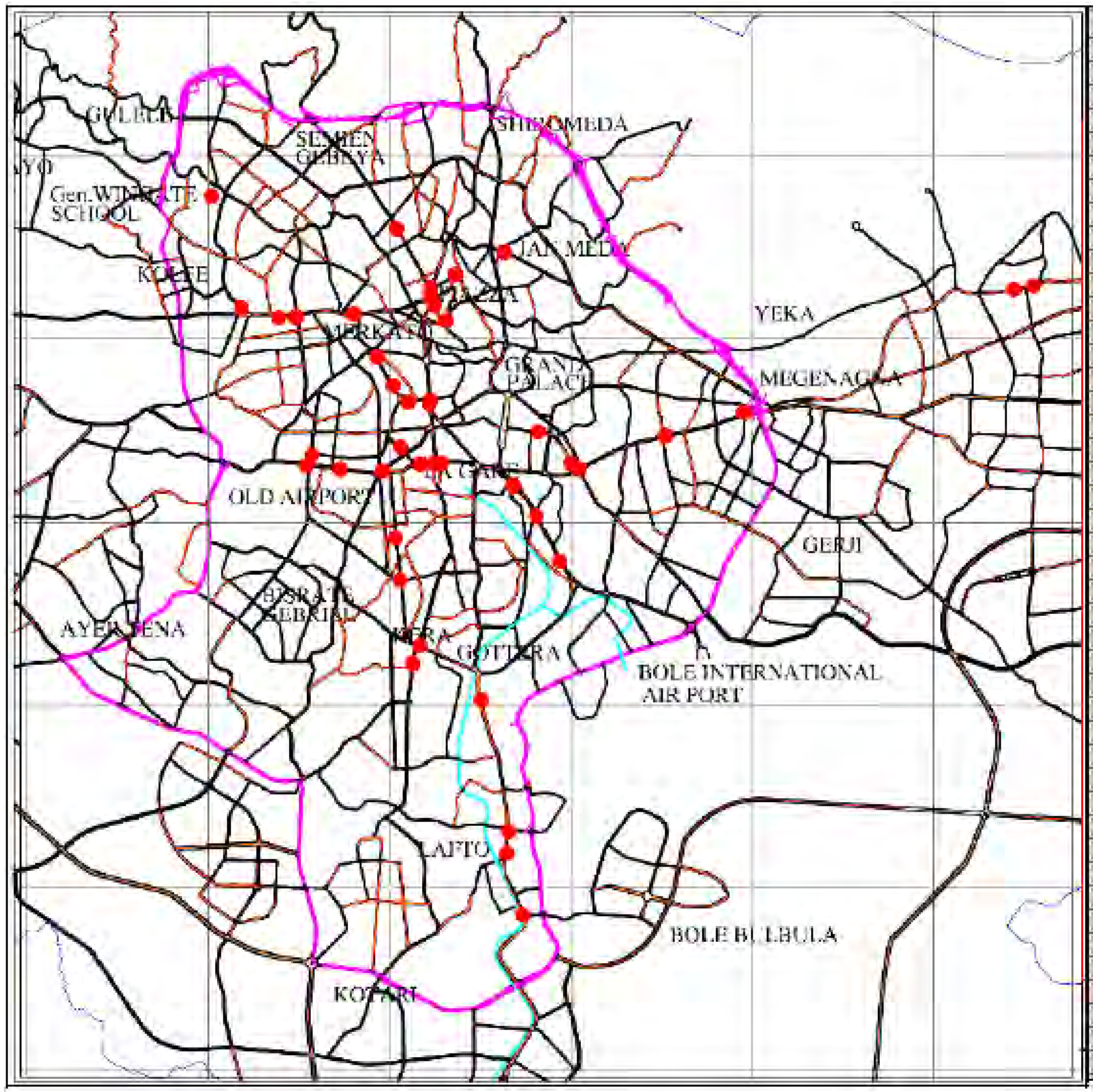
traffic lines

The 15 minutes averaged, maximum and minimum CO concentrations for the four on-traffic sites are indicated in Figure 6. An increased trend was observed during early morning and from early to late afternoon. Low level of CO concentration during lunch time was the characteristic of temporal variation for both maximum and averaged CO concentrations. The time trend was almost similar with the samples taken from road sides, except the presence of difference in the rate of variability and the overall weighted averages. The averaged traffic line CO concentration (5.4 ppm) was more than twice that of July and January samples taken together (2.3 ppm averaged for both)

The traffic line sampling assessed the daily variation in CO concentration. The summary data by days is indicated Figure 7. The level of CO concentration was consistent from Monday through Friday. The declining trend towards Saturday was obvious from the data. “Olympia” and “Legehar” Traffic Lights showed increased level of CO concentration all along the days. Post Office site had the least CO level.

Table 1: Distribution of 15 minutes averaged CO concentrations for the two sampling periods, July 2007and January 2008, Addis Ababa

SN	Sampling sites	Sampling distance, meter	**July 2007**	**January 2008**	Average
			CO, ppm Mean (SD)	**CO, ppm Mean (SD)**	
1	Legehar Megenagna Mini bus stop	2	**6.93 (3.55)**	**5.12 (2.31)**	**6.03**
2	Churchil, Pepsi Kiosk infront of Post Office	4	1.0 (1.0)	0.53 (0.70)	0.77
3	Autobus Tera-Andnet shop near Mesgid	4	0.41 (0.77)	2.90 (2.32)	1.67
4	Black Lion Hospital gate, in front of SIM	10	0	0	0
5	Autobus Tera shop, next to Z music	4	4.40 (2.13)	1.84 (1.48)	3.12
6	Autobus Tera Ismael shop near Z Music	5	4.28 (2.02)	1.03 (1.72)	2.67
7	Piassa Awash Stationary	5	2.23 (1.55)	0.78 (0.72)	1.51
8	Paissa infront of Commercial Bank	3	2.86 (2.48)	0.09 (0.30)	1.48
9	Gotera intersection, bread retailer	4	1.51 (1.12)	0.50 (0.90)	1.12
10	Gotera, infront of 3F, General shop	5	0.97 (0.99)	0.72 (1.34)	0.74
11	Bole road near Flamingo, Electronic shop	9	2.12 (2.91)	**10.61 (0.80)**	**6.37**
12	Bole Printing Press Coka Cola Kiosk	10.2	4.09 (4.95)	**7.32 (2.45)**	**5.71**
13	Kazanchis, Grocery, near Awash Bank	5	1.07 (1.11)	4.28 (2.07)	2.68
14	Kazanchis, ceramic shop, Urael direction	3	2.31 (2.06)	0.13 (0.24)	1.22
15	Megenagna, Yaekob Mobile center	7	0.35 (0.48)	1.62 (0.82)	0.99
16	Haya Hulet Mazoria, general shop	3	**7.72 (6.43)**	4.66 (1.82)	**6.19**
17	Kotebe College infront, dairy kiosk	2	0.20 (0.34)	0.05 (0.09)	0.13
18	Gofa intersection, Kokeb Fashion	4	4.92 (3.53)	**5.39 (2.58)**	**5.16**
19	Gofa intersection, Mebrat Hail	3	**5.61 (5.27)**	0.81 (0.90)	3.21
20	Saris, Blue Nile shoes, infront of Red Cross	5	0.18 (0.12)	2.34 (1.71)	1.26
21	Harer Fruit shop named Harer, Saris Chimad	4	1.0 (0.79)	1.86 (0.94)	1.43
22	Mesalemia Mimi Bakery shop	5	2.25 (1.86)	4.67 (2.06)	3.46
23	Autobus Tera, Alfa public book	4	0.48 (0.64)	2.62 (1.94)	1.55
24	Giorgis intersection Pepsi kiosk	2	1.57 (0.87)	1.24 (0.64)	1.41
25	Giorgis, Ato Teklu Barber Verandah	5	1.61 (1.78)	0.27 (0.40)	0.94
26	Giorgis Church translation and PC service	3	0.28 (0.58)	0.09 (0.17)	0.19
27	Dej. Bela Road, Marvlous PC center	5	0.65 (0.72)	0	0.33
28	Sidist kilo total, Hiwot stationary	4	0.18 (0.50)	0.75 (0.77)	0.47
29	Medhanialem School, MN shoe repair shop	5	0.35 (0.43)	3.45 (2.61)	1.9
30	Kotebe College end of fence, Harer shop	7	0.08 (0.19)	0.04 (0.08)	0.06
31	Teklehamanot, Kurtu Tyre shop	5	1.74 (1.11)	3.01 (2.10)	2.38
32	Teklehaimanot, Tsion Spare parts	4	2.46 (1.78)	4.07 (2.04)	3.27
33	Leghar, Watch and eye glass kiosk	2	2.96 (1.80)	3.10 (1.40)	3.03
34	Sengatera, electric shop	4	2.1 (1.93)	3.95 (1.89)	3.03
35	Lideta, Tele Center	5.5	0.39 (0.81)	**6.04 (2.14)**	3.215
36	Lideta, Temesgen shop, infront of Balcha	7.5	1.05 (0.95)	2.95 (1.89)	2
37	Lideta, near Desse Hotel Pepsi kiosk	3.5	0.94 (1.48)	3.31 (1.30)	2.13
38	Mexico Square Pepsi kiosk	7.5	0.46 (0.77)	**7.55 (1.70)**	4.01
39	Kera Discovery shop near Genet Hotel	2.5	4.48 (3.68)	**5.84 (2.11)**	**5.16**
40	Kera, Teka shop near Bulgaria Mazoria	5	2.97 (2.47)	0.19 (0.48)	1.58
	Over all	**4.68 (2.05)**	**2.03 (1.94)**	**2.64 (2.53)**	**2.34 (1.84)**



SN	Sampling site	UTM X	UTM Y
1	Legehar Megenagna Mini bus stop	472863	996952
2	Churchil, Pepsi Kiosk infront of Post Office	472660	996938
3	Autobus Tera-Andnet shop near Mesgid	471416	998417
4	Black Lion Hospital gate, in front of SIM	472315	996962
5	Autobus Tera shop, next to Z music	470463	998360
6	Autobus Tera Ismael shop near Z Music	470454	998362
7	Piassa Awash Stationary	473090	999061
8	Paissa infront of Commercial Bank	472939	998309
9	Gotera intersection, bread retailer	473522	992078
10	Gotera, infront of 3F, General shop	473971	989923
11	Bole road near Flamingo, Electronic shop	474051	995592
12	Near Bole Printing press Coka Cola Kiosk	474814	994357
13	Kazanchis, Grocery, near Awash Bank	474463	996479
14	Kazanchis, ceramic shop, Urael direction	474999	995958
15	Megenagna, Yaekob Mobile center	477855	996793
16	Haya Hulet Mazoria, general shop	476560	996417
17	Kotebe College infront, dairy kiosk	482325	998813
18	Gofa intersection, Kokeb Fashion	472508	992968
19	Gofa intersection, Mebrat Hail	472387	992681
20	Saris, Blue Nile shoes, infront of Red Cross	473939	989571
21	Harer Fruit shop Saris Chimad	474207	988558
22	Mesalemia Mimi Bakery shop	468548	998515
23	Autobus Tera, Alfa public book	470177	998354
24	Giorgis intersection Pepsi kiosk	472680	998838
25	Giorgis,Ato Teklu Barber Verandah	472742	998557
26	Giorgis church translation and PC service	472680	998709
27	Dej. Bela Road, Marvlous PC center	472124	999803
28	Sidist kilo total, Hiwot stationary	473800	999419
29	Medhanialem School, NN shoe repair shop	469057	1000341
30	Kotebe College, end of fence, Harer shop	482647	998872
31	Teklehamanot, Kurtu Tyre shop	472066	997242
32	Teklehaimanot, Tsion Spare parts	471800	997712
33	Leghar, Watch and eye glass kiosk	472518	996950
34	Sengatera, electric shop	472182	996227
35	Lideta Tele Center	470724	996089
36	Lideta Temesgen shop, infront of Balcha	471192	995863
37	Lideta, near Desse Hotel Pepsi kiosk	470633	995927
38	Mexico Square Pepsi kiosk	471880	995830
39	Kera Discovery shop near Genet Hotel	472099	994742
40	Kera, Teka shop near Bulgario Mazoria	472180	994047
41	Olympia Traffic posslight	474431	996099
42	Legehar Traffic Post light	472746	996958
43	Urael Traffic Post light	475133	996861
44	Post Offic Traffic post light	472676	997004

Figure 1: GPS locations of CO monitoring sites, Addis Ababa, July 2007 and January 2008, Ethiopia
(The Ring Road is represented by a pink curve line)

Table 2: Distribution of maximum averages of CO concentrations on the road sides, July 2007, Addis Ababa, Ethiopia

SN	Sampling sites	15 minutes max. averages (range), ppm	30 minutes max. averages (range), ppm	1 hr max. averages (range), ppm*	8 hrs max. averages (range), ppm*
1	Legehar Megenagna mini bus stop	18.2 (0-18.2)	14.5 (0.1-14.5)	12.1 (1.7-12.1)	**7.2 (6.2-7.2)**
2	Churchil, Pepsi Kiosk infront of Post Office	5.9 (0-5.9)	3.4 (0-3.4)	2.3 (0-2.3)	1.3 (0.8-1.3)
3	Autobus Tera-Andnet shop near Mesgid	3.9 (0-3.9)	3.3 (0-3.3)	1.7 (0-1.7)	0.4 (0.35-0.4)
4	Black Lion Hospital gate, in front of SIM	0	0	0	0
5	Autobus Tera shop, next to Z music	9.2 (0.2-9.2)	7.5 (0.4-7.5)	7.4 (0.6-7.4)	**5.1 (4.2-5.1)**
6	Autobus Tera Ismael shop near Z Music	9.5 (0.4-9.5)	8.1 (0.6-8.1)	7.5 (1.2-7.5)	4.6 (4.3 (4.6)
7	Piassa AwashStationary	6.4 (0-6.4)	5.7 (0-5.7)	4.7 (0-4.7)	2.3 (2.2-2.3)
8	Paissa infront of Commercial Bank	11.0 (0-11.0)	8.2 (0-8.2)	7.0 (0.2-7.0)	3.0 (2.7-3.0)
9	Gotera intersection, bread retailer	5.0 (0-5.0)	4.3 (0-4.3)	3.3 (0.43-3.3)	1.8 (1.4-1.8)
10	Gotera, infront of 3F, General shop	4.3 (0-4.3)	3.6 (0-3.6)	3.2 (0.1-3.2)	1.1 (0.8-1.1)
11	Bole road near Flamingo, Electronic shop	9.7 (0-9.7)	8.4 (0-8.4)	8.2 (0-8.2)	2.3 (2.3-2.3)
12	Bole printing press Coka Cola Kiosk	31.0 (0-31.0)	22.0 (0.5-22.0)	**14.9 (0.8-14.9)**	4.2 (3.0-4.2)
13	Kazanchis, Grocery, near Awash Bank	6.8 (0-6.8)	4.3 (0-4.3)	2.3 (0.2-2.3)	1.1 (1.0-1.1)
14	Kazanchis, ceramic shop, Urael direction	9.0 (0-9.0)	6.2 (0-6.2)	4.6 (0.3-4.6)	2.4 (2.1-2.4)
15	Megenagna, Yaekob Mobile center	2.5 (0-2.5)	2.0 (0-2.0)	1.4 (0-1.4)	0.4 (0.3-0.4)
16	Haya Hulet Mazoria, general shop	25.1 (0-25.1)	19.6 (0-19.6)	**17.7 (0.4-17.7)**	**8.2 (6.9-8.2)**
17	Kotebe College infront, dairy kiosk	1.8 (0-1.8)	0.9 (0-0.9)	0.5 (0-0.5)	0.3 (0.2-0.3)
18	Gofa intersection, Kokeb Fashion	16.6 (0.3-16.6)	14.1 (0.7-14.1)	**12.8 (1.6-12.8)**	**5.1 (4.8-5.1)**
19	Gofa intersection, Mebrat Hail	21.9 (0.2-21.9)	19.6 (0.3-19.6)	**15.1 (0.5-15.1)**	**6.1 (5.3-6.1)**
20	Saris, Blue Nile shoes, infront of Red Cross	0.5 (0-0.5)	0.4 (0-0.4)	0.3 (0.1-0.3)	0.2 (0.1-0.2)
21	Fruit shop named Harer, Saris Chimad	3.8 (0-3.8)	2.9 (0-2.9)	2.5 (0.1-2.5)	1.1 (1.0-1.1)
22	Mesalemia Mimi Bakery shop	7.5 (0-7.5)	6.7 (0.1-6.7)	5.5 (0.5-5.5)	2.5 (2.0-2.5)
23	Autobus Tera, Alfa public book	4.1 (0-4.1)	2.4 (0-2.4)	1.4 (0-1.4)	0.5 (0.4-0.5)
24	Giorgis intersection Pepsi kiosk	4.5 (0.1-4.5)	3.9 (0.2-3.9)	3.3 (0.6-3.3)	1.6 (1.4-1.6)
25	Giorgis,Ato teklu Barber Verandah	9.4 (0-9.4)	7.0 (0.1-7.0)	4.1 (0.2-4.1)	1.7 (1.4-1.7)
26	Giorgis church translation and PC service	3.4 (0-3.4)	2.2 (0-2.2)	1.2 (0-1.2)	0.2 (0.1-0.2)
27	Dej. Bela road, Marvlous PC center	3.9 (0-3.9)	3.2 (0-3.2)	2.3 (0.1-2.3)	0.7 (0.5-0.7)
28	Sidist kilo total, Hiwot stationary	3.3 (0-3.3)	1.9 (0-1.9)	1.2 (0-1.2)	0.2 (0.1-0.2)
29	Medhanialem School, MN shoe repair shop	2.4 (0-2.4)	1.3 (0-1.3)	1.1 (0-1.1)	0.4 (0.3-0.4)
30	Kotebe College end of fence, Harer shop	1.0 (0-1.0)	0.5 (0-0.5)	0.3 (0-0.3)	0.09 (0.08-0.09)
31	Teklehamanot, Kurtu Tyre shop	4.4 (0-4.4)	3.5 (0-3.5)	3.4 (0-3.4)	1.8 (1.7-1.8)
32	Teklehaimanot, Tsion Spare parts	7.7 (0-7.7)	6.4 (0.2-6.4)	5.2 (0.2-5.2)	2.6 (2.4-2.6)
33	Leghar, Watch and eye glass kiosk	7.7 (0.3-7.7)	6.7 (0.5-6.7)	6.1 (0.8-6.1)	2.9 (2.7-2.9)
34	Sengatera, electric shop	6.1 (0-6.1)	5.2 (0-5.2)	4.6 (0-4.6)	2.5 (1.7-2.5)
35	Lideta, Tele Center	4.1 (0-4.1)	4.0 (0-4.0)	2.8 (0-2.8)	0.5 (0.2-0.5)
36	Lideta, Temesgen shop, infront of Balcha	7.5 (0-7.5)	4.4 (0.2-4.4)	3.0 (0.3-3.0)	1.2 (0.9-1.2)
37	Lideta, near Desse Hotel Pepsi kiosk	6.8 (0-6.8)	5.1 (0-5.1)	4.6 (0-4.6)	1.1 (0.6-1.1)
38	Mexico square Pepsi kiosk	5.0 (0-5.0)	3.3 (0-3.3)	2.0 (0-2.0)	0.5 (0.4-0.5)
39	Kera Discovery shop near Genet Hotel	12.8 (0-12.8)	11.6 (0.1-11.6)	10.8 (0.2-10.9)	**5.1 (3.6-5.1)**
40	Kera, Teka shop near Bulgaria Mazoria	11.4 (0-11.4)	10.6 (0.2-10.6)	8.9 (0.9-8.9)	3.0 (2.3-3.0)
	No (%) exceeding 100% of the WHO guideline	None	None	None	None
	No (%) exceeding 50% of the WHO guideline	None	None	4 (10)	6 (15.0)

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25ppm; 8hr: 10 ppm; bolded numbers indicates values more than 50% of WHO guidelines.

Table 3: Distribution of maximum averages of CO concentrations on the road sides, January 2008, Addis Ababa, Ethiopia

SN	Sampling sites	15 minutes averages (range), ppm	30 minutes averages (range), ppm	1 hr averages (range), ppm*	8 hrs averages (range), ppm*
1	Churchil, Pepsi Kiosk infront of Post Office	3.8 (0-3.8)	3.1 (0-3.1)	1.9 (0.0-1.9)	0.5 (0.4-0.5)
2	Leghar, Watch and eye glass kiosk	6.5 (0.6-6.5)	5.9 (1.3-5.9)	5.2 (1.5-5.2)	3.5 (2.8-3.5)
3	Legehar Megenagna mini bus stop	11.4 (0.3-11.4)	9.5 (.1-9.5)	7.6 (2.0-7.6)	**5.8 (4.7-5.8)**
4	Sengatera, electric shop	7.9 (0.2-7.9)	7.2 (0.4-7.2)	6.7 (0.6-6.7)	4.5 (3.5-4.5)
5	Black Lion Hospital gate, in front of SIM	0	0	0	0
6	Teklehamanot, Kurtu Tyre shop	7.0 (0-7.0)	6.1 (0.1-6.1)	6.1 (0.2-6.1)	3.3 (2.9-3.3)
7	Teklehaimanot, Tsion Spare parts	9.2 (0.1-9.2)	7.6 (0.7-7.6)	6.8 (1.1-6.8)	4.7 (4.1-4.7)
8	Autobus Tera shop next to Z Music	9.4 (0.2-9.4)	8.1 (0.4-8.1)	6.3 (0.6-6.3)	2.0 (1.4-2.0)
9	Mesalemia Mimi Bakery shop	10.3 (0.2-10.3)	9.4 (0.6-9.4)	7.7 (1.8-7.7)	**5.2 (4.4-5.2)**
10	Autobus Tera Ismael shop near Z Music	8.4 (0-8.4)	7.4 (0-7.4)	6.4 (0.1-6.4)	1.4 (0.4-1.4)
11	Autobus Tera-Andnet shop near Mesgid	17.5 (0.4-17.5)	13.0 (0.6-13.0)	7.8 (0.8-7.8)	3.4 (2.5 (3.4)
12	Autobus Tera, Alfa public book	11.8 (0.04-11.8)	8.2 (0.3-8.2)	5.9 (1.0-5.9)	3.0 (2.7-3.0)
13	Kera Discovery shop near Genet Hotel	10.9 (1.4-10.9)	10.4 (1.7-10.4)	9.4 (2.9-9.4)	**5.9 (5.5-5.9)**
14	Kera, Teka shop near Bulgaria Mazoria	3.8 (0-3.8)	2.3 (0-2.3)	1.6 (0-1.6)	0.24 (0.03-0.24)
15	Gofa intersection, Kokeb Fashion	14.5 (0.1-14.5)	14.0 (0.8-14.0)	11.6 (2.5-11.6)	**6.0 (4.6-6.0)**
16	Gofa intersection, Mebrat Hail	5.5 (0-5.5)	3.6 (0-3.6)	2.4 (0.6-2.4)	1.0 (0.6-1.0)
17	Gotera, infront of 3F, General shop	5.9 (0-5.9)	5.5 (0-5.5)	4.8 (0-4.8)	0.9 (0.2-0.9)
18	Gotera intersection, bread retailer	5.6 (0-5.6)	4.4 (0-4.4)	2.6 (0.04-2.6)	0.6 (0.4-0.6)
19	Kazanchis, Grocery, near Awash Bank	15.1 (0.9-15.1)	9.9 (1.3-9.9)	6.5 (1.5-6.5)	4.2 (3.7-4.2)
20	Kazanchis, ceramic shop, Urael direction	1.2 (0-1.2)	0.7 (0-0.7)	0.6 (0-0.6)	0.1 (0.1-0.1)
21	Megenagna, Yaekob Mobile center	4.1 (0.2-4.1)	3.6 (0.6-3.6)	3.3 (0.7-3.3)	1.7 (1.4-1.7)
22	Haya Hulet Mazoria, general shop	11.0 (1.1-11.0)	10.5 (2.1-10.5)	8.7 (2.8-8.7)	4.8 (4.1-4.8)
23	Paissa infront of Commercial Bank	1.8 (0-1.8)	1.3 (0-1.3)	1.2 (0-1.2)	0.2 (0-0.2)
24	Piassa AwashStationary	4.5 (0-4.5)	2.9 (0.1-2.9)	1.8 (0.2-1.8)	0.8 (0.7-0.8)
25	Giorgis intersection Pepsi kiosk	3.8 (0.03-3.8)	2.8 (0.3-2.8)	2.3 (0.5-2.3)	1.3 (1.2-1.3)
26	Giorgis,Ato teklu Barber Verandah	2.5 (0-2.5)	1.4 (0-1.4)	0.8 (0-0.8)	0.3 (0.2-0.3)
27	Giorgis church translation and PC service	1.2 (0-1.2)	0.9 (0-0.9)	0.6 (0-0.6)	0.1 (0.03-0.1)
28	Dej. Bela road, Marvlous PC center	0	0	0	0
29	Kotebe College infront, dairy kiosk	0.5 (0-0.5)	0.4 (0-0.4)	0.3 (0-0.3)	0.1 (0.03-0.1)
30	Kotebe College end of fence, Harer shop	0.4 (0-0.4)	0.2 (0-0.2)	0.1 (0-0.1)	0.1 (0.04-0.1)
31	Bole road near Flamingo, Electronic shop	12.7 (8.5-12.7)	12.1 (9.1-12.1)	11.4 (9.8-11.4)	**10.7 (10.6-10.7)**
32	Bole printing press Coka Cola Kiosk	14.7 (3.1-14.7)	14.3 (3.4-14.3)	**13.7 (4.5-13.7)**	**7.7 (7.5-7.7)**
33	Mexico square Pepsi kiosk	13.7 (5.0-13.7)	12.5 (5.1-12.5)	11.7 (5.4-11.7)	**7.5 (7.0-7.5)**
34	Lideta, Temesgen shop, infront of Balcha	12.4 (0.1-12.4)	8.8 (0.3-8.8)	5.3 (0.5-5.3)	3.3 (3.0-3.3)
35	Lideta, Tele Center	10.0 (1.4-10.0)	9.3 (1.7-9.3)	8.9 (2.2-8.9)	**6.8 (5.4-6.8)**
36	Lideta, near Desse Hotel Pepsi kiosk	6.1 (0.5-6.1)	5.6 (0.7-5.6)	5.2 (1.6-5.2)	3.7 (3.3-3.7)
37	Sidist kilo total, Hiwot stationary	4.3 (0.1-4.3)	2.5 (0.1-2.5)	1.7 (0.2-1.7)	0.9 (0.8-0.9)
38	Medhanialem School, MN shoe repair shop	12.0 (0.9-12.0)	11.7 (1.2-11.7)	10.8 (1.5-10.8)	3.8 (2.4-3.8)
39	Fruit shop, named Harer, Saris Chimad	3.9 (0-3.9)	3.4 (0.03-3.4)	3.0 (0.07-3.0)	2.2 (1.7-2.2)
40	Saris, Blue Nile shoes, infront of Red Cross	6.3 (0-6.3)	5.8 (0.1-5.8)	5.3 (0.3-5.3)	2.8 (2.1-2.8)
No (%) exceeding 100% of the WHO guideline		None	None	None	1 (2.5)
No (%) exceeding 50% of the WHO guideline		None	None	1 (2.5)	8 (20.0)

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25 ppm; 8hr: 10ppm. Bolded numbers indicate values more than 50% of WHO guidelines.

Table 4: Distribution of maximum averages CO concentrations on traffic light posts, March-April 2008, Addis Ababa, Ethiopia

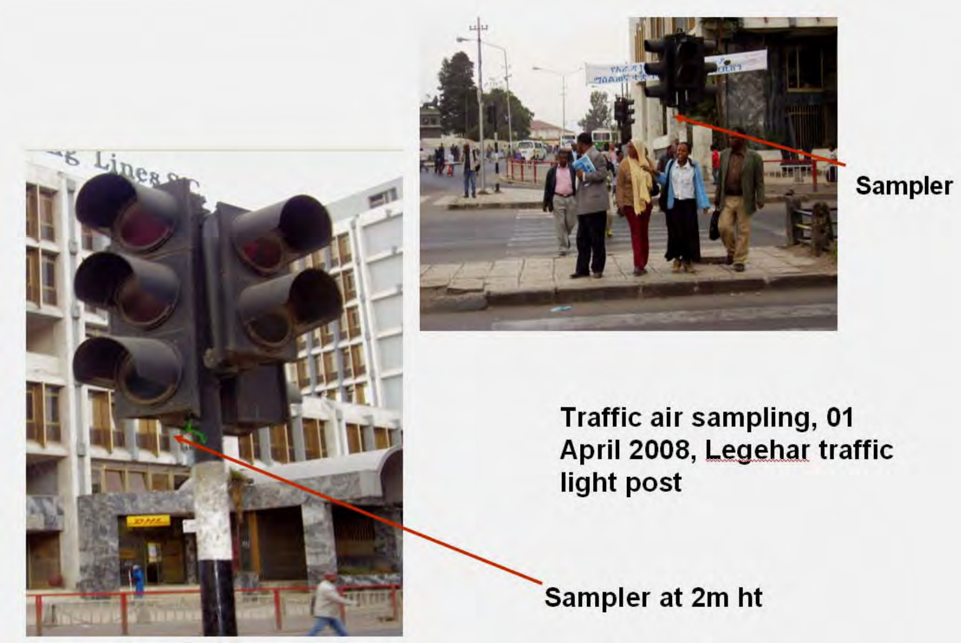
Sampling Days	**Sampling sites**	**15 minutes max average (range)**	**30 minutes max average (range)**	**1 hr max average (range)**	**8 hr max average (range)**
Day 1	1 (Post Office)	9.3 (0.8-9.3)	8.4 (1.3-8.4)	7.5 (1.8-7.5)	4.3 (3.4-4.3)
	2 (Post Office)	9.1 (0.1-9.1)	7.8 (0.2-7.8)	5.9 (0.8-5.9)	3.2 (2.5-3.2)
Day 2	3 (Post Office)	11.6 (0.4-11.6)	10.1 (0.7-10.1)	9.2 (0.9-9.2)	3.7 (2.1-3.7)
	4 (Post Office)	6.8 (0.3-6.8)	4.9 (0.4-4.9)	4.0 (0.8-4.0)	2.2 (1.8-2.2)
Day 3	5 (Post Office)	9.5 (0.2-9.5)	8.4 (0.6-8.4)	6.8 (0.7-6.8)	2.9 (2.3-2.9)
	6 (Post Office)	4.4 (0-4.4)	3.3 (0-3.3)	2.8 (0.1-2.8)	1.6 (1.1-1.6)
Day 4	7 (Legehar)	10.1 (2.0-10.1)	9.8 (2.5-9.8)	9.0 (3.2-9.0)	**5.5 (4.3-5.5)**
	8 (Legehar)	9.1 (2.1-9.1)	8.0 (2.9-8.0)	7.3 (3.6-7.3)	**5.3 (4.9-5.3)**
Day 5	9 (Legehar)	10.1 (3.2-10.1)	9.7 (3.7-9.7)	9.2 (4.0-9.2)	**6.1 (5.5-6.1)**
	10 (Legehar)	8.6 (1.8-8.6)	8.2 (2.9-8.2)	7.5 (3.5-7.5)	**5.4 (5.1-5.4)**
Day 6	11 (Legehar)	10.9 (2.0-10.9)	9.7 (2.8-9.7)	8.3 (3.0-8.3)	4.9 (4.5-4.9)
	12 (Legehar)	7.3 (1.9-7.3)	6.8 (2.7-6.8)	6.2 (2.9-6.2)	4.9 (4.4-4.9)
Day 7	13 (Urael)	11.0 (2.5-11.0)	10.1 (3.7-10.1)	9.4 (4.1-9.4)	**6.2 (5.6-6.2)**
	14 (Urael)	12.1 (2.9-12.1)	11.6 (3.5-11.6)	11.0 (4.0-11.0)	**6.2 (5.5-6.2)**
Day 8	15 (Urael)	9.3 (1.2-9.3)	8.2 (2.2-8.2)	7.4 (2.6-7.4)	**5.9 (5.2-5.9)**
	16 (Urael)	8.7 (2.2-8.7)	8.1 (2.6-8.1)	7.7 (3.2-7.7)	**5.1 (4.5-5.1)**
Day 9	17 (Urael)	8.6 (1.5-8.6)	7.8 (2.4-7.8)	7.0 (3.0-7.0)	4.7 (4.5-4.7)
	18 (Urael)	6.3 (0-6.3)	5.9 (0.2-5.9)	4.9 (2.3-4.9)	3.9 (3.6-3.9)
Day 10	19 (Olympia)	14.0 (3.9-14.0)	13.3 (4.4-13.3)	11.6 (4.8-11.6)	**7.5 (6.8-7.5)**
	20 (Olympia)	17.9 (5.6-17.9)	16.6 (6.4-16.6)	**14.8 (7.0-14.8)**	**9.5 (8.6-9.5)**
Day 11	21 (Olympia)	16.1 (3.45-16.1)	12.4 (4.2-12.4)	11.4 (5.3-11.4)	**8.3 (7.4-8.3)**
	22 (Olympia)	15.2 (4.5-15.2)	14.8 (5.2-14.8)	**14.1 (6.7-14.1)**	**9.7 (9.0-9.7)**
Day 12	23 (Olympia)	14.9 (4.0-14.9)	14.6 (5.5-14.6)	**12.8 (6.4-12.8)**	**9.3 (8.4-9.3)**
	24 (Olympia)	9.5 (0.9-9.5)	8.4 (1.6-8.4)	7.9 (2.6-7.9)	**5.9 (5.2-5.9)**
Number (%) exceeding 100% of the WHO guideline		**None**	**None**	**None**	**None**
Number (%) exceeding 50% of the WHO guideline		**None**	**None**	**3 (12.5)**	**14 (58.3)**

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25 ppm; 8hr: 10 ppm. Bolded numbers indicate values more than 50% of WHO guidelines.

Sample location: Gofa intersection Spare part shop to the side of Mebrat Hail, 16 July 2007

Sampler

Figure 2: Field location of CO monitor in road side sampling sites, Addis Ababa, Ethiopia, July 2007



Sampler

Traffic air sampling, 01 April 2008, Legehar traffic light post

Sampler at 2m ht

Figure 3: Field location of CO monitors on a traffic light stand, Addis Ababa, Ethiopia, April 2008

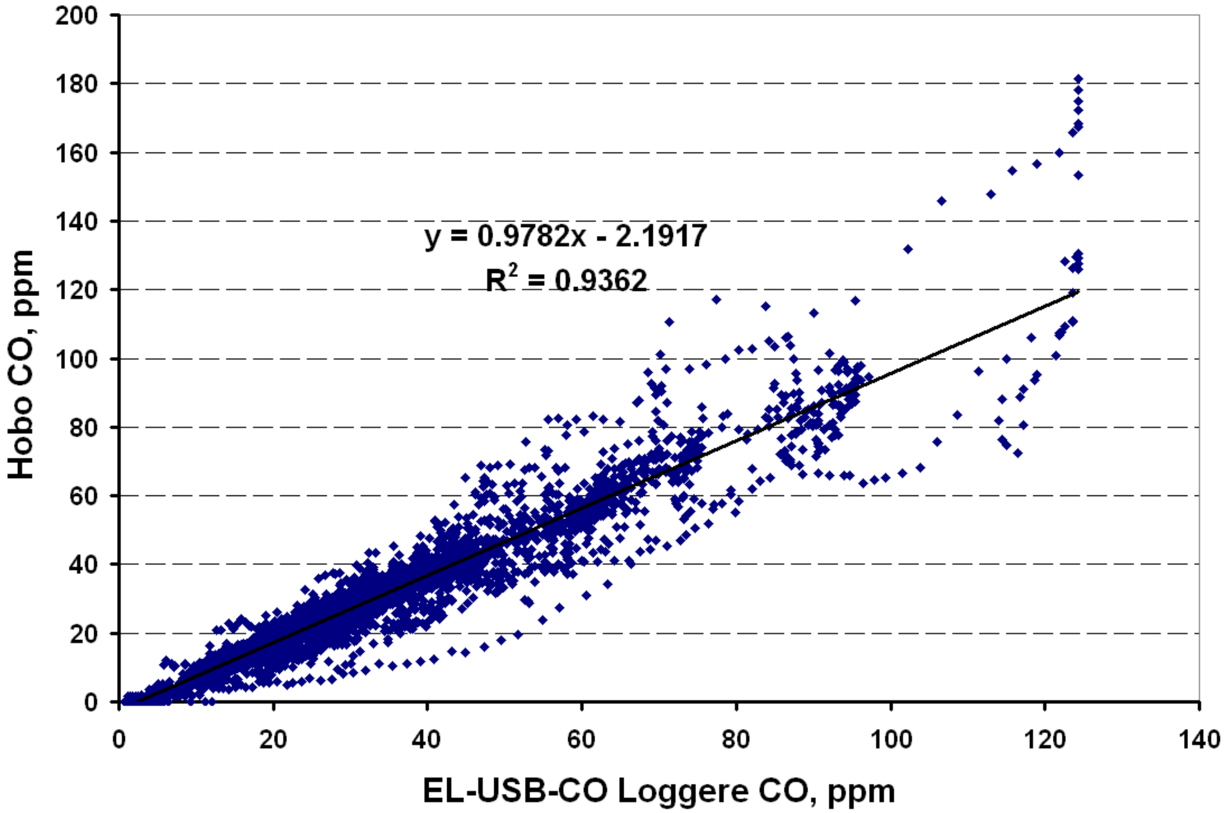


Figure 4: Scatter plot for two variants of CO data loggers: Hobo and EL-USB, December 2008

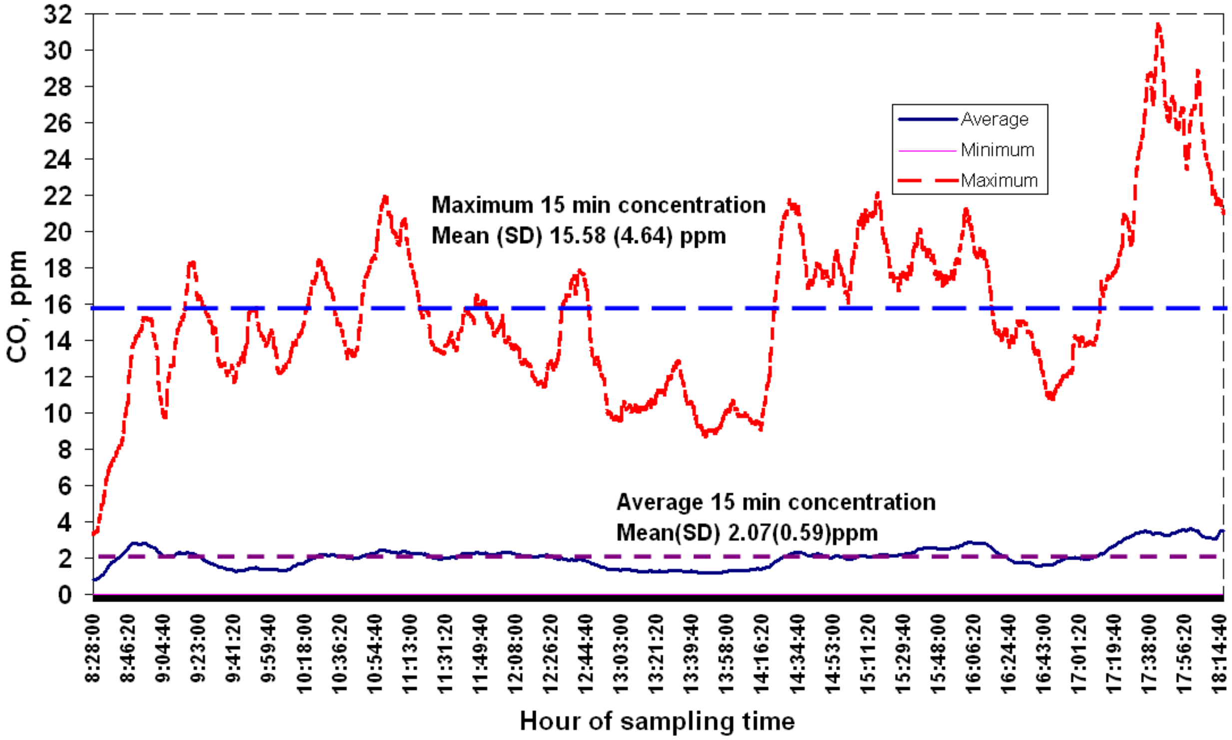


Figure 5a

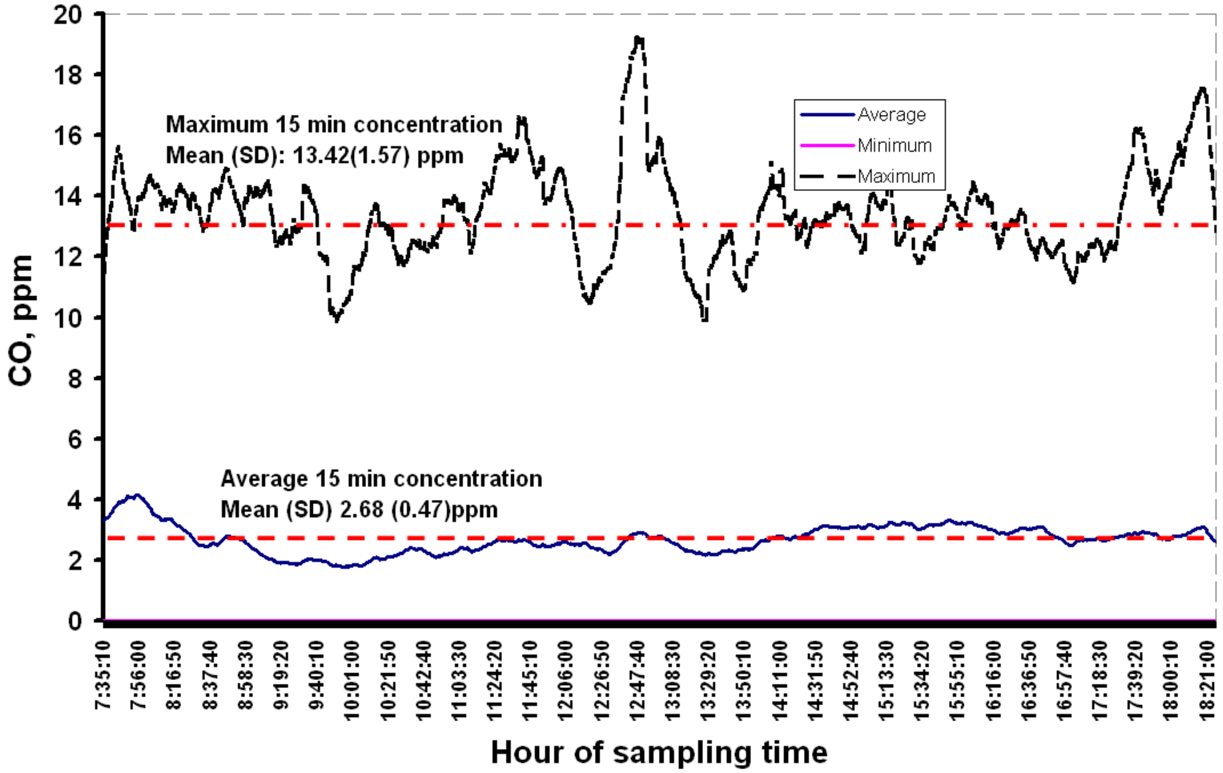


Figure 5b

Figure 5: CO concentrations averaged by 15 minutes; (5a) CO measured during wet

month of Ethiopia in July 2007 (n=40); (5b): CO measured during dry season of Ethiopia, January 2008 (n=40)

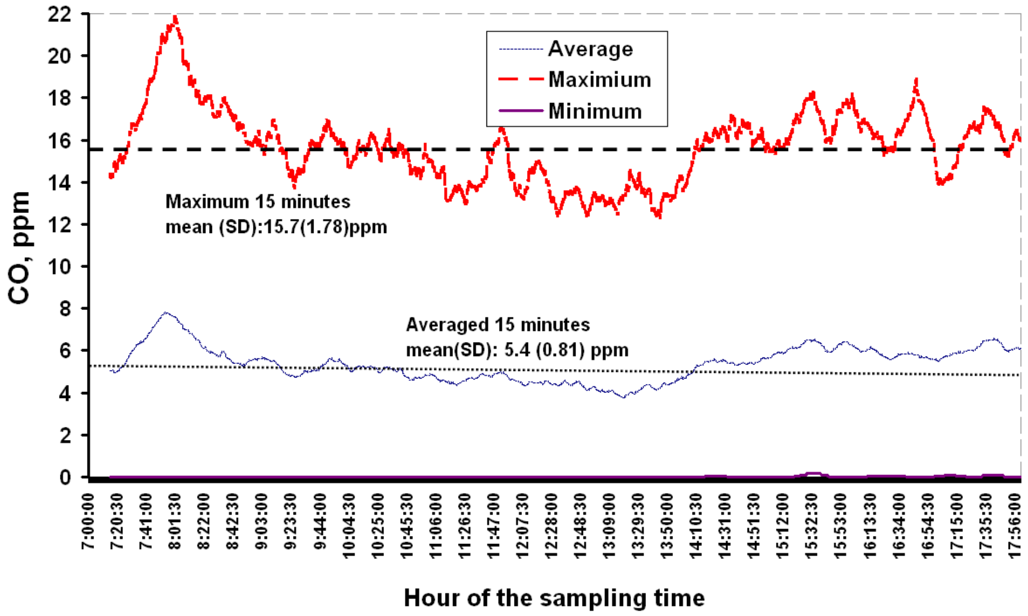


Figure 6: CO concentration averaged by 15 minutes in four traffic sampling points, Addis Ababa, April 2008 (n=24)

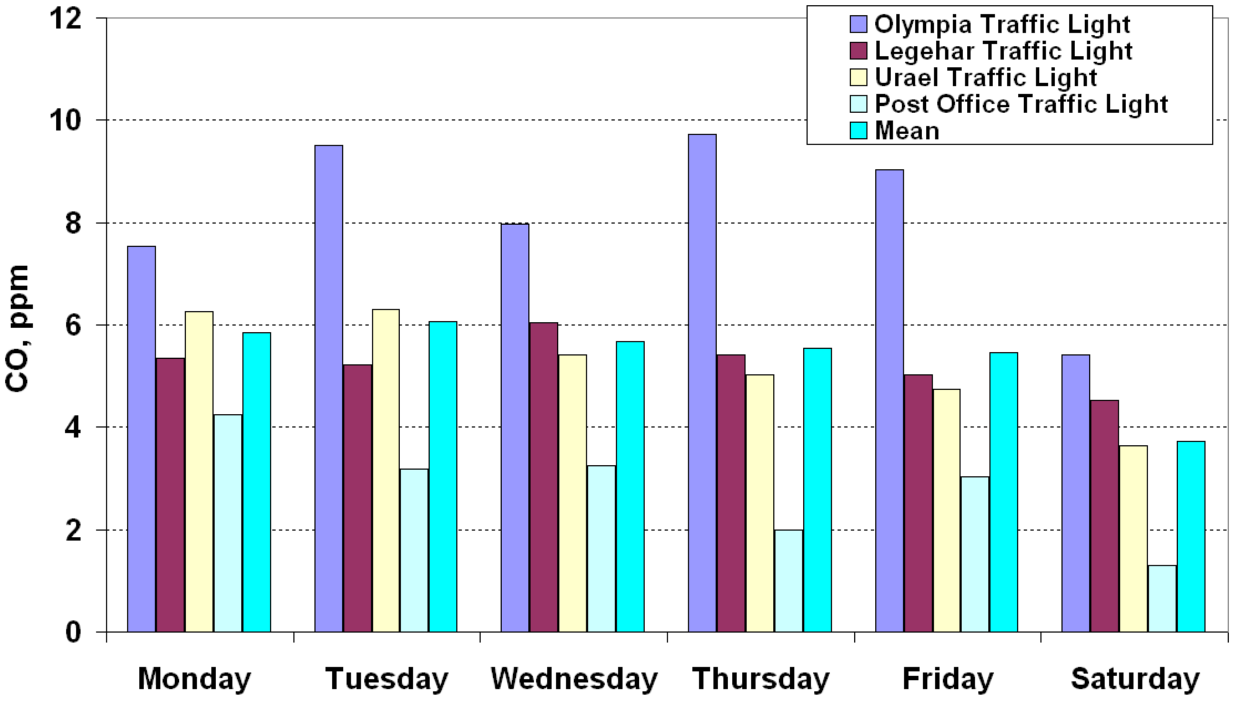


Figure 7: CO concentration by sampling days in four traffic sampling points, Addis Ababa, April 2008

Discussion

This study is the second attempt to look the situation of urban pollution in a rapidly growing City of Addis Ababa. The first effort was made by Etyemezian *et al* in 2004 (26 Jan-28 Feb 2004) in which only 12 air sampling residential sites with CO and other proxy measurements were addressed. The current study indicated two important finding: the presence of temporal and spatial variation and the likelihood of 24-hr PM_{10} to exceed the annual EPA/USA guideline (50 μgm^{-3}). The profile of CO concentrations by time was not similar between the earlier study and our study. The occurrence of high peaks in early mornings and late afternoons for both sampling months were apparent due to vehicular sources that actively commuted during those time periods. Other than vehicular sources, temperature stagnation that usually starts after midnight local time is another factor that contributed to the increased CO concentrations in early mornings [21]. The phenomenon “low level radiation inversion” occurs in Addis Ababa when the earth rapidly cools relative to the air mass during both winter and summer months. Thus, air pollutants including CO are trapped by the relatively warmer air mass, which explains the continued high level of CO concentration in early mornings until that time when the ground surface becomes relatively warm. This is usually observed during the winter season (*July-August*) and months of October-January (. The presence of low level temperature inversion is usually observed at a distant when the air space between mountain sides in Addis Ababa is filled up by yellowish to cloudy foggy air mass in early mornings. This mass is expected to contain much soil dust particles because of the high nature of organic matter blown to the air [21] and other air pollutants. A thin layer brown haze was used to be observed over the air of Toronto City in summer months of early mornings and afternoons when the air was highly polluted during those times [26].

The lack of difference in the weighted averaged CO concentrations between July and January was against our hypothesis. Three important events might explain this finding. First, although the traffic density in July is commonly less than that of January (personal observation and communication), the increased moisture is likely to be a factor for the dispersion of CO vehicular emission. Second, in January when traffic density is higher, the turbulence of wind plays major role in the dispersion of CO concentration. Third, the photochemical reaction that takes place in the day time might be another factor to explain the low level of CO in January. The sunlight energy under bright radiation has a capacity to transform CO into CO_2 in the presence of emitted hydrocarbons, there by limiting the detection of CO by the air sampler. However examining whether a photochemical process contributed or not to the low level CO concentration is beyond the scope of this research.

Schools are commonly closed during wet season and this could have minimized the transport needs, there by decreasing the number of on-road vehicles. The observed maximum average CO concentration during the month of July might be attributable to the poor air ventilation prevailing on the traffic zone and the underlying seasonal rain and temperature inversion. Rainfall and wind seemed to play important roles in characterizing the distribution of vehicular emissions. For instance, in cities, like Toronto, Kuwait, and Ontario [7, 26-27], increased on-road vehicles were main contributing factors to high levels of air pollutants.

The 1 hour and 8 hours averaged CO concentrations for each site was far less than the international practice (25) and the USA National Ambient Air Quality Standard [28]. However, there were six sampling sites (15% of total of 40) that demonstrated 57-69% of the 8 hours standard (10.0 ppm) representing the Air Quality Index to be moderate by EPA-USA CO indexing [29]. Those sites were located on "Kera" road, "Gofa" intersection, "Bole" road, and the road to "Megenagna". Those roads with high vehicle density were the major arteries bridging many other tributaries and explaining the difference in CO concentration between the two months. The low level of CO below the 1 hour and 8 hours standard, which was against our hypothesis, was in agreement with the recent findings [21]. Our assumption was that we could find high CO concentrations due to the prevailing old vehicles in Addis Ababa and apparent congestion of vehicles in narrow roads. Our results, however, are inconsistent with those reported by other investigators. The daily mean concentration of CO concentrations in 88% of traffic sampling locations (n=21) in the City of Kuwait had greater than or equal to 8 ppm [7] which was accounted to high level of traffic density. The level of CO in 7 kiosk venders located on traffic side out of 16 exceeded permissible limits of CO [8]. One out of 9 sites sampled at 7.5 m from the road side for CO had only greater than 50% 8 hours standard of 9 ppm in a highway in Pakistan [9]. The difference in the road side CO concentration levels in different studies might be in part due to difference in vehicle density, meteorological conditions, methods of CO sampling techniques and variation in equipment used for CO monitoring. It is clear that CO after its emission from the exhaust pipe of the vehicles has the capacity to quickly disperse in air with its proximity of generation.

There is a possible link between the traffic line and road side sampling sites in their CO concentration temporality. Three characteristics in pattern emerged on the traffic line pollution: short duration with highest peak in early morning, low level in lunch time, and extended but weakly plateaued CO concentration in the afternoons. The similarity in this pattern (Figure 5 and 6) explains that the source of road side traffic pollution is mainly of vehicular nature. We can speculate that this observed pattern of CO distribution by time could be sustained from Monday to Friday for the road side pollution given our observation of CO measurements taken in just traffic light zones for each day, where the vehicular emission is supposedly sampled by the monitor. Vehicular sources of traffic air pollution were obvious in a similar study in Addis Ababa [21]. Vehicles in Toronto contributed about 82% of traffic pollution. Generally, traffic pollution contributes 60-85% of the urban ambient air [30-32]. Although we have not found CO emission data inventory by source, exclusion of vehicular emission as a major source of CO in roads of Addis Ababa could not be possible.

Assuming days from Monday to Saturday are with high traffic activity, the weekly traffic on-road 15 minutes averaged CO concentration was 5.38 pmm (range 2.84-7.87 ppm), while the weighted mean for the two road-side sampling periods was about 2. 34 ppm. Although we could not find correlation between sampling distance and the level of CO concentration, we can guess in the worst condition that CO concentration within 5 meters road side could be at least half less than that of the traffic lines. Meteorological conditions like moisture, wind speed and direction might explain the lack of correlation.

Of all traffic lines, Bole road at Olympia traffic light attracts more attention as its 8 hrs maximum mean (SD) CO concentration observed in 5 out of 6 days in the day time was between 7.5-9.8 ppm. These values are in agreement with the WHO 10 ppm guideline and the USA EPA 9 ppm CO standard for 8 hrs. The road side CO concentrations at Bole road were also elevated compared to other sampling sites. Bole Road, directly leading to the air port and subsequently to the ring road, is usually busy to entertain high vehicular density through out the day. Traffic Polices are always present in this sampling site to watch out and manually instruct the flow of the traffic. Fortunately their placement on work based on shift (personal communication) might not expose them above the 8 hr standard level of CO. Our judgment is that CO level very soon might exceed this level given the continued traffic density in the city accompanied with 8-12% of annual growth rate.

In conclusion, although this study found low levels of CO concentration on both on-road and road side traffic zones in reference to 15 minutes, 1 hour, and 8 hours standards, it is reasonable to assume that certain road corridors will likely exceed these reported values in future, given the continued increase of vehicles in the city. These corridors are found on the "Bole" road, "Megenagna" to "Lideta" road, and "Kera" road on which the highest traffic densities are routinelyobserved. In addition, temperature inversion, seasonal rain, and road ventilation are specific factors to explain the presence of temporality and spatial variation in CO concentration in the roads of Addis Ababa. This study is the second of its type which demonstrated that traffic CO concentration in the city of Addis Ababa is below the 1 hour and 8hours guideline value. Since the city is packed with diesel engined old vehicles and prevailing gravel roads that disperse organic soil dust on the zone of traffic lines, the measurement of organic carbon and particulate matter along the proximity of traffic lines is relevant. In addition, the measurement of personal exposure through PM and CO using traffic polices and street vendors are another future direction for research.

Several important limitations must be considered when interpreting the results from our study. . The sampling might have missed some important sites under which the investigators were not very much aware, despite the fact that we assumed to maximize the opportunity of using 40 different sites. In addition, the sampling distance from the proximity edge of the side of the road could not be uniformly structured for reasonable comparisons between CO levels of different sites. The sampling time duration was only fixed to the day time to maximize the presence of high traffic activity. Given all these important methodological limitations, we can not deny the contribution of this study in assessing the level of traffic air pollution through the measurement of CO concentrations.

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