Indoor Air Pollution Monitoring Summary

For

Gaia Association-Ethiopia's CleanCook Stove Tests in Addis Ababa, Ethiopia

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and

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Purpose of Study

For the last two years Gaia Association (GA) has been collecting indoor air pollution (IAP) data under the guidance of University of California–Berkeley's Center for Entrepreneurship in International Health and Development (CEIHD). High levels of IAP contribute to a myriad of health issues. These high levels of IAP are prevalent in the homes of Addis Ababa, largely as a result of the burning of solid biomass fuels and kerosene for cooking.

Background of Gaia Association – IAP study in Addis Ababa, Ethiopia

The Gaia Association initiative (Project Gaia Research Studies) was created over four years ago with the purpose of promoting alcohol fuels for household and refugee use in Ethiopia. The association seeks to replace existing traditional fuels such as firewood, kerosene, charcoal, and dung, which have been shown to produce soot and other products of incomplete combustion that are harmful to human health. The vehicle for this change is the CleanCook stove, which is fueled in this study by ethanol.

Gaia Association over the last several years has formed strong partnerships within the Addis Ababa NGO community. The tests that were performed were done in collaboration with our partner organizations. A total of five samples were taken from the Good Shepherd Sisters Charities in the Kirkos Sub-City of Addis Ababa. The mission of the Good Shepherd Charities is to aid the poor and destitute of Addis Ababa. Their outreach programs focus on meeting the needs of women and children that face the hardships of poverty. The tests were performed in households that are associated with this organization.

The other four samples were taken at the Former Fuelwood Carriers Association in the Yeka Sub-City of Addis Ababa. The mission of the Former Fuelwood Carriers Association is to offer new income generating activities to women who were once solely dependent on the gathering of fuelwood. Gaia Association has partnered with this organization for the past two years to gain valuable data on the effectiveness of the CleanCook stove.

Methods

The study was conducted in a total of 9 households in Addis Ababa. The format of the study consisted of monitoring indoor air quality in homes for 48 hours both before and after the introduction of the CleanCook stove. Monitoring equipment was positioned in kitchens in accordance with the standard placement protocols given by CEIHD.

The requirements were:

1. 100 cm from the edge of the stove (combustion zone)
2. 140 cm above the floor
3. 150 cm from any openable door or window, where possible

The devices were placed for a 48 hr period in accordance with the above noted requirements. After the devices were placed in the Addis Ababa city households, sketches were made of the placement of the equipment and the kitchen and photographs were taken.

The CO concentrations in the room were measured with the HOBO CO logger (model # H11-001, Onset Computer Corporation, Bourne, MA, USA), which was set to record a concentration reading every minute. Fine particulate matter was measured by the University of California Berkeley Particle Monitor (UCB PM), which uses a photoelectric detector (Litton et al., 2004; Edwards et al., 2006; Chowdhury et al., 2007). The UCB PM measured the $PM_{2.5}$ concentration every minute (reported in units of milligrams per cubic meter of air, mg/m^3).

Six HOBO CO loggers were used in the study. These loggers were purchased by Gaia Association and calibrated at the Indoor Air Pollution Lab at the University of California-Berkeley using CO standard gas of 5 and 60 ppm. Before the start of the 'Before' and 'After' sampling, a CO-location calibration check was performed in the Gaia Association office kitchen to test whether or not the six HOBO loggers were working properly. The six HOBO loggers were tested against a seventh HOBO logger, which was called the "Gold Standard" (and was not otherwise used). This protocol was followed after each of the devices was used six times.

The UCB particle monitors were produced and calibrated in the IAP Lab at UC-Berkeley before they were used in Addis Ababa. The photoelectric chamber of each of the devices was cleaned with isopropyl alcohol after every five uses.

The above monitoring equipment was launched and downloaded on the premises of the office of Gaia Association in Addis Ababa. After this process the data was then organized and analyzed.

Pre and Post–Monitoring Questionnaires

A pre-monitoring questionnaire was used to measure the structure of the cooking areas. At the end of the 48 hr testing period, a post-monitoring questionnaire was administered to the 9 participating households. Also at this time, the monitoring equipment was taken down and end times recorded.

During the post-monitoring questionnaire, the main cook of each household was asked a series of questions to determine what the household conditions were like throughout the monitoring period. The questionnaire contained a total of 42 questions. These questions were designed to help interpret the IAP data collected during the 48 hr period. Questions such as what type of fuel was used and for how long the participating family cooked help explain why there may have been higher or lower levels of CO and PM recorded during the study.

Household Selection

The requirements for the test were sent to the directors of the respective organizations. With these criteria they then selected the homes. Each of the households that participated in the study was affiliated with either Good Shepherd Sisters or Fuelwood Carriers Association. The selected households were similar in construction.

The Good Shepherd homes are made up of a combination of metal, mud, and wood. The Fuelwood Carriers homes are similar in construction.

Results

Indoor Air pollution Concentrations.

The following results are for the 48-hour concentration measurements of $PM_{2.5}$ and CO in Addis Ababa Good Shepherd Sisters (GSS) and The Former Fuel Wood Carriers Association (FFWCA) members' kitchens. The selected 9 household samples used the kerosene stove for their primary stove and a metal charcoal stove for their secondary stove. In the after study (AS) a CleanCook stove was introduced.

In addition to the mean, minimum, and maximum PM concentrations recorded during each monitoring period, the UCB PM software calculated the highest, second highest, and third highest 15-minute average PM concentration. Each of these three metrics is taken during a consecutive 15-minute period, and none of the three periods overlaps. All values are displayed in Tables 1 and 2.

Table 1. Results of the 48-hour kitchen concentration measurements of $PM_{2.5}$ and CO in 9 households using a kerosene stove and a charcoal stove (Before).

HH ID	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)	
	# of records	Mean	Min	Max	Highest 15-min Ave	2nd Highest 15-min Ave	3rd Highest 15-min Ave	HOBO Mean	HOBO Max
GS001	3021	0.16	0.04	10.34	4.70	1.81	1.74	19.3	62.7
GS002	2994	0.33	0.04	15.97	5.45	5.28	4.77	23.4	135.7
GS004	2941	0.30	0.03	49.06	15.52	9.29	3.22	41.4	192.4
GS005	2884	0.18	0.10	14.50	4.85	2.27	2.24	26.7	137.7
GS006	2940	1.60	0.06	25.62	16.89	16.34	13.05	38.6	213.9
FW001	2889	0.57	0.05	15.73	12.77	11.94	10.32	18.8	120.8
FW003	2872	0.14	0.09	19.93	3.05	0.69	0.67	2.0	32.0
FW004	2890	0.65	0.08	39.08	21.73	19.06	13.20	26.0	338.9
FW006	2846	1.85	0.06	58.75	32.28	28.07	24.52	25.1	188.5

Table 2. Results of the 48-hour kitchen concentration measurements of $PM_{2.5}$ and CO in the same 9 households using the CleanCook Stove (After).

HH ID	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)	
	# of records	Mean	Min	Max	Highest 15-min Ave	2nd Highest 15-min Ave	3rd Highest 15-min Ave	HOBO Mean	HOBO Max
GS001AS	3078	0.09	0.05	6.81	1.69	1.16	0.95	1.2	36.9
GS002AS	2863	0.14	0.04	18.17	2.86	2.23	2.21	11.8	206.0
GS004AS	2866	0.15	0.08	17.78	3.69	2.61	2.53	4.5	55.9
GS005AS	2864	0.09	0.08	0.50	0.39	0.22	0.18	8.1	78.4
GS006AS	2997	0.77	0.04	13.83	10.85	8.23	8.02	13.7	251.0
FW001AS	2922	0.38	0.10	28.23	10.59	7.03	6.09	8.0	40.8
FW003AS	2860	0.12	0.09	3.07	0.84	0.81	0.44	1.3	13.4
FW004AS	2858	0.16	0.08	9.42	4.70	1.16	0.76	4.0	39.3
FW006AS	2843	0.12	0.07	8.69	2.45	1.29	1.21	0.3	5.1

Table 3 shows the means of the PM and CO data for the 9 households in the Before and After monitoring, along with the standard deviations. The percent differences are also shown, comparing the Before and After averages (the Before values were used as the denominator). Finally, the p values resulting from T-tests for significance of the differences are also shown.

Table 3. Average Kitchen Concentration and Percent Changes

	Before, Average	**Before, Std Dev**	**After, Average**	**After, Std Dev**	**Percent change**	**T-test (p value)**
PM: Average (mg/m^3)	0.64	0.64	0.23	0.22	-64%	0.05
PM: Minimum (mg/m^3)	0.06	0.02	0.07	0.02	17%	0.33
PM: Maximum (mg/m^3)	27.66	17.22	11.83	8.62	-57%	0.04
PM: Highest 15-min average	13.03	9.75	4.23	3.91	-68%	0.02
PM: 2^{nd} Highest 15-min average	10.53	9.26	2.75	2.87	-74%	0.03
PM: 3^{rd} Highest 15-min average	8.19	7.83	2.49	2.74	-70%	0.05
CO: Mean, HOBO (ppm)	24.6	11.5	5.9	4.8	-76%	0.0006
CO: Maximum, HOBO (ppm)	158.1	90.3	80.8	87.2	-49%	0.08

The average of the set of 9 48-hour average kitchen $PM_{2.5}$ concentrations went down from 0.64 mg/m^3 in the Before (Charcoal stove) phase to 0.23 mg/m^3 in the After phase, when the households were using the CC stove. This is a significant, 64% reduction ($p = 0.05$). As we might expect, the average minimum or baseline $PM_{2.5}$ concentrations were quite similar in both phases: 0.06 mg/m^3 in the Before phase and 0.07 mg/m^3 in the After phase. The average maximum $PM_{2.5}$ concentration dropped by 57% in the After sampling, relative to the Before phase (also significant, $p = 0.04$). The highest, second highest, and third highest 15-minute average $PM_{2.5}$ concentrations were also significantly lower after the introduction of the CC stove, by 68%, 74%, and 70%, respectively.

Similarly, the average 48-hour kitchen CO concentrations measured by the HOBO CO logger dropped from 24.6 ppm in the Before phase to 5.9 ppm in the After phase, a statistically significant reduction of 76% ($p = 0.0006$). The average of the maximum CO concentrations was reduced by 49% ($p = 0.08$).

Post-Monitoring Questionnaire Results

The important findings of the post monitoring questionnaire results are described below. The questionnaire was administered to the main cook of the household after the monitoring period was completed. The home that participated in the study used both charcoal and kerosene to fuel their stoves (5 of them used Lakech charcoal stove, 3 of them used Chinese kerosene stove (a wick stove), and the remaining 1 used metal charcoal stove) as their primary stove in the Before test. In the After study all the house holds used CleanCook stove for their primary cooking and 4 of them used three stone for their secondary cooking during the testing days. There was a slight, non-significant ($p = 0.3$) increase in the average number of people cooked for going from the Before to the After sampling phase (see Table 4 below).

Table 4. The number of people cooked for on the days of IAP sampling in the Before and After studies.

HH ID	Before, Number of people cooked for	After, Number of people cooked for
GS001	5	6
GS002	4	7
GS004	10	6
GS005	3	10
GS006	4	4
FW001	5	5
FW003	12	11
FW004	3	7
FW006	6	7
Average	5.8	7.0

Discussion

Comparison of Kitchen Concentrations to International Standards

The World Health Organization (WHO) sets air pollution guidelines to offer guidance in reducing the health impact of air pollution (both indoor and outdoor) based on current scientific evidence. The WHO recently set new Air Quality Guidelines (AQG) for $PM_{2.5}$, ozone, nitrogen dioxide, and sulfur dioxide, along with interim targets that are intended as incremental steps in a progressive reduction of air pollution in more polluted areas (WHO, 2005). The guideline for carbon monoxide was set in 2000 (WHO, 2000).

The results of the IAP monitoring in the 9 households are compared to the World Health Organization's AQG and interim target-1 (WHO, 2005) in Table 5 below. Note that the CO concentrations reported above in parts per million (ppm) were converted to mg/m^3 to match the unit used by WHO (by multiplying the gram molecular weight of CO, 28, and dividing by the conversion factor of 24.45).

Table 5. Comparison of kitchen concentrations to WHO guidelines.

	Before (charcoal and kerosene stove)	After (CleanCook stove)	WHO interim target-1	WHO Air Quality Guideline
$PM_{2.5}$	640 ug/m^3	230 ug/m^3	75ug/m^3 (24-hr mean)[1]	25 ug/m^3 (24-hr ave)[1]
CO	28.2 mg/m^3	6.8 mg/m^3	NA	10 mg/m^3 (8-hr ave)[2]

[1] WHO, 2005.
[2] WHO, 2000.

The average PM concentration in the kitchens was reduced after the households began using the CC stove (from 640 to 230 ug/m^3), a very significant improvement in indoor air quality, despite the fact that kerosene or solid fuels were still being burned in secondary stoves. Thus, the households moved closer to the WHO interim target-1 of 75 ug/m^3 for $PM_{2.5}$ (and the Air Quality Guideline of 25 ug/m^3) in the After phase. The average CO kitchen concentration in the charcoal and kerosene stove case (Before) was 28.2 mg/m^3 and dropped to 6.8 mg/m^3 with the CC stove, below the WHO guideline of 10 mg/m$^{3.}$

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