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Department of Public Health

The Effect of Chimney Fitted Improved Stove on Kitchen Fine Particulate Matter (PM2.5) Concentrations in Rural Ethiopia

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Presentation Outlines

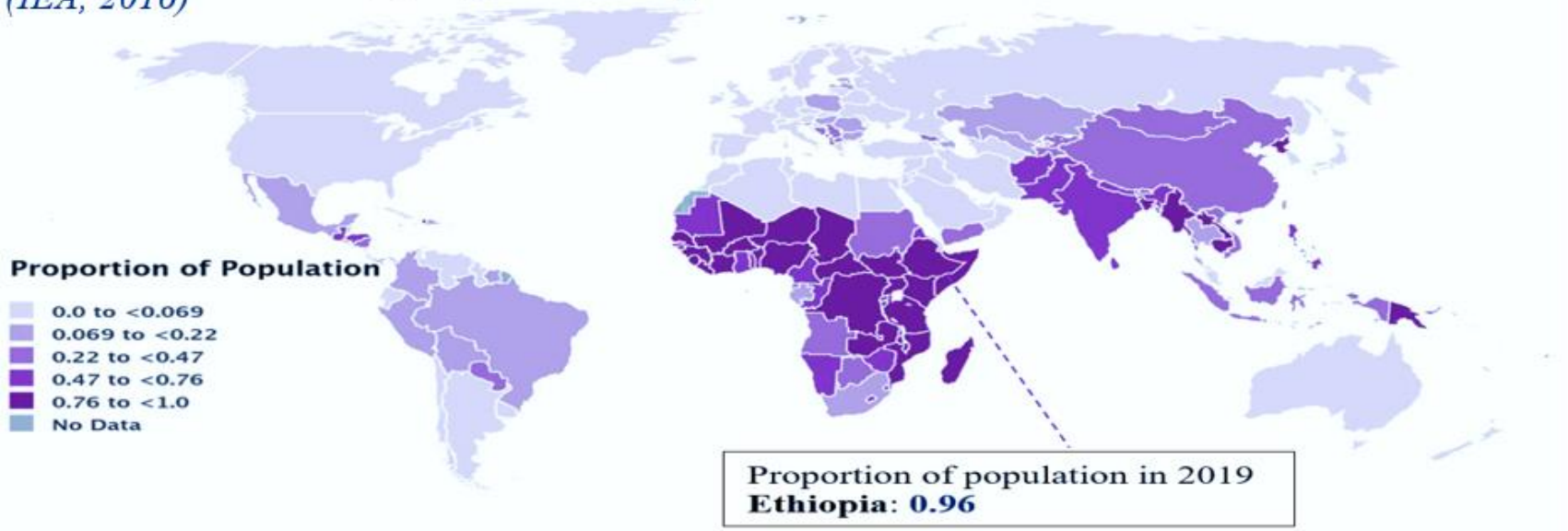
- Introduction
- Objectives
- Method and materials
- Result and discussion
- Conclusion
- Recommendations

Introduction

- Access to reliable **energy**...fundamental for basic and dev'tal needs
- About **3 billion** people use biomass fuel and traditional stove

... **primarily in rural remote area of LMICs**

(IEA, 2016)



- Global 40%
- SSA..... 81%
- East Africa ... 95%
- Ethiopia.....96%

- West Africa..... 83%
- Central Africa ... 77%
- Southern Africa...32%
- Northern Africa.. 13%

(IHME, 2022; Newell and Raimi, 2020)

Introduction...Cont'd

Household air pollution (HAP)

Typical cooking practices in the study area

- Rural HHs rely on traditional stoves
- These stoves often inefficient and lack ventilation
- Releases various pollutants

(WHO,2016; WHO,2021)

- **$PM_{2.5}$** and **CO** are the most important **markers** of HAP
  - a common proxy indicator used to measure levels of air pollution
- The **characteristics and quantity** of pollutants depends on the **fuel type**

(WHO,2014; Balmes J.,2019, Alberto P., 2016)

Introduction...Cont'd

What can be done about all of this?

Intervention options

- **Transition** to cleaner fuels... LPG, biogas, electricity...
- Adopt more **efficient stoves**....Improved stoves

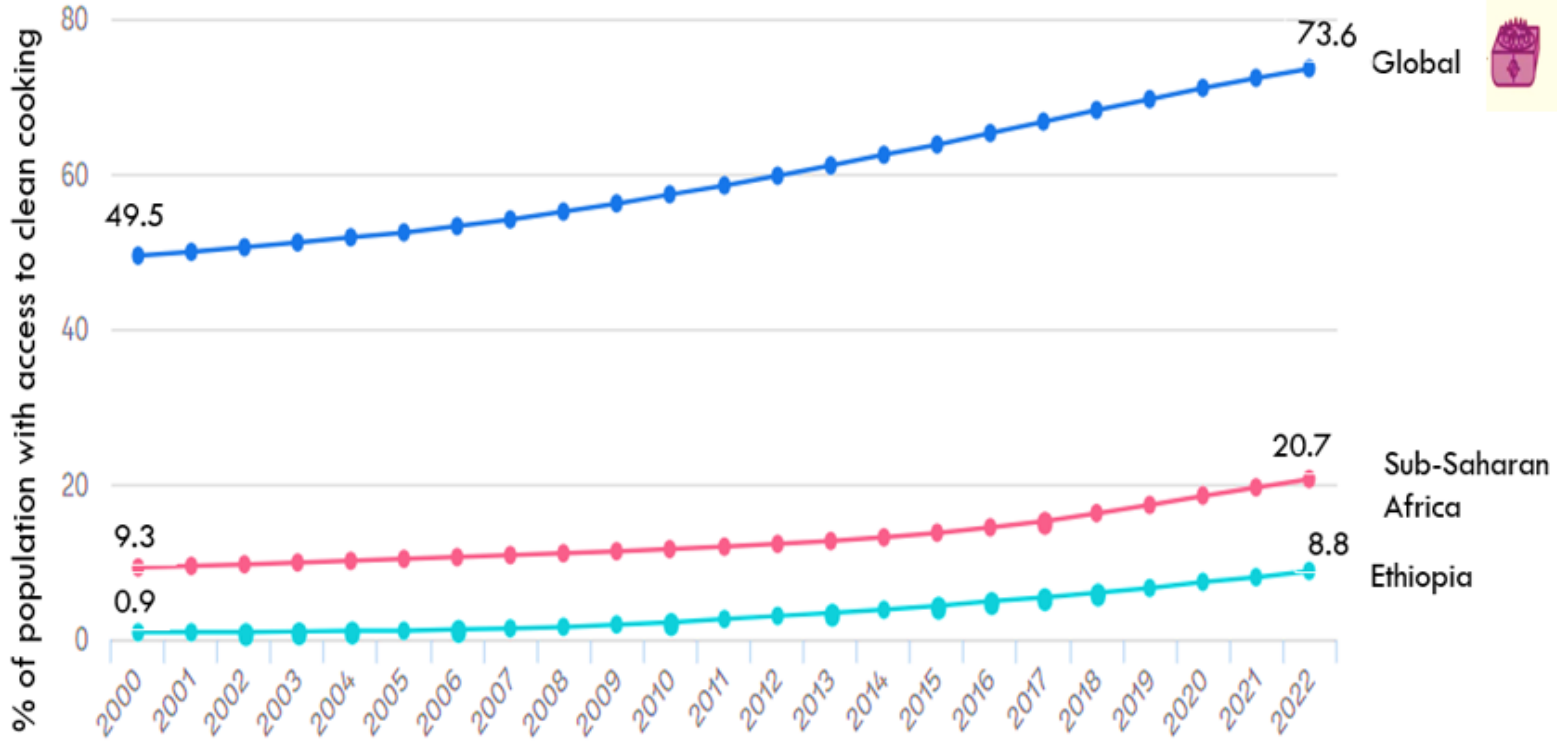
Solid fuels		Technologies		Pollutions
▪ Wood ▪ Animal dung ▪ Charcoal ▪ Agr. Residues...	+	▪ Inefficient stoves ▪ Poorly venting stoves ▪ Open fire ▪ mud modified stoves...	=	▪ Particulate matter ▪ Carbon monoxide ▪ Nitrogen oxides ▪ Sulfur oxides...
Making the clean available		Making the available clean		

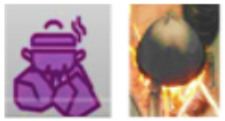
(WHO,2014; WHO,2021)

WHO classification...

Introduction...Cont'd

Ethiopia - slow transition to clean cooking
- intervention efforts vs population growth
- remarkable stability and expected to continue





(Raimi et al., 2022 ; tradingeconomics.com | World Bank, 2024)

Rationale of the study

Unsustainable biomass fuel use likely to remain stable in the future

- Low cost
- Lack of alternatives
- Cultural factors ...

Household air pollution

- Health impacts
- Environment impacts
- Economic impacts ...

Improved stoves

- Promising approach
- Sluggish transition to CC

Distribute 31 million stoves earlier than 2030

Effectiveness of improved stoves

- **Air quality**
- **Health outcomes**
- Fuel and time saving ...

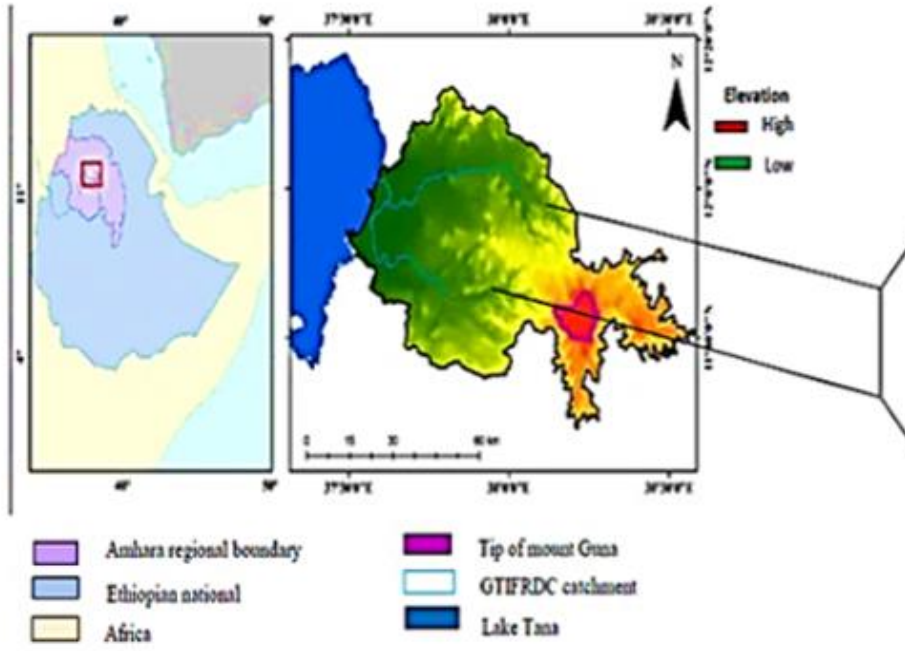
Communication gap between researchers and decision makers which interventions

Objective

- To measure the effectiveness of chimney fitted improved stove in reducing kitchen fine particulate mater (PM2.5) in Ethiopian rural household

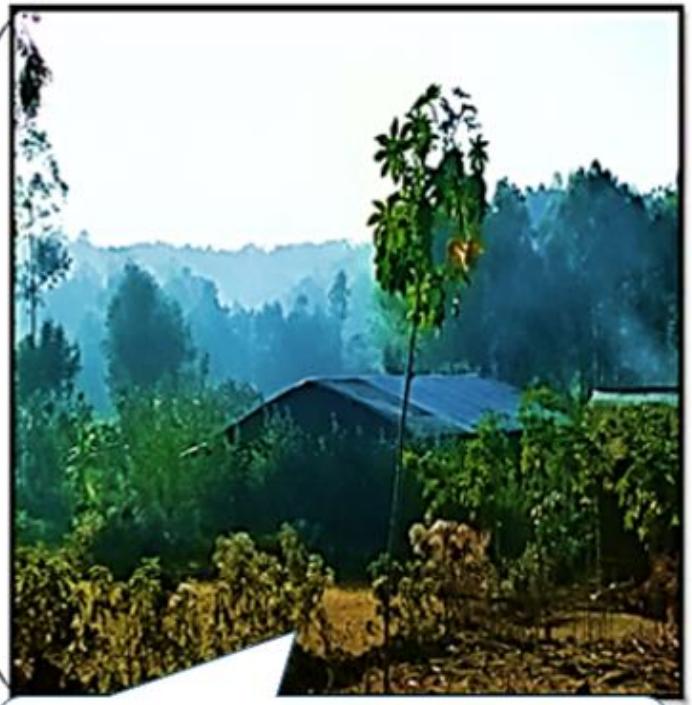
Method and Materials

Study Setting → Guna-Tana field research center



Gella Environ Syst Res, (2018)

Guna _Tana integrated field research and development center



The specific **HHs** where the study was conducted

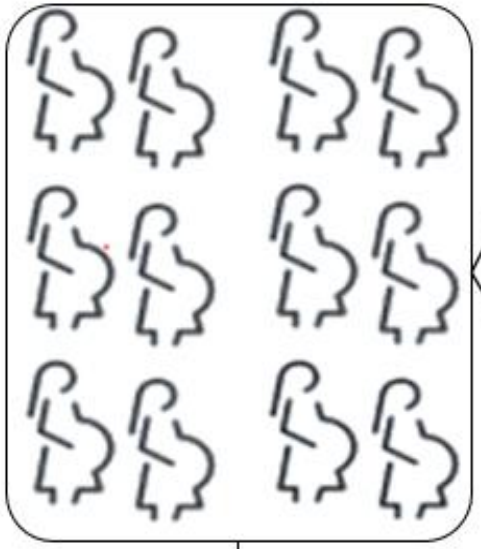
- Higher elevation depicted in **red** and lower in **green**
- It is a diverse landscape...forested, agricultural, and water bodies

Methods...Cont'd

Study design

Randomized controlled trial (RCT)

Two-arm, parallel, HH -level



1) Health risk Perception of HAP and Perceived benefits of improved stoves

2) Kitchen PM2.5 concentration

3) Pregnancy outcomes

- Birth weight
- Preterm birth
- Still birth
- Miscarriage ...

4) Acute respiratory infection

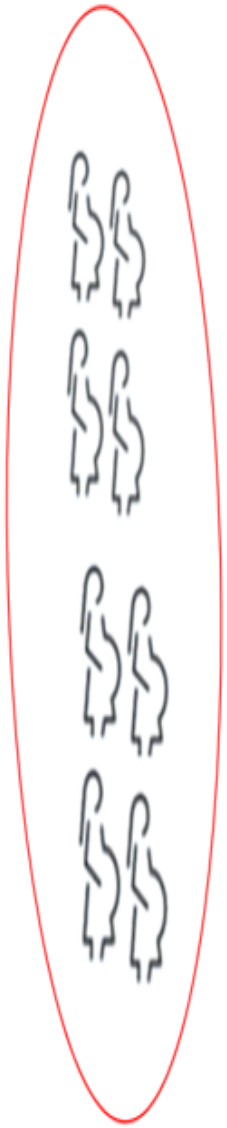
2) Kitchen PM2.5 concentration

3) Pregnancy outcomes

- Birth weight
- Preterm birth
- Still birth
- Miscarriage ...

4) Acute respiratory infection

Methods...Cont'd



Eligibility

Inclusion Criteria

- Age: 18-38 years
- 1st or 2nd (GA ≤ 24 weeks)
- Traditional biomass stove user
- Primary cook of the HH
- not known twin pregnant
- No known health conditions

Exclusion Criteria

- Planned relocation within 12 months
- Likely to switch to improved stoves
- Engaged in local alcohol production
- No enclosed kitchen (or unwilling to build one)

Methods...Cont'd

Sample Size

- All 648 pregnant women were approached
- Eligibility criteria were applied
- Eligible 422 participants were recruited

For PM2.5 sample

- Random subsample of **86** HHs (43 per group)
  - Desired power: 0.80 (high ability to detect effect)
  - Significance level: 5%
  - Expected PM2.5 reduction: 64% *(Randall Bluffstone et al.,2019)*
  - coefficient of variation: 0.7 *(Rufus Edwards et al., 2007)*

Methods...Cont'd

Intervention

- Locally-produced, Mirt stove with chimney
- Made from durable mortar mixture
- A promising option to tackling HAP and health burden
- Reduces fuel consumption by **40-50%**... *(Kedir et al., 2019)*
- Reduces kitchen PM2.5 concentrations
  - by **343** µg/m3 ... *(Adane et al.,2021)*
  - by **64** percent ... *(Randall Bluffstone et al.,2019)*
  - Improved child growth

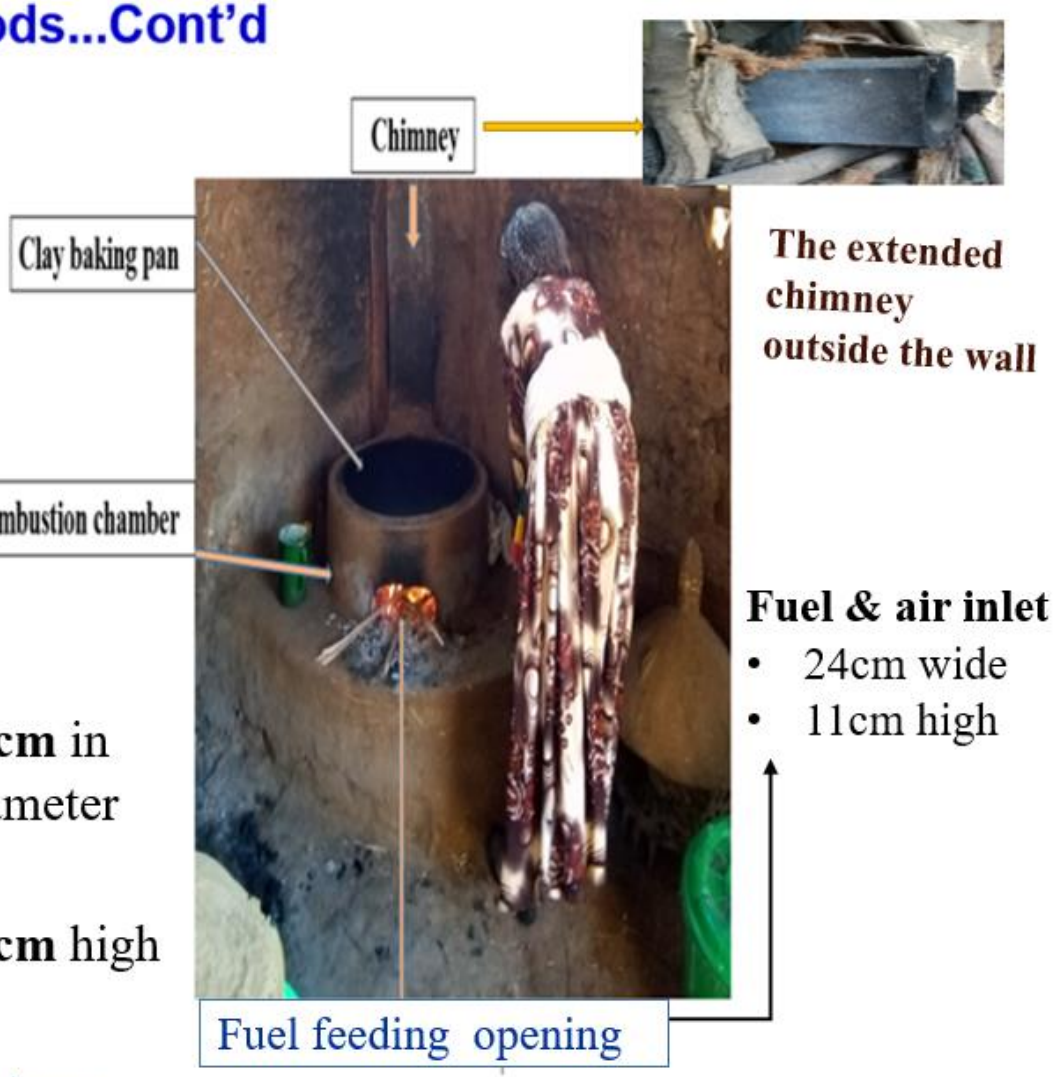
Intervention delivery

- Provided at half-subsidized cost (400 ETB, ~$8)
- Installed by trained local producers
- Repairs offered throughout the study

Methods...Cont'd

Injera baking Mirt stove

Improved stoves in the store



66cm in diameter

24cm high

The extended chimney outside the wall

Fuel & air inlet

- 24cm wide
- 11cm high

Advantage

- Works with all types fuels
- Easy to produce
- Creates employment
- Low emissions

Disadvantage

- Heavy weight 45-65 kg
- Big size

Methods...Cont'd

Data collection

Baseline data and stove installation

Kitchen PM2.5 **Birth weight** **ARIs**

Followed for 6 months

Nov to Dec, 2022	Nov, 2022 to Feb 2023	Jan to Aug ,2023	Aug 2023 to Feb ,2024
- Questionnaire - FGD guiding Qs - FAO guideline_DDS - Obs . checklists	- Questionnaire - PATS+ and Dylos - PICA software - Obs . checklists	- Questionnaire - Dr. care baby weighting scale	- Questionnaire-IMCI

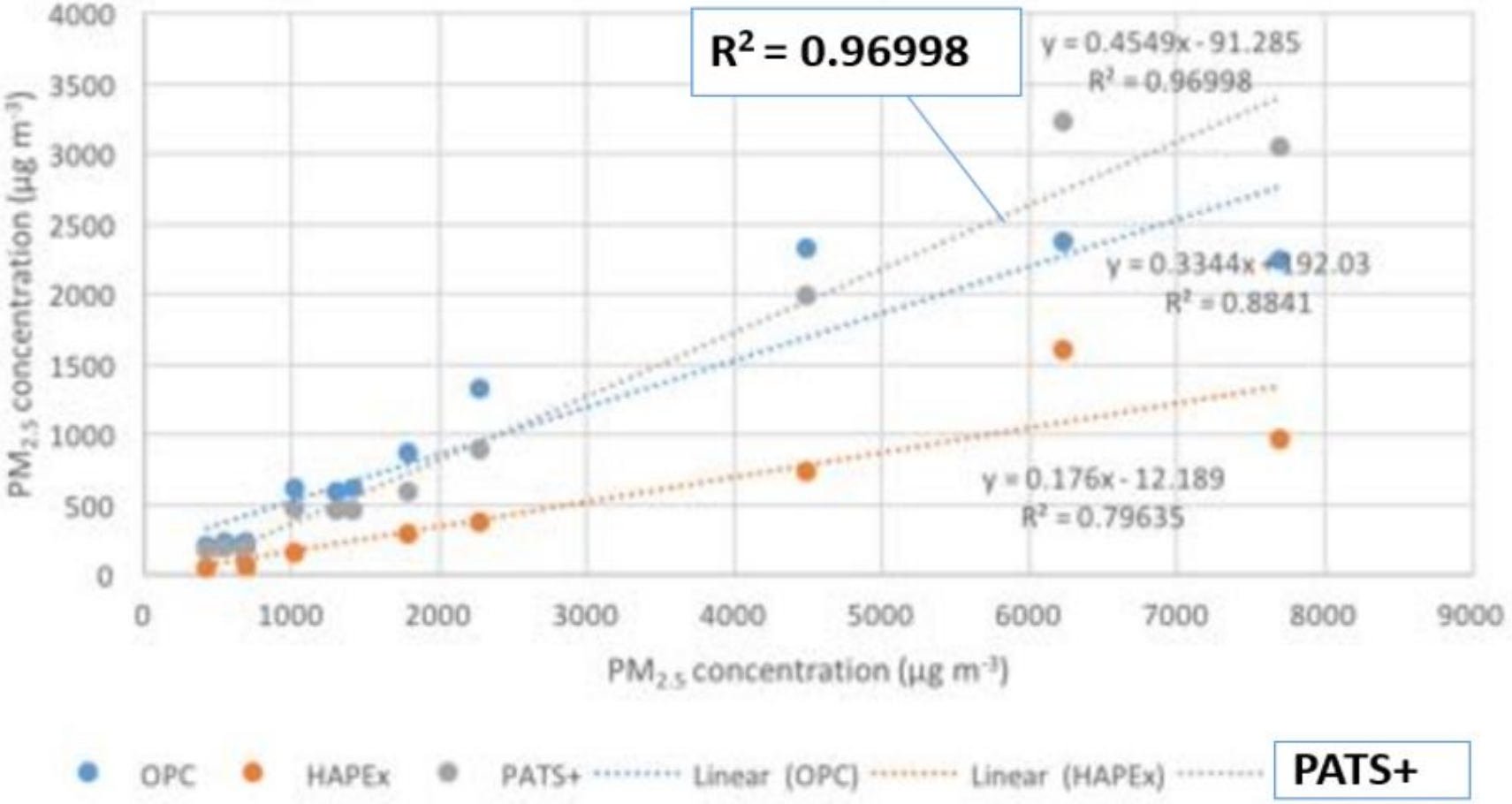
PATS+ air monitor

- Light scattering particle sensor
- Ease to use, space & battery life (80 hrs)
- Measurement range: 10 to 50,000 µg/m3
- Logging interval: every one minute

Validation and reliability

- From previous study, PATS+ correlates well with gravimetric air monitor
  - In laboratory settings, R^2 = 0.97
  - In rural households, R^2 = 0.74

(World Bank, 2017)

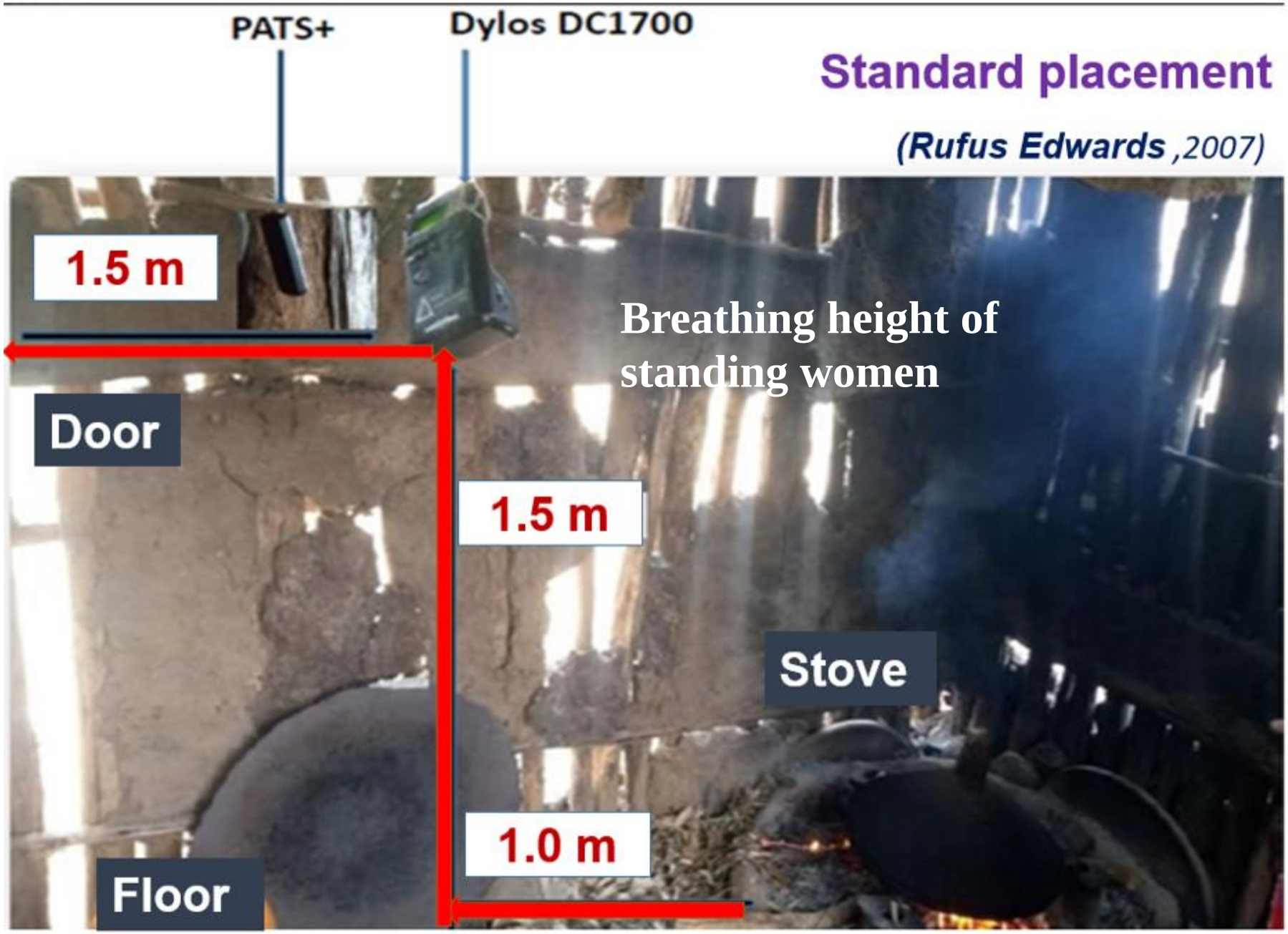


- In Ethiopia, PATS+ were calibrated against gravimetric filters in **50** homes over 24-hour periods
  - Resulted an adjustment factor of 0.8065 *(Bluffstone et al., 2019)*

- Furthermore, PATS+ and Dylos devices were directly compared in 11 kitchens

  - Resulted comparable readings, with a Pearson correlation coefficient of **0.78** (ranging from 0.75 to 0.86)

- Therefore, PATS+ provided acceptably accurate and reliable data in the rural Ethiopian context


PATS+
Dylos DC1700
Standard placement
(Rufus Edwards ,2007)
1.5 m
Breathing height of standing women
Door
1.5 m
Stove
1.0 m
Floor

PATS+ placing in different kitchens

Four PATS+ devices were distributed daily across four different kitchens

Data extraction

- Day_1_16_11_2022_MM
- DAY_2_19_11_2022_MM
- Day_3_22_11_2022_MM
- Day_4_24_11_2022_GM
- Day_5_28_11_2022_MYN
- Day_6_01_12_2022_AWZ
- Day_7_07_12_2022_GM
- Day_8_09_12-2022_GM
- Day_9_11_12_2022_GM
- Day_10_13_12_2022_AWZ
- DAY_11_15_12_2022_AWZ
- DAY_12_17_12_2022_AWZ
- DAY_13_19_12_2022_KYH
- DAY_14_21_12_2022_KYH
- DAY_15_23_12_2022_KYH
- DAY_16_25_12_2022_KYH
- DAY_17_27_12_2022_MYN
- DAY_18_29_12_2022_MYN
- DAY_19_01_01-2023_MYN
- DAY_20_03_01_2023-MYN
- DAY_21_05_01_2023_GM
- DAY-22_07_01_2023_MYN

text

- PM07733T
- PM07735W
- PM07736Y
- PM07736Z
- PM07738V

Excel

- MHH1_Bayush_P7733_16_11_2022_MM
- MHH2_Adisalem_P7735_16_11_2022_MM
- MHH3_Enatihun_P7736_16_11_2022_MM_...
- MHH4_Mantegibosh_P7738_16_11_2022_...

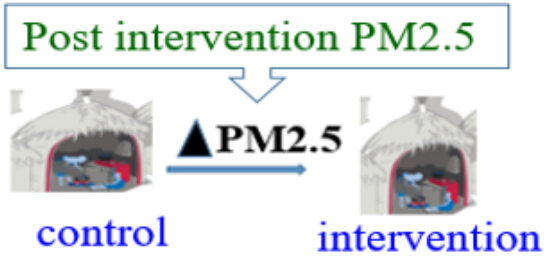
Intervention effectiveness

Paired (before-after) comparison

- Compare the same HH before and after
- Each HH serves as it's own control
- Aims to control for variations b/n HHs

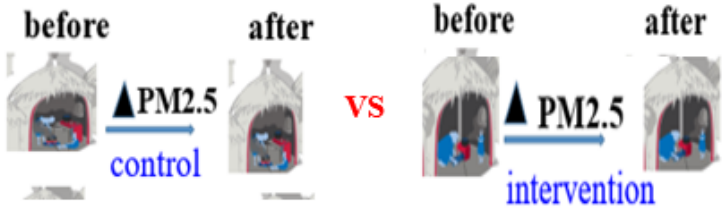
Between group comparison

- Comparison b/n intervention and control
- Change in PM2.5 level b/n each group
- To control **time** and **HH** level variations
- Control seasonal and other conditions



Difference-in-difference analysis

- Change in one group relative to the other
- Accounting for potential changes in both groups



Result and discussion

Some of the baseline characteristics

Characteristics	Overall	Control	Intervention	P-value*
Mean PM2.5, µg/m3	406 ± 221	482 ± 192	405 ± 248	**. 144**
Maternal age, years	28.7 ± 5.3	28.2 ± 5.1	29.3 ± 5.5	**. 344**
family size	4.5 ± 1.4	4.5 ±1.4	4.5±1.3	**. 940**
Kitchen area (m^2)	16.6 ± 3.4	16.6±3.0	16.5±3.6	**. 874**
Time spent in the kitchen, hrs	2.8 ± 0.9	2.8±0.8	2.7±0.9	**. 602**
Humidity (RH)	60.2 ± 3.8	60.3±4.0	60.1±3.6	**.779**
Temperature (T^0)	18.7± 2.6	18.4±2.5	19.0±2.5	**.299**

* $\chi 2$ tests for categorical variables and Independent sample t-test for continuous variables

- Minimal selection bias
- Reliable comparisons of the intervention's effects

Result and discussions...Cont'd

Kitchen PM2.5 level before and after stove intervention

Measurement	Category	Min	Max	Mean	SD	Median	IQR
Baseline, µg/m³	Control	82	971	**482**	±235	504	361
	Intervention	56	995	**405**	±229	370	416
post Inter , µg/m³	Control	180	896	**449**	±149	447	167
	Intervention	31	183	**104**	±44	100	79

(WHO, 2021) : **15 µg/m³ for 24-hrs average PM2.5**

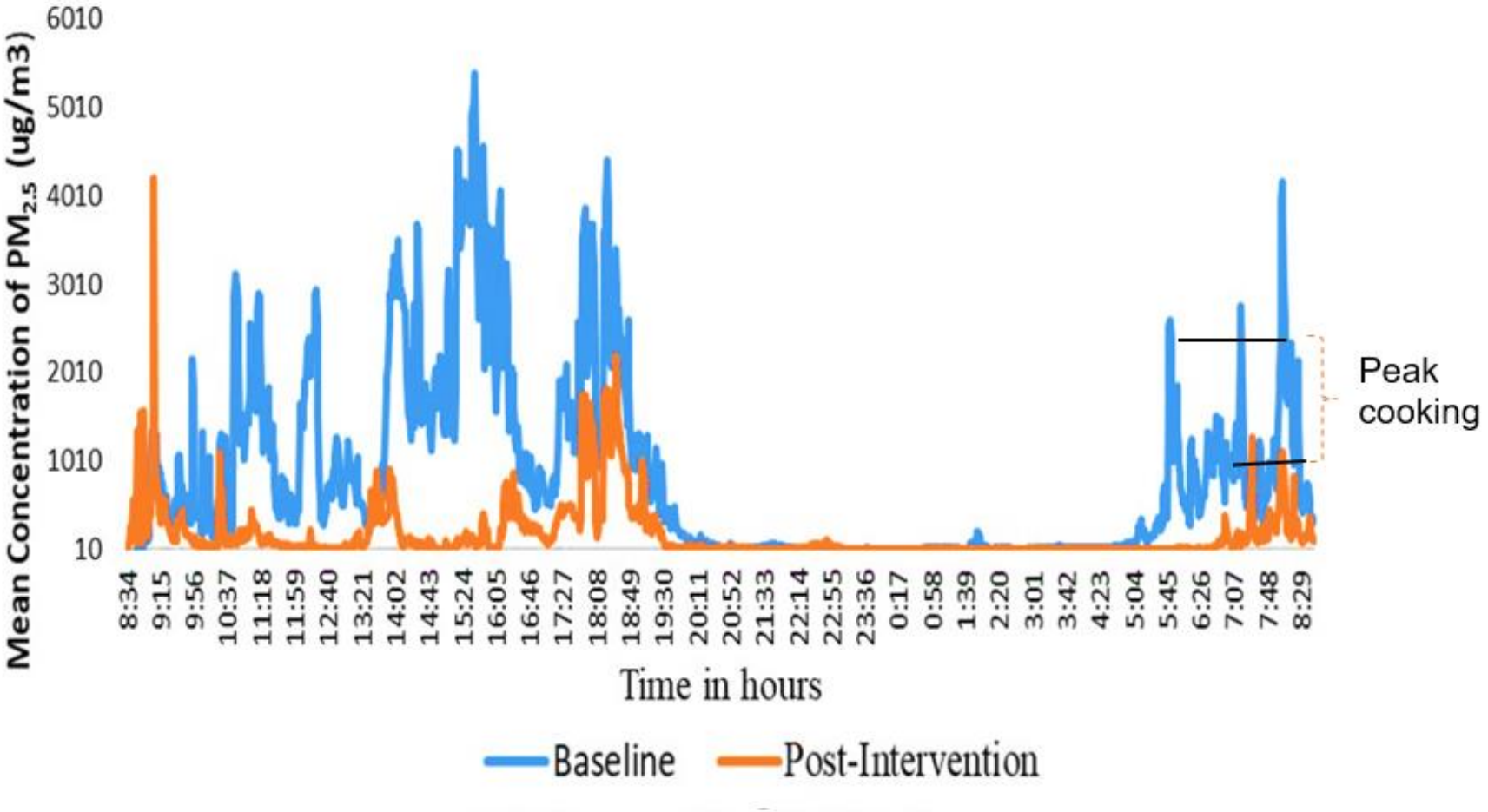
Post intervention PM2.5 levels

- **7x** greater for intervention group
- **30x** greater for control group

Result and discussion ...Cont'd

Daily variability in concentrations

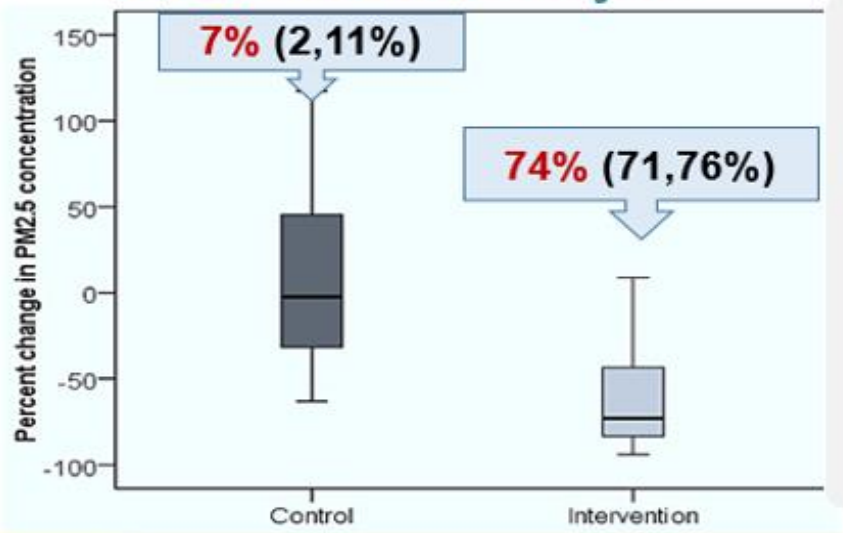
- Daily considerable and consistent declines
- Cooking time shortened



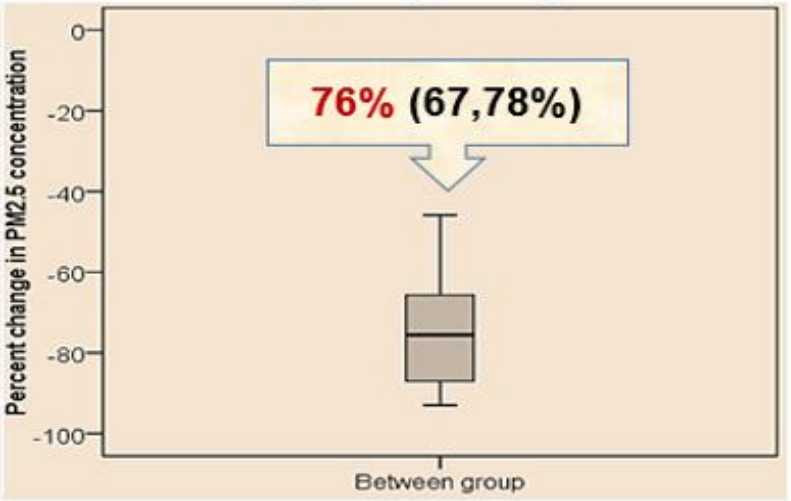
Result and discussions...Cont'd

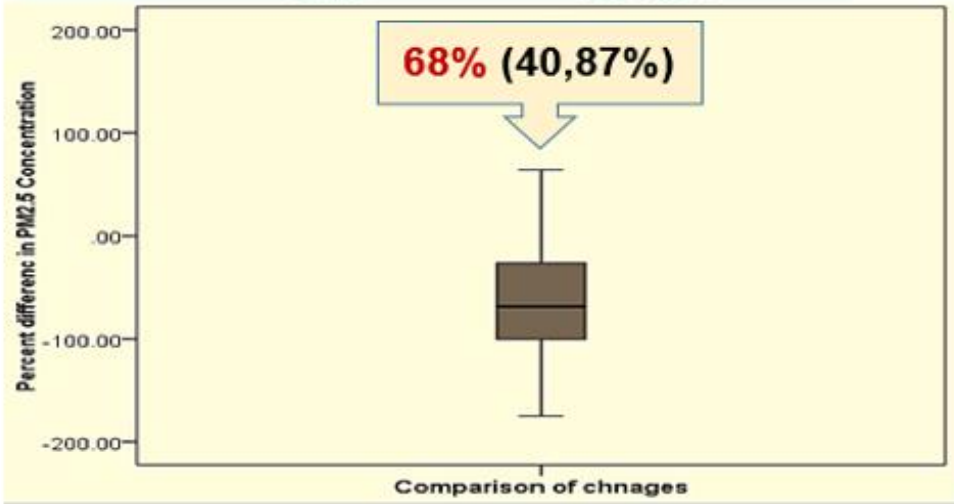
Intervention effectiveness...relative difference

Before and after analysis



Between-group comparison



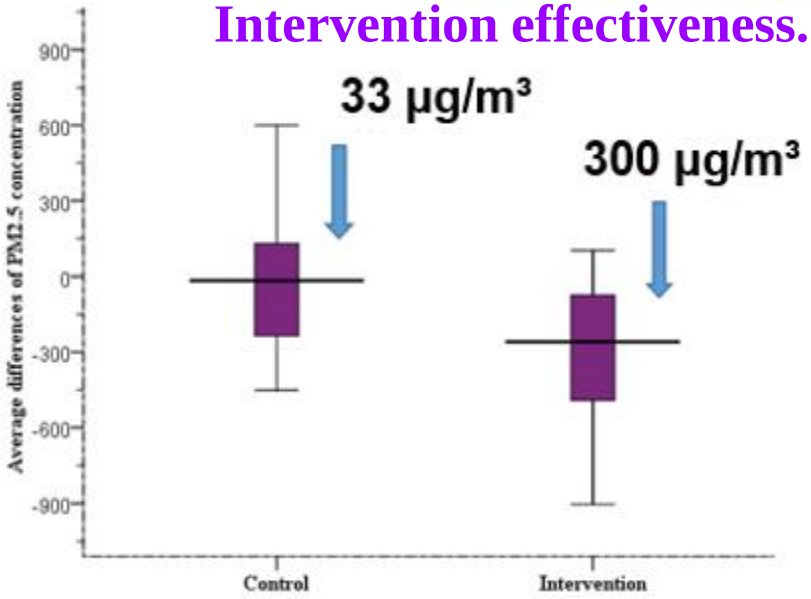


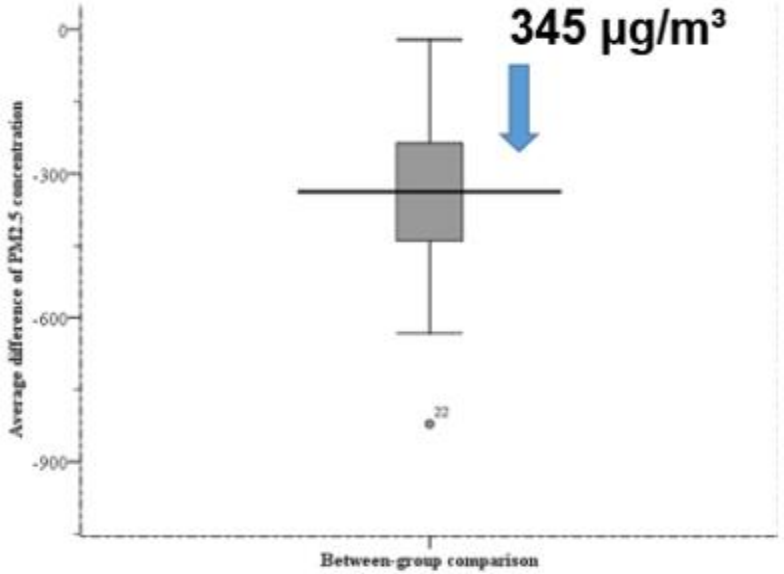
Difference -In -Difference analysis

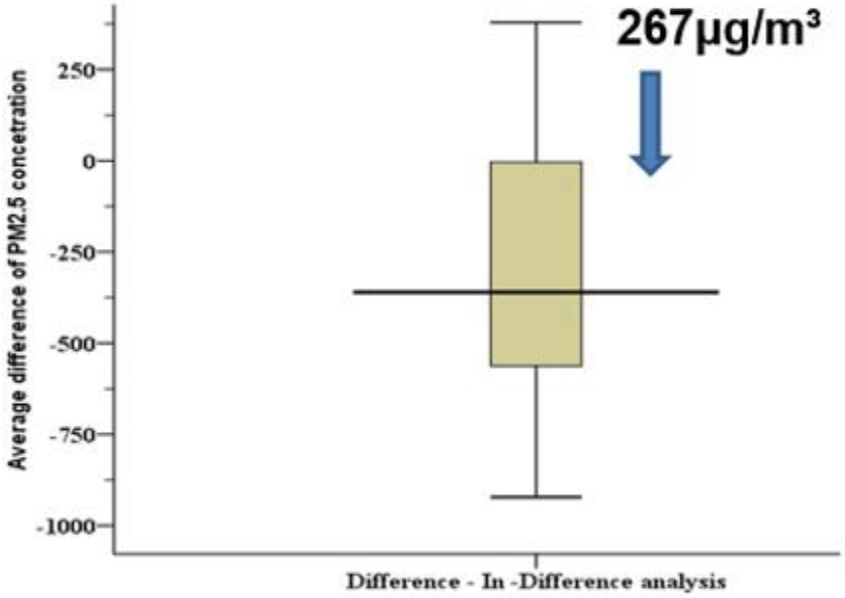
Soot accumulation

Result and discussion ...Cont'd

Intervention effectiveness...absolute difference







- 300 µg/m³ (95% CI: 213, 387) *(t = 6.97, p < .001)*
- *33 µg/m³ (95% CI: 44, 111) (t = 0.65, p = 0.512)*
- 345 µg/m3 (95% CI: 295, 399) *(t = 13.53, p < .001)*
- 267 µg/m³ (95% CI: 151, 382) *(t = 4.3, p < .001)*

Result and discussions...Cont'd

Variations in effectiveness

Categories	Average PM2.5 (95% CI) µg/m3				Average difference (95% CI) µg/m3	
	Control		Intervention		Crude[a]	Adjusted[b]
	baseline	end line	baseline	end line		
Overall (DID)	482 [408,557]	449 [401, 496]	405 [318,492]	104 [91, 118]	267 [151, 382]	**275 [49, 376]**
Educational						
can't R & W	489 [396,581]	461 [409,512]	401[288,512]	110 [91,130]	284 [138,431]	**286 [164, 409]**
Read & write	504 [236,773]	441 [224,658]	454 [-321, 412]	85 [72, 97]	109 [-209, 428]	**128 [-111, 368]**
primary (1-8)	425 [237,614]	400 [284,517]	406[240,571]	96 [72,120]	426[281, 570]	**394 [134, 654]**
Family size						
<5 occupants	447[331,563]	451 [382,520]	384[258,511]	91 [72,111]	295 [144, 445]	**276 [131, 421]**
≥ 5 occupants	516[414,618]	446 [376,517]	425[295,556]	117 [97,136]	255 [77, 432]	**273 [128, 418]**
Kitchen roof						
thatched	527[368,687]	513 [404,621]	548 [279,818]	114 [89,139]	240 [-51, 533]	**275 [79, 471]**
CIS	466[377,554]	425 [373,477]	371 [280,462]	102 [85,118]	288 [168, 408]	**275 [154, 395]**
kitchen area						
< 16 m^2	610 [457,763]	460 [344,577]	469 [253,685]	93 [61,125]	287 [169, 405]	**267 [153,382]**
≥16 m^2	446 [361,531]	445 [391,500]	379 [285,474]	108 [93,124]	226 [-139, 592]	**305 [71, 539]**
Baking Injera						
yes	568 [419, 717]	490 [389,590]	545 [398,691]	99 [77,121]	185 [-74, 445]	**234 [45, 423]**
no	442 [355, 529]	430 [375,484]	319 [218,419]	107 [88,126]	313 [190, 437]	**292 [170, 415]**

Conclusions

- The kitchen area PM2.5concentration was dangerously high
- The chimney fitted improved stove significantly reduced PM2.5 level
- The post-intervention PM2.5 levels remain high

Recommendations

- Comprehensive intervention focusing on awareness, stove and kitchen
- Accelerate clean cooking transition
- Support small scale enterprises to design and develop more efficient stove
- Promote universal improve stove use in the community

Thank you!