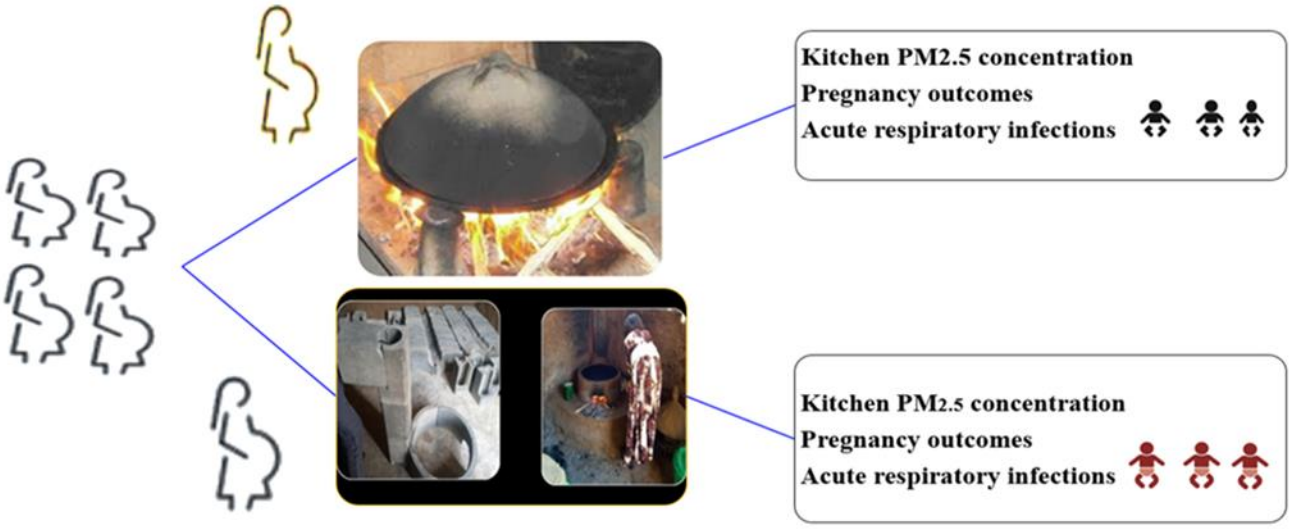
EFFECT OF IMPROVED STOVE ON KITCHEN AIR QUALITY, PREGNANCY OUTCOMES, AND INFANT RESPIRATORY INFECTIONS IN SOUTH GONAR RURAL HOUSEHOLDS: A RANDOMIZED CONTROLLED TRIAL



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OCTOBER, 2024

JIMMA, ETHIOPIA



JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INSTITUTE OF HEALTH, FACULTY OF PUBLIC HEALTH

DEPARTMENT OF ENVIRON'TAL HEALTH SCIENCE ANDTECHNOLOGY

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A PhD Dissertation Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy (Ph.D.) In Environmental Health

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OCTOBER, 2024

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Dedication

I would like to dedicate this dissertation to my beloved father Ato Demelash Enyew and beloved mother W/ro Beteha Mengistie, whose unwavering love, support, and sacrifices have shaped my character and fueled my ambitions. From childhood, they instilled in me strong moral values, teaching me the importance of honesty, integrity, and empathy. Their unwavering loyalty and unconditional love have been my constant source of strength. Through their discipline and guidance, they have prepared me for the challenges of life, equipping me with the tools to succeed. I am eternally grateful for their sacrifices and dedication.

Acknowledgements

This research project would not have been possible without the invaluable contributions and collaboration of numerous individuals and organizations. I extend my deepest gratitude to each of them for their unwavering support.

First, I would like to thank my God for providing me with the strength and perseverance to complete this dissertation.

Second, I would like to express my deepest gratitude to my esteemed promotor, Professor Seid Tiku Mereta. His dedication, insightful guidance, and unwavering support were instrumental throughout this dissertation journey. His mentorship significantly enhanced the quality of this work. I particularly appreciate his willingness to engage in thoughtful discussions, treating me as a valued colleague rather than solely a student. His patience with my questions and concerns, coupled with his inspirational approach, kept me motivated even during challenging times.

I am also indebted to Dr. Abebe Beyene Hailu, whose invaluable guidance and support extended throughout the entire research process. His guidance in selecting relevant course works and his unwavering encouragement during the planning stages of the research opportunity in Poland (unfortunately suspended due to COVID-19). His ongoing mentorship significantly improved the quality of the final dissertation.

I gratefully acknowledge the financial support provided by Jimma University, Debre Tabor University, and SEAL Awards (environmental advocacy organization). I also extend special thanks to Gaia Clean Energy Association, Ethiopia, for providing the particulate matter monitoring devices (PATS+) and GEOHealth for Research and Training for Eastern Africa, supported by the National Institutes of Health Fogarty International Center (NIH FIC), the National Institute of Environmental Health Sciences (NIEHS), the Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health (CDC/NIOSH), and the Stockholm Environmental Institute, Kenya, for providing the Dylos DC1700 air quality monitoring devices.

I would like to acknowledge the South Gondar Zone health department and the respective district health offices for their crucial cooperation in facilitating the initiation and execution of this study. Finally, I express my sincere gratitude to the data collectors and supervisors for their dedication to maintaining the quality of the data collected throughout the study and I extend my sincere gratitude to the study participants for their patience in answering all questions and fulfilling all requests.

Thank you to all who have contributed to this research!!!



Acronyms and abbreviations

ALRIs	–	Acute Lower Respiratory Infections
APGAR	–	Appearance, Pulse, Grimace, Activity and Respiration
AQG	–	Air Quality Guideline
CI	–	Confidence Interval
CO	–	Carbon Monoxide
COPD	–	Chronic Obstructive Pulmonary Disease
CSA	–	Central Statistics Agency
CSI	–	Clean Stove Initiative
DALYs	–	Disability adjusted life years
EDHS	–	Ethiopian demography and health survey
GACCS	–	Global Alliance for Clean Cook Stoves
GBD	–	Global Burden of Diseases
GTIRDC	–	Guna Tata Integrated Field Research and Development Center
HAP	–	Household Air Pollution
HDL	–	Health Development Leader
HEW	–	Health Extension Workers
COV	–	Coefficient of Variation
ICS	–	Improved Cook Stove
IUGR	–	Interutrin Growth Retardation
LBW	–	Low birth weight
LMICS	–	Low and Middle Income Countries
LMP	–	Last Menstrual Period
LPG	–	Liquefied Petroleum Gas
NGOs	–	Non-Governmental Organizations
OR	–	Odds Ratio
PATS+	–	Particle and Temperature Sensor Plus
PM	–	Particulate Matter
PM2.5	–	Particulate Matter $\leq$ 2.5 μm in aerodynamic diameter
PTB	–	Preterm Birth
RCT	–	Randomized control trial
SOGA	–	Sstate of Global Air
SSA	–	Sub-Saharan Africa
WHO	–	World Health Organization

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Executive Summary

Background: Household air pollution from biomass fuel use remains a significant global health concern, particularly in developing countries. In Ethiopia, the widespread use of traditional stoves contributes to high levels of household air pollution, exposing millions to harmful pollutants. Early exposure, particularly before birth and in early childhood, can negatively impact fetal development, potentially leading to premature birth, low birth weight, and deadly lower respiratory infections. While the World Health Organization recommends improved cook stoves as a potential solution for a safe transition to clean cooking in low-and middle-income countries, the effectiveness of locally-made models in reducing exposure to air pollution and associated adverse health outcomes needs further evaluation. Furthermore, since widespread adoption of effective stoves depends on community perception, understanding how communities perceive the health risks of household air pollution and the potential benefits of improved stoves is crucial.

Objectives: This study aimed to investigate the effectiveness of a locally-made chimney-fitted Mirt stove in reducing kitchen particulate matter concentration and improving health outcomes, including pregnancy outcomes and acute respiratory infections among infants in rural households of northwest Ethiopia.

Method: This study was conducted in a low-income rural community situated in the Guna-Tana integrated field research and development center of Debre Tabor University, within the South Gondar zone of Ethiopia. A cross-sectional mixed methods study at baseline explored pregnant women's perceptions of household air pollution risks and the potential benefits of improved stoves followed by a randomized controlled trial (RCT) to measure the stove's impact on kitchen air quality, pregnancy outcomes, and infant acute respiratory infections.

Following detailed discussions about the study protocol and eligibility criteria, 648 pregnant women from six kebeles were initially approached to assess their eligibility for the study. Then 422 women were deemed eligible and randomly assigned to either the intervention or control group in a 1:1 ratio following baseline data collection.

Baseline survey, focus group discussion, and observation were used to collect the demographic, economic and related characteristics of the respondents. Kitchen particulate matter concentration was measured using particle and temperature sensor plus (PATS+) air monitor devices. Then, descriptive statistics and logistic regression models were used for baseline data. Independent

samples t-tests for continuous variables and chi-square tests for categorical variables was conducted to assess baseline comparability between the study arms and to estimate the effectiveness of improved stove on birth weight. All audio-recorded focus group discussions were transcribed verbatim, translated into English, and analyzed using a thematic analysis approach.

Paired samples t-tests were used to assess changes in PM2.5 levels within each group before and after the intervention. For secondary outcomes including low birth weight, preterm birth, and miscarriage, chi-square tests were employed. Finally, Generalized Estimating Equations (GEE) models were used to analyze the impact of improved stoves on the occurrence of acute respiratory infections (ARIs) in infants.

Results: Participants reported a relatively high level perception of health risks associated with household air pollution (63%, 95% CI: 58, 68%) and expressed enthusiasm for improved stoves (74%, 95% CI: 70, 79%). Focus group discussions confirmed these findings, with nearly all participants acknowledging the health risks of household air pollution and the potential benefits of improved stoves. Older women, high asset index and larger families were positively associated with high perception of household air pollution as a risk. Whereas, younger women with young children, educated husbands, and dissatisfaction with current stoves were more likely to support improved stoves

The study found that both the control and intervention groups had initially high levels of PM2.5 (482 μg/m³ control, 405 μg/m³ intervention). However, the intervention group experienced a significant reduction of 74% in PM2.5 levels (104 μg/m³) after using improved stoves, while the control group's levels remained elevated at 449μg/m³. The result was consistent across different statistical methods, showing a reduction ranging from 68% to 76% with the corresponding concentration reduction ranged from 267 μg/m³ to 345 μg/m³. Furthermore, the study found that women with higher levels of education, larger kitchens, smaller families, and those who were baking Injera during air quality measurements experienced greater reductions in PM2.5 level.

Although there was non-statistically significant increase in birth weight among infants in the intervention group (3065g vs. 2995g) with unadjusted 69g (p=0.153) and adjusted 55g (p=.274) difference, gestational age was significantly longer (38 weeks vs. 36.5 weeks, p<0.001), resulting in a lower rate of preterm birth. However, there were no significant differences in low birth weight, pregnancy complications, stillbirth, or miscarriage rates between the two groups.

During the 6-month follow-up study, 12% of infants (43 out of 343) had at least one ARI episode. The intervention group had a slightly lower prevalence (11%) compared to controls (14%). While not statistically significant, the intervention group consistently showed a lower incidence rate of ARIs throughout the study (6.16 vs. 7.40 episodes per 100 infant-months). The analysis showed a lower incidence rate ratio in the intervention group compared to the control group, both before (IRR= 0.80, 95% CI: 0.56–1.15; p = 0.238) and after (IRR = 0.81; 95% CI: 0.56–1.16; P=.252) adjusting for maternal age. But, it is not statistically significant.

Conclusions and recommendations: High perceived risks of household air pollution and strong interest in improved stoves indicate a promising environment for promoting cleaner cooking technologies. Though it did not reach the recommended safe level, the improved stove significantly reduced kitchen fine particulate matter concentration. Pregnant women who were assigned to the intervention group also delivered babies with longer gestational age and leading to a reduced risk of preterm birth. While the intervention group showed slightly higher birth weights and lower acute respiratory infection rates, these differences were not statistically significant.

This study highlights the potential of improved stoves to reduce household air pollution and improve maternal and child health, though further research is needed to optimize intervention strategies and fully realize these benefits.

Policymakers can leverage this evidence to encourage the continuous development and promotion of stoves with higher combustion efficiency and effective ventilation systems to reduce the PM2.5 concentrations to acceptable level and consequently contribute to the improvement of pregnancy outcomes and reduction of acute respiratory infections. Implementing policies to incentivize the adoption of these improved stoves is crucial.

Local health care workers can create awareness about the health risks associated with air pollution emphasizing more serious chronic health outcomes to bridge the gap between positive perceptions and actual action. Further research with a larger sample size and longer follow-up could be conducted to explore the effectiveness of improved stoves.

Keywords: Improved stove; Intervention; Kitchen area; (PM2.5) concentrations, low birth weight, preterm birth, stillbirth, acute respiratory infections, Ethiopia

Chapter 1
Genera Introduction

1.1 Background

1.1.1 Household biomass fuels use

From the earliest times, our ancestors cooked using fire and wood (Chirinos, 2017, Symons, 2003). The rise of agriculture introduced crop residues, and even animal dung, as fuel sources alongside wood, and the discovery of coal provided an alternative fuel option, particularly in regions rich in coal resources like Britain and China (Jawahar et al., 2017). Today, these three (wood, agricultural waste, and coal) and even leaves and grass remain the primary cooking fuels for the 3 billion global population (UN, 2023, Newell and Raimi, 2020, IEA, 2016, Rosenthal et al., 2018). Burning of these biomass fuel is a daily activity as it is used for heating in the cold, lighting in the dark, and cooking food (Mock et al., 2018). In today's world, access to reliable energy is fundamental for meeting the basic and developmental needs of all communities (IEA, 2016, Rosenthal et al., 2018). At the same time, it is one of the major challenges the world faces today influencing all aspects of human lives (WHO, 2009b) and the most important factors effective in air pollution and exposure (Dehghani et al., 2023).

Despite nearly 60% of the world population now using cleaner fuels like natural gas, liquefied petroleum gas (LPG), and electricity, the transition is outpaced by population growth, primarily due to the continued reliance on biomass fuels among low-income communities (IEA, 2016, WHO, 2016b). Because, clean energy is too expensive or too irregularly supplied (Thomas et al., 2015a, WHO, 2018b) whereas, biomass fuels are readily available for self-collection or local market and can be easily used in inexpensive traditional stoves for cooking (Mock et al., 2018, Newell and Raimi, 2020). The primary source of biomass fuel in an area depends on available resources, with wood favored in forested regions and crops in areas with extensive farmland (WHO, 2016b). In rural households, biomass fuels are frequently gathered from the local environment, while in urban areas, they are often obtained from local market purchases (Romieu et al., 2013) (Figure 1).

Although increasing modernization has led to the supplementation of biomass by fossil fuels and electricity, nearly half global, 80% African, more than 85% Sub-Saharan African, and more than 95% Ethiopian population still rely on solid biomass fuels to meet their household energy needs (WHO, 2018c, Wolf et al., 2017, Puzzolo et al., 2019, CSA, 2016, Misganaw et al., 2023). These populations are concentrated in rural, remote areas of developing countries (Aemro et al., 2021). The highest rates of using biomass fuels remain high in low and middle income countries, particularly in eastern, central and western sub-Saharan Africa (SSA) and south east Asian (Gall et al., 2013, Newell and Raimi, 2020). More than 990 million children across Africa and Asia (over 350 million children in Africa and 640 million children in Asia) live in households where solid biomass fuels are used for domestic purposes (Rees, 2016).



(source: Burdens of Women Collecting Firewood in Africa)

Figure 1: Purchased (left) and Gathered (Right) firewood in Africa

The Central African Republic, South Sudan, Rwanda, Burundi, Niger, Mali, Madagascar, Tanzania, Uganda, and Guinea-Bissau are the top 10 African countries with the highest proportion of households cooking with biomass fuels where more than 97% of the countrys' population use solid biomass fuels for domestic purpose (Newell and Raimi, 2020). It was also reported that eighteen of the nineteen countries with a population relying on solid fuels for cooking at 95% or higher are in SSA (Rees, 2016). As of 2019, the dependence was particularly high in eastern Africa (95%), followed by western (83%) and Central Africa (77%) (HEI1, 2020). As shown in Figure 2, most of the sub-Saharan African countries including Ethiopia fall into the highest solid biomass pressure zone (Birol, 2023). From Ethiopian population, only 7.5% of (26.6% in urban 0.5% in rural areas) primarily relies on clean fuel/technologies (CSA, 2016, Mondal et al., 2018).

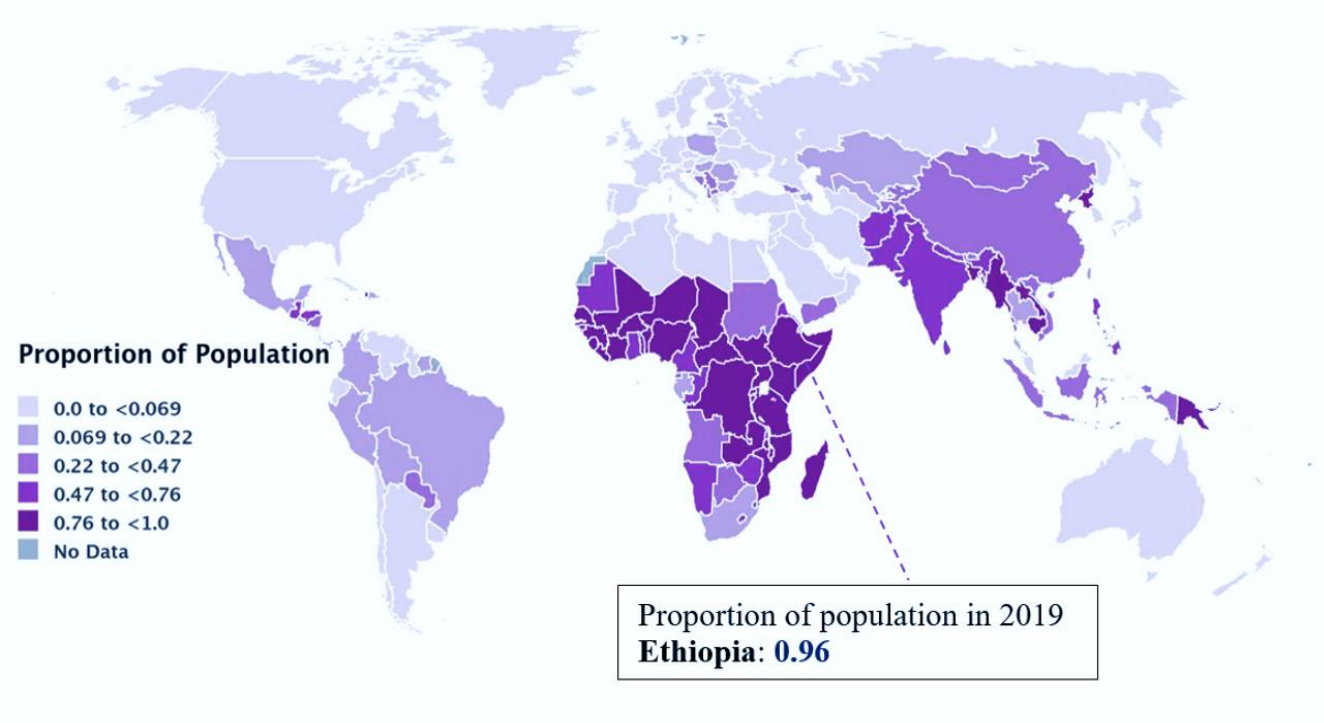


Figure 2: Global map of the proportion of each country's population cooking with biomass fuel in 2019. (source: *state of global air, 2020*)

The burning of biomass fuels using traditional stoves is under increasing scrutiny due to its devastating impact across multiple scales (Romieu et al., 2013, Kyayesimira et al., 2021, Yalew, 2022). In households and villages level, burning biomass fuels releases harmful air pollutants, leading to severe health problems and forcing women and girls to spend hours collecting firewood (Okello et al., 2018, Action, 2014, Njenga et al., 2021). Beyond the individual, unsustainable harvesting practices contribute to deforestation and ecosystem degradation at the community and national level (Specht et al., 2015, Haman et al., 2022). Finally, at the regional and global scale, inefficient stoves using these fuels release alarming amounts of black carbon and greenhouse gases (Bond et al., 2004, Tomlin and Fuels, 2021, Keywood et al., 2013) which had greater warming potential, accelerating global warming, especially when sourced unsustainably (EIA, 2019, Tomlin and Fuels, 2021). All these local and global issues are the current global agendas under a set of universally accepted goals named as sustainable development goals (Amegah and Jaakkola, 2016, Rosenthal et al., 2018).

The global population projected to use solid biomass fuel will reach 2.8 billion by 2030, indicating a persistent reliance on these energy sources and technologies (Ezzati and

Baumgartner, 2017, IEA, 2016). Unfortunately, intervention efforts are not keeping pace with population growth (Gall et al., 2013, LaFave et al., 2021), especially in Africa, where progress has been minimal over the decades (Energy, 2014, Aemro et al., 2021). Currently, more than 700 million people in Africa use solid fuels (Mitchell et al., 2019, Wright et al., 2019). Population growth is projected to outpace the adoption of clean cooking practices, leading to an estimated 900 million people relying on solid biomass fuels with traditional cooking stoves by 2030 (IEA, 2016).

Without significant intervention, Sub-Saharan Africa is projected to bear the brunt of the clean cooking access gap in 2030, with nearly 60% of people lacking access, and minimal improvement anticipated by 2050 (UN, 2023, Sanusi, 2023). Despite global trends towards cleaner energy sources, sub-Saharan Africa is expected to continue relying heavily on biomass fuels for many years (WHO, 2018b). In this region, despite projections of one billion people gaining access to electricity by 2040, nearly 530 million will still depend on solid biomass fuels (Bede-Ojimadu and Orisakwe, 2020). In 2016, around 800 million people in SSA relied on solid biomass for primary cooking, a slight decline from 2000 (Dagnachew et al., 2019). Progress in increasing the proportion of the population with access to clean cooking has been slower in the region (Keel et al., 2020, IEA, 2016) (Figure 3).

In Ethiopia, more than 95 % of the population uses solid biomass fuels for domestic purposes with a significant difference between rural and urban areas (99 % in rural and 26 % in urban) (CSA, 2016) and 50% of the biomass fuel is used to bake Injera (a flat bread-like pancake prepared from a tiny grain locally called Teff) (Tadesse, 2020). Data from Ethiopia's Demographic and Health Surveys (DHS) conducted between 2005 and 2016 reveals a concerning trend with percentage of households using biomass fuels only decreased by 6%, from 99% in 2005 to 93% in 2016 (CSA, 2016). The data has shown remarkable stability for the past decade and are expected to continue into the future. This slow progress highlights the limited upward movement on the energy ladder towards cleaner fuels in Ethiopia (CSA, 2005, CSA, 2016). Ethiopia's reliance on biomass fuels for cooking remains remarkably high, with nearly all the population (around 99% in 2000 and 91% in 2022) still using wood, dung, or other solid fuels for cooking (Raimi et al., 2022).

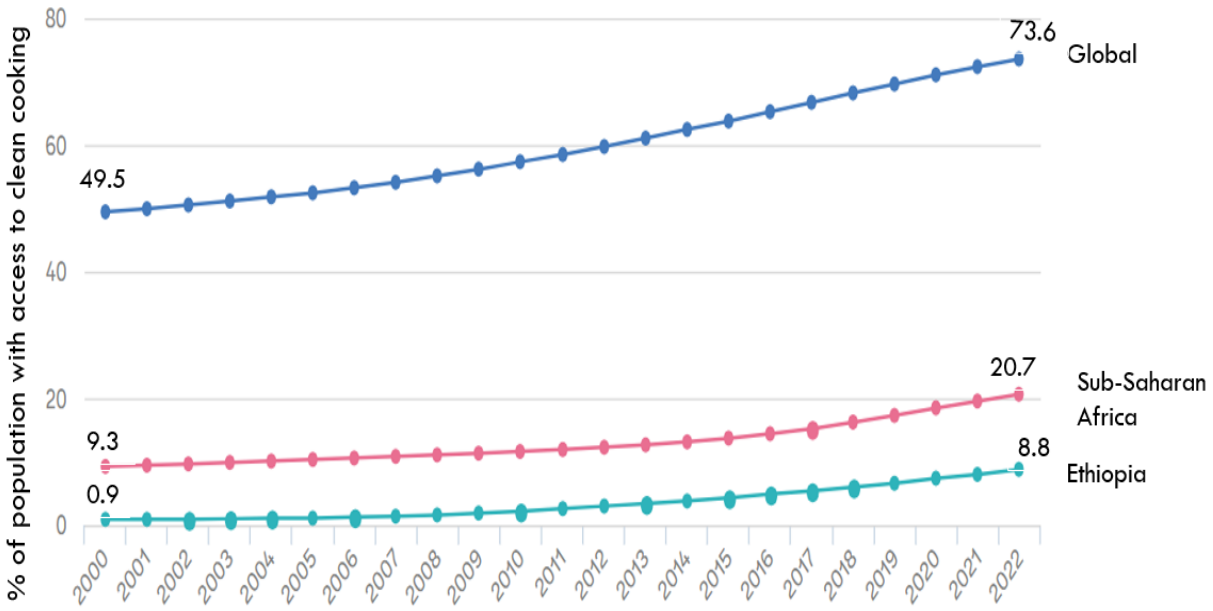


Figure 3:Trends of proportion of population accessing clean cooking from 2000 to 2022 at Global, sub-Saharan and Ethiopian scale. *(Raimi et al., 2022)*

While progress has been made, current projections estimate only 77% of the global population will have access to clean cooking solutions by 2030, leaving nearly 2 billion people reliant on traditional stoves and biomass fuels (Nizami, 2023). Nearly 78% of the global population lacking clean cooking fuel and technology access are concentrated in just 20 countries, with 10 of them in Sub-Saharan Africa and seven of these countries, all in Sub-Saharan Africa, have shockingly low access rates of under 10% (Nizami, 2023). Based on a recent central statistics agency (CSA) survey result, only about 10 % of households use energy saving stoves in rural areas and fewer than 6 % use improved and clean cooking stoves with only 0.6 annual percentage points (CSA, 2017) accounts for 103 million people lacking access to clean fuels and technologies (Nizami, 2023, Birol, 2023).

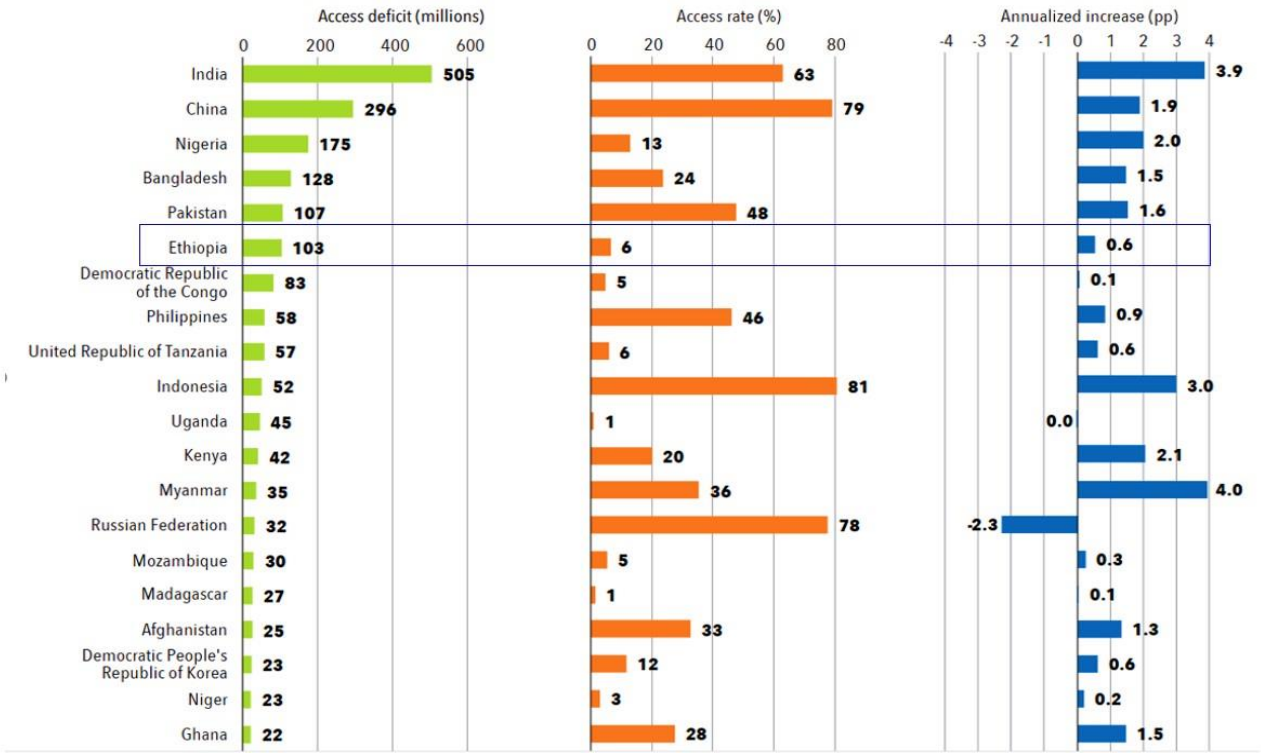


Figure 4: The 20 countries with the largest access deficit of clean cooking fuel and technology by population (green), 2017-2021 average. (*Source: WHO 2023*)

1.1.2 Household cooking stove use

Across rural and remote areas of developing countries, cooking is the single largest consumer of energy within homes (Aemro et al., 2021). All biomass fuels are burned in various types of stoves to provide the heat necessary for cooking (Bank, 2011) and for millennia, humans relied on open fires for cooking (Symons, 2003). While early humans cooked over open fires for meat roasting and protection, evolving pot shapes and sizes eventually led to shielded fires, with the simplest and most common form being the three-stone arrangement (Kumar et al., 2013). Today, cooking has evolved dramatically with the use of stoves, diverse contraptions that utilize fuel to produce heat for preparing food (Kumar et al., 2022, Jani et al.). This wide spectrum encompasses not only high-tech ovens but also simpler, open fires, reflecting local practices, fuel resources, and environmental realities across the globe (Nayak et al., 2022). The design and features of these stoves vary greatly depending on factors like cooking style, meal size, fuel availability, and local circumstances (Hooper et al., 2018). This variation has led to the emergence of numerous stove types, each tailored to the specific needs of different regions, particularly in developing countries (Mitchell et al., 2019, Rhodes et al., 2014). However,

concerns about air pollution, deforestation, and other negative impacts have driven efforts to improve stove designs (Thomas et al., 2015a, Gill, 1987). From the simple open fires to the efficient induction cooktops, the way we cook reflects not only technological advancements but also the economic and cultural traditions of various societies (Sarangi et al., 2023, Energy, 2014, Program, 2021).

1.1.2.1 Traditional cooking stoves

Traditional stoves, often referred to as three-stone fires or unvented mud/clay stoves, burn solid biomass fuels like wood or dung , releasing high levels of harmful air pollutants (Hooper et al., 2018, Malla and Timilsina, 2014). This simple yet ingenious cooking setup involves arranging three stones in a triangular formation where solid fuels, like wood or dung, is placed in the center, creating an open flame for direct cooking (Figure 4) (Wright et al., 2020). Globally, evidence suggests the earliest form of cooking involved open fires built on the ground (Symons, 2003). These traditional stove emit various pollutants (Chen et al., 2016, Okello et al., 2018) including polycyclic aromatic hydrocarbons, benzene, formaldehyde, and even dioxin were detected from biomass fuel smoke (Balmes, 2019, Ezzati and Baumgartner, 2017).

Traditional stoves have open type construction, therefore maximum heat get lost in atmosphere and causes indoor/outdoor air pollution increase greenhouse gas emissions (Puzzolo and Pope, 2017, Standard, 2016). These stoves, primarily impacting women, contribute to time poverty, and limited opportunities for personal and economic advancement (Hooper et al., 2018, Tamire et al., 2018, Yip et al., 2017). This is not only perpetuates gender inequalities but also subjects women to health hazards linked to household air pollution (Sanusi, 2023) indicating the currently most used solution, traditional stove combined with biomass fuels, yield the least overall socioeconomic and health benefits in Sub-Saharan Africa (Khavari et al., 2023). A key advantage of the three-stone stove was its versatility, by adjusting the stones to accommodate different pot sizes, it could be used for a wide variety of cooking tasks (Rhodes et al., 2014).



Figure 5: From *Injera* to Stews: Multipurpose cooking on a three-stone stove in rural Ethiopia

Unfortunately, most households in developing countries rely on traditional, inefficient, and poorly vented stoves for cooking and baking (Bruce et al., 2015, Gall et al., 2013, WHO, 2019c). Because, the development and market distribution of improved biomass cooking and baking stoves are at a very low level (Energy, 2014, Hooper et al., 2018).

In rural Ethiopia, several challenges faced in transitioning to clean energy (Beyene et al., 2018). Households in Ethiopia predominantly use open fire or inefficient traditional cooking stoves to burn these unclean energy sources (CSA, 2016, Mondal et al., 2018, Padam et al., 2018, Aemro et al., 2021). In general, traditional stoves contributed to both dangerous pollutants and unsustainable solid fuel harvesting which hinder progress towards sustainable development goals (Aemro et al., 2021, Nizami, 2023, Rosenthal et al., 2018).

1.1.2.2 Improved (transitional) cooking stoves

Improved biomass cook stoves, leveraging a diverse range of designs, optimize the use of traditional biomass fuels by incorporating advanced combustion and fuel loading methods, leading to reduced pollution (Phillip et al., 2023a). To promote health, the world health organization (WHO) classified fuels and technologies as clean, transitional, and polluting (WHO, 2021b). Transitional fuels and technologies offer some improvement in health outcomes, but they still fall short of meeting the recommended levels set by the WHO (Price et al., 2020, WHO, 2018b).

Compared to open fires and inefficient traditional three stone stoves, which are considered polluting by the WHO, "improved" stoves (mostly falling under the transitional category) offer significant advancements like chimneys and better combustion, leading to lower fuel consumption, reduce cooking time ,and potentially some reduction in smoke particles (Zaman et al., 2017, Hill et al., 2015). Stoves covered by this definition include basic chimney models, portable designs, and intermediate devices which are more efficient, emit less emissions or are safer than the traditional stoves (Grajeda et al., 2020, Woolley et al., 2022b).Though venting smoke outdoors reduces immediate indoor exposure, it can still seep back inside and contribute to broader air pollution problems (Commission, 1993).

The 1970s oil crisis spurred global research and development of improved cook stoves which leads to numerous improved cook stove programs in developing countries aiming to address the energy crisis, deforestation, and kitchen smoke reduction (Kumar et al., 2013). Currently, improved cooking and baking stoves have been offered as a potential tool for safe transition to reduce exposure to smoke and improve health outcomes (Beyene et al., 2015, Thakur et al., 2019) and over the past few decades, various initiatives have been attempting to distribute improved cooking stoves (Sharma and Jain, 2019, Singh et al., 2012a, Thomas et al., 2015a, WHO, 2016b). In many countries, including China, Ethiopia, Ghana, India and Kenya, various locally manufactured and relatively cheap improved stoves dominate the market as an intervention strategy for household air pollution (Mitchell et al., 2019, Thomas et al., 2015a).



Figure 6: Some of the improved stoves from different regions of the world. *(Smith et al., 2011, Katz et al., 2020, Romieu et al., 2009)*

While connecting all Ethiopians to the electricity grid remains the long-term vision, improving the performance of biomass stoves through collaborative research offers a viable short- and medium-term solution (Tadesse, 2020). The Ethiopian ministry (current Ethiopia Environmental Protection Authority) of environment, forest and climate change has disseminated millions of improved stoves in the country through various stove projects and private commercial stove producers (SNV, 2018). The main types of improved stoves distributed include; Mirt Injera baking stove, Gonziye cooking and Injera baking stove, Roket sauce-cooking stove, Tikikil cooking stove and Lakech and Merchaye charcoal-burning cooking stoves (Kedir et al., 2019, Tadesse, 2020, Mekonnen, 2022).

Previous studies have shown that improved stoves outperform traditional stoves in several areas, including fuel efficiency, time savings for fuel collection and cooking, reduced smoke emissions, and improved health outcomes (Mobarak, 2012, Clark et al., 2009, Dutta et al., 2007, Koala et al., 2023a). In general, while energy-efficient electric stoves offer a clear advantage for the environment, energy use, health, and long-term costs, improved stoves remain the most affordable option for rural and remote areas of developing countries in sub-Saharan Africa (Aemro et al., 2021).

1.1.3 Household Air Pollution (HAP)

Burning solid biomass fuels in traditional stoves emits a toxic mix of particles and chemicals collectively known as household air pollution (Balmes, 2019, Ochieng et al., 2017, Romieu and Schilmann, 2013). Household air pollution (HAP) is a mixture of harmful chemicals including irritants, inflammatory agents, and carcinogens, resulted from incomplete combustion of biomass fuel mainly wood (Lim and Seow, 2012, Zhou et al., 2024, Romieu and Schilmann, 2013). These complex smoke contains hundreds of pollutants like particulate matter, carbon monoxide, volatile organic compounds (VOCs), elemental carbon (EC), polycyclic aromatic hydrocarbons (PAHs), and formaldehyde (Awopeju, 2020b, Lim and Seow, 2012, Program, 2021, Dodds and Gross, 2007, Vassilev et al., 2010) which can cause a variety of health problems at all ages (Deka and Hoque, 2015, Eriksson et al., 2022, Wang et al., 2023). Household air pollution is the leading environmental health risk factor globally (Shupler et al., 2018b). Though various sources of HAP are documented, kitchen smoke from solid biomass fuels are the major source, particularly for rural households with limited access to cleaner alternatives (WHO, 2016b).

The amount and mix of toxic air pollutants unleashed by incomplete home fuel burning depend on several factors including the type and moisture content of the fuel, ventilation in the home, how people use the stoves, and the stove technology itself (Kumar, 2015, Diekman et al., 2014). Wet fuels and those with high lignin content typically produce more pollutants like particulate matter, carbon monoxide, and volatile organic compounds (Burling et al., 2010, Balmes, 2019). Poor ventilation allows pollutants to accumulate, increasing their concentration in the air people breathe (WHO, 2018c, Havens et al., 2017). Overloading stoves, using them in unventilated rooms, and in complete burning all contribute to higher pollutant levels (Fiddler et al., 2022). Improved stoves with better airflow and combustion chambers can significantly reduce pollutant output (Dutta et al., 2007, Koala et al., 2023a, Phillip et al., 2023a).

Incomplete combustion releases a mix of harmful pollutants, including particles of varying sizes, carbon monoxide, and volatile and semi-volatile organic compounds, and several others (Dodds and Gross, 2007). In addition to the pollutants mentioned above, burning coal releases additional pollutants like sulfur oxides (SOx) that exacerbate respiratory problems, heavy metals like arsenic (known carcinogen), and fluorine which damages teeth and bones (Deka and Hoque, 2015, Dodds and Gross, 2007). While numerous pollutants exist, particulate matter and carbon

monoxide have garnered the most attention in scientific literature due to its strong epidemiological, clinical, and toxicological links to respiratory and cardiovascular diseases (Liu et al., 2022, Hu et al., 2023) and they are just indicators for vast range of other pollutants (Jawahar et al., 2017).

1.1.3.1 Particulate Matter (PM)

Particulate matter (PM) refers to a mixture of solid particles and liquid droplets suspended in the air, with diameters small enough to resist settling due to gravity (Zhao et al., 2022). Particulate matter consists of organic and inorganic substances suspended in the air, contains sulfates, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water (Wright et al., 2020). Particulate matter is classified based on aerodynamic diameter as : coarse (PM $\leq$ 10 ug), fine (PM $\leq$ 2.5 ug), and ultrafine (PM $\leq$ 0.1 ug) (Polk, 2019). These particle sizes, in general, differ in origin and health effects (Smith, 2020).

Among different sizes of particulate matter, fine particles ($PM_{2.5}$) pose the greatest health risk because they can reach deep into the lungs and potentially enter to the bloodstream (Fatmi et al., 2020, Neelakanta et al., 2022, WHO, 2021a, Shupler et al., 2018c) and it is a common proxy indicator used to measure levels of air pollution (WHO, 2015). Coarse particles, while less hazardous than fine or ultrafine dust, can still adversely impact human health (Brunekreef and Forsberg, 2005). Coarse particles primarily originate from direct emissions, including those from construction, vehicle traffic, and wind-blown dust usually trapped by the nose and throat but can irritate the respiratory system, including the airways (Wabeke, 2013). While knowledge of PM0.1 is less extensive compared to PM2.5 and PM10, emerging research suggests that ultrafine particle poses a more significant health risk due to the smaller particle size allows for deeper penetration into the body (Münzel et al., 2018). But the precise role in many illnesses is still unknown (Schraufnagel and medicine, 2020, Münzel et al., 2018).

Fine particulate matter ($PM_{2.5}$), a pervasive air pollutant consisting of particles poses a significant health risk (WHO, 2021a, Smith, 2020). These particles are incredibly small, just 30 times smaller than a human hair (Shupler et al., 2018b) (Figure 7). Fine particles can enter deep into the lungs and deposit on the alveoli, the tiny sacs where oxygen is exchanged with carbon dioxide in the blood (Garcia et al., 2023, Zhou et al., 2024). This particle enters deep into our

lungs, potentially triggering heart disease, stroke, lung cancer, and chronic respiratory problems (Zhou et al., 2024, Garcia et al., 2023, Wang et al., 2022).

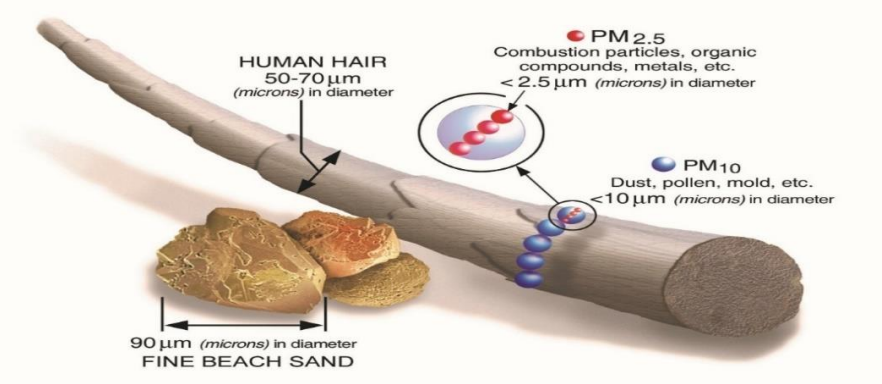


Figure 7: Size comparisons for PM particles. *(source: U.S. EPA, 2024)*

Fine particulate matter levels from biomass smoke vary greatly, ranging from tens to thousands of micrograms per cubic meter air (µg/m^3), with cooking activities causing peak exposures (Northcross et al., 2015, Okello et al., 2018). A WHO report revealed dangerously high levels of PM2.5 in regions where people rely on solid biomass fuels for cooking. PM2.5 concentrations reached an average of 972 µg/m^3, while women, who typically spend more time cooking, were exposed to an average personal level of 267 µg/m^3 (Bryden et al., 2015). In homes with inadequate ventilation, indoor smoke can contain concentrations of fine particles that are 100 times higher than the acceptable levels (WHO, 2023). Global estimates show that homes using traditional stoves have 290 µg/m^3 higher PM2.5 concentration compared to those using cleaner fuels like gas or electricity (Shupler et al., 2018c). Despite regional variations, PM2.5 levels far exceed the WHO's 24-hour safety limit of 15 µg/m3, posing a global health threat (WHO, 2021b, Rentschler and Leonova, 2023, Shupler et al., 2018a).

Women in rural Peru, Nepal, and Kenya face dangerously high levels of air pollution in their homes, with PM2.5 ranging from 615 to 1440 µg/m3 (41-96 times WHO's safe limit) with the lowest in Peru and the highest in Kenya (Rhodes et al., 2014). Across eight countries, homes using wood as the primary cooking fuel had an average PM2.5 concentration of 109 µg/m³ in kitchens, while those using animal dung had an even higher average of 224 µg/m³ (Shupler et al., 2020). Studies in Nepal and Paraguay reported alarmingly high levels of PM2.5 in homes using traditional cook stoves with daily concentration reached 1,376 µg/m^3 near stoves in Nepal

(Chen et al., 2016) and 741.7 μg/m^3 in wood-burning kitchens in Paraguay (Tagle et al., 2019). Based on the personal exposure measurement study in Ethiopia and Uganda, the average 24-hours PM2.5 personal exposures was 205 μg/m^3 and 177 μg/m^3 in Ethiopia and Uganda respectively (Okello et al., 2018).

While studies on household air pollution from solid biomass fuels in Ethiopia are limited, the available evidence suggests alarmingly trend (Admasie et al., 2018b, LaFave et al., 2021, Tefera et al., 2016). For instance, one study found an average PM2.5 concentration of a staggering 1,297 μg/m³ in rural homes, far exceeding the WHO safe limit (LaFave et al., 2021). Even urban areas are not spared, with measurements in Addis Ababa slums revealing a 24-hour average PM2.5 concentrations of 818 μg/m³ (Sanbata et al., 2014). Another study in southern part of Ethiopia shown that the mean kitchen concentration of PM2.5 was 413.27 μg/m^3 (Admasie et al., 2018b). Personal exposure data is scarce, with only one study measuring exposure during traditional coffee making. This study found geometric mean levels of 1028 μg/m³ for PM2.5 and 29 ppm for CO over 60 minutes (Tefera et al., 2016). Recent researches confirm the trend, with average kitchen PM2.5 concentrations of 1,297 μg/m³ and 859 μg/m³ reported in two separate studies (Adane et al., 2020b, LaFave et al., 2021).

From the type of fuel burned to the ventilation, a multitude of factors influence the levels of harmful pollutants lurking in indoor air (Shupler et al., 2020, Council, 1981). Fine particulate matter levels varied greatly across regions and even within regions with the same fuel-stove combos, highlighting complex factors at play (Shupler et al., 2018c). Low-income communities often face the burden of higher exposure and greater health risks from household air pollution (Rentschler and Leonova, 2023). Research report shows multiple factors shape cooking PM2.5 emissions, including cooking method, fuel type, stove design, ventilation and even the pan used and how the cook position it matter (Torkmahalleh et al., 2017, Fatmi et al., 2020). Diverse cooking practices, fuels, food types, kitchen size, and stove types across cultures and households create a complex mix of air pollutants, varying significantly from place to place (Akintan et al., 2018, Karaca et al., 2024). While all solid biomass fuels are bad for air quality, the less energy-dense ones like dung create the most harmful $PM_{2.5}$, posing a bigger health risk (Eriksson et al., 2022).

World Health Organization guidelines recommend a 24-hour average concentration of no more than 15 μg/m^3 for PM2.5 and 4 ppm for CO in household air (WHO, 2021b). However, all reported values from the research significantly exceed these guidelines, as evidenced by the blackening on walls, ceilings, and chimney interiors (WHO, 2016a) (Figure 8)). In low and middle income countries where many households rely on solid biomass fuels, HAP is well identified risk factors examined for many health problems (Khan et al., 2017, Lee et al., 2015, Smith et al., 2014). Hence, achieving universal access to clean cooking fuels and technologies by 2030 is a critical UN Sustainable Development Goal (SDG) (Foell et al., 2011). However, many regions are experiencing stalled progress towards clean energy transitions, jeopardizing this crucial target (Birol, 2023).



Figure 8: A typical kitchen in the study area showing blackened walls, ceilings, and a chimney.

Fine particles are deposited in the central and peripheral airways, where they may exert toxic effects (Romieu and Schilmann, 2013). These microscopic particles can bypass the body's natural defenses and penetrate deep into the lungs, even entering the bloodstream (Eriksson et al., 2022, Garcia et al., 2023, Zhou et al., 2024, Thangavel et al., 2022). This allows them to directly damage vital organs like the heart, lungs, and brain, increasing the risk of respiratory illnesses, cardiovascular diseases, and even dementia (Liu et al., 2022, Shi et al., 2024, Thangavel et al., 2022). But, the chemical composition of biomass smoke varies greatly depending on factors like fuel type, burning temperature, and even local weather (Awopeju, 2020a).

1.1.3.2 Carbon monoxide (CO)

Carbon monoxide (CO) is a colorless, non-irritant, odorless, and tasteless poisonous gas which is the most important contaminant emitted during incomplete combustion of wood and other fuels

(WHO, 2021a). Burning low-quality solid fuels in a small stove or fireplace can release harmful carbon monoxide fumes that can be deadly if they're not vented outside through a chimney during the entire burning process (Fatmi et al., 2020, Kansiime et al., 2022). This is especially common in developing countries where biomass fuels like wood and dung are used (Tomlin and Fuels, 2021, Kansiime et al., 2022, Shupler et al., 2018a). When combustion starts, the air is thick with particulate matter, mostly elemental and organic carbon. As the process continues, carbon monoxide takes center stage, becoming the dominant pollutant (Shams et al., 2022). Carbon monoxide from outside source including vehicles like cars, trucks, and machinery that use gasoline or diesel can seep into buildings through cracks or gaps (WHO, 2014a).

Carbon monoxide poses a threat because it outcompetes oxygen for binding sites on hemoglobin in red blood cells (Wilbur et al., 2013). By reducing the blood's capacity to carry oxygen and hindering its delivery to organs, especially the oxygen-sensitive brain, CO exposure causes common symptoms like fatigue, headaches, confusion, and dizziness (Gozubuyuk et al., 2017, Walker et al., 2020). Extremely high carbon monoxide (CO) levels can lead to hypoxia (oxygen deficiency), especially in organs with high oxygen demands like a developing fetus (WHO, 2014a). For people with cardiovascular disease, even short-term CO exposure can further reduce their already compromised ability to respond to the increased oxygen needs of exercise, exertion, or stress (Gaalema and prevention, 2022). In addition, babies born to mothers exposed to high CO levels during pregnancy may experience adverse developmental effects (Friedman et al., 2015).

Similar to fine particulate matter, CO levels in kitchens of developing countries are alarmingly high. Women in rural areas of Peru, Nepal, and Kenya face dangerous CO exposure in their homes, with levels ranging from 8.9 ppm (lowest in Peru) to a staggering 34.5 ppm (highest in Kenya) (Rhodes et al., 2014). Studies from Nepal and Paraguay indicated that traditional cook stoves contributed to the high levels of CO concentration to households. In Nepal, daily average CO levels near the stoves reached a concerning 10.9 ppm (Chen et al., 2016). Similarly, wood-burning kitchens in Paraguay showed even higher daily averages, with CO levels reaching 19.4 ppm (Tagle et al., 2019). Research from Pakistan also found a 24-hour average kitchen CO concentration of 3.72 ppm, with a standard deviation of 3.16 ppm (Shams et al., 2022). Similarly,

a study in Peru reported a geometric mean of 7.3 ppm for CO levels measured in kitchens across households (Commodore et al., 2013).

Limited research exists on household air pollution levels in Ethiopia, particularly regarding carbon monoxide. However, one study revealed an alarmingly high level, with a geometric mean of 29 ppm CO measured over a 60-minute period (Tefera et al., 2016). The study conducted in rural Tigray found alarmingly high levels of carbon monoxide (CO) in kitchens ranged from 310 – 600 ppm ppm (Usinger, 2008). A study in Addis Ababa, Shiro-Meda found an average 8-hour CO concentration of 16 ppm (ranging from 0.66 to 69 ppm) across 54 homes (Graham, 2011). A meta-analysis revealed an average carbon monoxide (CO) concentration of 18.82 ppm across studied locations, with urban areas reaching even higher levels (24 ppm) compared to rural areas (13.63 ppm) (Asefa and Mergia, 2022). While the existing evidences suggested concerning levels of indoor air pollution and a worsening trend in outdoor air pollution in Ethiopia, more robust research is urgently needed (Tefera et al., 2016).

1.1.3.3 Injera baking and household air pollution

Ethiopian households often rely a specialized two-stove for cooking. One large stove is dedicated to baking Injera, a staple flatbread with a unique, bubbly texture from fermentation (Tadesse, 2020). This spongy bread is a central element of Ethiopian cuisine, featuring prominently at festive occasions like national holidays and religious celebrations, as well as family gatherings like weddings, birthdays, and even funerals (Fanta, 2020, Adem and Ambie, 2017, Lamesgin Addisu Getnet, 2023, Tadesse, 2020). Injera is also a staple food across Eritrea and enjoyed in some regions of Somalia (Fanta, 2020). While there's no single standard size, Injera is typically around 310 grams and 52 centimeters in diameter (Adem and Ambie, 2017).



Figure 9: Ethiopian Injera together with 'wot' (sauce). *(Source: Neela and Fanta,2020)*

Many Ethiopians bake Injera on open-fire stoves made of three stones which are fueled by firewood, but they are inefficient and consume a significant amount of fuel (Kedir et al., 2019) and contributed longer cooking times (Embiale et al., 2021). When tested using a controlled cooking test (CCT) method, a typical three-stone open-fire stove uses about 930 grams of firewood to bake one kilogram of Injera (Assefa, 2007). Based on another report, in addition to the average specific fuel consumption of 1031 grams of wood per kilogram of Injera, baking a standard 16-kilogram batch of dough takes an average of 121 minutes. These figures are significantly higher compared to improved stoves, which typically use only 596 grams of wood per kilogram of Injera and require just 102 minutes to bake the same amount (Girma, 2011). In rural Ethiopia, baking Injera is a time-consuming process that consumes a significant portion of cooking fuel, ranging from 50 to 75% (Lamesgin Addisu Getnet, 2023).

Compared to other cooking activities in rural Ethiopia, baking Injera is a particularly significant contributor to household air pollution mainly due to the high amount of fuel consumption and the inefficient design of traditional stoves (Enyew et al., 2023, Adane et al., 2021a, Embiale et al., 2021, Asefa and Mergia, 2022). Based on the test results, indoor air pollution parameters for a three-stone open-fire stove were approximately 80 ppm for CO and 1.10 mg/m^3 for particulate matter (Tadesse, 2020). It was also reported that, the amount of particulate matter measured during Injera baking using a traditional stove in the wet season ranged from 50.3 - 591 mg/m^3. (Embiale et al., 2021). The average particulate matter (PM) concentration during Injera baking was 389 μg/m^3 in the wet season, while Total Volatile Organic Compounds (TVOCs) also

showed the highest average concentration of 1361.79 μg/m³ during this activity (Asefa and Mergia, 2022).

Traditionally prepared by women in Ethiopia, Injera baking with inefficient stoves exposes them to higher risks of health problems from HAP (Embiale et al., 2021). They spend significant time near inefficient, open-fire stoves which release harmful pollutants like particulate matter and carbon monoxide (Nayek and Padhy, 2017, Okello et al., 2018, Walker et al., 2020). Women, who are responsible for baking, are exposed to these pollutants for extended periods, putting them at higher risk of respiratory problems, eye irritation, and even heart disease (Tamire et al., 2020, Walker et al., 2020). Young children, close to Injera baking while playing or being carried, are exposed to the same dangerous air pollution as adults (Embiale et al., 2021). Therefore, the combination of traditional gender roles and the close proximity of children during Injera baking creates a unique vulnerability for these populations (Lamesgin Addisu Getnet, 2023, Tadesse, 2020). Since Injera will continue to be the staple food of Ethiopians in years to come, promoting the use of improved burning stoves, improving ventilation in kitchens, and educating families about the health risks of HAP are all crucial steps in protecting women and children from this invisible threat (Alamir, 2017, Asefa and Mergia, 2022).

1.1.4 HAP exposure assessments

Individual exposure to air pollutants is a dynamic web, woven from the threads of location, ever-shifting environmental conditions, and the constant interplay between them (Coffey et al., 2019, WHO, 2018c). It is a result of the spatiotemporal relationship between individuals and the pollution in their immediate surroundings as the frequency, type, and duration of interactions with air pollution sources, both direct and indirect, contribute to their cumulative daily exposure (Watson et al., 1988, Wang et al., 2023, Jin et al., 2006). Researchers studying household air pollution using various alternative strategies to assess exposure when directly measuring personal pollutant levels is not feasible (Northcross et al., 2015, Gilliland et al., 2005).

Like other pollutants, HAP exposure assessment follows the conventional framework (Figure 10), starting with identifying and characterizing sources and emissions, followed by tracking pollutant concentrations in the environment, individual exposure pathways, internal dose within the body, and ultimately, the resulting health impacts (Bind, 2019, Jawahar et al., 2017, Romieu and Schilmann, 2013). Transitioning from qualitative fuel and stove type identification to

biomarker-based exposure assessment brings a significant increase in both difficulty, unaffordability and complexity (Dai et al., 2020, Clark et al., 2013).

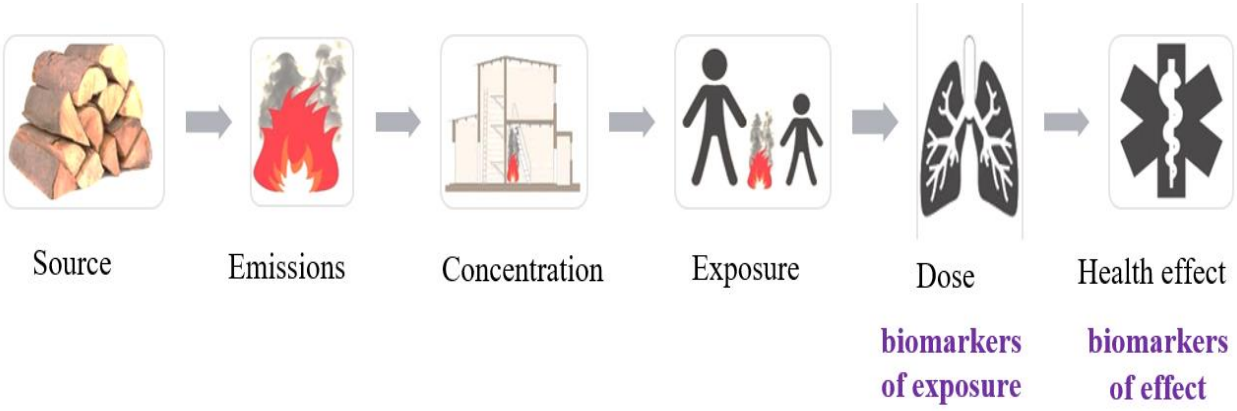


Figure 10: Classic environmental health pathways of pollutants. *(Source: Injury Prevention and Environmental Health,2017)*

On a global scale, various biomass fuels are burned in diverse stove types within different kitchen settings to cook a variety of foods (Bede-Ojimadu and Orisakwe, 2020, Kansiime et al., 2022, Newell and Raimi, 2020). The type of fuel burned heavily influences both the amount and severity of harmful pollutants released (Deka and Hoque, 2015, Edlund et al., 2020, Eriksson et al., 2022). In many rural areas including Ethiopia , animal dung, a commonly used cooking fuel, emits particularly toxic pollutants (Mudway et al., 2005, Geissler et al., 2013). While acknowledging limitations, data on biomass fuel types can inform exposure assessments through national and regional estimates of fuel usage and stove adoption (Clark et al., 2013, Watson et al., 1988, Demelash et al., 2015). In low- and middle-income countries with limited access to affordable air quality sensors, exposure assessments often relied on information about the types of fuel and stoves used (Kansiime et al., 2022, Elbayoumi and Albelbeisi, 2023, Awopeju, 2020b).

Another approach for assessing exposure to cooking-related air pollution is measuring emissions directly from biomass combustion during simulated or actual cooking cycles (Burling et al., 2010, Fiddler et al., 2022). These measurements capture the rate of pollutant release per unit time or fuel, but rarely reflect exposure over an entire day (Jawahar et al., 2017, Du et al., 2018, He et al., 2023). Measurements of emissions from biomass fuels serve to evaluating the efficacy of improved stoves in reducing pollution compared to traditional models, and to identifying the specific types and amounts of pollutants released by different fuel types (Kaur-Sidhu et al., 2020).

In addition, quantifying the amount of pollutant (concentration) present in the relevant environment is a key variable in exposure assessments (Bind, 2019). Though micro-environmental concentration can sometimes accurately reflect true exposure, this equivalence cannot be consistently assumed due to various factors influencing individual exposure patterns (He et al., 2023). Measuring kitchen air quality for 24 hours wouldn't necessarily reflect someone's exposure if they were not present for the entire period (Jawahar et al., 2017). This is because exposure depends on factors like time spent in the micro environment, and individual activity patterns (Benka-Coker et al., 2020, Shupler et al., 2024). This approach leverages exposure reconstruction to estimate individual exposure by combining time-activity data, like a diary recording time spent in different locations and near potential pollution sources, with area monitoring data that measures pollutant concentrations in various environments (Dickinson et al., 2015). Actual individual exposure refers to the concentration of pollutants at the point of breathing, which can be measured through personal air monitors worn by individuals (Jawahar et al., 2017).

When inhaled pollutants reach the body, they may leave behind unique molecules or biological changes that can be detected as biomarkers of exposure or effect (Suhaimi and Jalaludin, 2015, Garcia et al., 2023). Biomarkers of exposure reflect interactions between an external agent (pollutants) and a target within the body (molecule, cell, organ) (Jenkins et al., 2023). They indicate the dose absorbed from all exposure routes and environments. Examples include urinary polycyclic aromatic hydrocarbon (PAH) metabolites, which can signify biomass smoke exposure (Jawahar et al., 2017, WHO, 2009a). Biomarkers of effect represent biological changes following exposure and can indicate potential health risks or diseases (Zare et al., 2021).

1.2 Statement of the Problems

1.2.1 Household air pollution and health

Household air pollution is now the world's deadliest environmental hazard, linked to nearly 4 million premature deaths annually (HEI, 2024, WHO, 2021a). According to WHO estimates, approximately 7 million deaths, primarily attributed to non-communicable diseases, are linked to the combined impact of ambient and household air pollution (WHO, 2018a). Household air pollution, particularly from the combustion of solid biomass fuels, is now recognized as a major global health risk factor (Diekman et al., 2014, WHO, 2018c). It contributes to a broad range of

cardiorespiratory and reproductive health problems (Khan et al., 2017, Lee et al., 2015, Weber et al., 2020). It was also reported that smoke from biomass fuels is estimated to cause more premature deaths and illnesses globally than malaria and HIV combined (Schirnding et al., 2000). Regions with the most severe HAP burdens, (as shown in Figure 2), also see the highest numbers of deaths attributed to HAP (Figure 11).

While the global burden of household air pollution from solid fuel cooking reached 2.3 million deaths and 91.5 million disability adjusted life years (DALYs) in 2019, the impact is far from evenly distributed with Southeast Asia and Sub-Saharan Africa bear the brunt of this health crisis (HEI, 2019, Bede-Ojimadu and Orisakwe, 2020). In these regions, household air pollution-related death rates are close to 200/100,000 in several countries (Bede-Ojimadu and Orisakwe, 2020, HEI, 2018, HEI, 2019). The South-East Asia region had the highest burden due to HAP with 23.3 million DALYs and 0.57 million deaths, followed by the African region with 18.3 million DALYs and 0.72 million deaths with the highest burden was recorded in India followed by in China and Nigeria (Lee et al., 2015, WHO, 2018a). HAP from solid fuel cooking is currently perceived as the second-biggest health risk factor in Africa (Misganaw et al., 2023).This burden falls heavily on children, who are particularly susceptible to household air pollution and resulted pneumonia, and adults, who suffer from chronic obstructive pulmonary disease, lung cancer, stroke, and cardiovascular disease (Dherani et al., 2008, UN, 2021, Shupler et al., 2024). While the death rate from household air pollution has decreased in Ethiopia since 1990, it remains unacceptably high at 130 deaths per 100,000 people (Misganaw et al., 2023).

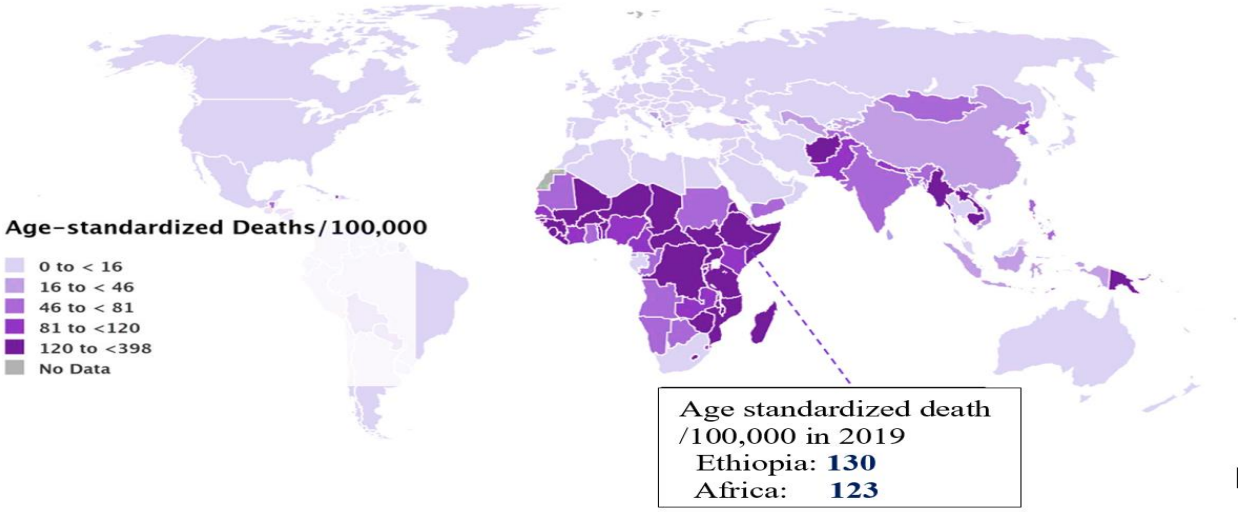


Figure 11: Age standardized death/100000 attributable to household air pollution from solid biomass fuel in 2019. (*source: state of global air,2020*)

Exposure to household air pollution increases the risk of various chronic and acute health problems across all population segments (Ezzati and Kammen, 2002, WHO, 2016a), However, it poses a particularly serious threat to mothers and children, increasing their risk of acute lower respiratory infections (ALRIs), cardiovascular diseases, and adverse pregnancy outcomes (Balmes, 2019, Lee et al., 2015, Smith et al., 2014). ALRIs including pneumonia in children and chronic obstructed pulmonary diseases particularly among women are the most common health problems due to solid biomass smoke (Adane et al., 2020b, Balmes, 2019, Mohammadi and Mohammadi, 2018). Evidences are also available on exposure to coal smoke in the home markedly increases the risk of lung cancer (Lee et al., 2015, Romieu and Schilmann, 2013).

Many new evidences have emerged which revealed that HAP in developing countries increase the risk of low birthweight, perinatal mortality (still births and deaths in the first week of life) asthma and middle ear infection for children, tuberculosis, nasopharyngeal and laryngeal cancer, and cataract in adults (Epstein et al., 2013, Liu et al., 2019b, WHO, 2007). There is an increased risk of under-five mortality in those exposed to cooking smoke compared to those not exposed (Naz et al., 2018) with nearly 400,000 children under 5 years old die each year as a result of HAP, primarily in Sub-Saharan Africa and Asia (Mock et al., 2018).

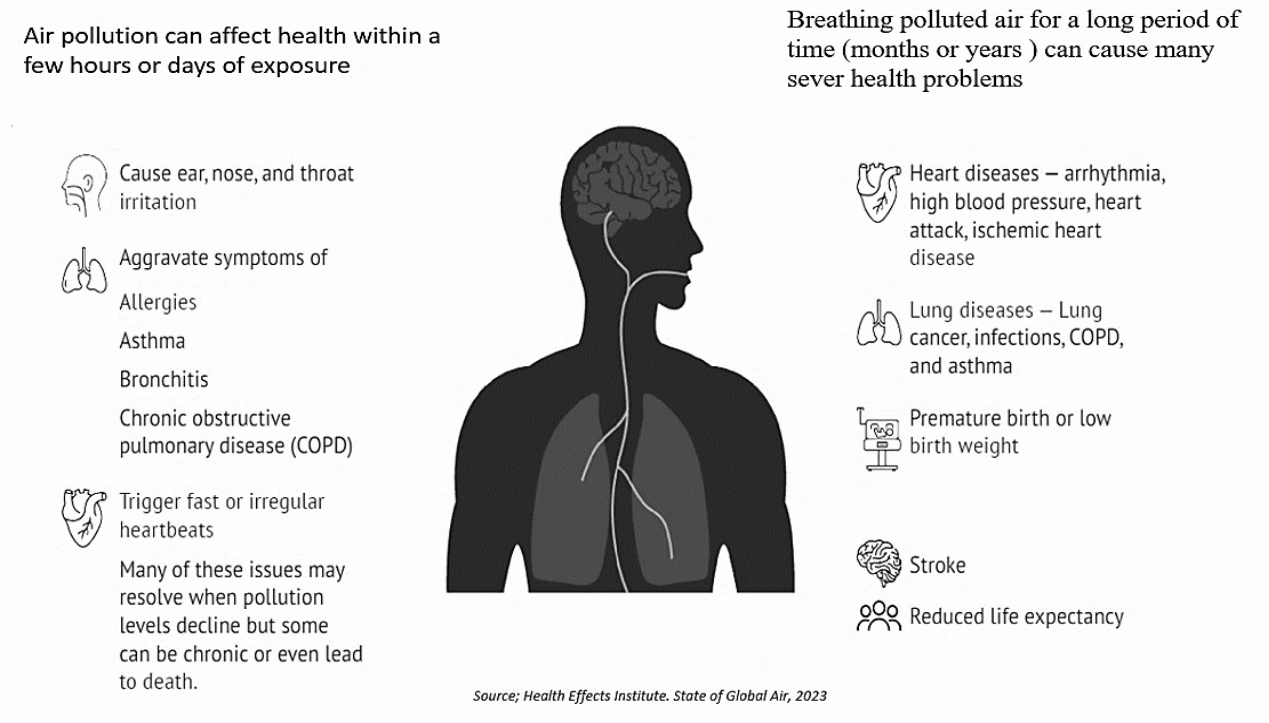


Figure 12: Common acute and chronic health problems due to exposure to air pollution

In Ethiopia, the heavy reliance on biomass fuel contributes significantly to air pollution, making it one of the top five leading causes of death in the country (Yigezu et al., 2023, Tefera et al., 2016). Over 77,000 Ethiopians are estimated to have died due to both ambient and household air pollutions in 2019, with household air pollution being the biggest culprit, more than 67,000 premature deaths and more than 3.1 million disability adjusted life–years per year (Misganaw et al., 2023, Beyene et al., 2018). These health impacts are particularly concerning for vulnerable groups, as 16% of air pollution-related deaths occur in children under five and 18% in elderly over 70 years old (Elbayoumi and Albelbeisi, 2023, Ranzani et al., 2024, Polk, 2019). The overall impact is a reduction in life expectancy by an average of 2.3 years for Ethiopians (HEI1, 2020). Lower respiratory tract infections are the leading cause of death linked to household air pollution, with an estimated 36,144 cases in 2016 with the highest impact occurring within the first 6 days of life (Beyene et al., 2018).

The burden of polluting fuels goes far beyond the harmful smoke, creating a cycle of drudgery, injuries, and lost time (WHO, 2016b). Household air pollution in Ethiopia inflicts a staggering economic burden, costing the country an estimated 281 trillion ETB (US$8 billion) annually – a staggering 4% of its GDP (UNDP and Health, 2024). Girls spend a significant amount of time

collecting wood, a burden disproportionately placed on them compared to boys (Beyene et al., 2018, Raimi et al., 2022). Gathering fuel puts women and children at risk of chronic physical strain, discomfort, and even violence (Njenga et al., 2021). Conversely, reducing household air pollution through cleaner energy sources offers immediate benefits including fewer illnesses, lower healthcare costs for families already struggling financially, and a crucial step towards poverty reduction (Alem and Demeke, 2020, WHO, 2016b, Rosenthal et al., 2018).

1.2.2 Trends of Disease Burden Attributable to HAP

Between 2010 and 2021, deaths associated with HAP has declined steadily by 23.8 % with known geographical variation (Lee et al., 2015). Areas with the highest use of solid fuels for cooking and heating have seen the greatest positive changes) (Bede-Ojimadu and Orisakwe, 2020, WHO, 2018a). Leading the way in reducing household air pollution deaths over the past decade are China and India where China has seen significant success through large-scale initiatives that replace coal-burning cook stoves with cleaner alternatives (Chang Liu 2021). India, on the other hand, has focused on expanding access to clean fuels like liquefied petroleum gas (LPG) nationwide (Carlos F Gould 2020). These combined efforts have resulted in a remarkable reduction of over 440,000 deaths attributable to household air pollution in both countries over the past ten years.

While several regions have witnessed a positive decline in the overall disease burden associated with HAP between 2010 and 2019, due to a decrease in reliance on solid fuels for cooking, the picture varies significantly at the country level. Notably, some of Africa's most populous nations, like Nigeria (128,000 deaths), Ethiopia (67,800 deaths), and the Democratic Republic of the Congo (58,000 deaths), still experience a significant disease burden from HAP (HEI1, 2020). Over all, the African and Western Pacific regions, where the burden of disease due to household air pollution is much higher, have experienced a modest reduction in burden over the past two decades (Bede-Ojimadu and Orisakwe, 2020, HEI, 2019). A systematic review and meta-analysis report indicated that while the burden of cardiorespiratory, pediatric, and maternal diseases related to HAP has decreased globally, it continues to be significant in the poorest regions of the world (Lee et al., 2020a).

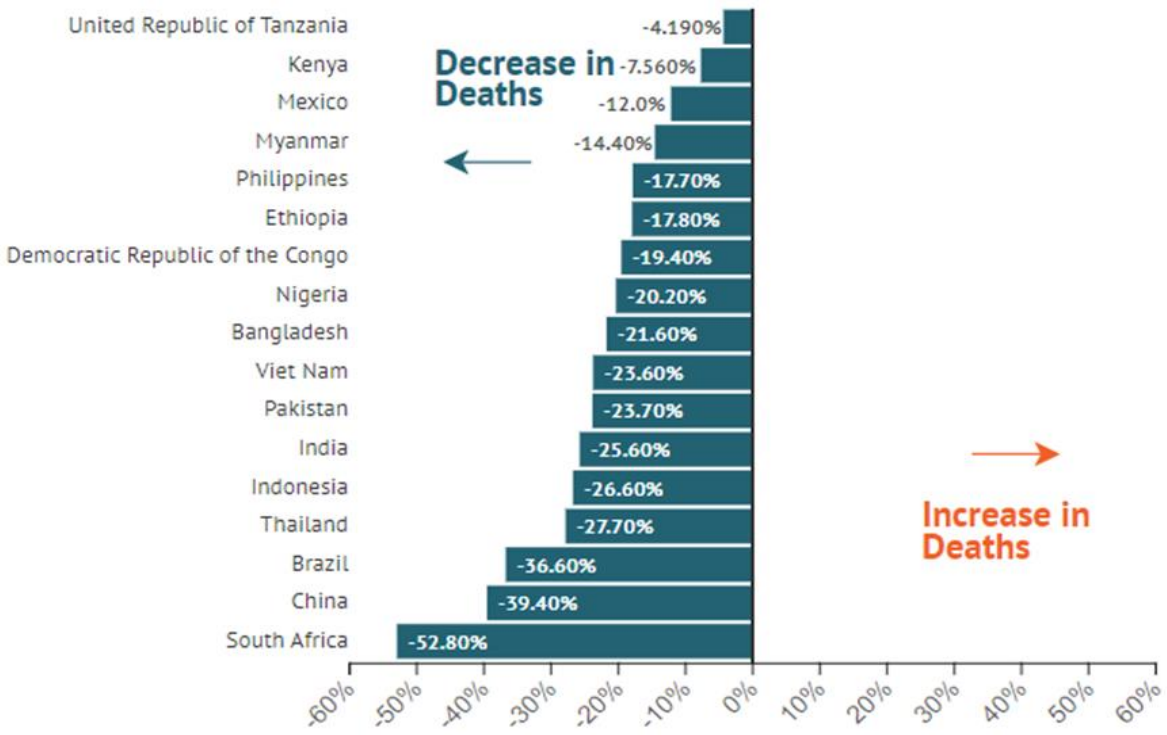


Figure 13: Percentage change in deaths attributable to HAP from 2010–2021 in the 17 countries. *(source: state of global air, 2019)*

1.2.3 Vulnerability and susceptibility to HAP

While exposure to HAP impacts individuals of all ages and sex, certain populations experience disproportionately greater burdens due to their increased vulnerability and susceptibility (HEI1, 2020, Polk, 2019, Wright et al., 2019). Pre-existing health conditions, immature immune systems, and occupational or environmental exposures can collectively contribute to varying degrees of susceptibility and vulnerability to negative health impacts (Kodavanti, 2019). People are susceptible to household air pollutants if they have a higher risk of experiencing health problems from pollutants due to their pre-existing medical conditions or other condition (WHO, 2016b, Zhao et al., 2022). Compared to the general population, susceptible individuals may experience more severe health effects even from lower levels of air pollution (Elbayoumi and Albelbeisi, 2023, Ranzani et al., 2024). Whereas, vulnerability to household air pollution describes people who face higher exposure due to factors like where people live or work and their socio-economic status which can make them more exposed (Okello et al., 2018).

Individuals, who spend more time indoors, such as children, the elderly, and women, are disproportionately affected by HAP (Dehghani et al., 2023, Okello et al., 2018, Rees, 2016, Annesi-Maesano et al., 2003, Kurata et al., 2020). Women and children in low- and middle-income countries bear the greatest burden of mortality and morbidity due to household air pollution (Gilliland et al., 2005, WHO, 2016b). Women face a double burden when it comes to HAP (Njenga et al., 2021), not only disproportionately exposed to harmful pollutants due to their traditional roles in cooking, child care, and fuel collection (Okello et al., 2018, Sepee and Tesfahun, 2023), but while the precise mechanisms are still remains unclear, their physiological makeup also makes them more susceptible to its detrimental effects (Clougherty and coletiva, 2011).

Fetuses, infants and toddlers are particularly susceptible to air pollutants (Palma et al., 2019, WHO, 2018a). Exposure to HAP during pregnancy and infancy can have lifelong consequences for lung health, including underdeveloped lungs and an increased risk of chronic respiratory diseases later in life (Currie et al., 2009, Kaali et al., 2023a). Studies have highlighted that exposure to pollutants, particularly from biomass smoke, during early development can have significant long-term consequences (Tielsch et al., 2009, Vanker et al., 2017, Shi et al., 2024). Because, during this critical period, organ systems are rapidly forming and are more susceptible to damage from environmental toxins due to increased cell division and changing metabolic processes (Saswata, 2005). Compared to adults, infants breathe more frequently and inhale more air per unit body weight, increasing their overall pollutant intake (Cipriani et al., 2018) and infants spend a significant portion of their time indoors, where air pollution levels can be higher than outdoors, further magnifying their exposure to harmful pollutants (HEI, 2019, Putti et al., 2015). Environmental pollution including air pollution affects our health throughout our lives, from pregnancy to old age (Figure 9) (Lacagnina, 2019). The specific effects of air pollution depend on our life stage. For instance, infants whose mothers were exposed to pollution during pregnancy may be born prematurely or with low birth weight (Cao et al., 2016a, Dai et al., 2020, Heggeseth and Aleman, 2018, Spann et al., 2016, Xia, 2020). Chronic exposure to severe air pollution during pregnancy can have long-term effects on a child's health and development (Rees, 2016).

As a result, young children are particularly susceptible to respiratory infections (Amsalu et al., 2019, Goshen et al., 2020). According to the Lancet report, a higher prevalence of acute

respiratory infections (ARIs) in children under the age of 2 years compared to older age groups (Stanaway et al., 2018). Similarly, a study from Wondo-Genet district of southern Ethiopia, younger children (2–12 months of age) were more likely to develop ARIs compared to older age (Abuka, 2017). Another study in North west Ethiopia revealed the odds of childhood ARIs was found to decrease by 41 % among three-years-old children than under one-year-old (Adane et al., 2020b).

The evidence is solid for infant mortality mainly due to particulate matter from HAP. During early life, the respiratory system grows and develops rapidly which leads to increasing the lung surface area and number of alveoli significantly (Lee et al., 2015, Olsson, 2014). Usually,lung development undertakes in early life, so that damage during the prenatal and postnatal stages is potentially irreparable (Lee et al., 2020a). Globally, from the neonatal deaths attributable to air pollution, nearly two-thirds (64%) are related to HAP (Pandey et al., 2021) and babies in regions where cooking with solid fuels is most prevalent like sub-Saharan Africa and South Asia have both the highest rates and the highest numbers of deaths attributable to HAP (Bede-Ojimadu and Orisakwe, 2020, Energy, 2014, Gordon et al., 2014).

Nearly 476,000 infants across the world died from the adverse effects of exposure to air pollution in 2019 (HEI, 2019) of which nearly two-thirds of those deaths were related to the burning of poor-quality fuels for cooking (HEI, 2018). In sub-Saharan Africa, about 80% of the nearly 236,000 deaths in the first month of life are attributable to household air pollution whereas 50 % of the 186,000 deaths are attributable to HAP in South Asia (Pandey et al., 2021). According to the 2016 Ethiopian demography and health survey, 48 infants died for every 1,000 live births, meaning , 7 in 10 of the deaths occur during infancy (CSA, 2016). In addition, due to their living conditions and limited resources, low-income populations often face increased exposure to air pollution (Avis et al., 2018).

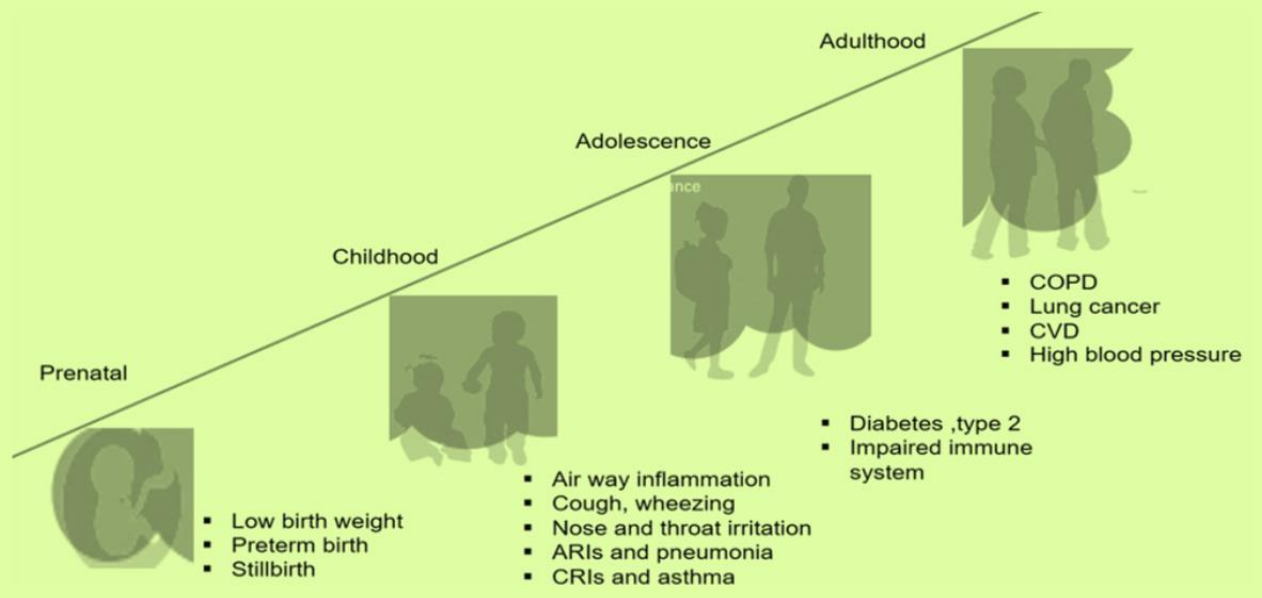


Figure 14: Lifelong effect of air pollution. *(Source, UNICEF,2016)*

1.2.4 Acute Respiratory Infections Attributed to HAP

Household air pollution from solid biomass fuel use is a confirmed risk factor for acute lower respiratory infections (Torres-Duque et al., 2008) which is among the largest causes of morbidity and mortality in children (Admasie et al., 2018b, Mohammadi and Mohammadi, 2018, Sanbata et al., 2014). Almost every seventh child who died in 2017 died of a lower respiratory infection which has remained the leading cause of mortality over the past three decades (Troeger et al., 2017). The burden of ARI is more sever in countries where biomass fuels are the primary sources of cooking energy with traditional or inefficient cook stoves (Khan et al., 2017, Rehfuess et al., 2009a). The deaths in five countries India, Nigeria, Pakistan, Democratic Republic of Congo, and Ethiopia accounted for more than half of all deaths from childhood pneumonia in 2017 (Troeger et al., 2017). The impact of solid biomass fuel smoke on lower respiratory infections is well documented in several epidemiological and experimental studies (Adane et al., 2020b, Admasie et al., 2018b, Hasan et al., 2019a, Oluwole et al., 2013a, Ranathunga et al., 2019). Systematic review and meta-analysis of studies from different part of the world also shown that acute lower respiratory infections(ALRIs) including pneumonia were found significantly associated with solid biomass fuel smoke exposure (Gordon et al., 2014, Jary et al., 2016, Po et al., 2011, Torres-Duque et al., 2008).

One of the underlying reasons for why HAP causes respiratory infection is that the air pollutants emitted from incomplete burning of solid biomass fuel impair the immune system to fight and clear the infection which predisposing children to ALRIs (Lee et al., 2015, Lee et al., 2020a, Rees, 2016). Since vulnerability to infectious diseases like ALRIs is not homogeneous and influenced by the extent of exposure to the pathogen, susceptibility to that pathogen and the ability to cope with the infection (Troeger et al., 2017), solid biomass fuel smoke causes inflammation of airways and alveoli and it is thus plausible that it increases the incidence of ALRIs (Lee et al., 2015). In addition, antenatal, in-utero household air pollution exposure has been shown to affect lung growth and predispose to development of ALRIs or wheezing disorders (Amegah and Jaakkola, 2016, Weber et al., 2020). As a result, HAP contributed to significant number for global deaths and morbidity due to respiratory disease (Das et al., 2018, Lee et al., 2015). The earlier the child's exposure to air pollution, the greater is the potential loss of healthy years of their life (Das et al., 2018, Lee et al., 2020a). Solid biomass fuel smoke pollutants and potential health effects of particulate matter (PM) causes bronchial irritation, inflammation and increased reactivity which reduced mucociliary clearance. Carbon monoxide (CO) binding with hemoglobin to produce carboxyhemoglobin, which reduces oxygen delivery to key organs and the developing fetus (Lee et al., 2015, Torres-Duque et al., 2008).

In many parts of the world where solid biomass is burned indoors for cooking and heating, small children are heavily exposed to HAP along with their mothers (Okello et al., 2018, Po et al., 2011, Rehfuess et al., 2009a). It is a global fact that very young children (< 2years old) generally spend more time in home than adults, which can result in greater exposure to household air pollution (Das et al., 2018, USAID/CIRCLE, 2017). In addition, infants and under five children are susceptible to household air pollution and adverse effects during their fetal development and in their earliest years (Holgate et al., 2016, Rees, 2016) mainly due to their faster breathe (taking in more air and, with it, more pollutants) and their maturing lungs and brains (Holgate et al., 2016, Lee et al., 2020a).

A systematic review of studies on ARIs risk indicated that exposure to smoke from solid biomass fuels are more likely to result ALRIs, compared to those without such exposure (Jary et al., 2016) . It is also evidenced from another study that intrauterine exposure to high levels of PM2.5 is associated with a higher risk of hospitalizations due to lower respiratory tract infections in infants (Sharon Goshen 2020). Similarly, the odds of infant and under-five child mortality

were higher in households with solid biomass fuel use compared with households with clean fuel use (Juwel Rana, 2019). Another systematic review and meta-analysis on the adverse health effects associated with household air pollution from 476 studies in low and middle income countries indicated that household air pollution was positively associated with asthma, acute respiratory infection in both adults and children (Lee et al., 2020a). In India, from the total DALYs 16 % and from the total death 11 % were from lower respiratory infections attributable to HAP in 2019 (Pandey et al., 2021). One in every 19 children born in Bangladesh dies before their 1st birthday and ALRI accounts for more than 50% of the infant mortality (Hasan et al., 2019a). Intervention must be enhanced to change the current situations of under-five mortality to achieve the sustainable development goal target of 25 per 1000 live births by 2030 in the sub-Saharan Africa region (Rosenthal et al., 2018).

In Ethiopia, most evidences on child health outcomes associated with exposure to HAP comes from observational studies which were comparing ARIs among under-five children who were exposed to biomass fuel smoke with clean fuel users (Adane et al., 2020b, Admasie et al., 2018b, Sanbata et al., 2014, Tefera et al., 2016). Based on the community based case-control study in Wolaita-Sodo, Southern Ethiopia, under five children from households using unclean fuel for cooking were two times more likely to develop acute respiratory infection (Admasie et al., 2018b) . It was also evidenced that acute respiratory infections among under five children found to decrease among under five children living in homes with chimney, eaves space and improved cook stove (Adane et al., 2020b). Based on the analysis of three Ethiopian demographic and health survey, the risk of having an infection in under-five children in households that cooked food outdoors was 44 % lower compared to those households that cooked the food inside the house (Geremew et al., 2020). Our recent study on HAP from solid biomass fuel use found that children under five from biomass fuel-using households were three times as likely to develop ARIs compared to those from non-user households (Enyew et al., 2021a). Evidences also generated from two randomized controlled trials which evaluated the health impacts among users of traditional biomass stoves and open fires compared with users of improved stoves (Adane et al., 2020b, LaFave et al., 2021).

Exposure to household air pollution from burning biomass fuel significantly increases the risk of acute lower respiratory infections in Ethiopian children under one-year-old as compared to

three-year-olds where children under one have a 41% higher chance of experiencing an ALRI (Adane et al., 2020b). This highlights the significant health risk young children face, and emphasizes the need for research into effective and culturally appropriate interventions to reduce their exposure to HAP and the associated risk of respiratory illnesses (Alemayehu et al., 2019, Geremew et al., 2020).

1.2.5 Household air pollution and pregnancy outcomes

Pregnancy is a critical time for a baby's health and future well-being (Dai et al., 2020, Gómez-Roig et al., 2021, Heggeseth and Aleman, 2018, Shi et al., 2024). This idea is known as the Developmental Origins of Health and Disease (DoHaD) (Gluckman and Hanson, 2006, Lacagnina, 2019). During pregnancy, a baby's organs are developing rapidly, making them more sensitive to harm due to the fast pace of cell growth and changing body processes (Johnson et al., 2022b, Miron-Celis et al., 2023). Exposure to harmful chemicals before birth, including those found in HAP, cigarette smoke, and pesticides, has been linked to negative pregnancy outcomes and evidence is continuing to grow (Demelash Enyew et al., 2023, Gómez-Roig et al., 2021).

Pregnancy outcomes are the best indicators of the health of neonates and infants (WHO, 2019d). Adverse pregnancy outcomes such as intrauterine growth retardation, low birth weight, and impaired early childhood growth are recognized for their long-term consequences, including higher childhood mortality and morbidity (Starfield et al., 1982, Cosmi et al., 2011), and an increased risk of developing hypertension, coronary heart disease, and non-insulin-dependent diabetes in adulthood (Lee et al., 2020a, Olsson, 2014, Tipre et al., 2018, Apte and Salvi, 2016b). A range of maternal and environmental factors were identified as contributing to increased risk of adverse pregnancy outcomes (Gedefaw et al., 2020, Demelash et al., 2023, Wu, 2018) and specifically, household air pollution exposure shows potential links to increased risk of adverse pregnancy outcomes (Khan et al., 2017, Luo et al., 2023, Tipre et al., 2018, Younger et al., 2022). Additional evidences also shown the potential perinatal risks associated with from biomass smoke (Lee et al., 2020a, Tipre et al., 2018, Weber et al., 2020).

There are epidemiological evidences associated maternal exposure to HAP from the combustion of polluting fuels in the home and the following preterm birth (birth before 37 weeks gestation) (Tipre et al., 2018, Weber et al., 2020, WHO, 2007). This potential risk extends beyond early delivery, as maternal HAP exposure has also been linked to small for gestational age (SGA)

babies, which can have long-term health and development consequences for the child (Liu et al., 2019b). Furthermore, a Ghanaian study found an increased likelihood of perinatal mortality and lower APGAR scores associated with using polluting fuels for cooking (Weber et al., 2020). This link between HAP and negative birth outcomes was further supported by a Zambian study that demonstrated a statistically significant association between HAP exposure and preterm delivery (Mulenga et al., 2018).

Babies born underweight, defined as less than 2,500 grams regardless of gestational age (and typically measured only in live births (WHO, 2007), one of the most concerning and common negative outcomes for newborns(Wardlaw, 2004, WHO, 2019d). This major public health issue carries a ripple effect of negative consequences, impacting not only babies' immediate survival but also their long-term health (WHO, 2019d) and development in early life (Hartinger et al., 2016, Stanaway et al., 2018, WHO, 2019d). It is a good summary measure of multifaceted public health problems that include maternal exposure to HAP, malnutrition, ill health and poor health care during pregnancy (Bililign N, 2018, Mahumud et al., 2017). It is also a significant prognosticator of high infant morbidity and mortality, inhibit growth and cognitive development and leads to chronic diseases later in life (Troeger et al., 2017, WHO, 2019d). As well documented, babies born small or very small are more likely to die in infancy compared to those with average or larger birth weights (Cutland et al., 2017, McGovern, 2019). Even if they survive, they face a higher risk of complications, including lower respiratory infections and other infectious diseases throughout early childhood and heart disease and diabetes later in life also increases (HEI, 2019). A systematic review confirms the link between low birth weight and higher under-five mortality (Bede-Ojimadu and Orisakwe, 2020) and economic study in low-income settings demonstrate that reducing low birth weight saves lives and reduces costs for families, healthcare systems, and increases productivity (Jeuland et al., 2015).

Worldwide, a staggering 15-20% of babies, amounting to over 20 million annually, are born with LBW where developing countries bear the brunt of this burden, with over 91% of LBW babies born there, primarily in South Asia (48%) and sub-Saharan Africa (24%) (WHO, 2019d). The magnitude of LBW varied widely across regions ranged from 7 % in more developed region to 18 % in low and middle income countries with Sub-Saharan Africa accounting 13 to15 % (HEI, 2019, Mahumud et al., 2017). The national data from Ethiopian Demographic and Health Survey (EDHS) estimate the magnitude of LBW to be 13 %, although approximately 14 % of newborns

are not weighed at birth due to low institutional delivery (CSA, 2016). Additional evidences from two systematic reviews and meta-analyses revealed that the pooled national prevalence of LBW was estimated to be 17 % (Endalamaw et al., 2018) and 18 % (Dasa et al., 2020) respectively. However, it is under-reported and undoubtedly much higher than the estimates provided from national survey data (Alemu et al., 2022).

Several epidemiological studies have identified a number of factors associated with LBW, including being pregnant with twins or triplets, various aspects of a mother's health, including chronic health conditions, malnutrition, and tobacco use (Bililign N, 2018, Dasa et al., 2020, Demelash et al., 2015, Mahumud et al., 2017). As a result, women in countries with low levels of socio economic development are especially at risk for adverse birth outcomes, with the related consequences for their children (WHO, 2019d). At present, a growing body of both epidemiological and toxicological research links air pollutions with increased risks of LBW and preterm birth (Epstein et al., 2013, Khan et al., 2017, Liu et al., 2019b, WHO, 2007).

Although the biological reasons for this linkage are not fully known, it is thought that air pollution may affect a pregnant woman, her developing fetus, or both through pathways similar to those of tobacco smoking, which is a well-known risk factor for LBW and preterm birth (Mulenga et al., 2018). One plausible mechanism is that pollution particles may move across the membranes of the lungs and be carried to other parts of the body, affecting placental function and the fetus (Figure 11) (Lee et al., 2020a). Another potential mechanism is that pollutants may initiate systemic inflammation or oxidative stress that affects the health of both the woman and her baby (WHO, 2007). But, researchers are recommended further studies to identify critical periods of susceptibility (windows of vulnerability) during pregnancy when exposure might have the greatest impact, differentiate adverse birth outcomes based on specific characteristics to understand potential variations in risk factors and measure biological markers (biomarkers) that reflect the underlying mechanisms by which exposure might influence health outcomes (Chin, 2017).

Exposure to solid biomass fuel was associated with increased risk of LBW (Tielsch et al., 2009). Based on systematic review and meta-analysis reports, combustion of solid biomass fuels at home increases the risk of a wide range of adverse pregnancy outcomes (Khan et al., 2017, Mulenga et al., 2018). In rural Guatemala ,babies born to women using wood fuel were 63 grams

lighter than those born to women using gas or electricity, after adjustment for socioeconomic and maternal factors (Thompson et al., 2011). According to analysis of five studies, the mean birth weight difference between high and low exposure was ranged from 59 to 175 grams lower with the higher exposure (WHO, 2007). Cohort study on the impact of biomass fuels on pregnancy outcomes in India showed that women who use gas fuel were delivered infants that were on average 112 grams lighter than women who used wood fire and more likely to be preterm and still birth (Epstein et al., 2013). In Zimbabwe, babies born to mothers cooking with wood, dung, or straw were 175 g lighter compared with babies born to mothers using liquefied petroleum gas (LPG), natural gas, or electricity (Mishra et al., 2004). Another study on biomass fuel smoke exposure during pregnancy and LBW revealed a significant association (Ahmed et al., 2015). Recent studies have found associations between LBW and common airborne pollutants in developing countries (WHO, 2007). Smokes from biomass fuel combustion may also affect the health of fetuses in utero thereby leading to birth defects too (Haider et al., 2016).

Similarly, a study in New Jersey estimated that a one unit change in mean CO during the last trimester of pregnancy increases the risk of low birth weight by 8 % and a one unit change in mean CO during the first two weeks after birth increases the risk of infant mortality by 2.5 % relative to baseline levels (Currie et al., 2009) . When the mother is exposed to air pollution, so is the fetus through placenta that exchanges substances between the two (Ezzati and Kammen, 2002, WHO, 2019d). Inhaled pollutants can cause oxidative stress, damage DNA and reduce absorption of nutrients by the fetus which leads to LBW (Liu et al., 2019b, WHO, 2007).

Exposure to harmful chemicals during pregnancy is a serious concern, with early and late stages of pregnancy being particularly critical windows of vulnerability (Rani and Dhok, 2023). Because, in pregnancy, each part of the fetus' body forms during a specific time which is known as critical periods of development(Joseph Davey et al., 2020, Reh et al., 2020). During these times, the baby's organs and systems are very sensitive to things the mother is exposed to, such as pollution, medications, alcohol, infections, or other health conditions(Dai et al., 2020, Demelash Enyew et al., 2023, Gómez-Roig et al., 2021). While all pregnancies have a small chance (3-5%) of birth defects, this risk can increase if the mother is exposed to harmful substances during pregnancy (Reh et al., 2020). Exposures during this time can lead to birth defects, growth restrictions, and an increased risk of miscarriage(Zilversmit Pao et al., 2019).

The second trimester is also a crucial period as the baby's brain continues to develop at a fast pace. Evidence from China revealed that the third trimester is the susceptible window for PM2.5 exposure and preterm birth (Qiu et al., 2023). Chemical exposures during this stage can result in learning disabilities, behavioral problems, and other neurological issues. While risks remain throughout the entire pregnancy (Figure 12), the first and second trimesters are when a developing baby is most sensitive to the devastating effects of harmful chemicals.

Because of its magnitude and impact on public health, reducing LBW and other pregnancy outcomes has long been recognized as a public health priority with the adoption of the global targets as a global commitment (WHO, 2019d). During the 65th world health assembly, member states endorsed the target of a 30% reduction in LBW globally between 2012 and 2025. However, progress in reducing LBW has been remains a challenging and stagnant and the world is not on track to meet the global target on LBW (WHO, 2014b). Because, the underlying causes of LBW are multifactorial and the biological pathways and preventive strategies are quite different (Cutland et al., 2017).

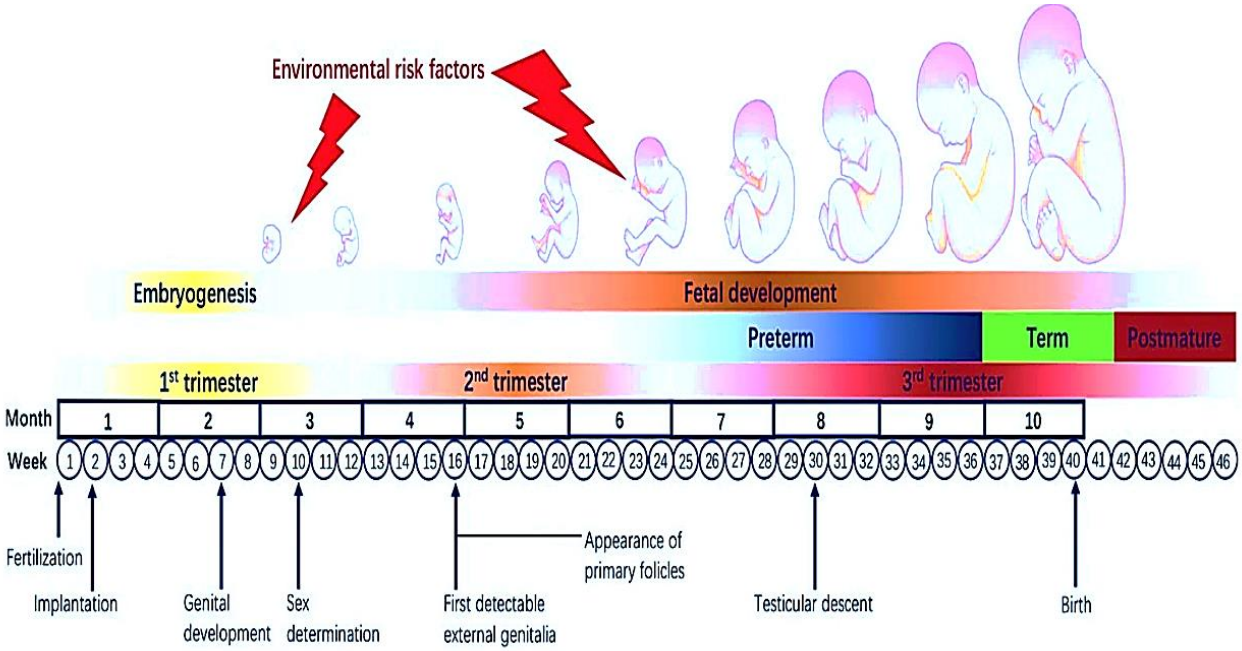


Figure 15:The embryo and fetus are heavily influenced by environment during pregnancy. *(Wei Wu, 2018)*

1.2.6 Health Risk Perceptions of HAP

Risk perception is how people understand and judge potential dangers to their health and well-being, both immediate and long-term (Dillon, 2020, Paek and Hove, 2017). Risk perception is

not just about facts, it is also about personal beliefs, cultural norms, and even gut feelings (Crighton et al., 2013, Dillon, 2020, Kati Orru 2022). This complex mix plays a big role in how we understand and react to potential hazards (Nriagu, 2019). Perceived health risk is assumed to have a positive impact on averted behavior (Li and Folmer, 2023). While scientists assess health risks based on hard data, our brains often take shortcuts, leading to "perception gaps" between objective and subjective risk (Nobanee et al., 2021, Howarth, 1988). In social sciences, including studies on preventive behavior, subjective risk plays a crucial role in decision-making (Li and Folmer, 2023). This happens because many environmental risks involve low-probability events with potentially severe consequences, making them hard to grasp (Egondi et al., 2013).

Likewise, given that the health consequences of indoor air pollution typically manifest gradually, certain communities might underestimate the associated risks and exhibit reduced enthusiasm towards engaging in intervention initiatives (Bedeau, 2020, Evans et al., 1997). This phenomenon is amplified as threats become more immediate, making risk perceptions more negative (Ferrer and Klein, 2015). Notably, personal experiences like family members having a certain illness significantly increase individuals' perceived susceptibility to that same disease (Egondi et al., 2013, Ferrer and Klein, 2015, Orru et al., 2018).

Despite being a major health threat, household air pollution often has been received less attention by the community than it deserves in low-income countries (Ochieng et al., 2017). People in African cities often lack awareness about how air pollution harms their health (Abera et al., 2021, Smith et al., 2014). In Ethiopia, though relatively high risk perception (Tamire et al., 2018), the overall practices of mothers towards indoor air pollution prevention was reported to be low (Girsha et al., 2024). Therefore, combining community education on air pollution and its health impacts with practical solutions to reduce exposure can effectively tackle the problem (Muindi et al., 2014, Nwankwo et al., 2018, Samy Bauomy et al., 2022).

1.2.7 Household air pollution interventional efforts

Though cooking is a fundamental and universally shared daily practice of every family, for more than half of the world’s population can also be deadly due to continued high dependence on traditional biomass fuels and stoves (Alem and Demeke, 2020, HEI, 2019). This act of nourishing their families produces several household air pollutants that affects human health and environment (WHO, 2019c) which needs replacing traditional stoves with fuel-efficient and

lower-emitting improved stoves (Ezzati and Kammen, 2002, Rosenthal et al., 2018) and providing clean energy options (Puzzolo et al., 2019, Rosenthal et al., 2018, WHO, 2016b) to mitigate these problems.

While universal access to clean energy for cooking, lighting, and heating holds the key to solving these issues (Birol, 2023), affordability and availability barriers currently prevent low and middle-income countries from accessing these solutions (UN, 2023, Sanusi, 2023). As the "Energy Ladder" illustrated in Figure16, household energy sources shift with income where low-income families rely on wood and biomass, while wealthier households use charcoal, coal, and cleaner options (Alem and Demeke, 2020, Roser, 2023). In the absence of readily available clean cooking fuels, efforts in low-income countries have primarily focused on promoting improved stoves to lessen harmful emissions (WHO, 2016b, Zuk et al., 2007). As income and development rise, they transition to cleaner, non-solid fuels such as LPG or electricity. However, a middle-income stage often involves using both solid and non-solid fuels (Roser, 2023).

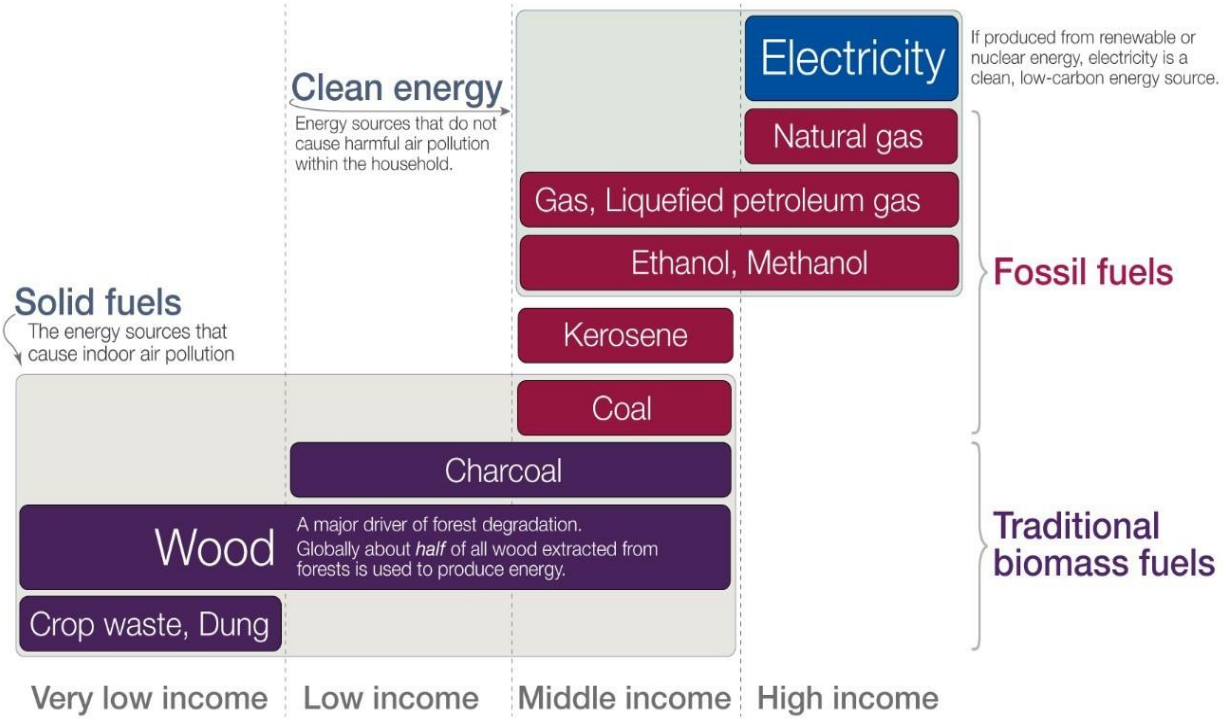


Figure 16:The energy ladder showing the dominant energy sources for cooking and heating by level of income. *(Source: World Bank, WHO, 2020)*

Recognizing the public health impact of HAP and considering the use of biomass fuels in low income countries is likely to remain stable in the near future, WHO suggested improved (more

advanced combustion) stoves to be prioritized for clean cooking transition (WHO, 2016b, WHO, 2016a, WHO, 2018c). As a result, there have been a number of efforts to promote improved biomass cook stoves in many parts of the world (Mitchell et al., 2019, Thakur et al., 2019, Zaman et al., 2017). Here the word "improved" tends to refer the potential reductions of fuel use and toxic pollutant emissions compared to traditional stoves (Edwards et al., 2007, Thomas et al., 2015a). The potential benefits extend well beyond and can also include safety, time savings, financial benefits and others (Edwards et al., 2007, Putti et al., 2015, Zaman et al., 2017). In addition, actions to reduce household air pollution in developing countries should also helpful to achieve a range of health-related sustainable development goals (SDGs) targets as clean cooking is a key driver for the success of SDGs (Rosenthal et al., 2018, WHO, 2019c). Successful improved stove installation will also enhance other developmental objectives such as entrepreneurship and job creation, use of local resources, women's empowerment and forest protection (Ezzati and Kammen, 2002, Gebreegziabher et al., 2018a, Negash et al., 2021).

Accordingly, improved stove distribution programs are expanding and being implemented around the world (HEI, 2019, IEA, 2016). The global alliance for clean cook stoves (GACCS) has been set goals to distribute 100 million clean cook stoves and fuels by 2020 (Rosenthal et al., 2018). Furthermore, the world bank and East Asia and Pacific region's clean stove initiative (CSI) have launched a number of regional clean cooking initiatives to promote, disseminate and adoption of clean cooking solutions for rural poor households through country-specific technical assistance (Malla and Timilsina, 2014, Mock et al., 2018). Besides these global initiatives, there are several national initiatives to promote clean cooking such as national biomass cook stoves program by Indian government to provide 160 million improved cook stove to households (Putti et al., 2015) , in Rwanda 80.9 million clean or efficient stoves that emit lower indoor emissions have been distributed since 2010 (GACC, 2017) and in Uganda, 250,000 Rocket Lorena stoves were distributed from in 2008 to 2010 (Putti et al., 2015).The most successful and largest improved stove dissemination in history is the Chinese national improved stove program distributed nearly 200 million improved cook stove (Smith and Deng, 2010).

Similarly, bearing in mind that solid biomass fuel is likely to remain the dominant source of energy for cooking throughout the country for the foreseeable future, the Ethiopian government gave attention on the importance of improved stoves (SNV, 2018) to reduce demand for firewood and health burden (Adem and Ambie, 2017). As a result, the federal government has

proposed to distribute 31 million households with improved stoves by 2030 to reduce the demand for biomass fuel and related smoke by increasing fuel efficiency as a strategic priority (CSA, 2017, Gemechu). National improved cooking stove programme was designed to implement government plan in distributing improved stoves though a sustainable and vibrant market (Gebreegziabher et al., 2018a). In addition, attempts were made to improve the stove to increase efficiency by reducing fuel consumption that results in an incremental change in reduction in emission of pollutants during cooking and baking (Adane et al., 2020b, Adem and Ambie, 2017) .

In Ethiopia, improved stove initiatives have been started with the introduction of wood saving biomass cook stoves in the early 1970s (Gemechu). But the large-scale distribution to consumers was started in the mid-1980s with the introduction of the Lakech charcoal stove followed by the Mirt Injera baking biomass stove and the Tikikil wood stove and then by the national biogas program (Tadesse, 2020). A diverse range of improved cooking and baking stoves have been developed and used across Ethiopia over time, including the Mirt, Gonziye, Burayou Injera baking, Sodo, Awuramba fixed, and Tehesh stoves, among others (Kedir et al., 2019, Berhanu, 2017).

Most importantly, the developmental patterns of stoves are based on the aim to reduce specific fuel consumption as well as efficiency by reducing energy losses during baking and cooking (Endalamaw et al., 2018, Kedir et al., 2019, Tadesse, 2020).Thus, it is determined that the average specific fuel consumption of three stone open fire was 929 g/kg of Injera, Mirt stove is 535g/kg of Injera, Gonziye is 617 g/kg of Injera, Awuramba is 573 g/kg of Injera while Sodo is 900 g/kg of Injera (Tadesse, 2020). Another study in the central highlands of Ethiopia showed that switching from a traditional three-stone open fire to improved cook stoves significantly reduced fuel consumption ($p<0.01$). The Mirt stove with biogas achieved the highest fuel efficiency improvement (54%), while the mud stove without biogas showed the least improvement (32%) (Negash et al., 2021).

Though a big global push for improved cooking stoves has occurred, the available evidences on their effectiveness on health and fuel use in real-life settings have shown varying results and often unsuccessful (ACC, 2011, Khandelwal et al., 2017, Thakur et al., 2019). Until recently the main emphasis of improved stove programs has been to reduce the use of biomass and the limited available research findings indicated that health benefits are often smaller than

anticipated (Adane et al., 2020b, LaFave et al., 2021, Quansah et al., 2015, Zaman et al., 2017). Similarly, despite the effort made in developing countries over the last three decades, problems with household air pollution constantly persisting (Khandelwal et al., 2017, Putti et al., 2015). Recent evidences from a systematic review and meta-analysis across a variety of interventions suggested that improved burning biomass-fueled cook stoves do not deliver the expected health benefits (Quansah et al., 2015). In contrast, evidence form another review suggests improved stove interventions can reduce exposure to HAP resulting from solid fuel smoke (Thomas et al., 2015a).

Few randomized control trail studies were also conducted on the effectiveness of various improved stove and clean energy interventions on HAP reduction and related health impacts and most of the results are inconclusive (Asante et al., 2019, Beyene et al., 2015, Hartinger et al., 2016, Lee et al., 2020a). Some studies found no evidence of an intervention stove reduced the risk of various health problems such as childhood acute lower respiratory infections and low birth weight compared with the continuation of an open burning traditional stove method (Adane et al., 2020b, Katz et al., 2020). However, there is an evidence that a chimney stove reduced wood smoke exposures and was associated with reduced LBW occurrence (Thompson et al., 2011).

Similar to other improved stoves worldwide, the Mirt stove in Ethiopia demonstrates a restrained influence on air pollution reduction, with an average decrease of merely 10% (Beyene et al., 2015). Despite fuel efficiency improvements, real-world testing shows many popular stoves fall short in their ability to significantly reduce harmful emissions (Gebreegziabher et al., 2018a, Mondal et al., 2018). While some improved stoves like those used in a Northwest Ethiopia study showed significant air quality improvements (reducing pollution by 343 $\mu g/m^3$), there is still room for research on their impact on specific health outcomes like pregnancy outcomes and infant respiratory infections (Adane et al., 2020b).

The limited effectiveness of improved stove interventions can be attributed to several factors, including insufficient public awareness, incompatibility with traditional cooking practices, and the absence of affordable, high-performance stoves (Khandelwal et al., 2017). It is also observed that improved stoves often complement, rather than replace, traditional cooking methods, leading to continued use of both (Jewitt et al., 2020, Khandelwal et al., 2017, Shankar et al., 2020).

Hence, the acceptance and continuous utilization of cleaner, safer, and more efficient biomass stove technologies continue to pose a significant obstacle on a global scale (Jewitt et al., 2020, Putti et al., 2015, Quansah et al., 2015). While numerous clean cooking programs exist in Sub-Saharan Africa, their focus on specific technologies may overlook diverse needs across different settings (Dagnachew et al., 2019, Malla and Timilsina, 2014). Additionally, clean cooking initiatives often suffer from fragmentation and a lack of coordinated resources and expertise among stakeholders (Ezzati and Kammen, 2002, SNV, 2018). The findings from the Malawian study suggest that a large-scale cook stove intervention trial is feasible, provided careful community engagement and sensitization efforts are implemented (Jary et al., 2016).

1.3 Rationale of the study

Household air pollution due to biomass combustion remains a critical public health concern, disproportionately affecting women and children in Ethiopia (Misganaw et al., 2023, Fisher et al., 2021) and has negative implications for the country's economic development (Fisher et al., 2021). Despite the well-documented adverse health impacts associated with exposure to household air pollutants, the predominant use of biomass fuel is projected to persist in low income countries, including Ethiopia (Raimi et al., 2022, Puzzolo et al., 2019, CSA, 2016). While transitioning to clean fuels and electricity offers the ideal path to reduce exposure (Geissler et al., 2013), these options remain unavailable, unaffordable, or unreliable for many rural Ethiopians and other low income countries in sub-Saharan Africa (CSA, 2016, Asefa and Mergia, 2022, Edlund et al., 2020).

Similarly, nearly all Ethiopian households, particularly those in rural areas, have relied primarily on biomass fuels for cooking and heating for the past 15 years (CSA, 2005, CSA, 2016) because of its low cost, lack of available alternatives and sometimes because of cultural factors (Beyene et al., 2015, Geissler et al., 2013). Consequently, the health of many is at risk, with mothers and children, who spend significant time near cooking fires, being particularly vulnerable (Okello et al., 2018, Asefa and Mergia, 2022). Though more than 80% of the Ethiopian population resides in rural areas and almost all use biomass fuel for cooking, research on the burden of household air pollution and related health problems in these areas is limited. Most importantly, Injera which is a staple Ethiopian food and energy-intensive to bake and its traditional preparation methods using biomass significantly contribute to household air pollution, particularly harming public

health in rural areas (Embiale et al., 2021, Tadesse, 2020) that calls for interventional efforts (Bruce et al., 2015, Thomas et al., 2015a).

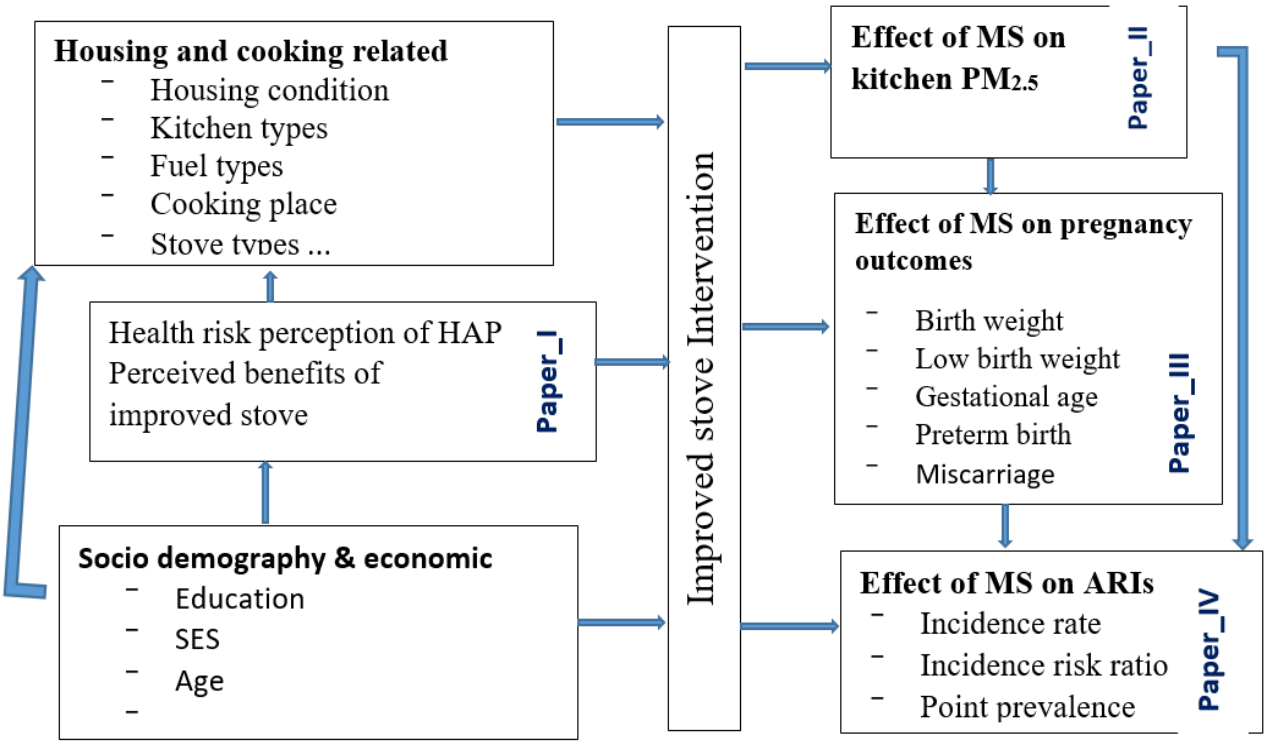
Distributing improved stoves has emerged as a promising approach to mitigate household air pollution and a safe transition towards cleaner cooking practices in resource-limited rural African settings like Ethiopia (Dagnachew et al., 2019). It is also expected that implementation of improved cooking technologies for households offer enormous promise to advance at least four sustainable development goals (WHO, 2016b): Goal-3 good health and well-being; Goal-5 gender equality; Goal-7 affordable and clean energy and goal-13 climate action (Rosenthal et al., 2018, WHO, 2016b, WHO, 2019c).

Despite the potential benefits of locally produced improved stoves, their effectiveness in reducing harmful pollutant exposure and improving health outcomes has not been adequately assessed. A lack of rigorous evidence hinders the widespread adoption and scaling up of these interventions. Successful stove programs require a combination of effective technologies, efficient distribution systems, and thorough evaluation. Given the substantial resources and time required for large-scale stove deployment, it is essential to evaluate the impact of different models to optimize resource allocation. Furthermore, the absence of standardized stove certification processes emphasizes the need for robust evidence to demonstrate the performance of specific stoves.

Previously conducted research in Ethiopia focuses on Mirt stove without chimney and targeted children under five year of age (Adane et al., 2021b, LaFave et al., 2021). Currently, the Mirt stove has been improved with a chimney designed to vent pollutants out of the kitchen and reduce indoor pollution. Intervening air pollution exposure before and during pregnancy has been recommended for significant health outcomes (Johnson et al., 2022b, Liao et al., 2023). Therefore, investigating whether a culturally accepted, locally produced, and chimney-fitted Mirt stove can potentially reduce household air pollution (measured by fine particulate matter concentration) and impact pregnancy outcomes and acute respiratory infections (ARIs) in the study area will contribute valuable evidence to inform future stove promotion efforts and resource allocation for improved public health in Ethiopia.

1.4 Conceptual framework

This study focuses on the impact of chimney fitted Mirt stove on fine particulate matter, pregnancy outcomes (birth weight, prematurity, miscarriage, stillbirth) among pregnant women and acute respiratory infections (ARIs) in their newborns within the first 6 months of life. It is also known that many factors can influence pregnancy duration, birth weight, and infant ARIs. Beyond measuring fine particulate matter ($PM_{2.5}$) from cooking, we are also considered these potential influencing factors including mother's socio-economic background, housing characteristics (windows, doors), kitchen types (location, ventilation, chimney), mother's perception of HAP risks and stove benefits, cooking practices (cooking traditions, fuel type) and mother's nutritional status. These factors could affect the outcomes and need to be accounted to understand the true picture. Based on research and existing theories, we developed a conceptual framework (Figure 17) that shows variables we measured (PM2.5 concentrations, pregnancy outcomes and ARIs) and expected relationships between these variables.



Note: MS; Mirt stove, SES; socio economic status

Figure 17: Conceptual framework or assessing the impact of improved stoves on household air pollution and health outcomes

1.5 Research questions, objectives and hypothesis

1.5.1 Research questions

Household air pollution is a major threat to health, particularly in developing countries. To address this issue, this study evaluates the effectiveness of a promising intervention: the locally-produced, chimney-fitted Mirt stove. We aim to generate robust data that can inform successful large-scale programs in real-world settings. Our primary objective is to determine if the Mirt stove reduces indoor PM2.5 concentrations and improves pregnancy outcomes and acute respiratory infections in Northwest Ethiopia. To rigorously assess this intervention, we have formulated the following four key research questions:

- How do pregnant women perceive the health risks associated with HAP and the benefits of improved stoves?
- Can the chimney fitted Mirt stove intervention reduce the level of Kitchen PM2.5 concentrations?
- Can the chimney fitted Mirt stove intervention during the 1st and 2nd trimester pregnancy reduces adverse pregnancy outcomes?
- Can the chimney fitted Mirt stove intervention during pregnancy reduce the incidence of ARIs among new born babies within their 6 months of life?

1.5.2 Objectives

This study was aimed to investigate the effectiveness of chimney-fitted Mirt stoves in reducing household air pollution and improving health outcomes in Northwest Ethiopia. It was conducted within the Guna-Tana Integrated Field Research and Development Centre catchment area, located in the South Gondar Zone.

Specifically, our research objectives are:

1. To assess the community perceptions regarding the health risks from household air pollution and the benefits of improved stoves in Northwest Ethiopia
2. To estimate the effectiveness of Mirt stoves with chimney installations in reducing kitchen PM2.5 levels in Northwest Ethiopia.
3. To evaluate the impact of chimney fitted Mirt stove intervention on pregnancy outcomes in Northwest Ethiopia.

4. To evaluate the impact of chimney fitted Mirt stove intervention on the incidence of acute respiratory infection among the new born babies in Northwest Ethiopia

1.5.3 Research Hypothesis

In this study, we hypothesized that introduction of chimney fitted Mirt stove could reduce kitchen particulate matter load (PM2.5 levels) and consequently reduce the incidence of adverse pregnancy outcomes and infants' respiratory infections.

1.6 Outline of the dissertation

This section outlines the dissertation's structure, drawing upon published and under review manuscripts in reputable, peer-reviewed journals.

Chapter 1: This introductory chapter serves as the cornerstone of the dissertation, meticulously laying the groundwork for a deep dive into the multifaceted issue of household air pollution (HAP). It embarks on a comprehensive exploration of various components that intertwine to create this critical public health challenge. The chapter begins by illuminating the diverse cooking fuels and stove types employed across the globe, analyzing their inherent connection to HAP. It delves into the smoke and soot generated by traditional cooking practices, providing a clear understanding of the sources of this invisible threat. In addition, the chapter delves into the devastating health impacts of HAP including the respiratory illnesses, pregnancy outcomes and other chronic health conditions linked to exposure, particularly highlighting the vulnerabilities faced by children and pregnant women. It describes how factors like socio-economic status, geographic location, and cultural practices contribute to disproportionate exposure and risk. It also explores various intervention efforts implemented to combat HAP, including the promotion of improved stoves, cleaner fuels, and housing.

Chapter 2: This chapter serves as a comprehensive blueprint for the research, outlining the methodological approach and measurement instruments employed to examine the intricate relationships among study variables and achieve the dissertation's objectives. By delving into the specific research context, including the study location, cultural nuances, and characteristics of the target population, this chapter provides essential background information for comprehending the study's findings. Through a transparent exposition of the research design, data collection strategies, and analytical techniques, this chapter aims to enhance the study's credibility and replicability.

Chapter 3: Recognizing the crucial link between perceptions and actions, this chapter dives into risk perceptions of household air pollution (HAP) and benefits of improved stoves among pregnant women in study area using a combination of quantitative and qualitative research methodologies. It goes beyond data to explore their beliefs, concerns, and decision-making around HAP risks and the potential benefits of cleaner cooking technologies. It explores their understanding of the dangers associated with HAP exposure, examining how they perceive risks to their own health, the health of their unborn fetus and the health of their family. The chapter further investigates the perceived benefits of improved stoves through the lens of these women's experiences and aspirations. It analyzes their understanding of the potential advantages of switching to improved stove technologies, exploring their hopes for improved health and reduced workload. By analyzing their perspectives and aspirations, the chapter offers valuable insights for designing effective interventions.

Chapter 4: This chapter delves into the effectiveness of chimney-equipped Mirt stoves in reducing harmful PM2.5 concentrations within kitchens. It investigates the impact of the intervention on kitchen PM2.5 concentrations, addressing the critical question: can the Mirt stove significantly reduce household air pollution? The chapter goes beyond simply measuring PM2.5 levels before and after stove implementation. It explores key factors influencing the effectiveness of these interventions, acknowledging the multifaceted nature of achieving cleaner air. This analysis paves the way for more targeted and impactful interventions in the future.

Chapter 5: This chapter tackles a critical question: can chimney-fitted Mirt stoves improve pregnancy outcomes? A rigorous study investigates the impact of introducing these stoves on key outcomes like birth weight, preterm births, stillbirth, and miscarriage. By assessing these critical factors, the study explores the potential of Mirt stoves to improve maternal and child health in HAP-burdened communities.

Chapter 6: This chapter focuses on infant health and household air pollution (HAP), assessing the potential of chimney-fitted Mirt stoves to reduce the incidence of acute respiratory infections (ARIs) among newborns. It provides a clear overview of the study design, participant selection, intervention procedures, and data collection methods employed in the larger research framework. Embracing a meticulous approach, the chapter then delves into the follow up study specifically focused on newborn babies. It describes the recruitment process, inclusion criteria, and follow-up

procedures implemented to monitor their health for six months after birth. This intensive monitoring period allows for robust data collection and accurate assessment of ARI occurrence.

Chapter 7: This final chapter translates research into action for a future of clean cooking. It brings together the findings from various studies, weaving them into a clear picture of the challenges and opportunities for tackling household air pollution (HAP) in the local area and beyond. Drawing on a powerful mix of research methods, the chapter first meticulously synthesizes key findings from individual studies. It identifies common threads, clarifies any inconsistencies, and creates a unified understanding of current knowledge about HAP and its impacts. Looking beyond immediate solutions, the chapter proposes directions for future research. It identifies crucial areas where further investigation is needed to refine our understanding, address unresolved questions, and develop even more effective solutions.

Chapter 2

General Research Methods and Materials

2.1 Study Setting

This study was conducted in a low-income, rural community within the Guna-Tana Integrated Field Research and Development Center, South Gondar Zone, northwest Ethiopia. The research center was established in 2013 by Debre Tabor University considering its potential to facilitate the teaching and learning processes through integrating with the research and community services. It is located 666 km northwest of Addis Ababa, the capital city. Guna-Tana research center consists of ten kebeles (2 urban and 8 rural) purposefully selected across the three districts of Guna, Farta, and Fogera mainly to ensure generalizability of the health research findings to a wider population. These kebeles were chosen to represent the varied characteristics of the research center.

However, for the purposes of this study, the two urban kebeles (kebele 01 from Deber Tabor city and kebele 01from Wereta town) were excluded. Because, the objective of the study is to evaluate the impact of chimney fitted Mirt stove in the reduction of household air pollution and associated health impacts in exclusively biomass fuel and traditional stove users in typical rural kebels. In addition, two kebels in Fogera district (characterized by lowland and a hot climate) were excluded due to the high prevalence of malaria in that district, which could potentially impact birth outcomes or incur additional expenses for distributing insecticide-treated bed nets and conducting malaria tests. But, it is worth noting that malaria is uncommon in the other two districts due to their higher elevations. Due to the above exclusions, the study was conducted in

the remaining six rural kebeles. According to the reports from health extension workers in respective kebeles, the total population is 22,019 with 11,186 females and 10,833 males.

The Guna-Tana integrated field research and development center is bounded by the Guna mountain to the east, Lake Tana to the west, the Ribb river to the north, and the Gumara river to the south which slopes gradually to lake Tana, the largest lake in the country, situated at an altitude of 1500 meters above sea level (Figure18). The rural nature of the area and the widespread use of biomass fuel with traditional stoves characterize the exposure scenario in this region. The study population mirrors many low-income rural communities in Amhara regional state in terms of fuel, stove and meal types. Similarly, acute lower respiratory infections including pneumonia, conditions often linked to household air pollution are a major concern in the region (Andualem et al., 2020).

The study site selection considered the strategic research importance of the location. To ensure the intervention's feasibility, we identified a site where the Mirt stove, a locally produced and culturally accepted improved cook stove, is readily available for distribution. The trial's smooth implementation was facilitated by valuable support and collaboration from the South Gondar Zone health department, respective district health offices. This strong partnership with the community and health officials within the chosen kebeles ensured effective trial management.

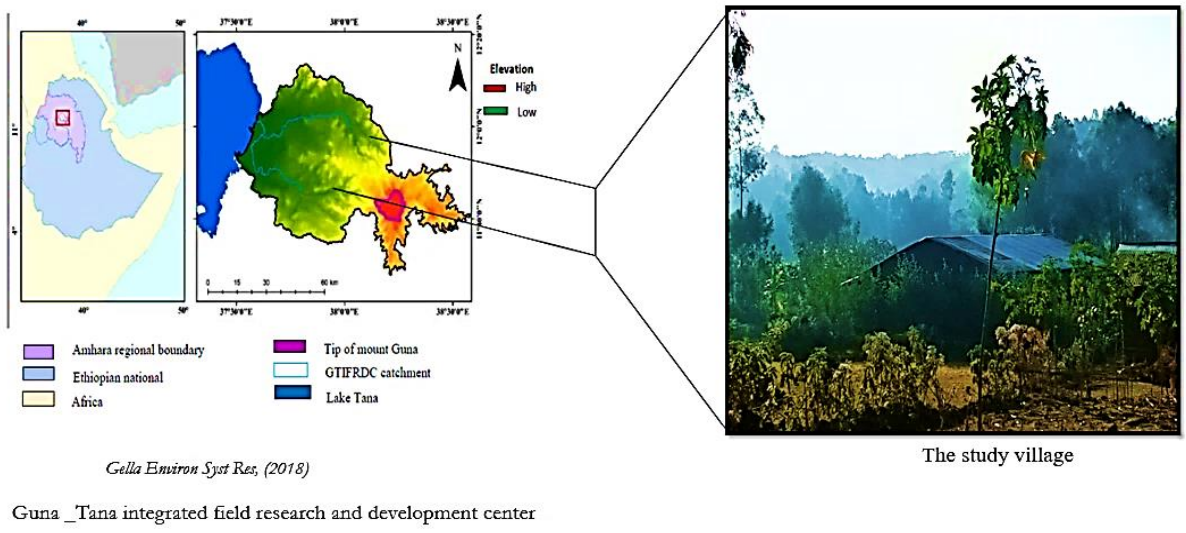


Figure 18: Location map of Guna-Tana integrated field research and development center and the study households

2.2 Study Design

A two-arm, randomized controlled trial (RCT) was conducted at the household level to evaluate the effectiveness of chimney-fitted Mirt stoves in improving kitchen air quality and pregnancy outcomes. A preliminary cross-sectional study, using both quantitative and qualitative methods, assessed pregnant womens' perception of household air pollution risk and the potential benefits of improved stoves. Following this, participants were randomly assigned to either the intervention group, receiving a chimney-fitted Mirt stove, or the control group, continuing to use traditional stoves. Pregnant women were followed until birth to measure infant birth weight and other pregnancy outcomes. Newborn infants were then followed for six months to compare the incidence of acute respiratory infections between the two groups.

2.3 Study population

The wider population source includes all pregnant women living in the catchment area of the Guna-Tana research and development center in northwest Ethiopia. This catchment area represents a geographically defined region where the center provides various services. Therefore, all pregnant women living within this area constitute the broader pool from which potential participants for the study could have been recruited. On the other hand, the study population comprises all pregnant women from the six kebeles who met the established eligibility criteria. These criteria ensure that the pregnant women included in the study share specific characteristics relevant to the research question.

Eligibility criteria: Candidate pregnant women were identified through collaboration with nearby health centers, health extension workers, health development army leaders, and community leaders. The regular monthly maternal meetings at the health post served as a platform for reaching potential pregnant women. Additionally, records from health centers and door-to-door surveys were used to identify potential study participants. To be eligible for this study, pregnant women had to meet the following criteria: aged 18-38 years, first or second trimester (gestational age ≤ 24 weeks), confirmed by self-reported Last Menstrual Period (LMP) or ultrasound (where available), exclusively use traditional biomass fueled stove, the primary cook in the household and carrying a live singleton fetus (not known twins), and women with no known pre-existing health conditions.

Pregnant women who didn't meet any of the following criteria were excluded from the study: planned to move permanently outside the study area within the next 12 months, likely to switch to any improved stoves soon, engaged in local alcohol production, as their cooking practices and stove usage patterns differ significantly from the average household (longer daily cooking times), lacked an enclosed kitchen structure (or were unwilling to construct one within the specified timeframe) as the study focused on enclosed kitchens. Prior to enrollment, all participants received detailed information about the study objectives in their local language (Amharic). Written or verbal informed consent was then obtained according to participant preference. The informed consent obtained from participants included their agreement to participate in the study and to allow their newborn infants to be followed for six months to monitor the development of acute respiratory infections.

2.4 Sample size

Given the limited population of eligible pregnant women in the study area, a census approach was adopted to include all potential participants residing within the catchment area of the Guna-Tana research and development center. To determine the total pregnant women, collaboration was made with health extension workers and local health development army leaders in each kebele. Based on their reports, a total of 648 pregnant women were identified as residing within the six kebeles of the catchment area. Following this comprehensive enumeration, all 648 pregnant women were approached to assess their eligibility for participation in the study according to the inclusion and exclusion criteria. After applying these criteria, the number of

study participants was reduced to 422, from whom baseline data were collected. These participants were then randomized into intervention and control groups for follow-up.

But, the required subsample for kitchen air quality sampling was determined based on standard conventional power calculations in the HAP (Edwards et al., 2007). Accordingly, to achieve a statistical power of 0.80, two-tailed tests significance level of 5% and detecting nearly 60% PM2.5 reduction (Adane et al., 2020b). Since no reliable estimates of coefficient of variation in pollutant reduction were available in Ethiopia, we adopted a conservative estimate of 0.7 based on published literature (Edwards et al., 2007). This led to a required sample size of 43 households per group (86 total households), ensuring sufficient power to detect the expected effect with a 5% chance of error (two-tailed test). Therefore, measurement of kitchen PM2.5 concentrations was collected in a random subsample of 86 of the total recruited households before and after the intervention period.

2.5 Screening and enrollment

All pregnant women residing in six specific kebeles situated within the Guna-Tana research and development center was invited to participate in the study. The decisions about who to study are set out in the inclusion and exclusion criteria listed in the eligibility section. Studies have shown that breathing polluted air in the middle and later stages of pregnancy can increase the risk of babies having a low birth weight (Kaali et al., 2023a, Johnson et al., 2022b) suggesting that efforts to reduce this risk need to happen before the second trimester. It was also evidenced that kitchen smoke exposure during the window of developmental susceptibility in early life is particularly detrimental (Olsson, 2014, Tielsch et al., 2009). A recent findings from China indicated that the third trimester is a particularly susceptible period for PM2.5 exposure and its association with preterm birth (Qiu et al., 2023). Therefore, this study included pregnant women in their first and second trimesters, as exposure to air pollution during these periods can have significant impacts on fetal development.

To ensure comprehensive recruitment of potentially eligible pregnant women, we implemented a multi-pronged approach including monthly maternity meetings in the health post of respective kebeles. These regular meetings occurred on the 5^{th} day of every month led by midwives and health extension workers and centered around pregnancy and childbirth topics. These familiar gatherings provided an opportunity to introduce the study and invite participation. Additionally, we engaged in community outreach efforts. Our field data collectors collaborated with health

extension workers local health development leaders and kebele administrative leaders to visit the homes of women who might not attend the monthly meetings. Furthermore, we utilized data from antenatal care clinic registries at health centers to identify potential participants. These combined approaches enhanced the likelihood of reaching all eligible women in the community, irrespective of their typical healthcare attendance patterns.

2.6 Randomization

After identifying eligible pregnant women in each kebele, obtaining informed consent, and collecting baseline data, participants were randomly assigned in a 1:1 ratio to either the intervention group, using a Mirt stove, or the control group, continuing to use their traditional three-stone stove. An independent epidemiologist conducted the randomization process using an Excel random number generator to minimize bias and ensure a fair comparison between groups. Then, a balance check of baseline characteristics was performed to assess comparability between the intervention and control groups.

Individual-level randomization is considered the most efficient approach in RCTs (Twisk, 2021). Accordingly, we opted for individual randomization over a cluster design for the following reasons: First, individual randomization directly assigns participants to intervention or control groups, enabling more precise comparisons. This can potentially increase statistical power, allowing us to detect even subtle effects. Second, given the lower priority of improved stoves and their limited market availability, the control group is less likely to acquire them on their own. This mitigates contamination, a common drawback of individual randomization. Third, individual randomization allows for personalized monitoring and intervention adjustments based on specific needs and preferences. This can yield richer insights into the intervention's effectiveness for different user profiles. Fourth, a cluster design might violate key assumptions of randomized controlled trials (RCTs). These are: (a) all individuals are independent, and (b) analysis is done at the randomization level. In a cluster design, people within the same cluster share characteristics and respond similarly to interventions. This reduces the power of the study because outcome variations between practices are smaller than in individual randomization. Cluster RCTs require larger samples and specific statistical methods to account for these cluster effects. Fifth, Significant variations in population density across clusters can make it difficult to achieve balanced group sizes between intervention and control arms. This could lead to unequal intervention exposure and compromise the study's statistical power. Therefore, considering these

factors, an individual-level RCT was determined to be the most suitable design to achieve our study goals and ensure the accuracy and interpretability of our findings. As blinding was not feasible in certain circumstances, the nature of this trial made blinding regarding the type of intervention unfeasible.

2.7 Intervention

The intervention for this study was a locally-produced, biomass-fueled, and chimney-equipped stove (locally named "Mirt", which means best), (Figure 19). Henceforth, the term "Mirt stove" will exclusively refer to the chimney-fitted version throughout this document. Mirt stove is a unique Ethiopian invention designed made from a durable mortar mixture of river sand and cement and boasts an average lifespan of five years (Alamir, 2017). It is accepted by the Amhara regional water and energy bureau as improved and fuel saving cook stove and is being promoted to rural households since 1998 by the German technical assistance agency GIZ. Mirt stove has four parts fit to make a cylindrically shaped enclosure where the firewood is burned under a baking pan. The baking surface is a clay pan used for baking Injera which is the staple food for most Ethiopian. The cylindrical enclosure has opening which has a semi-elliptic shape, at the lower front of the enclosure. It is used as fuel and air inlet. The chimney is installed as smoke outlet.

Mirt stove is well-accepted, culturally appropriate, locally sourced, and functioned well when maintained correctly. From previous studies, it has a specific fuel consumption reduction of 40 to 50% (Kedir et al., 2019) and even without chimneys, it reduced kitchen PM2.5 concentrations by 58% compared to traditional open-fire stoves (Adane et al., 2021a) and adding a chimney is expected to further enhance this reduction. The intervention stoves were provided with half subsidized to study participants and were procured from a local producer for the unit market price of Ethiopian birr 400 (approximately US dollars of $8 at the time). Based on our community engagement, the local purchasing power for 400 birr varies depending on household income and expenses. However, we can confidently confirm that 200 Ethiopian birr generally falls within the affordable range for the target population in the study area as reported from our focus group discussions and no households declined participation due to the cost of the stoves after the half-subsidy. Besides the provision of the stoves, no attempts were made to alter participants' choices of fuel for cooking.

Trained local producers were produced and installed these stoves in each household, ensuring proper functioning and offering repairs throughout the study. If the kitchen was not convenient for the stove installation during the first visit, the couple was instructed to make the necessary preparations. This is because some kitchens require modifications before a new stove can be installed. By replacing traditional open fires with Mirt stove, we aimed to compare the kitchens PM2.5 concentrations and the health outcomes in the intervention and control groups.



Figure 19: Chimney fitted Mirt stove before and after installation in a participants' kitchen

2.8 Data collection procedures

2.8.1 Baseline Survey

A structured and pretested questionnaire which was adapted from relevant literatures (CSA, 2016, FAO, 2016a, Newell and Raimi, 2020, Edwards et al., 2007, O'Sullivan and Barnes, 2007) was administered through face to face interview by trained field data collectors with the assistance of health extension workers and health development army leaders in each Kebele. Data was collected by first degree environmental health professionals who took a three days training on the content of the questionnaire. Each data collector was conduct pre-tests independently. Two supervisors who took similar training were recruited for logistic arrangement, scheduling, contacting local administrators, supervising the completeness, accuracy

and consistency of data. Completed questionnaire was collected and signed by supervisors after checked for any of concerns that could affect the quality of the data.

The baseline visit was cover a range of topics including demographic and economic status, housing characteristic, kitchen types, cooking behaviors, fuel type, cooking hours per day, types of cook stoves, health risk perception of HAP, perceived benefits of improved stoves, sources of drinking water, household sanitation practices, and pregnancy-related information. The eligible participants were asked about their health status, including medication use and all of the other characteristics that are potentially associated with the outcome variables (pregnancy outcomes). These baseline data were used for randomization balance tests to check whether the baseline characteristics between the treatment and control groups are distributed similarly or not.

Recognizing the critical influence of diet on pregnancy outcomes, we employed the Women's Dietary Diversity Score (WDDS) to assess the nutritional status of the pregnant women. The Food and Agriculture Organization (FAO) guidelines was used to assess dietary diversity scores (Kennedy et al., 2010). Based on their scores in WDDs, we classified the women into two groups: those with adequate dietary diversity and those with inadequate dietary diversity. Participants were asked to recall the foods they ate in the previous 24 hours, first spontaneously then by probing to ascertain that no meal or snack was left out. A detail list of all the ingredients of the dishes, snacks, or other foods consumed was generated to enable better classification of mixed dishes. The foods were then categorized into the 9 food groups mentioned. The nine food groups used to calculate WDDS are Starchy staples (cereals and white tubers), dark green leafy vegetables, other vitamins A rich fruits and vegetables, other fruits and vegetables, organ meat, meat and fish, eggs, legumes, nuts and seeds, milk and milk products. All the baseline data was collected between November 15-December 27, 2022.

2.8.2 Follow-up data collections

Following a comprehensive baseline survey and random assignment to either the intervention or control group, participants were tracked throughout their pregnancy to assess birth outcomes. To optimize participant access, the study's follow-up schedule was aligned with the existing health extension program's home visit schedule. For comprehensive data collection, information on maternal health, stove usage, and other relevant events were collaboratively gathered by data collectors, health extension workers, and local health development army leaders. Stove

utilization was monitored throughout the study for both intervention and control groups, employing a combination of direct observation and participant interviews. The intervention group was received ongoing encouragement to continuously utilize the improved stove throughout the entire study period.

We also designated one family member or neighbor for each household to report on events during the follow-up period. The assigned family members or neighbors were also instructed to promptly notify local health development leaders, data collectors, or health extension workers if the enrolled woman went into labor. After birth, data on the baby's birth weight, gestational age at birth, sex, and mode of delivery were collected. Furthermore, we requested the family to report any adverse pregnancy outcomes such as miscarriage. For institutional deliveries, midwives equipped with training were tasked with birth weight measurement and recording.

After birth, all newborns were tracked for respiratory illnesses throughout the study period, with follow-up visits at 2, 4, and 6 months of age. A well-recognized approach which combines health promotion, disease prevention and management strategies to ensure early detection, effective treatment, and healthy habits within families and communities known as Integrated Management of Childhood Illness (IMCI) (FMOH, 2011) was used to track episodes of acute respiratory infections. Trained midwives visited each infant's home every two months throughout their six months of life. During the scheduled active surveillance, data collectors directly asked mothers if their infants had experienced fever, persistent cough, and wheezing/difficulty breathing before the visits. In addition, mothers were encouraged to report any respiratory symptoms observed in their infant between visits. The follow up continued until each infant reached six months of age, at which point they were discharged from the study. In addition to the outcome variable, data were collected on the potential factors that may affect the occurrence of ARIs including vaccination status for age, exclusive breast feeding and ANC follow-up during pregnancy.

2.9 Data processing and management

Data collection for this study involved a combination of paper and electronic forms. After being collected, the data underwent a thorough review process to ensure accuracy. This process included checking for errors, missing values, inconsistencies, and out-of-range values. Any errors identified were corrected by the principal investigator, and if necessary, relevant forms were sent back to the field for clarification. To ensure proper data management, each questionnaire was assigned a unique identification number which contains the unique household

ID with kebeles and Gots for future tracing purpose. Following data entry into SPSS version 24, a separate data cleaning process was conducted. This involved checking for missing values, completeness, inconsistencies, and outliers within the dataset. Air quality data was collected electronically from two air monitoring devices: PATS+ and DyloseDC1700. The Platform for Integrated Cook Stove Assessment (PICA) software was used with the PATS+ device, while Dylos data logger software was used with the Dylose DC1700 device to down load the air sampling data.

2.10 Data Analysis

Prior to the main statistical analyses, we employed descriptive statistics (proportions, means, standard deviation and medians) to summarize sociodemographic, housing and cooking related characteristic, PM2.5 concentrations, and other variables depending on the specific objectives. This initial exploration helped to gain insights into the data distribution; identify potential outliers, and variability of key variables. Then, additional statistical approaches were applied to compare different variables including outcome variables between the intervention and control group. Shortly, i) descriptive statistics to summarize variables ii) bivariate analysis to examine relationships between pairs of variables, group comparisons to compare characteristics between intervention and control groups to ensure initial balance, iii) impact assessment to compare PM2.5 concentrations, birthweight and incidence of ARIs outcomes between intervention and control groups and iv) finally multivariate analysis to explore factors influencing outcome variables using regression models, adjusting for relevant variables.

To analyze the data, the following specific statistical approaches were applied; For continuous outcomes (birthweight, gestational age, PM2.5 concentration), independent samples t-tests were used to compare mean differences between groups, while linear regression models were employed to assess associations between variables and adjust for potential confounders. For categorical outcomes (low birth weight, preterm birth, stillbirth, miscarriage), Poisson regression with robust error variance was used to estimate relative risks and confidence intervals for these outcomes. Finally, for Acute respiratory infections (ARIs), Generalized Estimating Equations (GEE) were used to compare the incidence of ARIs between the intervention and control groups, accounting for potential correlation within repeated measurements and estimating adjusted risk ratios for specific outcomes while considering other relevant factors.

2.11 Quality assurance

Numerous efforts were made to enhance the credibility, accuracy, dependability, and reliability of the data gathered throughout the study. Firstly, community engagement approach was adopted to promote the acceptance and continual use of the intervention stoves. Secondly, uniform methods were employed to evaluate birth outcomes and infant respiratory illnesses in both the intervention and control groups, facilitating better comparability. Thirdly, field staff and supervisors underwent standardized training to maintain uniformity in data collection practices across all participants. Supervisors meticulously reviewed questionnaires for completeness and coherence.

The study's follow-up design and the baseline data collection on potential risk factors enabled adjustments in analyses to mitigate the impact of confounding variables. Individualized codes were assigned to households to ensure accurate data linkage. Additionally, training sessions were conducted for data collectors and supervisors on the proper handling and transportation of PM2.5 monitoring equipment. Inter and intra comparison was done between each air monitoring device and with Dylos air monitor before the actual measurements. Time-weighted averages from various devices within the same kitchen were compared, while Cronbach's alpha and Pearson correlation coefficients were computed to evaluate measurement reliability.

2.12 Ethical Consideration

The trial was approved by the institutional review boards of the Jimma university with ethical clearance provided (Ref No: IHRPGD/538/2021) to conduct this study. Following a thorough explanation, the women were asked to provide Verbal or written (as appropriate) informed consent by signing a consent form. The agreement includes both the parents' consent for their own participation and the infant's assent to participate in the follow-up ARIs study. Infants who were too ill to be treated at home were referred to the nearest health center. Official letter of co-operation was given to South Gondar Zone health department and respective district health offices and permission to conduct the study was obtained. The information obtained from the study participants was not used for other purpose other than to the objectives clearly stated on the consent paper. The right of the respondent to withdraw from the interview or not to participate was respected. The research was not imposing any risk to the participant as well as to the whole family. During kitchen PM2.5 monitoring sessions, field staff received permission from

participants to place air monitoring devices in their kitchens. Devices chosen for pollution monitoring have no risk for participants. Since the intervention stove had a positive impact on the kitchen PM2.5 concentration reduction, communication has been made to distribute the improved stove to the control group. The trial is registered on the Pan-African clinical trials registry at (https://pactr.samrc.ac.za/Identifier: ACTR202111534227089).

Table 1: Summary of methodological frame work

Sections	**Objectives**			
Titles	**Objective –I**	**Objective -II**	**Objective-III**	**Objective -IV**
	Assessing health risk perceptions the of HAP and the health benefits of improved stoves	Estimating the effect of Mirt stove on kitchen PM2.5 concentration	Estimating the effect of Mirt stove on pregnancy outcomes	Estimating the effect of Mirt stove on the incidence of ARIs among infants
Study population	All 422 eligible pregnant women in the selected kebeles of GTIFRDC	86 HHs Randomly selected (43 HHs from each study arm)	All pregnancy outcomes from randomized pregnant women	All infants born from randomized women
Sample Size	422 pregnant women	86 households	372 known pregnancy outcomes	355 mother-infants pairs
Data collection tools	Structured questionnaire Open guiding questions	– Observational check-lists – PATS+ and Dylos air monitor – PICA data Logger	– Questionnaire – Seca scale for birth weight measurement	Questionnaire (IMCI) Observation
Data analysis	– Descriptive – Bivariate and Multivariable logistic regression, Odds Ratio	– Descriptive statistics – Independent sample T-test – ANOVA	– Descriptive statistics – Independent sample T-test	– Descriptive – Independent sample t-tset – Chi-square test – GEE – Poisson Regres

Abbreviations: GTIRDC; Guna –Tana Integrated Research and Development center, HHS; Households, GEE; Generalized Estimating Equation

Chapter 3

Health Risk Perceptions of Household Air Pollution and Perceived Benefits of Improved Stoves Among Pregnant Women in Rural Ethiopia: A Mixed Method Study

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Health risk perceptions of household air pollution and perceived benefits of improved stoves among pregnant women in rural Ethiopia: a mixed method study

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Abstract

Objective: Since community perceptions significantly influence the adoption and sustained use of interventions, this study aimed to assess pregnant women's perceptions of health risks from kitchen smoke and the benefits of improved stoves.

Design: This is a community-based cross-sectional mixed method study with convergent parallel design using the baseline data.

Setting: In six kebeles of low-income rural community in Guna –Tana integrated field research and development center situated in South Gondar Zone, Northwestern Ethiopia.

Participants: Completed data were collected from 422 eligible pregnant women.

Result: Nearly two-thirds (63%, 95% CI: 58, 68%) of pregnant women perceived that kitchen smoke can cause various health problems. Perception in the benefits of improved stoves was even stronger, with nearly three-quarters (74%, CI 70, 79) perceiving improved stove to positively impact their health and families' well-being. The perspectives shared by focus group participants reinforced the results obtained from the survey. Factors including old age group, higher asset index, membership in women's groups, and larger family size, were associated with a heightened perception of kitchen smoke health risks. Whereas, presence of under five children, husbands with primary and higher education, high perception of kitchen smoke health risks, and dissatisfied with current stoves were associated with perceived benefits of improved stoves.

Conclusion: These findings hold significant promise for interventions aimed at reducing household air pollution and improving public health in low-income settings. High level community perception of the health risks associated with household air pollution and the benefits of improved stoves presents a valuable opportunity to stimulate demand for cleaner energy sources and plan effective stove intervention. Policymakers and public health professionals can leverage these findings to encourage widespread adoption of improved stoves.
Keywords: perception, risk factors, public health, epidemiologic studies, benefits

3.1 Introduction

Burning solid biomass fuels in traditional stoves releases harmful air pollutants that negatively impact human health throughout life (Liu et al., 2022, Balmes, 2019). A growing body of studies links household air pollution from biomass fuel use with increased risks of several acute and chronic health conditions (Merkeb and Adane, 2020, Ezzati and Baumgartner, 2017) and adverse pregnancy outcomes (Liu et al., 2019b, Khan et al., 2017). The rate of these health burdens remains high in low and middle-income countries (Raimi et al., 2022, Siddharthan et al., 2018, WHO, 2018a). In Ethiopia, where more than 95% of the energy is supplied by solid biomass sources, cooking smoke was associated with various health problems (Admasie et al., 2018b, Sanbata et al., 2014, Tefera et al., 2016, Balidemaj et al., 2021).

Improved stoves and clean fuels are common public health interventions implemented to reduce HAP exposure (Hooper et al., 2018, Hartinger et al., 2016). World health organization (WHO) suggested improved stoves be prioritized for clean cooking transition (WHO, 2016b, WHO, 2016a, WHO, 2018c) and there have been several efforts to promote improved biomass cook stoves in many parts of the world (Mitchell et al., 2019, Thakur et al., 2019, Zaman et al., 2017). The global alliance for clean cook stoves (Rosenthal et al., 2018) , world bank and East Asia and Pacific region's clean stove initiative have launched several clean cooking initiatives to promote and disseminate improved cooking solutions for rural poor households (Malla and Timilsina, 2014, Mock et al., 2018). Similarly, the Ethiopian government gave attention to the importance of improved stoves (SNV, 2018) to reduce demand for firewood and health burden (Adem and Ambie, 2017). As a result, the federal government has proposed to distribute 31 million households with improved stoves by 2030 to reduce the demand for biomass fuel and related smoke by increasing fuel efficiency as a strategic priority (CSA, 2017, Gemechu).

However, many interventions have a "one-size-fits-all" approach, neglecting the social and cultural context (Jewitt et al., 2020, Mamuya et al., 2018, Gebreegziabher et al., 2018a). As a result, various initiatives which have been attempting to distribute improved cooking stoves over the past few decades demonstrated little evidence of health benefits (Beyene et al., 2015, UN, 2021) mainly due to incomplete adoption and stove staking (concurrent use of traditional and improved stoves) (Quansah et al., 2015, Singh et al., 2012a, Thakur et al., 2019). Poor understanding of the sociocultural context is identified as the main factor for the poor adoption and utilization of improved stoves (Evans et al., 2018, Hollada et al., 2017, McCarron et al., 2020). In addition, the perception of the community on the health risk of HAP and the benefits of improved stove intervention is fundamental for risk communication and determining which hazards people care about and how they deal with them (Crighton et al., 2013, Dillon, 2020).

Despite efforts by governments and non-governmental organizations (NGOs) to distribute improved stoves in Ethiopia, getting people to consistently use them remains a challenge (Tadesse, 2020, Tessema and Mekonnen, 2021). Factors including local cooking habits, awareness of health risks from air pollution, and perceived benefits of the improved stoves all play a role in stove adoption (Hollada et al., 2017, Kaba et al., 2019). This study uses the baseline data from the main trial study to assess the common cooking practice, level of health risk perceptions and perceived benefits of improved stoves for promoting exclusive adoption of improved stoves.

3.2 Methods and materials

3.2.1 Study design

This study, conducted as part of the stove trial research in the Guna-Tana Integrated Research and Development Center of the South Gondar Zone, Northwest Ethiopia, employed a community-based, cross-sectional mixed methods design. This approach, which combines quantitative and qualitative data collection (concurrent parallel design), was used to gain insights for the next stove intervention trial. Specifically, the study aimed to assess local cooking practices, perception of health risks from kitchen smoke, and the benefits of using improved stoves among pregnant women. The integration of the study took place during result interpretation, where the qualitative result was examined for its alignment or divergence with the quantitative findings. Mixed method designs are particularly recommended in low- and middle-

income country settings, where understanding the social, economic, and cultural context is essential to improve the effectiveness of health interventions (Ozawa and Pongpirul, 2014).

3.2.2 Variables, context definitions, and assessment methods

Health risk perception of HAP: In this study, we define a woman's perception of health risks from HAP as her belief about how likely she and her families are to get sick from it (Paek and Hove, 2017). To assess the perceptions, eight questions were adapted from existing literatures (Chakraborty et al., 2017, Kati Orru 2022, Alex et al., 2018) and tailored to the local context. Participants responded using a five-point scale: "Strongly Agree" = 5, "Agree" = 4, "Neither" = 3, "Disagree" = 2 and "Strongly Disagree" =1. A higher score indicated a stronger perception in the health risks associated with HAP. This format with multiple answer choices allowed for a more nuanced understanding of perceptions.

The questions covered a range of health concerns associated with HAP exposure, including eye irritation, headaches, childhood pneumonia, abortion, heart problems, and high blood pressure. These concerns were chosen to comprehensively assess participants' perceived risks of HAP. Participants were then categorized as having high or low perceived risk based on their scores on the questions.

Perceived benefits of an improved stove*:* Women's perceptions of the benefits of improved stoves was assessed through questions related to time and fuel savings, reduced exposure to harmful air pollution, and improved overall health. To minimize acquiescence bias (the tendency to agree with statements regardless of content), we used a mix of positively and negatively worded statements about the benefits. Participants rated their agreement on a five-point scale ranging from "strongly agree" to "strongly disagree." Participants were asked them six questions adapted from previous literatures (Nazneen and Iqbal, 2018, Bhojvaid et al., 2014) where they could choose how much they agreed with statements about the benefits and scores ranged from 6 to 30, with higher scores indicating a stronger belief in the benefits of improved stoves. To ensure the questions functioned well together (internal consistency), we assessed their reliability using Cronbach's alpha, which yielded a score of 0.6, an acceptable level of reliability.

Family size: Family size is expected to influence the exposure status of the women to biomass smoke. The idea is that larger families might cook more often and in larger quantities, potentially leading to greater smoke exposure. To assess family size, we counted everyone permanently living in the household, including men, women, and children under five. We then grouped the households

into two categories: those with less than five occupants and those with five or more occupants. This grouping is based on the average family size in Ethiopia (CSA, 2016).

Educational status: Educational level might influence how women perceive the health risks of household air pollution (HAP) and the benefits of improved stoves. To explore this, we categorized the women and their spouse education into three groups: (a) unable to read and write, (b) able to read and write only, and (c) completed primary school or higher.

Asset index: As socioeconomic status (SES) is linked to a wide range of health problems, we assessed the socioeconomic status of the respondents in terms of asset index. The asset index is recommended than using income or expenditure to characterize the SES of the respondents as it is less affected by short-term economic shocks and likely a better proxy of longer-term household wealth (Rutstein and Johnson, 2004). The ownership of twelve assets (radio, mobile, watch, solar, modern bed, cows, oxen, hens, chairs, goat/sheep, farmland, bank account) and three household utilities (main drinking water sources, toilet type, and kitchen type) were collected to construct a composite index representing the SES. These assets and utilities were selected based on their local value and importance to distinguish relatively "wealthy" households and relatively "poor" ones. Four variables/assets (cycles, horses, carts, and honey bees) were excluded from the analysis as these assets were owned by less than 5% of the respondents. The asset index was estimated using principal component analysis (PCA) and divided into three quintiles, ranking from the poor to the rich.

Kitchen location: Where the kitchen is located can also affect a person's exposure to smoke. We observed the location of each household's kitchen and categorized them into four groups: (a) separated from the main house, (b) attached to the main house but with a separate entrance, (c) located within the main living area of the house, and (d) an open fire used for cooking without a designated kitchen area.

Primacy fuel use: Since different cooking fuels create different levels of pollution, we asked participants what type of fuel they primarily used for cooking. Their options were: (a) firewood, (b) cow dung, (c) agricultural residues, and (d) charcoal.

Multiple fuel use: Using more than one fuel per cook is expected to emit more pollutants than using a single fuel. In this study, multiple fuel use was assessed by providing spaces to list the most common fuel mix used during dry and rainy seasons. Finally, the frequency was calculated for each common fuel mix.

Cooking frequency: The number of times the cook lights the fire each day can affect their exposure to smoke. We asked the participants how often they typically cook per day, with the options being: (a) once, (b) twice, (c) three times, and (d) four or more times.

Frequency of Injera baking: Injera is a flat bread-like pancake prepared from a tiny grain called Teff (its scientific name is Eragrostis teff*)*. It is Ethiopian staple food and very energy intensive to cook which uses for approximately more than 50% of all primary energy consumed in the household. The frequency of baking Injera was assessed with categories of (a) once per week, (b) twice per week, and (c) three and more times per week.

3.2.3 Data collection

In the quantitative study, face-to-face interviews using questionnaires and checklists covering a range of topics was conducted. The questionnaires were developed based on existing literatures and tailoring some of them to the local context (O'Sullivan and Barnes, 2007, Vrijheid et al., 2021, WHO, 2018b, WHO, 2009b, Garland et al., 2016). Interviews were conducted in Amharic, the local language and was pretested on 20 pregnant women (5% of participants) before being used in the actual study to ensure clarity.

For qualitative study, focus group discussions were held to gather a wider range of perspectives. Compared to individual interviews, participants in focus group discussion capitalize on group interaction and can explore and clarify their views in a way that is not possible in individual interviews. To generate a diverse range of opinions on the fuel types, perception of HAP and related health problems, and perceived benefits of using improved stoves, pregnant women, lactating women, and young newly married girls were included in the FGDs. In total, four FGDs comprising six to nine participants with an age range of 18 to 45 years were conducted. The discussion themes were framed as common fuel types, seasonal variation of fuel types, health risk perception of HAP, and perceived benefits of improved stoves. Each FGD line of discussion was stopped at the saturation point (when no new information was generated regarding the pre-specified themes). The discussions were modulated by two public health experts with appreciable experiences in qualitative data collection.

3.2.4 Data quality control

Data collectors were selected based on their familiarity with the local customs and practices to facilitate amiable interactions during data collection. Each question in the questionnaire was meticulously reviewed, and a pretest was carried out in a different kebeles within the study area

before the actual research initiation. The aim of the pretest was to determine the approximate time required for questionnaire administration without causing discomfort to participants, and to gather feedback on the appropriateness of the content and accuracy of translations. Responses obtained were subjected to principal component analysis (PCA) to assess the contribution of each question to the perceived health risks of HAP and the perceived benefits of improved stoves by analyzing component correlation coefficients. This analysis helped identify irrelevant questions, which were subsequently eliminated. In addition, the qualitative data collection was conducted on appropriate days and places to avoid the unnecessary rush by the discussants and modulators. To promote free exchange of ideas, the FGDs included only women with no clear marked hierarchical link between them.

3.2.5 Data analysis

The initial analysis involved separate examinations of the quantitative and qualitative data. For quantitative data, descriptive statistical analysis was conducted for socio economic and other characteristics to elucidate basic features in the data and to identify gross outliers. Logistic regression was used to detect any association between health risk perceptions of HAP and perceived benefits of improved stoves with socioeconomic and other housing or cooking-related variables. The significance level was set at P value < 0.05 with a 95% confidence interval (CI) for the odds ratio (OR).

Since a well-fitting model without multicollinearity issues is crucial for accurate and reliable results, the model fit was assessed using the Hosmer and Lemeshow goodness of fit test, while multi-collinearity among the independent variables was examined using the variance inflation factor (VIF) with a threshold set at 10. The data analysis was conducted utilizing the Statistical Package for the Social Sciences (SPSS) software for windows, version 24.0 (IBM Corp., Armonk, NY, USA) (Corp, 2017). The final report adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist, ensuring that all essential items for cross-sectional study reports were included (Ovseiko et al., 2007).

Regarding the qualitative data, all focus group discussions were audio-recorded, transcribed verbatim into Amharic (the local language), and then translated into English by an experienced translator for analysis. We employed an inductive thematic approach, where themes emerge directly from the data itself, rather than being imposed by the researchers beforehand. We

conducted a detailed analysis of the transcripts to identify recurring patterns and themes. The transcripts were manually coded according to the final thematic codes developed through this iterative process. Codes with similar patterns were merged to identify overarching themes from the data. During analysis, modifications were made to existing codes and themes based on insights from subsequent interviews. To ensure inter-coder reliability, the principal investigator independently reviewed the coding. Any discrepancies were resolved through discussion. After multiple discussions, codes were refined and summarized in a thematic report for each theme. These reports included relevant quotes and textual evidence to support the identified themes. Finally, themes were triangulated with data collected through the quantitative methods employed in the study.

3.3 Results

3.3.1 Sociodemographic characteristics

Our analysis is based on data from 422 pregnant women out of 455 who were initially eligible (93% response rate). As shown in Table 1, most participants were between the ages of 25-31 years (mean age: 28.9 years, SD=5.3). All participating pregnant women were Amhara by ethnicity, Orthodox Christian, and most of them were currently married. Two hundred sixty-six (63%) of the participating women cannot read and write with only 13% of the respondents having primary and above educational level. About 45% of the pregnant women were members of any womens' group (womens' association, womens' development group, women support group etc.) in their respective villages. Households had an average of 4.5 occupants (SD=1.6) and approximately 42% of the participants had on average one child aged under five years and only 31% of the participants belonged to the rich socio-economic background of the asset index.

Table 2: Socio-demographic Characteristics of pregnant women in South Gondar Zone, Northwest Ethiopia

Characteristics	Frequency (n)	Percentage (%)
Age group, years (28.9± 5.3)		
18 - 24	84	19.9
25 - 31	195	46.2
32 - 38	143	33.9
Current marital status of the women		
currently married	405	96.0
currently not married	17	4.0
Educational status of the women		
unable to read and write	265	62.8
read and write only	104	24.6
primary and above grade	53	12.6
Educational status of the husband		
unable to read and write	164	38.9
read and write only	169	40.0
primary and above grade	89	21.1
Occupational status of the women		
housewife	355	84.1
farmer	67	15.9
Family size of the household		
<5 individuals	231	54.7
≥5 individuals	191	45.3
Presence of under-five children		
yes	176	41.7
no	246	58.3
Membership in any women's groups		
yes	189	44.8
no	233	55.2
Asset index		
poor	142	33.6
middle	147	34.8
rich	130	30.8

In our qualitative study, 25 women without any noticeable hierarchical link between them participated in the four focus group discussions (FGDs). The ages of the FGD participants ranged from 18 to 45 years (mean: 29.4 years, SD=7.7). Most of them had primary and above education, were married, and already had children. More than half of the discussants had less than five family sizes. There were no refusals to participate in the study, and all households reported farming as their primary means of income.

3.3.2 Housing characteristics and cooking practices

The study participants lived in homes with average age of 7.4 years (SD=2.7), earthen floors, wood/mud walls, and corrugated iron sheet roofs. Most kitchens (60%) were located outside the main house, with nearly half (47%) being fully enclosed. Over half (56%) of the participants cooked in the same kitchen year-round. Traditional three-stone stoves were the primary cooking method for the majority (82%) of women. Firewood was the dominant fuel source for three-quarters (76%) of the respondents, but seasonal variations existed (Table 3). Most women (78%) used a combination of fuels; including firewood and agricultural residue were the most common mix during the dry season (45%), while firewood and cow dung were used more frequently during the rainy season (54%).

Regarding the cooking habits, over half (56%) of the women lit their stoves at least three times a day and spending an average of more than three hours daily in the kitchen. Injera was baked at least twice a week by 81% of the participants. Fuel efficiency seems to be a priority, as 80% of participants reported drying their firewood beforehand. However, ventilation practices were less common, with only 44% intentionally opening windows or doors while cooking. Encouragingly, there is a positive outlook on improved stoves with more than three-fifths (64%) of the participants expressed interest in purchasing and using them in the future. Information about the improved stove is also high, with 94% having heard about improved stoves. However, utilization remains limited, with only 23% having experience with locally modified stoves.

Table 3: Housing conditions and cooking practices among pregnant women in South Gondar Zone, Northwest Ethiopia (n= 422)

Characteristics	Frequency(n)	Percentage (%)
Number of rooms in the living house		
one room	53	12.6
two rooms	208	49.3
three or more rooms	161	38.2
Number of windows able to open		
no window able to open	140	33.2
only one window	185	43.8
two windows	75	17.8
three and above windows	22	5.2
Location of cooking kitchen		
separated from the main house	254	60.2
attached to the main house	109	25.8
in the living house	14	3.3
open fire without a kitchen	45	10.7

Kitchen Structure		
four-walled kitchen structure	199	47.2
three-walled kitchen structure	128	30.3
no walls, but a covered roof	95	22.5
Cooking in the same place all year round		
yes	234	55.5
no	188	44.5
Most frequently used stove type		
three stone traditional stove	344	81.5
other locally modified stoves	78	18.5
A perceived disadvantage of the traditional stove		
use lots of firewood	133	31.5
takes a long time to cook	65	15.4
emits lots of smoke	119	28.2
difficult to light the fire	46	10.9
not safe for cooking	59	14.0
Frequency of cooking per day		
once	107	25.4
twice	238	56.4
thrice and above	77	18.2
Frequency of Injera baking per week		
once	69	16.4
twice	342	81.0
three and more times	11	2.6
Ever heard about improved stoves		
yes	398	94.3
no	24	5.7
Reasons for not having an improved stove		
financial constraints	145	34.4
don’t know where to find	126	29.9
negligence	96	22.7
no interest	55	13.0
Ever had locally modified types of stove		
yes	98	23.2
no	324	76.8
Having the plan to buy the improved stove		
yes	269	63.7
no	153	36.3
The primary fuel used for cooking		
firewood	322	76.3
cow dung	65	15.4
agricultural residue	35	8.3
Using more than one fuel per cook		
yes	331	78.4
no	91	21.6
Did you try anything to reduce exposure?		
yes	176	41.7
no	246	58.3
Drying fuel before use		
yes	339	80.3
no	83	19.7

Findings from both quantitative survey and qualitative focus group discussions converged on firewood as primary cooking fuel in the area. However, participants reported using a variety of fuels throughout the year, often in combination with firewood. During the dry season, crop residues, plant leaves and straw, became more prominent fuel sources alongside firewood. In contrast, the rainy season necessitated a switch to a combination of firewood and cow dung, likely due to the reduced availability of other dry biomass. The rainy season presents a challenge in terms of obtaining cooking fuel. To address this, families often prepare in advance by collecting and storing sufficient firewood, dung, or other fuel sources during the dry season. This forward-thinking approach ensures a steady supply of fuel throughout the year.

> *In the dry season, we typically gather wood, dried plant leaves and crop residuals for cooking. However, in the rainy season, we resort to using cow dung, which has been stored since the dry season, alongside firewood for cooking purposes. The dry season, characterized by sunny weather and dry conditions, facilitates easy fire starting, whereas in the rainy season, drying the fuels becomes challenging. As a result, preparations need to be made before the onset of the rainy season. (Participant aged 32-45, FGD one) ... cooking smoke exposure is a year-round issue for us, but it worsens during the rainy season when firewood and cow dung absorb moisture from the rain. (Participant aged 32-45, FGD four).*



Figure 20: Typical photo taken inside and around the kitchen at study households

Focus group participants underscored the substantial variation in smoke emissions across different biomass fuels commonly used in households. While acknowledging the ubiquitous role of biomass in their daily lives, they specifically identified cow dung as a particularly potent

source of irritating smoke, especially during the rainy season when its moisture content exacerbates the issue.

> *...we mostly cook with firewood, cow dung, and dried leaves. The problem is, cow dung smokes a lot more than the others. Even firewood smokes a bunch if it's not well-dried. In my opinion, the solutions are simple: dry the firewood properly and try to use less cow dung. (Participant aged 18-24 years old, FGD 1)...the use of cow dung as a cooking fuel exacerbates kitchen smoke emissions. Consequently, I refrain from utilizing cow dung for cooking and opt for firewood and dried plant leaves as the primary fuel sources. (Participant aged 25-31, FGD two) ... the use of cow dung as a fuel results in significantly more smoke emission compared to other fuel types. However, currently, many of us use cow dung primarily as compost, reducing its usage as a fuel source. Other biomass fuels also emit significant smoke during the rainy season, primarily due to high moisture content. (Participant aged 25-31, FGD three)*

In rural kitchens, the process of fire initiation often necessitated the use of supplementary fuels, leading to the generation of substantial smoke. Participants reported employing a diverse range of kindling materials, including paper, dried plant leaves, and even petroleum-based products such as kerosene, plastics and other high-polluting fuel sources (Figure 21). These materials, characterized by lower ignition points, facilitated rapid fire starting and aided in the combustion of primary fuels like wood or dried animal dung. However, it is crucial to acknowledge the detrimental environmental and health implications associated with burning kerosene and plastics, as these substances release hazardous pollutants into the indoor environment

> *When the rain makes the firewood damp and hard to light, I use kerosene to get the fire going. (Participant 18-24 years old, FGD four) … I usually used paper dipped in kerosene and straw to start the fire (Participant aged 25-31 years old, FGD two) …I use dried plant leaves to start a fire. First, I spread the leaves on the kitchen floor to dry them up the night before and use them to start a fire in the morning. (Participant aged 32-45 years old, FGD two)*



Figure 21: Igniting the fire using different materials in rural kitchen

3.3.3 Health risk perception of household air pollution

Survey participants evaluated their agreement with eight statements regarding the health risks associated with household air pollution (HAP) exposure. To assess the internal consistency of these items as a measure of women's perceptions of HAP-related health risks, Cronbach's alpha reliability was calculated and found to be .76, indicating a satisfactory level of reliability. A sensitivity analysis was conducted by removing each item individually, resulting in Cronbach's alpha values ranging from .71 to .76. These findings further support the construct validity of the scale, suggesting that all items contribute meaningfully to the measurement of womens' perceptions of HAP health risks.

About three-quarters (72%) of participants were in agreement (37% strongly agreed, 35% agreed) with the general statement that 'I believe that exposure to smoke from burning biomass fuels leads to various health problems' (Figure 22). Participants were then asked about specific health problems associated with biomass smoke and over 70% of participants acknowledged potential risks, including for eye irritation (73% in agreement with 32% strongly agreed, 41% agreed), for acute respiratory infections (ARIs) in children (70% in agreement with 36% strongly agreed, 34% agreed)), and for pneumonia in children (59% in agreement with 30% strongly agreed, 29% agreed). Additionally, 53% of participants recognized the risk of miscarriage or abortion due to kitchen smoke exposure (26% strongly agreed, 27% agreed). But, the statement about kitchen smoke causing high blood pressure received the most uncertain responses, with 33% of participants neither agreeing nor disagreeing.

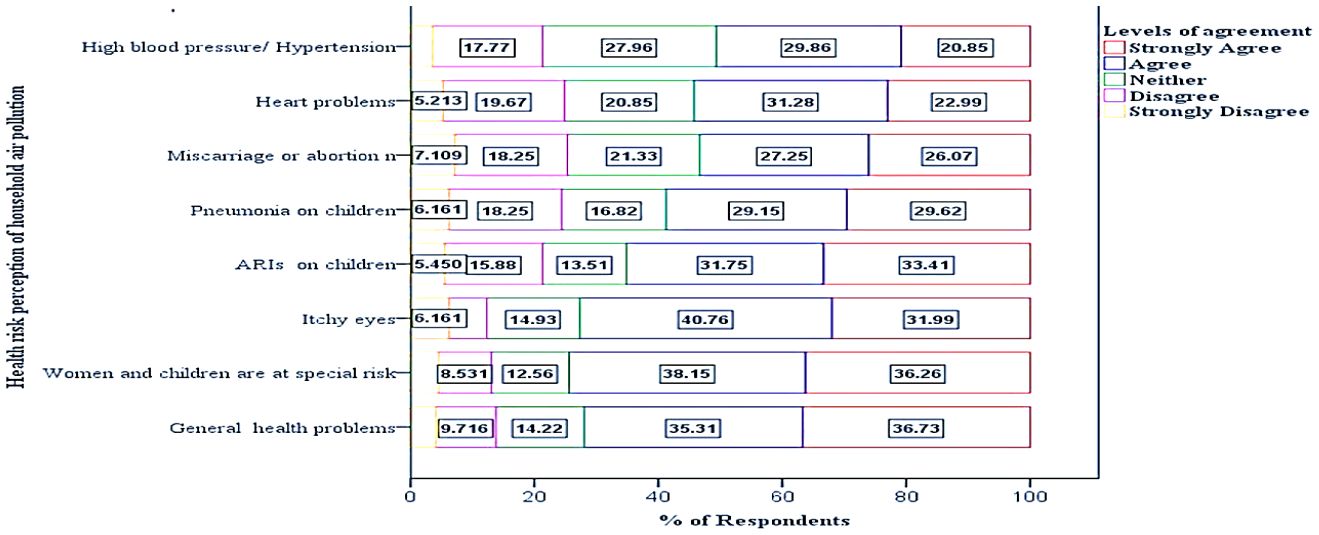


Figure 22: Perceived health risk associated with household air pollution among pregnant women in the South Gondar Zone, Northwest Ethiopia

Similarly, the health risks of household air pollution were a central topic of discussion during the focus group discussions, providing participants with an opportunity to explore their views on the issue. Most participants acknowledged the presence of air pollution in their homes/kitchen and its potential health consequences. These concerns encompassed a variety of respiratory problems, including coughing and pneumonia, eye irritation like itching, fatigue, dizziness, and even pregnancy complications such as miscarriage. Heat-related issues, like skin burns due to open fire cooking also emerged as a concern during the discussions. While the discussion captured a range of health concerns, most were acute symptoms associated with short-term exposure, rather than deadly chronic health effects.

> *Almost all community members in this village were aware of the health impacts associated with smoke emitted from their kitchens. The smoke tends to irritate the eyes, with its particles settling in the lungs and potentially leading to respiratory issues. Additionally, it can induce sensations of dizziness and exhaustion. Unfortunately, our reliance on biomass fuels and traditional three-stone stoves for cooking limits our options for cleaner burning alternatives. (Participant aged 32-48, FGD two) ... The smoke irritates the eyes, causing them to tear excessively. This irritation can be uncomfortable and even painful. (Participant aged 18-24, FGD one)*

In all discussions, the participants perceived that household air pollution is associated with various health problems. Although respiratory problems are widely recognized issues associated with biomass smoke exposure, eye health emerged as a more prominent concern during the discussions. Some participants believed that smoke exposure could lead to hair growth in the eyes and nearly all participants reported experiencing eye irritation, highlighting the immediate and personal impact of indoor air pollution on their well-being.

> *... exposure to kitchen smoke induces eye irritation which leads to intense discomfort and vision interference. (Participant aged 32-45, FGD one) ...the exposure leads to eye irritation. (Participant aged 25-31, FGD two) ...the smoke causes eye irritation, resulting in eye discharge. It also blurs vision, making tasks like using a mobile phone challenging. (Participant aged 32-45, FGD four)*

The focus group discussions also underscored the disproportionate burden of household air pollution, primarily caused by the combustion of biomass fuels, on vulnerable segments of the population. Participants expressed deep concern over the adverse health impacts of kitchen smoke, particularly on children and pregnant women. Individuals with pre-existing health conditions were identified as being at heightened risk due to their compromised health status.

This inequity arises from women's primary role in food preparation and the frequent presence of young children, particularly those under five, in the cooking area. This pattern was universally acknowledged by participants in the focus group discussions.

> *...in an asthmatic woman, kitchen smoke exposure causes shortness of breath and exacerbation of asthmatic symptoms. In pregnant women, it harms both the mother and her unborn fetus. (Participant aged 25-31 years old, FGD three)...I usually have my little one on my back while cooking, which exposes her to smoke-induced eye irritation and raises the risk of pneumonia. (Participant aged 25-31, FGD three) ... it is common for us to have our kids around while cooking, hence exposing them to kitchen smoke. (Participant aged 25-31, FGD three) ... being exposed to kitchen smoke poses dangers to pregnant women and their unborn fetus. The heat can cause dizziness in expectant mothers and affect the well-being of the growing fetus. (Participant aged 32-45, FGD four)*

3.3.4 Perceived benefits of improved stoves

Respondents in the quantitative study widely recognized the benefits of improved stoves. Nearly three-quarters (72%) of participants acknowledged that improved stoves could improve their family's health (with 40% strongly agreeing). Similarly, time-saving was a major perk, with 73% of participants acknowledging faster meal preparation (38% strongly agreeing). Fuel efficiency was another noteworthy benefit, with 62% (27% strongly agreeing) recognizing that improved stoves require less fuel. Safety was also a key advantage, with more than two-thirds (67%) believing improved stoves reduce the risk of burns among children (35% strongly agreeing). While some perceived improved stoves as a luxury item (53%, with 20% strongly agreeing), this view was not as widespread. Taste was not a major concern either, with 45% (20% strongly agreeing) confident that food cooked with improved stoves is just as good or even better than traditional methods (Figure 23).

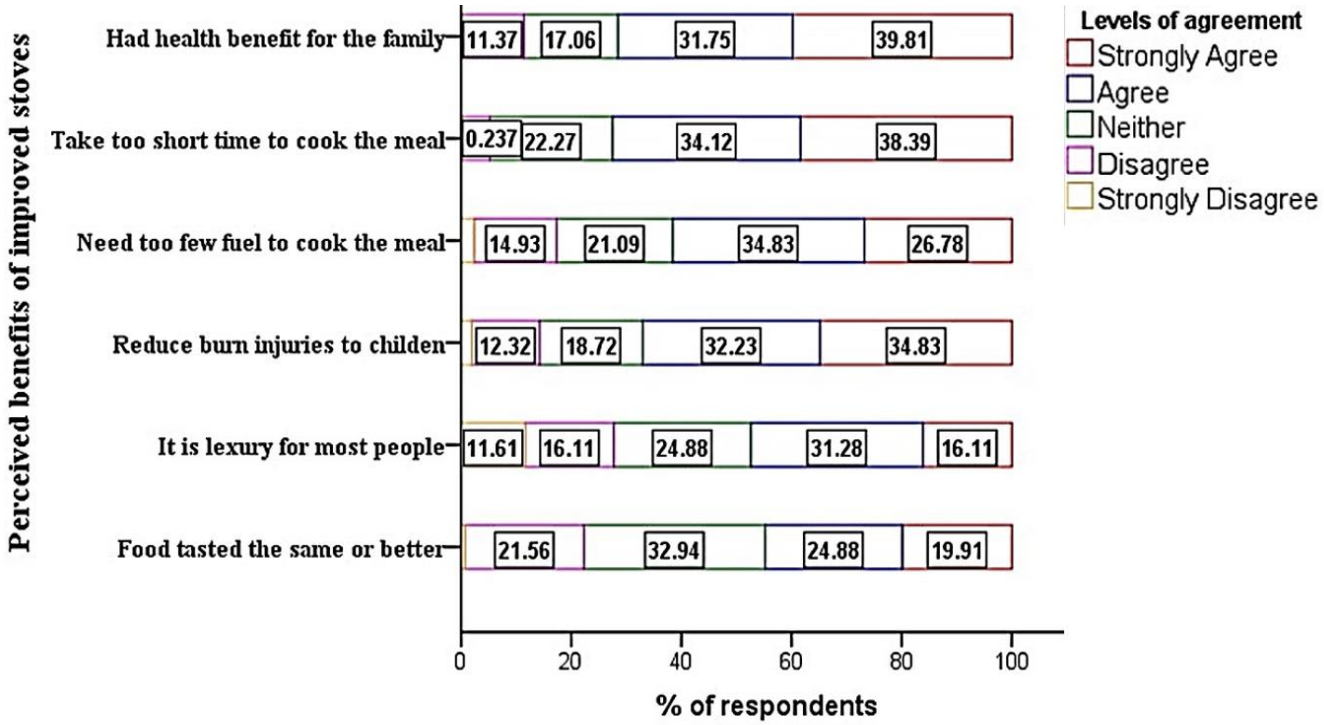


Figure 23: Perceived benefits of improved stove among pregnant women in the South Gondar Zone, Northwestern Ethiopia

Both quantitative and qualitative findings consistently underscored the perceived benefits of improved stoves. Participants overwhelmingly expressed a strong preference for improved stoves over traditional methods, highlighting their potential to significantly enhance overall well-being.

> *...I can personally attest to the significance of utilizing an improved stove, as I have incorporated it into my daily cooking routine. This stove not only shields me from excessive heat and smoke but also exhibits greater fuel efficiency when compared to traditional models. (Participant aged 25-31, FGD three) ... an improved stove reduces smoke emissions and utilizes fuel more effectively than traditional models. Moreover, it aids in averting health complications such as heart disease linked to smoke exposure. (Participant aged 18-24, FGD one)*

Some participants in the FGD had prior experience using mud-made improved stoves. They shared their previous experiences with using mud-made improved stoves. These individuals highlighted the positive impacts of these stoves on their daily lives and expressed a strong desire to adopt advanced models if the opportunity arose.

> *... we attempted to construct and use locally modified stoves, even though they were prone to crumbling easily. We are excited about adopting improved stoves if they become available in our village. We believe that using an improved stove is not a luxury but a*

necessity, as it helps prevent health issues related to biomass fuel use. (Participant aged 32-45, FGD one) … for the past nine years, I have been using improved stoves crafted from mud. These stoves allow me to simultaneously cook stew and Injera. By enclosing the fire within the stove, it reduces the risk of fire accidents and conserves fuel. Given my heart condition, I can attest that if I had continued using traditional stoves, I might not have survived. (Participant aged 32-45, FGD one)

The barriers hindering the widespread adoption of improved stoves within the community were discussed and most of them aligned with factors quantified in the quantitative survey. Participants consistently cited limited availability and the high initial cost of these stoves as major barriers. These findings underscore the critical importance of affordability and accessibility in driving the transition from traditional to improved cooking technologies.

...currently, improved stoves are too expensive for many farmers, with prices exceeding 200 Ethiopian birr. (Participant aged 32-45, FGD two) ...we would be eager to use improved stoves if they were available in our village, as they offer health benefits like reduced smoke exposure and lower fuel usage. (Participant aged 32-45, FGD three) ... I believe the main barriers to using improved stoves are unavailability and financial limitations. I have heard that they are expensive, although I am not sure about the exact price. (Participant aged 32-45, FGD three) ... we all understand the advantages of using improved stoves. If they were available, we would use them, because no one wants to cook in extreme heat and smoke. (Participant aged 25-31, FGD four).

3.3.5 Factors associated with health risk perception of kitchen smoke

To understand pregnant women's perceptions of health risks linked to kitchen smoke from burning biomass fuel, we initially planned to calculate an average risk score based on their composite score to eight questions. However, the distribution of the mean score exhibited positive skew (towards higher risk perceptions), which violated the normality assumption for many statistical tests. Even after exploring data transformations, normality was not achieved. Therefore, we shifted our focus to analyzing agreement levels with the health risk statements. Participants were categorized into two groups based on their responses: "not certainly agreed" (including those who strongly disagreed, disagreed, or were neutral) and "certainly agreed" (including those who agreed or strongly agreed). This approach allowed us to analyze risk perception based on broad agreement categories rather than relying on a potentially skewed average score. Based on this categorization, nearly two-thirds, 63% (95% CI: 58%, 68%) of

pregnant women certainly agreed with statements concerning health risks associated with air pollution from burning biomass fuel in kitchen.

As depicted in Table 4, certain factors were associated with increased concerns about the health risks of household air pollution. Pregnant women aged 32-38 years were almost twice as likely to have high concerns (OR= 1.71; 95% CI: 1.07, 2.73) compared to those aged 18-24 years. Similarly, participants with a higher socioeconomic status (based on asset index) were more likely to express strong concerns (OR = 2.12; 95% CI: 1.32, 3.41) than those with the least asset index. Having young children at home (OR= 1.92; 95% CI: 1.26. 2.91) and involvement in women's groups (OR= 1.92; 95% CI: 1.29, 2.85) were also linked to an increased likelihood of significant worries about health risks from household air pollution. However, the study did not identify associations between the education level (of the women or their spouses) and their perception of health risks from household air pollution.

Table 4: Factors associated with health risk perception of household air pollution among pregnant women in the South Gondar zone, Northwest Ethiopia, 2022

Characteristics	Perception		COR (95% CI)	P-value	AOR (95% CI)	P-value
	high	low				
Age group						
18 - 24	46	38	1		1	
25 - 31	117	78	2.12[1.21, 3.73]	.009	1.13 [0.81, 1.57]	.452
32 - 38	103	40	1.86 [1.39 , 2.50]	.000	1.71 [1.07, 2.73]	.022*
Asset index						
poor	104	35	1		1	
medium	81	59	2.16 [1.30, 3.60]	.003	2.09 [1.31, 3.341]	.002*
rich	78	62	2.36 [1.42, 3.92]	.001	2.12 [1.32 , 3.41]	.002*
Member of women's groups						
yes	100	89	2.20 [1.47, 3.29]	.000	1.92 [1.29 , 2.85]	.001*
no	166	67	1			
Women educational status						
unable to read and write	164	101	1		1	
read and write only	69	35	1.25 [0.71, 2.19]	.424	1.01[0.59, 1.71]	.962
Primary and above	33	20	1.93 [1.11, 3.34]	.018	0.76 [0.44, 1.30]	.323
Presence of children in the house						
yes	135	82	1.93 [1.46 - 2.55]	.000	1.92[1.26, 2.91]	.002*
no	131	74	1		1	

Family size (4.75± 1.61)	1.22 [1.08, 1.38]	.001	1.19 [1.05, 1.34]	.004*

Abbreviations: **COR**: crude odds ratio; **CI:** confidence interval; **AOR**: adjusted odds ratio; *: p-value < 0.05

3.3.6 Factors associated with perceived benefits of improved stoves

The data from perceived health risk were analyzed in a similar way to the health risk perception, focusing on whether participants generally agreed or disagreed with the benefit statements. We divided participants into two groups: those who strongly disagreed, disagreed, or were neutral, and those who agreed or strongly agreed. This created a simple "yes" or "no" answer for each person (coded as 0 or 1). Once again, we used a logistic regression statistical method to explore the relationships between these groups and other factors in the survey.

A strong positive perception of improved stoves emerged from the analysis, with nearly three-quarters (74%, 95% CI: 70, 79%) of respondents believed that improved stoves have health and well-being advantages for the families. As detailed in Table 5, various factors linked to a higher likelihood of perceiving significant benefits. Accordingly, younger women (aged 18-24) were almost twice as likely (OR=1.94; 95% CI: 1.07, 3.53) as those aged 32-38 to perceive substantial benefits. Similarly, the presence of children under five at home doubled the odds of perceiving significant advantages (OR=1.72; 95% CI: 1.08, 2.74). Women whose husbands had at least primary education were also nearly twice as likely (OR=1.89; 95% CI: 1.04, 3.44) to perceive these benefits. Women with a heightened perception of health risks from household air pollution were nearly three times more likely (OR=2.61; 95% CI: 1.49, 4.58) to recognize the advantages of improved stoves. Furthermore, women who were dissatisfied with their current stoves were more likely (OR=1.69; 95% CI: 1.03, 2.78) to perceive significant benefits from improved stoves. But, the study did not find significant association between perceived benefits and factors such as the practice of drying fuel before use, or having a house without operable windows.

Table 5: Factors associated with perceived benefits of improved stove among pregnant women in the South Gondar zone, Northwest Ethiopia, 2022

Characteristics	Perceived benefit		COR (95% CI)	P-value	AOR (95% CI)	P-value
	high	low				
Age group in years						
18-24	54	30	1.92 [1.06, 3.49]	.031	1.94 [1.07, 3.53]	.029*
25-31	149	46	1.07 [0.64, 1.79]	.794	0.80 [0.46, 1.39]	.438
32-38	111	32	1		1	
Presence of children in the house						
yes	118	58	1.92 [1.23, 2.99]	.004	1.72 [1.08, 2.74]	.022*
no	196	50	1		1	
Husband education						
unable to read and write	125	39	1		1	
read and write only	133	36	0.86 [0.52, 1.45]	.588	0.97[0.56, 1.67]	.931
primary and above	56	33	1.94 [1.07, 3.53]	.029	1.89[1.04, 3.44]	.035*
Drying fuel before use						
yes	261	78	1.89 [1.13, 3.16]	.015	0.73 [0.41, 1.29]	.287
no	53	30	1			
Health risk perception of HAP						
yes	215	51	3.40 [1.99, 5.81]	.000	2.61[1.49, 4.58]	.001*
no	99	57	1		1	
Like the current stove						
yes	78	43	1		1	
no	235	65	1.99 [1.25, 3.16]	.003	1.69 [1.03, 2.78]	.036*
Window able to open						
yes	222	60	1		1	
no	92	48	1.93 [1.23, 3.03]	.004	1.34 [0.81, 2.22]	.251

* p-value < 0.05. Abbreviations: COR; crude odds ratio: AOR; Adjusted odds ratio: CI; confidence interval

3.4 Discussion

Using a mixed-methods approach, this study investigated cooking practices and perceived health risks of smoke from biomass fuel use and perceived benefits of improved stoves among pregnant women in rural Ethiopia. The aim was to assess cooking practices, including the primary energy sources, stove and kitchen types, cooking frequency, and women's perceptions of household air pollution and potential benefits of improved stoves, which can inform the development of effective interventions to reduce exposure to household air pollution.

Results from qualitative and quantitative studies showed that firewood is the primary cooking fuel, often combined with other biomass fuels based on availability and season. Most cooking takes place in separate, semi-enclosed, or enclosed kitchens within the study area. Similar biomass fuel use and cooking practices were reported from previous studies (Tamire et al., 2020, Adane et al., 2020a, Hooper et al., 2018, Balidemaj et al., 2021, Admasie et al., 2018a). This suggests that, like many rural households, the participants in this study occupy the lower left corner of the energy ladder (Roser, 2023). This finding could be explained by the fact that unprocessed biomass fuels including firewood, cow dung and agricultural residues are the cheapest source of energy available and almost all rural women in low and middle-income countries rely on them to meet basic energy needs (Alem and Demeke, 2020, IEA, 2016, WHO, 2009b, Benti et al., 2021, James et al., 2020).

Seasonal variation in the type of biomass fuel was reported with firewood and agricultural residue commonly used during the dry season while firewood and cow dung was the main fuel mix during the rainy season. Our qualitative data also revealed that firewood and cow dung were the main energy sources with different mixes at different seasons of the year. A similar report from another study stated that households switched fuel sources between seasons due to practical factors of biomass fuel use (Wardle et al., 2021). Evidence generated from the systematic review also reported that weather and season played a role in determining the dominant biomass fuel sources (Amy McCarrona, 2020). It was also reported that fuel consumption varied seasonally and more consumption of solid biomass fuel was recorded in winter as compared to summer seasons (Sidhu et al., 2017). Seasonal variation in the type of biomass fuel was reported in another study in rural Senegal (Hooper et al., 2018)

In this study, participants demonstrated a high level of concern about the health risks associated with HAP. This is in agreement with other qualitative (Tamire et al., 2018, Devakumar et al., 2018, Woolley et al., 2022a) and mixed (Kyayesimira and Muheirwe, 2021, Fan et al., 2022) studies that reported most participating women believed household air pollution from biomass fuel use negatively affects their families' health. Similarly, a study in Rwanda showed that almost all of the respondents reported being concerned for their and their family's health associated with HAP (Campbell et al., 2021). Study participants in Kenya mentioned chest pain, sneezing, irritating eyes, breathing problems, and congestion of the throat as health problems

mainly due to HAP exposure (Nzengya et al., 2021) and nearly 90% of the respondents in rural households of Bangladesh realized that HAP is harmful to health (Mobarak, 2012).

One possible explanation for the relatively high level of health risk perception of HAP observed is that women are more concerned about indoor air pollution than men due to the social dimensions of womens' roles as also evidenced from other studies (Shin et al., 2019, Marcon et al., 2015, Chakraborty et al., 2017, Krupp, 2000). Though we only studied women, the literature showed that gender is a dominant factor in the perceived risk as stated in similar findings from Finland and Estonia women which confirmed women perceive general risks from wood smoke higher than men (Orru et al., 2022). Women might be more likely to prioritize the overall health of the family and perceive HAP as a threat to everyone's well-being (Crighton et al., 2013).

Another explanation for the higher health risk perception observed in this study may be that pregnant women are more concerned about environmental exposures during pregnancy because they are influenced by some personal, psychological, and social factors. (Dillon, 2020, Reames and Bravo, 2019, Tamire et al., 2018). Evidence from previous studies also reported similar high-level health risk perceptions towards environmental exposure including household air pollution during pregnancy (Daniel et al., 2020, Jafarian and Aghalari, 2018). Because, maternal exposure to biomass smoke during pregnancy has been suggested to be associated with increased risks of adverse birth outcomes such as preterm birth, low birth weight and small gestational age, and intrauterine growth retardation (Amegah et al., 2014, Gómez-Roig et al., 2021, Jayaraj et al., 2019, Johnson et al., 2022b, Palma et al., 2019). But, while perceiving the risk of HAP, community members primarily associated it with immediate symptoms such as eye irritation and coughing as evidenced from previous study (Shine et al., 2023)

In this study, womens' age, socioeconomic status, membership to any womens' group in their residence, presence of under five children in the house, and family size were significantly associated with health risk perception for HAP from biomass fuel use. Thus, the health risk perception tends to be double in the age group of 32-38-year-old women. This result is similar to the findings of previous perception studies where women in the middle age group were more likely than younger respondents to score high levels of health risk perception of environmental hazards including HAP (Shin et al., 2019, Marcon et al., 2015, Krupa et al., 2012, Orru et al., 2018). But, literature suggested that the relationship between age and perception of HAP risk is

U-shaped in that people under the age of 25 are often not concerned with HAP risk, but people between the ages of 25 and 55 have an increase in risk perception (Scalia, 2017, Krupp, 2000).
It was also observed that the odds of health risk perception are double among pregnant women with high levels of socioeconomic status as compared with their poor comparators. This is in alignment with the existing evidence demonstrating people with a relatively high monthly income had significantly increased degree of risk perception of air pollution (Hsu and Ting, 2020, Chen et al., 2019, Bickerstaff, 2004). This is mainly because poverty inhibits getting information from various sources and create risks that may be disproportionally affecting (Krupp, 2000). In contradiction to our result, the high risk perception was also statistically significant among those in lower (poor) categories of the wealth index (Amugsi et al., 2020).

The health risk perception of HAP was also nearly double among those who participated in any women group in their locality than non-participated women. This might be because as evidence suggests women's groups are successful in achieving information sharing and awareness creation on different health agendas (Ashebir et al., 2020). Health risk perception levels were found to be significantly higher for those exposed to health-related information through different women groups (Damtew et al., 2018). Family size was also significantly associated with womens' health risk perception of HAP in this study. It was observed that the odds of having a high level of health risk perception were 19% higher for a unit increase in the family size. Previous research has also demonstrated that lower family size is negatively associated with levels of perceived risk (Amugsi et al., 2020). It might be due to more than one stoves, high frequency and prolonged cooking is common for large families' cooking needs. Moreover, the size of the family also influenced the quantity of fuel used (Sidhu et al., 2017).

It was also observed that women with under-five children in their house were twice more likely to have a high level of health risk perception of HAP as compared to women without under-five children. This is aligned with other research findings where women with young children in their houses were perceived high health risk of HAP exposure (Crighton et al., 2013) and having one or more children was associated with a higher risk perception (Daniel et al., 2020). It was also reported that a positive association between having young children and the adoption of indoor air pollution prevention practices by mothers (Girsha et al., 2024). The possible reason might be women are often concerned about the risks to their fetuses, infants, and children (Krupp, 2000). But it is not always true as a contradicting result also reported on women with children in the

household had lower odds of being concerned than those without children (Reames and Bravo, 2019).

Positive perceived benefits of improved stove were observed in this study with nearly three-quarters of participating women believed improved stoves would be useful, a finding supported by the qualitative data. This is also reported in similar previous studies where almost all participating women believed that improved stoves were superior to traditional stoves (Hooper et al., 2018, Campbell et al., 2021) and had positive attitudes towards using improved stoves, especially on the reduction of the amount of wood used and time needed to cook food (Tamire et al., 2018, Pattanayak et al., 2016). Previous studies in Ethiopia have also reported similar results (Bersisa et al., 2021a, Adane et al., 2020a). Consistent with these findings, broad satisfaction with the improved biomass stove was reported in Ethiopia (Gebreegziabher et al., 2018b). The contradicted result was also reported in Rwanda where over half of the respondents had no prior awareness of improved stoves (Campbell et al., 2021) and in Uganda where most participants were unable to describe improved stoves (Martin et al., 2013).

Factors including younger women, the presence of under-five children at home, the education level of their husbands, dissatisfaction with the stove they are currently working on, and higher awareness of the health risk of HAP were associated with their perceived benefits of improved stoves. The result is in agreement with other studies where increasing age was associated with decreased preference for improved stoves (Hooper et al., 2018) and younger women adopt improved stoves than their older counterparts (Belachew and Melka). The possible justification might be younger women are more likely to understand new technologies and change their cooking behavior more flexibly than older women who had greater intention to stick to traditional cooking technologies as reported by other previous studies (Tessema and Mekonnen, 2021, Akomolafe and Ogunleye, 2017, Mamuye et al., 2018). Perceived benefits of the improved stove are positively associated with education and perceptions of health risks of pollution (Bhojvaid et al., 2014). Results from previous studies link the perceived benefit and adoption of improved stoves with the educational level of household heads and greater family size (Kare et al., 2022, Tamire et al., 2018).

Participants from both quantitative and qualitative data understood the health risks associated with biomass fuel smoke and the advantages of using improved stoves. However, they identified the high cost and limited availability of improved stoves as significant barriers to adoption. This

evidence was supported by other studies where perceived health benefits, cheap prices, and availability of improved stoves were found to be facilitators for the adoption of improved stoves (Adane et al., 2020a, Kebede et al., 2022, Bersisa et al., 2021a). Since cooking has a locally specific culture, it is suggested that intervention efforts should take into account the sociocultural and other important issues to implement clean cooking solutions for the community (Akintan et al., 2018, Tamire et al., 2018).

The reported high level health risks perception of HAP and perceived benefit of improved stove in this study are promising for the effectiveness of future prevention efforts. Because, the health risk perception of any hazards and perceived benefits of certain intervention are reported as key component of many health behavior change theories (Amugsi et al., 2020, Dillon, 2020, Hollada et al., 2017, Woolley et al., 2022a). Consequently, any public health interventions aimed at reducing HAP in this setting in particular and in LMICs in general need to consider local culture including perception towards the health risk and benefits of intervention for effective adoption and use of interventional technologies as evidenced in previous studies (Kaba et al., 2019, Wilkinson et al., 2021).

3.5 Conclusion

Households in this study primarily relied on affordable but highly polluting biomass fuels, reflecting their position on the lower end of the energy ladder. Pregnant women were aware of the immediate health risks associated with household air pollution, such as eye irritation and respiratory problems, but often underestimated the severe long-term consequences like hypertension, stroke, and pregnancy complications. To effectively promote clean cooking solutions, interventions should prioritize raising awareness of these long-term health impacts. Intervention efforts must consider diverse socioeconomic and cultural contexts to be effective. Additionally, addressing the cost and availability of improved stoves is crucial for increasing adoption rates.

Chapter 4

The Effect of Chimney Fitted Improved Stove on Kitchen Fine Particulate Matter ($PM_{2.5}$) Concentrations in Rural Ethiopia: Evidence from a Randomized Controlled Trial


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The effect of chimney fitted improved stove on kitchen fine particulate matter (PM2.5) concentrations in rural Ethiopia: Evidence from a randomized controlled trial

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Abstract

Background: Millions of Ethiopians rely on traditional stoves fueled by highly polluting biomass, releasing harmful pollutants that contribute to a significant public health crisis. While improved stoves offer a potential solution, their effectiveness in the Ethiopian context remains uncertain. This study evaluates the impact of the chimney-fitted Mirt stove on kitchen PM2.5 levels in rural Ethiopian homes.

Method: In the main trial, 422 rural households with eligible pregnant women were randomly assigned to Mirt stove intervention and control groups. But, a random subsample of 86 households (evenly divided between the control and intervention groups) was chosen to estimate the effectiveness of the intervention in reducing kitchen PM2.5 concentrations. The 24-hour average kitchen PM2.5 concentrations was measured using Particle and Temperature Sensor plus (PATS+) twice at baseline and after intervention. The sociodemographic and cooking related characteristics were collected at baseline and dynamic characteristics were updated during air monitoring visits. Three distinct statistical models, including independent sample t-tests, paired

sample t-tests and one-way analysis of variance were used to analyze the data using Statistical Package for the Social Sciences (SPSS) software for windows (v 24.0).

Result: At baseline, the average 24-hour kitchen PM2.5 concentrations were 482 μg/m^3 (95% CI: 408, 557) for the control and 405 μg/m^3 (95% CI: 318, 492) for the intervention groups and the difference was not statistically significant (t = .65, p = .512) ensuring a comparable starting point for evaluating the intervention effectiveness. Despite remaining elevated at 449 μg/m^3 (95% CI: 401, 496) in the control group, PM2.5 concentrations reduced to 104 μg/m^3 (95% CI: 90, 118) in the intervention group, indicating a statistically significant difference (t= 6.97, p < .001). All three statistical analyses delivered remarkably consistent results, estimating a PM2.5 reductions of 74% with the before-and-after approach, 76% when comparing groups, and 68% for difference in difference analysis. In addition to the general reductions, kitchens with women who completed primary school education, larger kitchen spaces, smaller family sizes, and baking Injera observed significant declines in PM2.5 concentrations.

Conclusion: Pregnant women in rural households of Ethiopia faced alarmingly high levels of PM2.5 in their kitchens. While the Mirt stove intervention significantly reduced kitchen PM2.5 levels, concentrations remained above the World Health Organization's 24-hour average air quality guideline of 15 μg/m^3. Kitchen smoke from neighbors, cooking other food items other than Injera with other stoves, low combustion capacity of the intervention stove, and other sources including lighting and heating could be potential explanations for the unmet reduction of PM2.5. This underscores the necessity for exploring additional interventions, such as cleaner burning fuels or improved ventilation strategies, to create truly safe cooking environments.

Keywords: Improved stove, kitchen area, intervention, PM2.5 concentrations**,** Ethiopia.

4.1 Introduction

The world is far from being on track to achieve universal access to clean cooking fuels and technologies by 2030, which is one of the united nations sustainable development goals (Putti et al., 2015, Rosenthal et al., 2018). Based on the international energy agency's projections estimate, approximately 2.3 billion population will remain without access to clean cooking facilities by 2030, considering the present policies and population trends (IEA, 2016). Since other cleaner cooking options like biogas, ethanol, solar, liquefied petroleum gas (LPG), or electric remain unavailable, inaccessible, and unaffordable for these rural and poorer households

(Das et al., 2018, Smith et al., 2014), biomass fuels are still a necessary and viable energy solution for rural low-income households (WHO, 2016b, WHO, 2019a).

At its most critical, these solid biomass fuels are often burnt in inefficient and inadequately ventilated stoves, leading to the release of elevated levels of harmful air pollutants owing to incomplete combustion (WHO, 2019b, Bruce et al., 2015). Pollutant concentrations in the kitchen area are further aggravated by the lack of chimneys that characterizes many of the kitchens in rural areas of developing countries (Nadadur and Hollingsworth, 2015). As a result, thousands of compounds have been identified and measured in solid biomass fuel smoke, including well-known toxic chemical species, such as polycyclic aromatic hydrocarbons, benzene, formaldehyde, and even dioxin (Balmes, 2019, Ezzati and Baumgartner, 2017). But, fine airborne particles measuring less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) and carbon monoxide (CO) are the most commonly studied and monitor air pollutants (Chen et al., 2016, Okello et al., 2018) which are increasingly recognized as a major health pressing proxy in the developing world (Amegah and Jaakkola, 2016, Apte and Salvi, 2016a).

The situation in Ethiopia is particularly dire, with approximately 93-99% of households still relying primarily on solid biomass fuels for cooking over the past fifteen years (CSA, 2016, CSA, 2005). Consequently, household air pollution from biomass smoke and its associated health problems persist as major public health concerns in the country (Admasie et al., 2018b, Sanbata et al., 2014, Tefera et al., 2016, Misganaw et al., 2023). Most recently, significantly large population utilized solid biomass fuels for domestic purposes and were exposed to kitchen smoke (CSA, 2016) with women and young children being significantly affected by hazardous pollutants (Admasie et al., 2018b, Demelash et al., 2015, Balidemaj et al., 2021, Enyew et al., 2021a, Tamire et al., 2022, Tamire et al., 2020). Since household cooking and childcare are traditionally and often involuntarily delegated to women due to ingrained gender roles and societal expectations, they are especially vulnerable to the impact of HAP (Admasie et al., 2018b, Padam et al., 2018, Okello et al., 2018).

In response to the critical need to address the problem of HAP and its associated negative health outcomes, improved stoves were prioritized with an ambitious proposal to distribute 31 million units by 2030 (SNV, 2018, Hameer and Ejigu, 2020) and various improved cooking and baking stoves have been in use across various regions of the country at different times in Ethiopia (Kedir et al., 2019, Tadesse, 2020). However, while global research demonstrates significant reductions

in kitchen PM2.5 with chimney-equipped stoves (Islam et al., 2022b, Grajeda et al., 2020, McCracken et al., 2007, Thompson et al., 2011, Katz et al., 2016, Masera et al., 2007), data specific to Ethiopia is limited, with only two RCT studies addressing non-chimney equipped improved stoves and their impact on HAP (Adane et al., 2021a, Bluffstone et al., 2019).

This data scarcity highlights the critical need for local research, as "one-size-fits-all" solutions for improved stoves are ineffective due to the diverse influences of fuel types, meal practices, cooking behaviors, and local environments on stove performance and emission reduction (Dagnachew et al., 2019, Pope et al., 2021a, Pilishvili et al., 2016, Grajeda et al., 2020, Kaba et al., 2019, Goodwin et al., 2015, Pope et al., 2017a). This is further emphasized by the unique cultural element of Injera baking in Ethiopia, requiring dedicated stove designs and necessitating localized data for accurate assessment (Tadesse, 2020, Adem and Ambie, 2017). Therefore, robust studies are urgently needed to ensure locally produced improved stove interventions effectively reduce air pollution and improve health outcomes for Ethiopians.

4.2 Methods and materials

4.2.1 Study design

This study employed a randomized controlled trial design, which is a before-and-after approach with a control group to evaluate the effectiveness of Mirt stove in reducing PM2.5 concentrations. The control group helps to control external factors that might affect air quality over time, isolating the specific impact of the intervention. A random subsample of pregnant women from the main improved stove intervention study were chosen separately from the intervention and control groups. All participants met the inclusion criteria detailed in general methodology part (chapter 2).

4.2.2 Sample size

The number of households with eligible pregnant women were determined based on standard conventional power calculations in the HAP intervention studies (Edwards et al., 2007). We aimed for a high chance (80%) of detecting a significant difference in average PM2.5 concentrations between households using traditional and Mirt stoves and a p-value of 5% in two-tailed tests. We also considered the expected reduction in PM2.5 level based on previous studies (64%) (Bluffstone et al., 2019). Since a reliable, Ethiopia-based, estimate of the coefficient of variation(COV) in HAP reduction was not available to compute the minimum sample size, a

conservative COV estimate of 0.7 (Edwards et al., 2007) was used which gave a minimum sample size of 43 households in each arm (a total of 86 households) to detect the intervention effect.

4.2.3 Data collection

4.2.3.1 Household survey

Prior to receiving the intervention stoves, a baseline survey was conducted in Amharic, the participants' native language. This survey gathered comprehensive baseline data for the main trial on socioeconomic factors, demographics, housing characteristics, kitchen features, and cooking practices which potentially influencing kitchen air quality. Subsequent follow-up surveys also collected on capturing dynamic variables that could fluctuate over time, such as daily kitchen usage duration, meal types, and fuel types. These additional data points were used to obtain a more comprehensive picture of the kitchen environment throughout the study period. The general method section provides an overview of the baseline data collection, with further details available in (chapter 3). Combining this detailed information with the air quality readings, we conducted analysis of the intervention stoves' impact on PM2.5 levels, while also considering the influence of other relevant factors within the kitchen environment.

4.2.3.2 Kitchen PM2.5 concentrations

We initially intended to use DylosDC1700 air monitors to measure personal PM2.5 exposures throughout the day. However, we encountered challenges with participant compliance during the pilot and baseline measurement period. Wearing the backpack-mounted monitors proved impractical for rural pregnant women in the study area. The backpacks hindered daily activities due to its size and potential discomfort, and the DylosDC1700 internal battery only lasted for six hours after a full charge, falling short of the required 24-hour monitoring period. Therefore, instead of directly wearing air monitors, we measured the biomass fuel smoke within the kitchens as a proxy for individual exposure using a handy sensor called Particle and Temperature Sensor Plus (PATS+). These measurements focused on fine particulate matter ($PM_{2.5}$) due to its well-established health risks and association with household fuel combustion, as highlighted by the WHO's air quality guidelines (WHO, 2014a).

Particle and temperature sensor plus (PATS+) is a light-scattering particle sensor developed by Berkeley Air Monitoring Group, California University. It is quite popular in this field as they are

easy to carry and place, required less space and had internal power supply for 80 hours of continuous measurement after being completely charged and provide data in a small interval of time (WB, 2017, Ajay Pillarisetti 2017). The device had a lower and upper particulate matter concentration detection limits of 10 $\mu g/m^3$ and 50,000 $\mu g/m^3$ respectively with a logging interval of one minute. In addition to measuring mean PM2.5 concentrations, PATS+ also measured relative humidity and temperature of the study area.

Previous field validation tests have reported that PATS+ relates well to gravimetric (gold standard device to monitor indoor air pollution) PM2.5 estimates in laboratory settings (R^2 = 0.97) and in rural biomass-using households (R^2 = 0.74) (WB, 2017). Additionally, side-by-side inter-comparison tests among PATS+ and DylosDC1700 air monitoring devices were conducted in 11 kitchens in this study , following standardized experimental procedures (UCB, 2016), yielding comparable data across PATS+ devices (Pearson correlation coefficients of 0.78, ranged from 0.75 to 0.86).

The devices were placed in the main kitchen at least 1meter away from the edge of the stove (to prevent from damaging as the devices cannot tolerate extreme temperatures and to represent the general cooking area), at a height of 1.5 meters above the floor (the approximate breathing height of standing women),1.5 meters away from doors, windows, and other openings horizontally (minimize ambient air entering the room) (IAPT, 2005), and at a safe location to minimize the risk of interrupting normal household activities or being disturbed (Figure 24). The air monitors were attached to a wall or suspended from the ceiling and run for 24 hours to consider households' typical daily cooking activities. Four PATS+ devices were distributed daily across four different households. For step-by-step guidance on indoor air sampling using PATS+, please refer the standard operation procedure manual (UCB, 2016). Kitchen PM2.5 concentrations was measured twice: once at baseline and again a month after installing the improved stoves. A waiting period of at least three weeks is recommended between distribution and follow-up measurements to allow users to adapt to the new technology (Garland et al., 2016).



Figure 24: Air monitor placement in rural households kitchens northwest Ethiopia

4.2.4 Data quality

Before conducting the analysis, a series of quality assurance and data cleaning measures were implemented. Field workers underwent training on the operation of sampling equipment (PATS+ and Dylos DC1700), using a comprehensive manual with visual aids developed by the Berkeley Air Monitoring Group (UCB, 2016). The standard operating procedures for installing indoor air monitoring instruments in a home (IAPT, 2005) in collecting kitchen air samples were strictly followed. To ensure that each 24-hour period was representative (to capture a typical number of events), measurements of PM2.5 concentrations were removed from analysis when the total sampling time was shorter than 20-hours.

From previous study, the validation of PATS+ against gravimetric(gold standard method) samples in Ethiopian settings revealed a strong linear correlation ($r^2 > 0.90$) (Bluffstone et al., 2019). Additionally, side-by-side inter-comparison tests among PATS+ and DylosDC1700 air monitoring devices were conducted. Before and after deployment in the kitchens, all PATS+ devices were zeroed in a plastic bag for 10 minutes. Relative humidity levels in the study area were recorded between 53 to 61%, and this value was deemed unlikely to impact readings by more than 5% according to previously reported literature (Wang et al., 2016).

To minimize the impact of dust on PM2.5 concentrations, participants were advised not to clean the kitchen and its surroundings during the air sampling period. Furthermore, the kitchen air

monitoring was carried out a month after stove installation under similar climatic conditions to those during the monitoring of traditional open-fire stoves to prevent seasonal variations of kitchen air quality due to differences on fuel type, cooking behavior and other factors as recommended to conduct the before-and-after sections of the study in the same season (Edwards et al., 2007). To ensure consistent data collection, if households were baking Injera on the baseline visit, we scheduled the post-intervention measurement to coincide with another Injera baking day. Because, Injera baking is a distinct cooking practice, characterized by unique cooking styles and high fuel consumption (accounting for over half of household energy use). This distinct practice is expected to significantly impact household air pollution (HAP) levels and potentially influence the overall effectiveness of the intervention.

4.2.5 Data analysis

Descriptive statistics, including frequencies and percentages for categorical variables and mean and standard deviation for continuous variables, were calculated and presented using tables. Baseline household characteristics of control and intervention groups were compared using parameters describing maternal age, family size, kitchen area, average time spent in the kitchen, types of kitchen roof, Injera baking event, frequency of cooking per day, fuel types, and asset index. These factors are likely to influence kitchen PM2.5 concentrations.

Data from the PATS+ air monitor was downloaded in electronic form using the platform for integrated cook stove assessment (PICA) software to the computer with CSV format Excel spreadsheets and text files. The 24-hour averages concentrations were calculated for valid measurements of kitchen PM2.5 concentrations in control and intervention groups by measurement phases (baseline and post-intervention).

To evaluate the effectiveness of the intervention stove in reducing kitchen PM2.5 concentrations, we compared changes in kitchen PM2.5 concentrations between baseline and post-intervention measurements within the intervention and control groups. As the air monitors were not calibrated for this specific study, we focused on relative rather than absolute differences to estimate intervention effectiveness. However, absolute differences are also reported for context. To account for the numerous factors influencing stove effectiveness within and between homes over time, we conducted three distinct analyses to assess the intervention stove's impact on kitchen

PM2.5 concentrations. Each approach addressed different sources of variation and provided complementary insights.

Paired (Before-After) Analysis: This approach focuses on changes within each household by calculating the individual difference ($\Delta PM_{2.5}$) between baseline and post-intervention PM2.5 levels. Percentage change ($\%\Delta PM_{2.5}$) is calculated for each group as: (post-intervention concentration - baseline concentration) divided by baseline concentration. This method aims to control for inherent variations between households, such as kitchen size or cooking habits.

Between-Group Comparison: This approach compares PM2.5 concentrations between the intervention and control groups during the post-intervention period. The main parameter of interest for this approach is time variation for measurements. It essentially examines the difference ($\Delta PM_{2.5}$) between the average PM2.5 levels in the intervention group versus the control group after the intervention. ΔPM2.5 in this approach is calculated as: (post-intervention concentration for intervention group - post-intervention concentration for control group) divided by post-intervention concentration for control group. This method focuses on the overall intervention effect on PM2.5 levels across all participating households.

Difference-in-Differences Analysis: This approach considers the differential changes in PM2.5 levels between the intervention and control groups over time. It estimates the change in PM2.5 concentrations within the intervention group relative to any changes observed in the control group. ΔPM2.5 here is calculated as: post-intervention concentration - baseline concentration for intervention group - post-intervention concentration - baseline concentration for control group divided by Post-intervention concentration for control group. This method isolates the specific impact of the intervention by accounting for potential changes in PM2.5 levels that might have occurred in both groups regardless of the intervention. For all three approaches, the percentage change was determined by multiplying ΔPM2.5 by 100.

Normality assessments indicated our data was approximately normally distributed in terms of skewness 0.276 (SE=0.264) and kurtosis of −0.738 (SE=0.523) fell within acceptable ranges for normality. While the Shapiro-Wilk test p-value (0.05) was marginally significant, visual inspection of histograms and boxplots further supported the approximate normality assumption. Therefore,

assuming that the average kitchen PM2.5 concentrations are approximately normally distributed in each of the two groups, then we used the average concentration for the summary measure and the relative difference in the average concentration scores between the two groups for the comparative summary measure as recommended (Twisk, 2021). Differences in PM2.5 levels between control and intervention groups were evaluated using three distinct statistical models, including independent sample t-tests for comparing intervention and control groups at baseline, paired sample t-tests for evaluating within-group changes, and one-way analysis of variance for examining effects across multiple comparison groups. Data were analyzed using SPSS software for windows (v.24.0).

4.3 Results

4.3.1 Baseline characteristics

As illustrated in Table 6, the average age of participants was 28.7 years (29.3 years for intervention and 28.2 years for control group). Nearly two-third, 54 (63%) of participants reported being unable to read and write. Cooking fuel choices offered a glimpse into household energy resources: 41% relied on a combination of firewood and cow dung, while 33% used firewood exclusively. Corrugated iron sheets dominated kitchen roofing, present in a substantial 77% of households. Daily cooking routines revealed a significant time commitment, averaging 3 hours per day. No statistically significant differences were observed in any baseline characteristics between the intervention and control groups, suggesting minimal selection bias and a strong foundation for unbiased comparisons of intervention effects.

Table 6: Baseline characteristics and group balance among pregnant women in a South Gondar Zone, Northwest Ethiopia

Characteristics	Overall	Control	Intervention	P-value*
Mean kitchen PM2.5 con, µg/m3 , (mean ± SD)	406 ± 221	482 ± 192	405 ± 248	. 144
Maternal age, years (mean ± SD)*	28.7 ± 5.3	28.2 ± 5.1	29.3 ± 5.5	. 344
family size, (mean ± SD)	4.5 ± 1.4	4.5 ±1.4	4.5±1.3	. 940
Kitchen area (m^2), (mean ± SD)	16.6 ± 3.4	16.6±3.0	16.5±3.6	. 874
Time spent in the kitchen, hours, (mean ± SD)	2.8 ± 0.9	2.8±0.8	2.7±0.9	. 602
Humidity (RH) (mean+SD)	60.2 ± 3.8	60.3±4.0	60.1±3.6	.779
Temperature (T^0), (mean, SD)	18.7± 2.6	18.4±2.5	19.0±2.5	.299
Educational status, n (%)				
illiterate	54 (62.8)	29 (67.4)	25 (62.8)	.090
read and write only	22 (25.6)	7 (16.3)	15 (25.6)	
primary(1-8 grade)	10 (11.6)	7 (16.3)	3 (11.6)	
Types of kitchen roof, n (%)				

corrugated iron sheet	66 (76.7)	31 (72.1)	35 (81.4)	.310
thatched roof	20 (23.3)	12 (27.9)	8 (18.6)	
Fuel types for cooking, n(%)				
firewood	28 (32.6)	14 (32.6)	14 (32.6)	.739
cow dung	14 (16.3)	7 (16.3)	7 (16.3)	
agricultural residues	9 (10.5)	3 (7.0)	6 (14.0)	
mixed fuels	35 (40.7)	19 (44.2)	16 (37.2)	
Types of fuel used for firing, n(%)				
dried leaves	23 (35.4)	11(31.4)	12 (40.0)	.715
straw/grass	20 (30.8)	10 (28.6)	10 (33.3)	
papers	13 (20.0)	8 (22.9)	5 (16.7)	
kerosene	9 (13.8)	6 (17.1)	3 (10.0)	
Baking Injera during monitoring , n(%)				
yes	29 (33.7)	13 (30.2)	16 (37.2)	.494
no	57 (66.3)	30 (69.8)	27 (62.8)	
Asset index				
low	40	19 (46.3)	21 (48.8)	.931
medium	23	11 (26.8)	12 (27.9)	
high	21	11 (26.8)	10 (23.3)	

*Intervention and control groups compared using $\chi 2$ tests for categorical variables and independent sample t-test for continuous variables

4.3.2 Kitchen PM2.5 concentrations

A total of 172 air quality measurements were conducted across 86 households (43 in the control group and 43 in the intervention group) in two rounds. Usable data was obtained from 98% of the households. Four measurements were excluded from the analysis for the following reasons: I) one air monitor was moved from the kitchen to the main house by a participant to prevent theft. II) another air monitor was covered with cloth by a participant to protect it from tampering by children. III) the third air monitor from the baseline measurement was discarded due to an insufficient sampling period (18 hours) and IV) one post-intervention measurement was discarded due to the absence of cooking activity in the kitchen during the entire 24-hour monitoring period.

Based on the analysis of the valid baseline measurement, the average 24-hour kitchen PM2.5 concentrations were 482 μg/m^3 (95% CI: 408, 557) for the control and 405 μg/m3 (95% CI: 318, 492) for the intervention groups. These average PM2.5 concentrations significantly exceed the WHO's 24-hour guideline limit of 15 μg/m³, and even surpass the most relaxed interim target of 75 μg/m³ (WHO, 2021a), indicating the severity of kitchen air pollution levels in the rural

kitchen under study. Interim targets are provided for countries with very high air pollution levels to encourage gradual improvements in air quality (Bruce et al., 2015).

Despite remaining elevated at 449 μg/m^3 (95% CI: 401, 496) in the control group, PM2.5 concentrations reduced to 104 μg/m^3 (95% CI: 90, 118) in the intervention group after replacement of the traditional stove with chimney fitted Mirt stove, indicating a significant reduction. Unfortunately, even with this reduction, both groups still surpassed the recommended WHO's safe limit indicating the need for further improvements on the intervention stove.

Table 7: The average kitchen concentration of PM2.5 before and after stove intervention by study arms

Measurement	Category	Minimum	Maximum	Mean	SD	Median	IQR
Baseline , μg/m^3	Control	82	971	482	±235	504	361
	Intervention	56	995	405	±229	370	416
End line , μg/m^3	Control	180	896	449	±149	447	167
	Intervention	31	183	104	±44	100	79

4.3.3 Daily variability in concentrations

When examining the daily variability in concentrations from baseline to post-intervention measurements, considerable and consistent declines in kitchen PM2.5 concentrations became apparent (Figure 25). Even during peak cooking hours, the average kitchen PM2.5 concentrations were higher during baseline measurements compared to the intervention phase. Moreover, there also seemed to be a reduction in the total count and duration of elevated kitchen area concentration events during the monitoring conducted after the improved stove intervention. The high PM2.5 readings matched cooking times, showing cooking is a major source of air pollution in the kitchen.

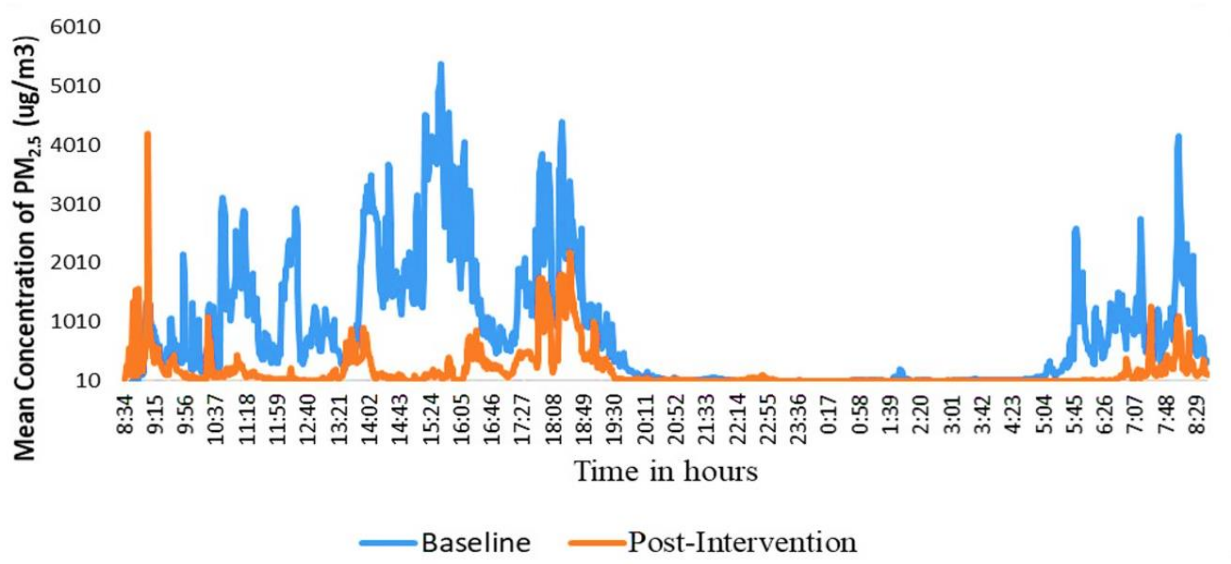


Figure 25: Kitchen area PM2.5 concentrations by the minute of a days at baseline and post-intervention samples for intervention groups

4.3.4 Intervention effectiveness

To effectively explain the intervention effectiveness, visuall comparision was done using the box plots for both groups at baseline and post intervention measurments. This visual comparison highlights the changes in the distribution of PM2.5 concentrations over time and the differential impact of the intervention. Accordingly, box plot analysis indicates a positive impact of the intervention on reducing PM2.5 concentrations, as evidenced by lower median and overall distribution at post intervention compared to baseline. The intervention group exhibited reduced variability in PM2.5 levels, suggesting a more consistent effect. The box plot for the intervention group demonstrates a significant reduction in median PM2.5 levels, a decreased range (narrower box), and lower variability (shorter whiskers) from baseline to post-intervention, while the control group exhibits minimal change, strongly supporting the intervention's effectiveness in reducing PM2.5 concentrations (Figure 26). The non-overlapping boxes between the intervention and control group further suggests a pronounced effect of the intervention

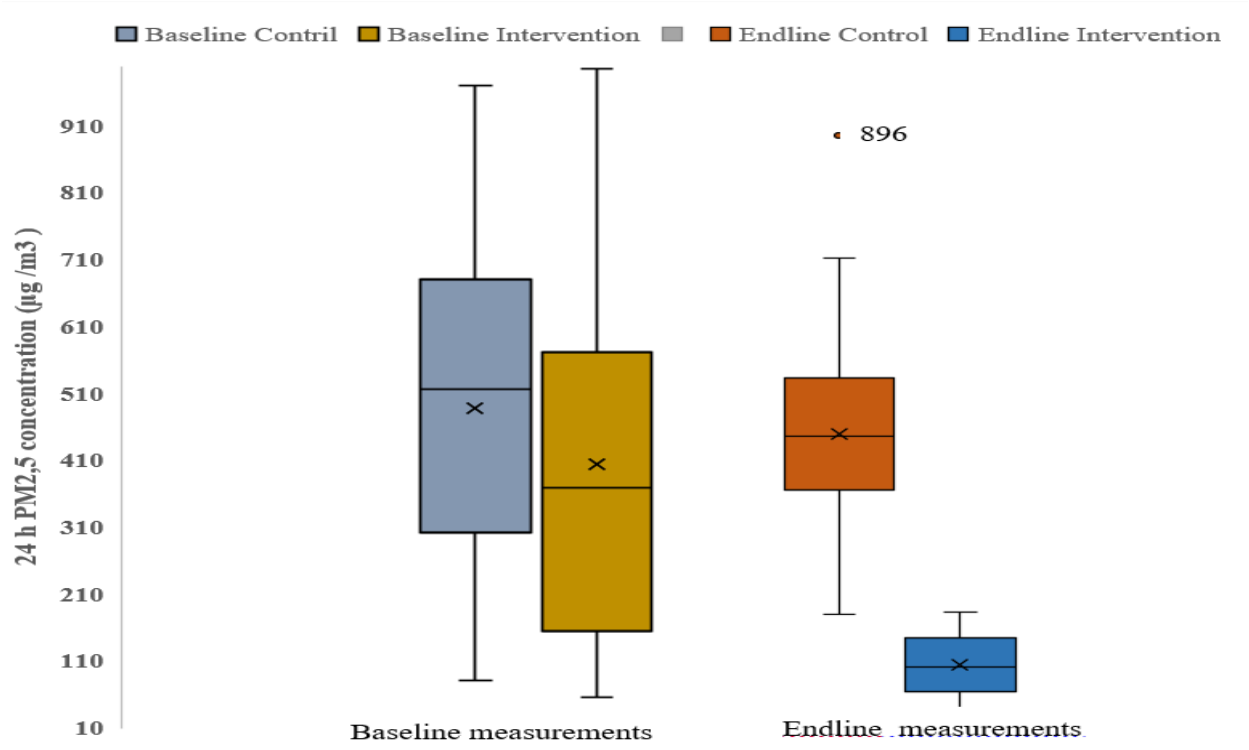


Figure 26: Box and whisker plots of 24-hour PM2.5 concentrations for a control and intervention group at baseline and post intervention measurements. The box represents the interquartile range, with the median marked by a horizontal line and the mean indicated by an '**x**'. The whiskers extend to the 10th and 90th percentiles. Due to exceptionally high PM2.5 levels in the end line for control group, the upper whisker is not shown to scale and is instead represented numerically.

In addition to visual comparison, statistical analysis was done to estimate the effectiveness of the intervention stove in reducing kitchen PM2.5 concentrations. The following three approaches were used to control different factors that might influence the effectiveness of the intervention stove.

a) Before and after comparison

In this approach, only paired measurements obtained from the same households before and after the intervention were used to assess the relative reduction of PM2.5 due to the improved stoves. Data from both the control and intervention groups were analyzed separately to compare post-intervention with baseline measurements. The baseline average kitchen PM2.5 levels were 482 $\mu g/m^3$ in the control group and 405 $\mu g/m^3$ in the intervention group. Whereas, the post-intervention average kitchen PM2.5 concentrations were 449 $\mu g/m^3$ in the control group and 104 $\mu g/m^3$ in the intervention group. Hence, the percent reduction in the average kitchen PM2.5 concentrations between the traditional stove and improved stove was 74% (95% CI: 71, 76%

lower) in the intervention group, while the control group exhibited a minimal reduction of 7% (95% CI: 2, 11% lower).

Paired sample t-tests analysis revealed a significant difference in average PM2.5 concentrations between baseline and post-intervention measurements in the intervention group. The average reduction of 300 μg/m³ (95% CI: 213, 387) was statistically significant ($t = 6.97$, $p < .001$). However, no statistically significant difference was found in the control group ($t = .65$, $p = .512$), with an average reduction of 33 μg/m³ (95% CI: 44, 111) (Figure 27A).

b) Between-group comparison

In this analysis, a comparison of post-intervention kitchen PM2.5 concentrations across study arms was conducted to assess the intervention's effectiveness. The intervention stove significantly reduced the average PM2.5 concentrations by 76% (95% CI: 67, 78%). This difference in post-intervention concentrations, as illustrated in (Figure 27B), was confirmed by an independent samples t-test, which revealed a statistically significant difference in post-intervention average kitchen PM2.5 concentrations between the control and intervention groups ($t = 13.53$, $p < .001$). This substantial average difference of 345 μg/m3 (95% CI: 295, 399) provides robust evidence for the effectiveness of the intervention in lowering kitchen air pollution levels.

c) Difference - in-difference comparisons

This analysis is used to estimate the changes in kitchen PM2.5 concentrations in the intervention arm (baseline versus post-intervention), relative to any changes experienced in the control arm over the same period. Compared to the control group, the intervention group experienced a 68% reduction (95% CI: 40, 87%) in PM2.5 concentrations. This translates to an estimated absolute reduction of 267 $\mu g/m^3$ (95% CI: 151, 382 $\mu g/m^3$ lower) attributable to the improved stoves, a difference statistically confirmed by a t-test ($t = 4.3$, $p < .001$) (Figure 27C).

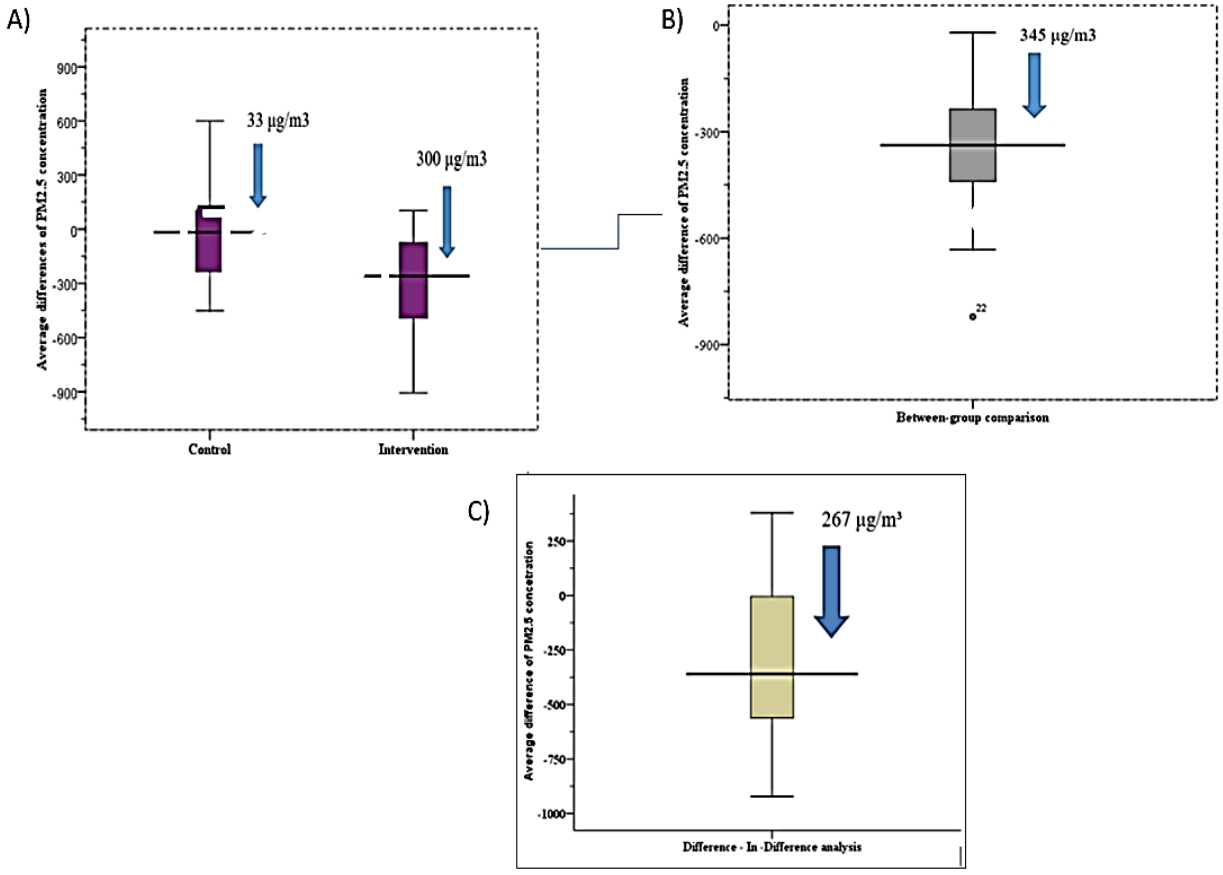


Figure 27: The average reduction in kitchen PM2.5 concentrations after using improved stoves using before and after analysis (A), between-group comparison (B) and difference -in – difference analysis (C)

4.3.5 Subgroup analysis

This study demonstrated a significant overall reduction in PM2.5 levels following the implementation of chimney-fitted Mirt stoves. A subgroup analysis revealed subtle variations in effectiveness, ranging from 73% to 81% percentage reduction. The absolute unadjusted reduction ranged from 103 to 478 µg/m³, while the adjusted reduction (adjusted for baseline PM2.5) ranged from 128 to 394 µg/m³. The greatest adjusted reduction, 394 µg/m³ (95% CI: 134, 654), was observed among pregnant women with primary education, suggesting a potential interaction between educational background and stove utilization. Additionally, smaller family size and larger kitchen areas were associated with higher reduction rates. These findings, detailed in Table 8, highlight the importance of considering various factors when implementing improved stove interventions to maximize their impact.

Table 8: The effect of improved stove use on kitchen PM2.5 concentrations, northwest Ethiopia

Categories	Average concentration of PM2.5 (95% CI) µg/m3				Average difference (95% CI) µg/m3	
	Control		Intervention		Crude[a]	Adjusted[b]
	before	**after**	**before**	**after**		
Overall (DID)	482 [408,557]	449 [401, 496]	405 [318,492]	104 [91, 118]	267 [151, 382]	275 [49, 376]
Educational status						
can't read & write	489 [396,581]	461 [409,512]	401[288,512]	110 [91,130]	284 [138,431]	286 [164, 409]
read & write only	504 [236,773]	441 [224,658]	454 [-321, 412]	85 [72, 97]	109 [-209, 428]	128 [-111, 368]
primary (1-8) grade	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]
corrugated iron sheet	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]
fuel types for cooking						
firewood	454 [311, 596]	418[318, 519]	346 [215, 477]	109 [82,136]	291[81, 500]	266 [97, 435]
cow dung	513 [329, 697]	488 [379, 597]	371 [72, 670]	119 [84,153]	300 [90, 511]	322 [76, 569]
agricultural	231[-139,602]	403 [292,514]	243[52, 433]	86 [45,127]	478 [237, 720]	338 [-55, 731]
mixed fuel	590 [453, 727]	450 [358, 541]	589 [379, 798]	99 [73,126]	103 [-143, 351]	169 [-33, 373]
additional fuel as fire starter						
yes	451[371, 531]	424 [373,476]	446 [345, 547]	99 [83,115]	300 [182, 418]	278 [164,391]
no	635 [434, 837]	566 [484,649]	313 [133, 492]	115 [86,144]	156 [-232, 546]	262 [125, 517]
window/door opening						
yes	381 [278, 484]	451[374, 528]	278 [181, 376]	90 [69, 110]	387 [236, 537]	331 [174, 488]
no	634 [197, 107]	472 [189, 756]	439 [221, 657]	103 [45, 161]	298 [-390, 986]	392 [57, 727]

[a] Estimated reduction in PM2.5 concentration using the difference-in-differences (DID) method between the study arms

[b] Adjusted for baseline PM2.5 concentrations and all reductions are statistically significant ($p < .05$)

4.4 Discussion

This study investigated the impact of chimney-fitted Mirt stoves on PM2.5 concentrations in kitchens of rural households with pregnant women in south Gondar zone, northwest Ethiopia. The study is among the few in rural Ethiopia to quantify PM2.5 concentrations using small light scattering air monitors (Adane et al., 2021a, Tamire et al., 2021, Bluffstone et al., 2019). By employing robust methodology and controlled conditions, we aimed to provide reliable data on the stove's effectiveness in reducing indoor air pollution. Our findings contribute to the limited body of research on PM2.5 in rural Ethiopia, offering valuable insights for policy makers and public health interventions.

Baseline kitchen PM2.5 concentrations were alarmingly high, exceeding both the WHO's 24-hour standard (15 $\mu g/m^3$) and the most flexible interim target (IT-I) of 75 $\mu g/m^3$ (WHO, 2021b) which can put pregnant women at greater risk and contribute to poor pregnancy outcomes. This result is approximately comparable to those reported in previous studies in Ethiopia (Bluffstone et al., 2019, Tamire et al., 2021, Pennise et al., 2009, Embiale et al., 2021) and other studies conducted out of Ethiopia (Hill et al., 2015, Pennise et al., 2009). The estimated pooled average concentration from a systematic review and meta-analysis in Ethiopia also reported almost similar results (Asefa and Mergia, 2022). Since a significant number of the Ethiopian population cooking for a long period using polluting fuels in small poorly ventilated kitchens in rural area, these high-level PM2.5 concentration reports are expected (CSA, 2016).

In this study, participants in the control group faced persistent exposure to high PM2.5 levels (449 $\mu g/m^3$) even after the intervention period. However, the intervention group experienced a dramatic improvement, with PM2.5 concentrations dropping to 104 $\mu g/m^3$. Based on the paired comparisons among intervention groups from before and after model showed an overall reduction of 74% kitchen area 24-hour PM2.5 concentrations. This reduction aligns with the effectiveness seen in other improved stove and energy interventions across various countries, including an 84% reduction for ethanol stove in Ethiopia (Pennise et al., 2009), 79% reduction for Bondhu Chula stove in rural Bangladesh (Zaman et al., 2017), 71% reductions for Patsari stoves in rural Mexico (Zuk et al., 2007), 68% reduction for LPG in a multicounty study (Guatemala, India, Peru, and Rwanda) (Johnson et al., 2022a), 73% reduction for African Clean Energy (ACE-1) stove in rural Lao (Hill et al., 2015), 63 % reduction for Pothole mud improved

cook stove in rural Nepal (Singh et al., 2012a) and 73% reduction for Justa stove in Hondurans (Clark et al., 2009). While moderate, 49% reduction was reported from Bhagyalaxmi stove in India (Dutta et al., 2007) , 52% reduction for Gyapa wood stove in Ghana (Pennise et al., 2009) and 43% lower for chimney stoves in Peru (Hartinger et al., 2013). However, a study in Malawi reported a null effect, with no significant difference in PM2.5 concentrations before and after the intervention (Saleh et al., 2022).

Based on the second approach (between-group comparison), the average post-intervention kitchen PM2.5 concentrations of the intervention arm were decreased by 76% in comparison with the control arm. Despite the complexities arising from the use of various intervention technologies, indoor air monitors, and summary metrics, our results align with the significant reductions observed in previous studies (UN, 2021, Quansah et al., 2015, Woolley et al., 2022b). Rural Indian households with improved chimney stoves saw a 66% reduction compared to those without (Islam et al., 2022b)**,** and LPG interventions in multicounty study achieved a 61% reduction (Johnson et al., 2022a). Notably, our findings surpass the 58% reduction reported in a similar Ethiopian study (Adane et al., 2021a) , 64 % reduction for who bake Injera in their main living areas (Bluffstone et al., 2019) and are lower than clean cook ethanol stove interventions averaging 84% reduction (Pennise et al., 2009). Relatively small reduction, 32% was reported in rural Nepal (Katz et al., 2020). While the improved stoves led to a decrease in PM2.5 concentrations, these levels still exceeded the WHO's recommended standards (WHO, 2014a, WHO, 2021b).

A difference-in-differences analysis also revealed a 68% reduction in PM2.5 concentrations in the treatment group compared to the control group during the post-intervention period. This result is nearly consistent with study reports from rural India at 66% reduction (Islam et al., 2022b) and 62% reduction for LPG interventional studies conducted in multicounty study (Johnson et al., 2022a). Previous studies have linked improved stoves resulted in significant reductions in PM2.5 concentrations in the kitchen areas which ranged from 20–80% (Sharma and Jain, 2019).

In our subgroup analysis, we found the largest PM2.5 reductions among women with primary education, kitchen area exceeding 16 square meters, families with less than 5 occupants, and

during periods when Injera was baked. Similarly, in Guatemala, LPG stoves worked better for women with better education, while chimney stoves benefited those with less educated (Grajeda et al., 2020). The possible reason might be, in rural Ethiopia, improved stoves appears to be the only advanced technology and preferred option among more educated women (Eshetu, 2014, Ganewo et al., 2023, Bersisa et al., 2021b), while in Guatemala, LPG takes the top spot, with the chimney fitted improved stove serving as a secondary choice for less educated women. Based on evidence reported from India, kitchen enclosure was also contributed to the high reduction of PM2.5 (Sharma and Jain, 2019). Previous Ethiopian study have revealed that Mirt stove was working better for those who bake Injera in their main living areas, have lower income, live in remote rural areas, use less preferred fuels (Bluffstone et al., 2019). Because, households with lower incomes and living in remote rural area might have fewer options for fuel and stoves, making the Mirt stove a more attractive and accessible choice and households using lower-quality fuels might benefit more from the improved combustion efficiency of the Mirt stove. Additionally, households that used the Mirt stove for multiple cooking purposes and baked Injera more frequently experienced greater reductions in PM2.5 concentrations compared to the control group (Adane et al., 2021a). Furthermore, education, wealth, and other sociodemographic factors have been shown to influence both the adoption and effectiveness of improved stoves (Mamuye et al., 2018, Gizachew and Tolera, 2018, Pennise et al., 2009).

The effectiveness of improved stove or clean energy interventions in reducing PM2.5 remains shrouded in uncertainty, with diverse factors potentially influencing their success (Thomas et al., 2015a, Quansah et al., 2017a). Multifaceted array of factors, including stove design, real-world performance, fuel type and its moisture content can influence PM2.5 reduction effort (Pilishvili et al., 2016). The absence of a chimney in the improved stove design appears to be a key factor contributing to the limited PM2.5 reduction (Asefa and Mergia, 2022, Kumar and MOUSTAFA, 2022, Reed and Bernstein, 2021). Cultural practices like type and number of meals, dish size, cooking frequency, cooking habits and preferences for specific fuel types, and traditional dishes, along with environmental factors like wind speed, direction, and seasonality, intricately weave the patterns of smoke dispersion and PM2.5 levels within kitchens (Woolley et al., 2022b, Gebremeskel Kanno and Hussen Kabthymer, 2021). The reported reduction values also vary due to differences in sample size, air monitoring devices, sampling periods, sampling locations, other

sources of air pollution, background levels of ambient air pollution and participants' living styles (Ajay Pillarisetti 2017, Grajeda et al., 2020, Pope et al., 2021a).

Despite the overall observed reductions, the average 24-hour PM2.5 kitchen area concentration was far greater than the WHO 24-h recommended safe standard and interim targets (Zhao et al., 2022). This evidence aligned with previously conducted systematic reviews and meta-analyses which concluded that though most of the improved cook stoves showed a reduction in harmful emission levels compared to the traditional three-stone fire, the concentrations were higher than the WHO-recommended safe levels (Pope et al., 2017a, Phillip et al., 2023a, Thomas et al., 2015b). Insufficient adoption and sustained use of improved stoves, coupled with the practice of using both traditional and improved stoves (stove stacking) and ongoing community-level pollution, contributed to the limited success of stove interventions in significantly reducing indoor air pollution and improving health outcomes (HEI, 2018, Quansah et al., 2017a).

However, for rural women battling the daily grind of cooking over traditional stove, chimney-fitted improved stoves offer a glimmer of hope (Hooper et al., 2018, Shankar et al., 2014, Adler, 2010). A kitchen chimney is more than just ventilation; it represents a significant investment in kitchen comfort, safety, cleanliness, and environmental and financial well-being. (WHO, 2018a, Negash et al., 2021). Even a partial reduction is a significant improvement over the hazardous levels generated by open fires (Zaman et al., 2017, van Gemert et al., 2019, Binaya et al., 2017). Several studies have demonstrated the potential for reducing harmful exposures, suggesting significant public health benefits could be achieved through widespread adoption of cleaner fuels and energy sources if implementation challenges can be overcome (HEI, 2018). The chimney stove reduces fuel consumption that translates to cost savings, less time spent gathering firewood, and a lighter burden on women's already taxed shoulders (Negash et al., 2021, Anenberg et al., 2013). Chimney stoves shield users from open fire's intense heat, creating a safer, cooler kitchen especially for pregnant women and children (Liu et al., 2019a). While acknowledging that these improved stoves may not completely eliminate health risks, they substantially reduce indoor air pollution. Continued investment and focus on clean cooking solutions are essential to further improve health outcomes (Putti et al., 2015).

4.5 Conclusion

Pregnant women in the study area faced dangerously high levels of PM2.5 while cooking in their kitchens. The intervention stove significantly reduced kitchen PM2.5 concentrations, offering a crucial step towards a healthier cooking environment. While further improvements are needed to reach WHO's recommended safe levels, this study highlights the potential of improved stoves to mitigate household air pollution and potentially improve maternal and infant health outcomes.

To maximize intervention effectiveness, future efforts should incorporate multipurpose stoves, target specific community contexts, and implement community-level interventions. Engaging communities in the design and implementation of stove interventions can further increase their effectiveness and sustainability. Additionally, research exploring targeted interventions for households with lower PM2.5 reduction rates could optimize the overall impact of improved stove technology in achieving clean air environments. Encouraging local small-scale enterprises to develop more efficient and multipurpose stoves suited to community needs could also play a vital role in promoting widespread adoption of clean cooking practices.

Chapter 5

Effect of Chimney-Fitted Improved Stove on Pregnancy Outcomes in Northwest Ethiopia: A Randomized Controlled Trial

RESEARCH Open Access

Effect of a chimney-fitted improved stove on pregnancy outcomes in Northwest Ethiopia: a randomized controlled trial

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Abstract

Background: Pregnancy is a particularly sensitive period during which chemical exposure can lead to various birth complications. A growing body of research suggests a strong association between household indoor air pollution generated by cooking fires and negative health consequences for newborns, particularly low birth weight, in resource-limited settings. Improved stoves have been implemented to address fuel and health related concern. However, the effectiveness of various stove interventions in reducing kitchen smoke and subsequently improving pregnancy outcomes remains unclear in Ethiopia.

Method: Individually randomized stove replacement trial was conducted among 422 households in six low-income rural kebeles of Northwestern Ethiopia. Pregnant women without known health conditions were recruited at ≤ 24 weeks of gestation and randomized to an intervention or control group with equal allocation ratio. A baseline survey was conducted and analyzed to ensure the comparability of the intervention groups. Two-sided independent samples t-test for continuous outcomes and chi-square for categorical variables were used to compare the effect of the intervention between the groups. Mean differences with 95% confidence intervals were calculated and a p-value of <0.05 was considered statistically significant.

Result: The average birth weight was 3065 grams (with a variation of 453 grams), which was not statistically different from the average weight of 2,995 grams (with a variation of 541 grams) seen in the control group. Infants born to mothers who used the intervention stove weighed, on average, 69 grams more (95%CI: -31 to 170) than those whose mothers relied on traditional stove. However, the difference was not statistically significant (P = .153). After adjusting for maternal age, daily dietary intake, educational status, prior pregnancies and body mass index, the adjusted difference was decreased to 55 grams (95% CI: -43, 153) and still lacking statistical significance (p = 0.274). The respective percentages for low birth weight were 8% and 10.3% for intervention and control groups respectively (P = 0.346). However, babies born to mothers in the intervention group delivered on average nearly one week later (38 weeks) compared to the control group (36.5 weeks). This difference of 0.91 weeks was statistically significant (95% CI: 0.52 to 1.30 weeks; p < 0.001). The corresponding difference in risk ratio for preterm birth is 0.94 (95% CI:0.92 to 0.97; p< 0.001). The percentages for maternal complications, stillbirth, and miscarriage in the intervention group were not statistically different from the control group.

Conclusions: This study found that babies born to mothers using improved stoves had a statistically significant longer gestational age on average (nearly one week), compared to the control group. However, the study did not find a significant impact on birth weight or other pregnancy outcomes like stillbirth, miscarriage, or maternal complications.

Keywords: Improved stove, intervention, randomized control trial, low birth weight, preterm birth, stillbirth, Ethiopia

5.1 Background

Pregnancy is the foundation for a healthy life, shaping a baby's well-being for years to come (Lacagnina, 2019, Barnes et al., 2016). A healthy pregnancy with good food, enough rest, regular checkups, and a clean environment is key to a thriving baby (WHO, 2019d). Being exposed to toxic chemicals in the womb can raise the risk of problems with development, health problems as an adult, and even for future generations (Stillerman et al., 2008). Because human bodies are most sensitive to damage during the early stages when different parts are forming, if something harmful enters the body during this critical time, it can cause more serious problems (Lacagnina, 2019, Gluckman and Hanson, 2006). Fetuses are particularly vulnerable to environmental pollutants due to rapid development and metabolic changes (Mulenga et al., 2018, Olsson, 2014). The problem is especially significant in low- and middle-income countries where pregnant

women face heightened exposure to hazardous environments (Demelash et al., 2023, Gómez-Roig et al., 2021).

One of the most common environmental dangers for pregnant women and their fetus in rural household of low and middle income countries is air pollution inside their homes due to biomass fuel use for cooking (Siddharthan et al., 2018, Ye, 2021, Enyew et al., 2023). Burning of polluting biomass fuels like wood, dung, and charcoal using inefficient traditional stoves emit smoke that can harm human bodies in many ways leading to a variety of health problems, including adverse pregnancy outcomes (Franklin et al., 2019, Kanno et al., 2021, Luo et al., 2023) and impairing cognitive function (NAS, 2020, Cipriani et al., 2018). Pollutants including PM2.5 can be absorbed into the maternal blood stream and potentially affecting fetal growth by directly crossing the placenta (Chiarello et al., 2023).

Emerging epidemiological evidences indicate associations between HAP and detrimental pregnancy outcomes (Lee et al., 2020a, Tipre et al., 2018, Weber et al., 2020) encompassing conditions such as low birth weight (LBW), pre-term birth (PTB), congenital anomalies (Demelash Enyew et al., 2023, WHO, 2007) and post-neonatal infant mortality (Palma et al., 2019). These birth outcomes are also known to have implications for later health status during childhood and adulthood (Lee et al., 2020a, Olsson, 2014, Tipre et al., 2018). A meta-regression analysis estimated that in 2019, PM2.5 in household air pollution contributed to over 3.9 million preterm births and 1.8 million low birth weight infants globally, a factor in approximately 910,000 child deaths under five years old that same year (Ghosh et al., 2021).

Several successful intervention efforts have focused on providing pregnant women with vaccinations, insecticide-treated bed nets distribution, nutritional interventions, anthelmintic therapy, and treatment of specific infections and these interventions can significantly improve maternal and fetal health (Zavala et al., 2022). In addition, the significant adverse effects of biomass fuels on birth outcomes underscore the need for additional diverse intervention strategies (Bruce et al., 2015, Thomas et al., 2015a) and distributing improved stoves is a top priority for effecting a safe transition to cleaner cooking in impoverished rural African settings (Dagnachew et al., 2019). Studies suggest that interventions delivered during critical windows of fetal development, particularly during the second trimester (Yang et al., 2023), early pregnancy

(Kaali et al., 2023a), early pregnancy to late first trimester (Miron-Celis et al., 2023) can demonstrably improve birth weight and other health outcomes for babies. Furthermore, improved stoves are expected to be a major driver of advancing sustainable development goals (WHO, 2016b). This has led to the implementation of various types of improved stoves in different parts of Ethiopia over time (Kedir et al., 2019, Tadesse, 2020).

While numerous improved stove designs have been implemented to address household air pollution related issues, rigorous testing to evaluate the effectiveness of these specific intervention stoves on pregnancy outcomes remains limited (Alexander et al., 2018, Grajeda et al., 2020). In Ethiopia, only two randomized controlled trials have been done specifically examining the impact of improved stoves on indoor air quality and childhood respiratory illness (Adane et al., 2020b, LaFave et al., 2021). Both studies implemented Mirt stove without chimney which is deliberately designed for Injera preparation. These findings, like the many prior studies in different part of the world, once again leave us asking why improved stove interventions do not appear to improve health since the trials did not yield a significant decrease in the occurrence of acute respiratory infections (Adane et al., 2020b). But, improvement was reported in child growth (LaFave et al., 2021) and in reducing the concentration of PM2.5 compared to the traditional stove (Adane et al., 2020b).

Efficient combustion and smoke removal is a cornerstone of improved stoves, often achieved through combustion chambers and chimney respectively (Grajeda et al., 2020, Adem and Ambie, 2017, Tadesse, 2020). Though, chimney-equipped Mirt stoves show promise in reducing significantly high levels of kitchen air pollution and potentially improving health outcomes, robust evidence from randomized controlled trials to evaluate the impact on pregnancy outcomes remains scarce in Ethiopia. This study addresses this critical gap by investigating whether introducing chimney fitted Mirt stoves during the first or second trimester of pregnancy can significantly improve fetal outcomes, particularly newborn weight, a key indicator of infant health (Ma et al., 2024).

5.2 Methods and materials

5.2.1 Variable definitions and measurements

This section provides operational definitions for the outcome variables used to measure the intervention effectiveness and potential confounders believed to influence both the outcomes and the intervention itself. These definitions specify how all these variables were measured.

Birth Weight: Birth weight is defined as the first weight of a newborn baby, measured within 48 hours of birth (ideally 24 hours) (Cutland et al., 2017). For all institutional delivery, birth weights were measured and recorded by midwives who took sensitization training on measuring and recording at the health centers. The newborn's weight was then recorded along with a unique identifier for the mother to link it to baseline data and facilitate future follow-up. For home deliveries, a field worker who took intensive training measured the weight of the newborn babies using the same and a regularly calibrated portable digital scale (Dr. care digital baby weighing scale). To ensure timely weight measurement, a specific family member in each household was assigned to contact the data collectors via mobile phone immediately upon a birth. For households without mobile phones, arrangements were made to contact a designated neighbor with a mobile phone for delivery updates. This was done after discussing the appropriate neighbor with the respondent. However, practical challenges like delayed notification and remote locations necessitated considering weights measured up to 48 hours later. Sometimes, measuring the weight of the newborns at the household level was carried out by measuring the mother's weight with and without the baby, and the difference was considered the newborn's weight. Birth weight was measured twice to the nearest gram and the average was taken. If the two weight measurements differ by more than 10 grams, then a third weight measurement was taken and the average of the two was recorded.

Low birth weight: This study also analyzes the proportion of newborns with low birth weight (LBW), defined as the weight of the new born baby < 2500 grams (WHO, 2007) in both intervention and control groups.

Gestational age: Gestational age (GA) refers to the length of pregnancy, calculated from the first day of the woman's last menstrual period (LMP) to a specific point in time. In this study, GA was estimated twice: at enrollment and at delivery. For enrollment, we used a combination of self-reported information and ultrasound data, when available. During our data collection period, a coinciding ultrasound screening campaign was happening in the South Gondar zone. This allowed us to utilize their results for GA estimation, after obtaining proper permissions.

Sometimes, health extension workers documented menstrual details only after having in-depth discussions with the pregnant women as menstruation was a sensitive topic in the study area.

Preterm birth: Births were classified as preterm if the gestational age at birth was less than 37 weeks and as term if the gestational age at birth was 37 weeks or more. Stillbirth refers to fetal demise after 28 weeks of pregnancy, while miscarriage denotes fetal loss before 28 weeks of pregnancy (WHO, 2007).

Fetal loss: It refers to the spontaneous termination of a pregnancy without a live birth, occurring before the end of labor. This definition excludes induced abortions, medical terminations of pregnancy, and ectopic pregnancies (Ballester and Iñiguez, 2011).

Maternal complications: These are conditions that include antepartum or postpartum hemorrhage, prolonged or obstructed labor, postpartum sepsis, complications of abortion, pre-eclampsia /eclampsia, and ruptured uterus. If one of these conditions occurs, we count it as a maternal complication.

Asset index: We assessed the socioeconomic status of the respondents in terms of asset index as recommended rather than using income or expenditure to characterize the respondents. Because it is less susceptible to short-term economic shocks and likely a better proxy of longer-term household wealth (Rutstein and Johnson, 2004). The detailed description of the methodology used to determine the socioeconomic status of the respondents is presented in chapter three of this document.

Dietary diversity score: Since woman's dietary intake is the proxy indicator for pregnancy outcomes, information on woman's minimum dietary diversity score (WDDs) was collected using the FAO guidelines (FAO, 2016b). The details are described in the general method section of this document.

Maternal body mass index: Maternal height and weight were measured upon enrollment to calculate the maternal body mass index (BMI) which is derived by dividing weight in kilograms by the square of height in meters (kg/m^2). Most of these measurements were taken at the health center or health posts during regular monthly meetings and ANC follow-up appointments. To ensure a wider participant pool, additional outreach and appointment scheduling efforts were undertaken.

Improved water source: Improved water sources are defined as those that are likely to be protected from outside contamination, and fecal matter in particular (WHO, 2022). In this study,

if the respondents reported protected dug wells, protected springs, and community standpipes as their main drinking water source, we considered as improved water sources.

Improved sanitation facilities: an improved sanitation facility is one that likely hygienically separates human excreta from human contact (WHO, 2022). In this study**,** pit latrines with slabs and/or cover were considered as improved sanitation facility.

5.2.2 Intervention

The intervention in this trial was replacing the traditional stoves that are used earlier in the enrolled pregnant womens' household in the intervention group with a locally sourced and chimney-fitted improved stove (locally named as 'Mirt Midija' which means best stove). With their husbands' consent and consultation with field workers, participants in the intervention group chose suitable spots in their kitchen for their new stoves. Trained local producers installed the Mirt stoves, moving from house to house in each Kebele within one month of randomization. The key features of the stove and its purpose are described in chapter two and Figure 19. Locally-produced improved stoves were offered at half-price to participants. Health extension workers and local health development army leaders promoted exclusive stove use and monitored conditions during their regular home visits. The stove's fuel efficiency and smoke reduction make it well-suited for the local community's needs, leading to high adoption rates.

5.2.3 Data collection procedures

Data collection in this particular study was multi-faceted and collaborative work. All baseline data, including kitchen types, cooking behaviors, household characteristics, sociodemographic information, medical and obstetric history, dietary diversity and household water and sanitation status were collected before randomization using face-to-face surveys and observation checklist for kitchen, housing and sanitation related data. Participants were then randomly allocated to either the intervention or control group. Throughout pregnancy, all recruited women were monitored through a combination of regular home visits, health checkups (including visits to health posts and health centers), and phone calls. This comprehensive approach allowed us to track their health condition and stove use.

As soon as participants went into labor, the assigned family members or neighbors called the field data collector or health extension worker for home delivery. After delivery, information on birth outcomes (birth weight and gestational age) and any pregnancy complications, including miscarriage was collected. As women were recruited at different stages of pregnancy, birth

weight measurement needed to be tracked for at least 6 months to capture deliveries from all participants.

5.2.4 Data quality control

Specific data quality control measures were implemented to ensure the accuracy and reliability of the collected information for this particular study. Thorough training on baby weighting scale calibration, usage, and data recording procedures was provided to data collectors. A pre-test conducted at both health facilities and community levels further mitigated inter - and intra-observer inconsistencies. During the pretest, observers from different health centers or measurement teams were paired to independently measure the birth weight of newborns to evaluate the agreement between their measurements. Each observer also repeatedly measured the birth weight of newborns within a single session to assess their consistency in taking measurements. Scales were placed on a clean, flat surface with the display clearly visible. To ensure accuracy, scales were calibrated every morning using known 2kg weights and regular audits were conducted to detect and rectify any errors.

Interviewers of baseline data were also undergoing training to minimize misinterpretation and maintain consistent methods including a detailed discussion to ensure consistent application of FAO guidelines for collecting 24-hour dietary intake data, promoting reliable assessment across participants. Supervisors conducted random 5% duplicate home visits to independently verify information collected by fieldworkers, identifying any discrepancies. Regular feedback sessions addressed challenges and inconsistencies encountered during data collection, refining the process and maintaining data quality. In addition, health development army leaders, and health extension workers collaborated to ensure smooth and efficient data collection, avoiding unnecessary last-minute efforts.

5.2.5 Data analysis

Descriptive statistics were used to summarize baseline data on sociodemographic characteristics, economic factors, and cooking activities. Frequencies and percentages were used for categorical variables, while means and standard deviations were used for continuous variables. Missing data for certain variables were also reported. Comparability between the intervention and control groups was checked on characteristics that potentially influence birth outcomes. Chi-square test was used for categorical variables and independent sample t-test was used for continuous variables.

The average birth weight was compared between the intervention and control groups using independent samples t-tests. Mean differences were reported with 95% confidence intervals (CIs) and all tests were conducted at a 5% significance level.

In addition to overall comparisons of average birth weight, subgroup comparison of differences in average birth weight between the two arms by infant sex, gestational age, kitchen roof type, time spent in the kitchen per day, and pregnancy period at which intervention was introduced. We additionally conducted secondary analyses for primary outcomes (low birth weight) and secondary outcomes including preterm birth, stillbirth, and miscarriage and compared using relative risk and 95% confidence intervals from poison regression models with a log link and robust variance.

In addition to unadjusted comparisons, adjusted comparison was made after adjusting for maternal age, dietary diversity score, maternal and paternal education, parity, and maternal body mass index. Adjustment was made for baseline variables that showed statistically significant differences at $p < 0.25$ between the groups. This adjustment was performed because these variables were considered potential confounders that could influence the outcome variable.

5.3 Result

5.3.1 Participant eligibility and randomization

After a collaborative work with health extension workers, health development armies and kebele administrators, a total of 648 pregnant women were approached to assess for eligibility in the six kebeles of the Guna-Tana integrated field research and development center, South Gondar zone during November-December 2022. Then, 226 pregnant women were excluded due to reasons such as unwillingness to participate (n=29), being outside the age range (n=35), having certain health conditions (n=15), planning to permanently move to a nearby town (n=8), not primarily being responsible for cooking (n=24), and have reported a gestational age exceeding 24 weeks (n=115). Finally, 422 households with eligible pregnant women were enlisted for the study and underwent randomization with equal size allocation ratio (211 assigned to the intervention group and 211 assigned to the control group). But, three participants in the intervention group did not receive the improved stoves due to reasons including a preference for their existing stove (1) and unwilling to change the baking pan (2). But, no participants in the control group switched to improved stoves during the study period. Throughout the study, 30 pregnant women (13 from the intervention group and 17 from the control group) were excluded due to lost to follow-up

(participants can't be reached for data collection), non-adherence (participants don't follow the intervention protocol), and withdrawn (participants choose to leave the study) (Figure 28).

Except for three participants who refused to change their baking pan and kitchen location at the beginning of the study, all participants remained in their assigned groups. The high acceptability of the intervention stove within the community, due to its cultural suitability for baking Injera, ease of use, reliance on readily available biomass fuel, and lack of cultural resistance, contributed to their adherence.

5.3.2 Maternal and infant characteristics

The average age of the participants was 28.9 years old (SD=5.3), with the largest group (47%, n=198) falling between 25 and 31 years old. Regarding educational status, the majority of the participants, (62%, n =265) were unable to read and write, and nearly all were married at the time of enrollment. Due to strong cultural disapproval of smoking in the study area, none of the participating women were smokers themselves or lived with a smoker. Participants were enrolled at an average of 18 weeks of gestation (range: 12-24 weeks) and over half (54%, n=231) of the participants were already in their second trimester (at least 18 weeks pregnancy) when they enrolled in the study. The average number of previous live births was 2.7 children (2.6 vs 2.7) for intervention and control groups, respectively. Marginally more infants were born in home among the control group (11.4%, n=19) than in the intervention group (8.2%, n=16). Sex ratios of the new born babies were comparable between the two groups, with approximately half of the infants being male (intervention: 50%, n=95; control: 53%, n=98).

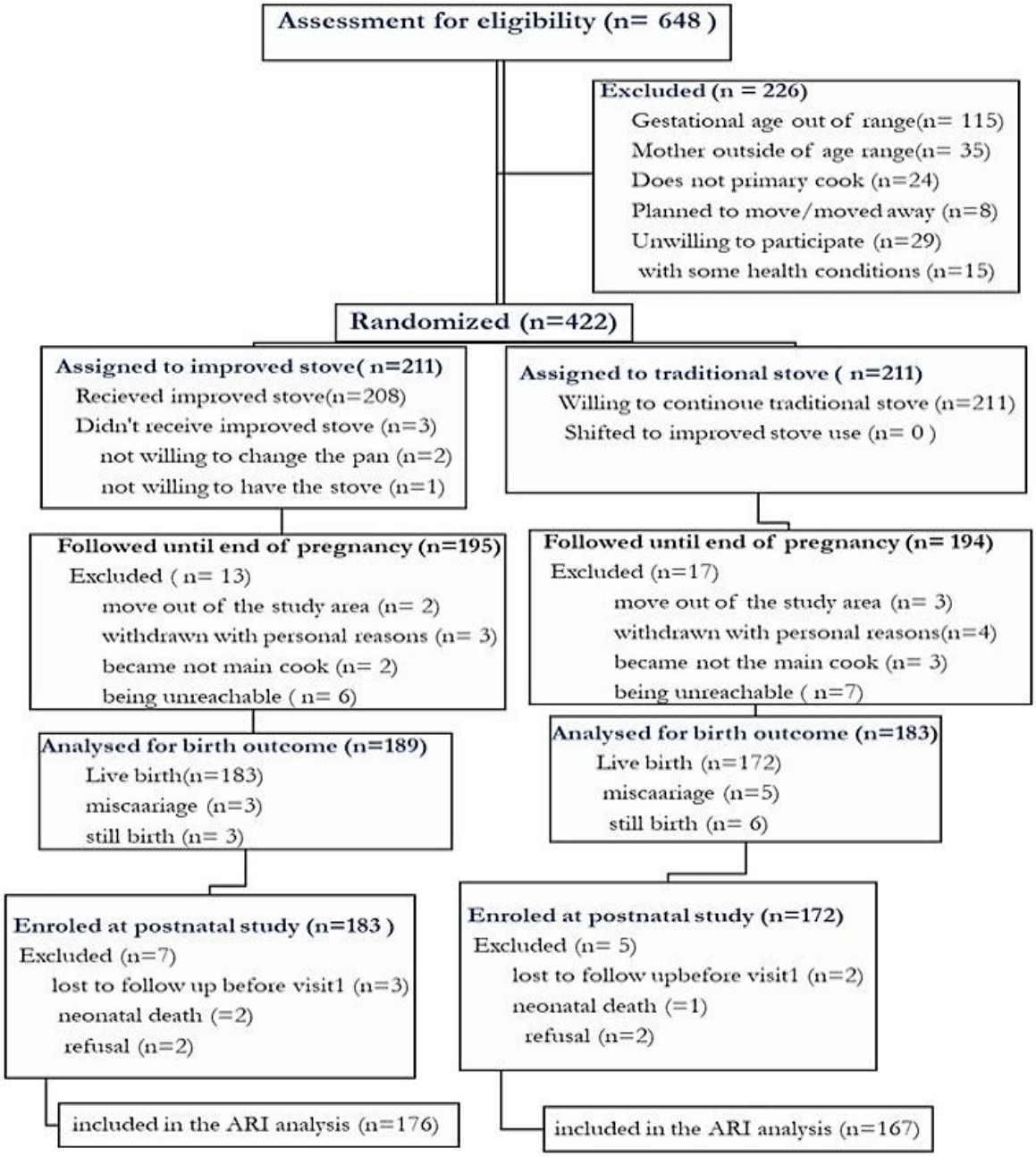


Figure 28: The consolidated standards of reporting trials (CONSORT) flow diagram

The average Dietary Diversity Score (DDS), which measures the variety of food groups consumed in the last 24 hours before the survey, was 3.87 with (3.94 vs 3.81) specific scores for control and intervention participants respectively. More than three-quarters (76%, n = 321) of the participating pregnant women consumed inadequate dietary diversities (77% vs 75%) in the intervention and control groups respectively. Both groups received an average of two ANC visits

and prior miscarriage experience was reported by 17 % of the intervention group and 15.6% of the control group (Table 9).

Table 9: Baseline demographic and cooking characteristics by intervention arms among pregnant women in south Gondar zone, northwestern Ethiopia

Characteristics	Over all	Control (n=211)		Intervention (n=211)		P-Value*
Maternal age at entry, yrs (Mean ±SD)	28.9±5.3	29.2 ±5.3	-	28.6±5.1	-	.244
Maternal age groups, n(%)						
18-24	79 [18.7]	35	16.7	44	21.0	.451
25-31	198 [46.9]	99	47.1	99	47.1	
32-38	143 [33.9]	76	36.2	67	31.9	
Marital status, n (%)						
currently married	405 [96.0]	201	95.3	204	96.7	.458
currently not married	17 [4.0]	10	4.7	7	3.3	
Maternal education level, n(%)						
unable to read and write	265 [62.8]	142	67.3	123	58.3	.073
read and write only	104 [24.6]	42	19.9	62	29.4	
primary and above grade	53 [2.6]	27	12.8	26	12.3	
Paternal education level, n (%)						
unable to read and write	164 [38.9]	92	43.6	72	34.1	.080
read and write only	169 [40.0]	74	35.1	95	45.0	
primary and above grade	89 [21.1]	45	21.3	44	20.9	
Family size, Mean, SD	4.8±1.6	4.7+1.6	-	4.7+1.5	-	.952
< 5 occupants	191[45.3]	95	45.0	96	45.5	.500
≥ 5 occupants	231[54.7]	116	55.0	115	54.5	
Had under-five child, n (%)						
yes	176 [41.7]	85	40.3	91	43.1	.622
no	246 [58.3]	126	59.7	120	56.9	
GA at entry in weeks, (Mean ± SD)	18±3.7	17.8 ± 3.8	-	18.1±3.8	-	.501
Trimester at entry						
First (≤ 12 weeks)	41 [9.7]	23	10.9	18	8.3	.511
Second (≤ 24 weeks)	381 [90.3[	188	89.1	193	91.5	
Gravidity, n (%)						
primigravida	34 [8.1]	22	10.4	12	5.7	.074
multigravida	397 [94.1]	198	89.6	199	94.3	
Prior miscarriage						
yes	69 [16.4]	36	17.1	33	15.6	.793
no	353 [83.6]	175	82.9	178	84.4	
Dietary diversity scores, mean (SD)		3.9±.9	-	3.8±.9	-	.154
adequate (≥ 5 food groups)	101[23.9]	53	25.1	48	22.7	.324
inadequate (<5 food group)	321[76.1]	158	74.9	163	77.3	
Currently, alcohol drinking, n (%)						
yes	211[50.0]	112	53.1	99	46.9	.461
no	210 [49.8]	119	56.4	91	43.1	
BMI (kg/m2), mean (SD)	20.8±2.2	20.9 ± 2.3	-	20.8±1.9	-	.476
Asset index, n(%)						
low	139 [32.9]	68	32.2	71	34.1	.387
medium	140 [33.2]	77	36.5	63	30.3	
high	140 [33.0]	66	31.3	74	35.6	
Cooking time spent in hrs , mean (SD)	2.7±.9	2.7 ± .9	-	2.8±.9	-	.558

Number of ANC visits mean (SD)	2.0±.9	1.9 ± .9		1.9±.7		.952
Drinking water sources, n(%)						
improved	119 [28.2]	57	27.0	62	29.4	.333
unimproved	303 [71.8]	154	73.0	149	70.6	
Sanitation facility, n(%)						
improved	105 [24.9]	48	22.7	57	27.0	.284
unimproved	317 [75.1]	163	77.3	154	73.0	
Handwashing facility, n(%)						
yes	70 [16.6]	36	17.1	34	16.1	.448
no	352 [83.4]	175	82.9	177	83.9	

*Intervention and control groups were compared using $\chi 2$ - tests for categorical variables and independent sample t-tests for continuous variables. **Abbreviations**: GA, Gestational Age; SD, Standard Devation; BMI, Body Mass Index; ANC, Antenatal Care

5.3.3 Effect of the intervention

Out of the 422 pregnant women enrolled and randomly assigned to groups, 389 completed the trial. Among those who completed the trial, valid data on pregnancy outcomes could only be obtained from 372 participants (189 from the intervention group and 183 from the control group). This is because 17 additional participants (6 from intervention and 11 from control) declined to participate in visits to assess birth outcomes. Therefore, valid birth weights were measured for 355 newborns. In the intervention group, 183 babies had their birth weight measured, while in the control group, there were 172 babies with measured birth weight.

As illustrated from Table 9, the average birth weight of infants born to mothers using the Mirt stove (3065 grams, SD=453) was slightly higher than those born to mothers using traditional stoves (2995 grams, SD=541). However, the 69-gram difference (95% CI: –31,170) was not deemed statistically significant (P = 0.153). This observation persisted even after considering factors like maternal age, dietary diversity, maternal and paternal education, prior pregnancies, and BMI, with the adjusted birth weight difference decreasing to 55 grams (95% CI: -43,153), still lacking statistical significance (p = 0.274).

Fewer babies born to mothers using the intervention stoves had low birth weight (8.1%) compared to those born to mothers using open fires (10.3%). While the intervention group showed a 21% lower incidence of LBW than the control group, this difference did not reach statistical significance (p = 0.346). The estimated rate of low birth weight was only 2% lower among Mirt stove users (adjusted RR = 0.98; 95% CI: 0.96, 1.02; p=.419), and the difference was not large enough to consider it conclusive.

We also conducted analysis of secondary endpoints, including gestational age (GA), miscarriage, stillbirth, and maternal complications. Accordingly, there was a statistically significant difference in mean gestational age at birth between the intervention and control groups, with the intervention group showing a higher mean of 38.0 weeks (SD= 8.2) compared to 36.5 weeks (SD= 9.6) in the control group ($p < 0.001$). This difference remained statistically significant after adjusting for potential confounders (unadjusted difference: 0.93 weeks, 95% CI: 0.48, 1.39; adjusted difference: 0.91 weeks, 95% CI: 0.52, 1.30; $p < 0.001$ for both). Furthermore, unadjusted analysis revealed a lower incidence of preterm births (born before 37 weeks) in the Mirt stove group (5 cases, 2.6%) compared to the control group (21 cases, 11.3%). This translates to a risk ratio of 0.95 (95% CI: 0.93, 0.98; $p < 0.001$), indicating a statistically significant protective effect of Mirt stoves against preterm birth. The adjusted risk ratio remained significant (0.94, 95% CI: 0.92, 0.97; $p < 0.001$).

The number of miscarriages (fetal loss before 28 weeks) was low in both groups (3 cases, 1.4% in the intervention group; 5 cases, 2.4% in the control group). Similarly, stillbirths (fetal loss at or after 28 weeks) were uncommon (3 cases, 1.5% and 6 cases, 3.1% in the intervention and control groups, respectively). Due to these small numbers, neither miscarriage nor stillbirth showed statistically significant differences between the groups. Additionally, no significant differences were observed in maternal complications between the intervention and control groups.

Table 10: Pregnancy outcomes by intervention arm among pregnant women in south Gondar zone, northwest Ethiopia

Pregnancy outcomes	Treatment arms		Unadjusted difference		Adjusted difference	
	Intervention	Control	(95% CI)	p-value	(95% CI)	p-value
Mean birth weight in grams, SD	3065 ± 453	2995 ± 541	69 [-31 , 170]	.175	55 [-43 , 153]	.274
range	1700 - 4200	1315 - 4162				
missing	13	17				
Gestational age at birth, wks	38.0 ± 8.2	36.5 ± 9.6	.93 [.48 ,1.39]	p< .001	.91 [.52 ,1.30]	p<0.001
range	34-42	32-42				
missed	9	13				
Low birth weight, n(%)					.	
<2500 grams	16/198 [8.1]	20/194 [10.3]	.99 [.96 , 1.02]	.445	.98[.95, 1.02]	.346
≥2500 grams	182/198 [91.9]	174/194 [89.7]				
missed	13	17				

Preterm birth, n(%)						
< 37 weeks	5/189 [2.6]	21/186 [11.3]	.95 [.93, .98]	.001	.95 [.92 , .97]	p<.001
≥ 37 weeks	184/189 [97.4]	165/186 [88.7]			.	
missing	22	25				
Miscarriage, n (%)						
yes	3/202[1.4]	5/204[2.4]	1.65[.40, 6.81]	.489	1.53[.38, 6.18]	.548
no	199/204[94.3	199/204[94.3				
missed	9	7				
Still birth , n(%)						
yes	3/196 [1.5]	6/192 [3.1]	.99 [.98, 1.00]	.299	.98 [.97 , 1.00]	.165
no	193/196 [98.4]	186/192 [96.8]				
missed	15	19				
Maternal complications, n(%)						
yes	31/182 [17.0]	26/194[13.4]	1.02[.98, 1.06]	.328	1.02 [.97, 1.06]	.458
no	151/182 [83.0]	168/194[86.6]				
missed	29	17				

Differences for continuous variables (birth weight and gestational age) come from linear regressions. Estimates shown represent differences in the mean of the study group and 95% CI as compared with the control group. Differences for categorical variables (low birth weight, pre-term birth, stillbirth, miscarriage, and maternal complications) come from Poisson regressions with robust estimates. Estimates shown represent risk ratios and 95% CIs as compared with the control group. Differences replicate unadjusted models and additionally adjust for maternal age, dietary diversity, maternal and paternal education, maternal body mass index, and gravidity.

5.3.4 Subgroup analysis

While acknowledging the limitations imposed by our sample size, we employed a subgroup analysis to pinpoint the specific groups who demonstrably benefited from the improved stove intervention. Accordingly, we compared the intervention and control groups across several subgroups, including infant gender, kitchen roof types, time spent cooking in the kitchen, gestational age at birth, and gestational age when the intervention was introduced. As illustrated in figure 29, female infants born to mothers using intervention stoves exhibited an average weight of 109 grams more (95% CI: -47, 266; P = .167) than those female infants born to mothers in the control group. Similarly, non-statistically significant increases in birth weight was observed among term infants (102 grams more; 95% CI: -6, 210; P = 0.113), those exposed to the intervention earlier (before 18 weeks; 98 grams more; 95% CI: -40, 236; P = 0.158), infants of mothers spending over three hours daily in the kitchen (92 grams more; 95% CI: -46, 232; P = 0.191), and those born to mothers with corrugated iron sheet roof kitchens (96 grams more; 95% CI: -27, 220; P = 0.120) compared to their counterparts in the control arm. However, the subgroup analysis for preterm births and thatched roof kitchens yielded contrasting results. Infants born to mothers with thatched roof kitchens had an average decrease in birth weight of 7 grams (95% CI: -190, 176; P = 0.774), and preterm infants experienced a decrease of 57 grams

(95% CI: -545, 432; P = .796). Due to the small number of participants, the subgroup analysis in these group may not have been sufficiently powered to detect an impact from the intervention.

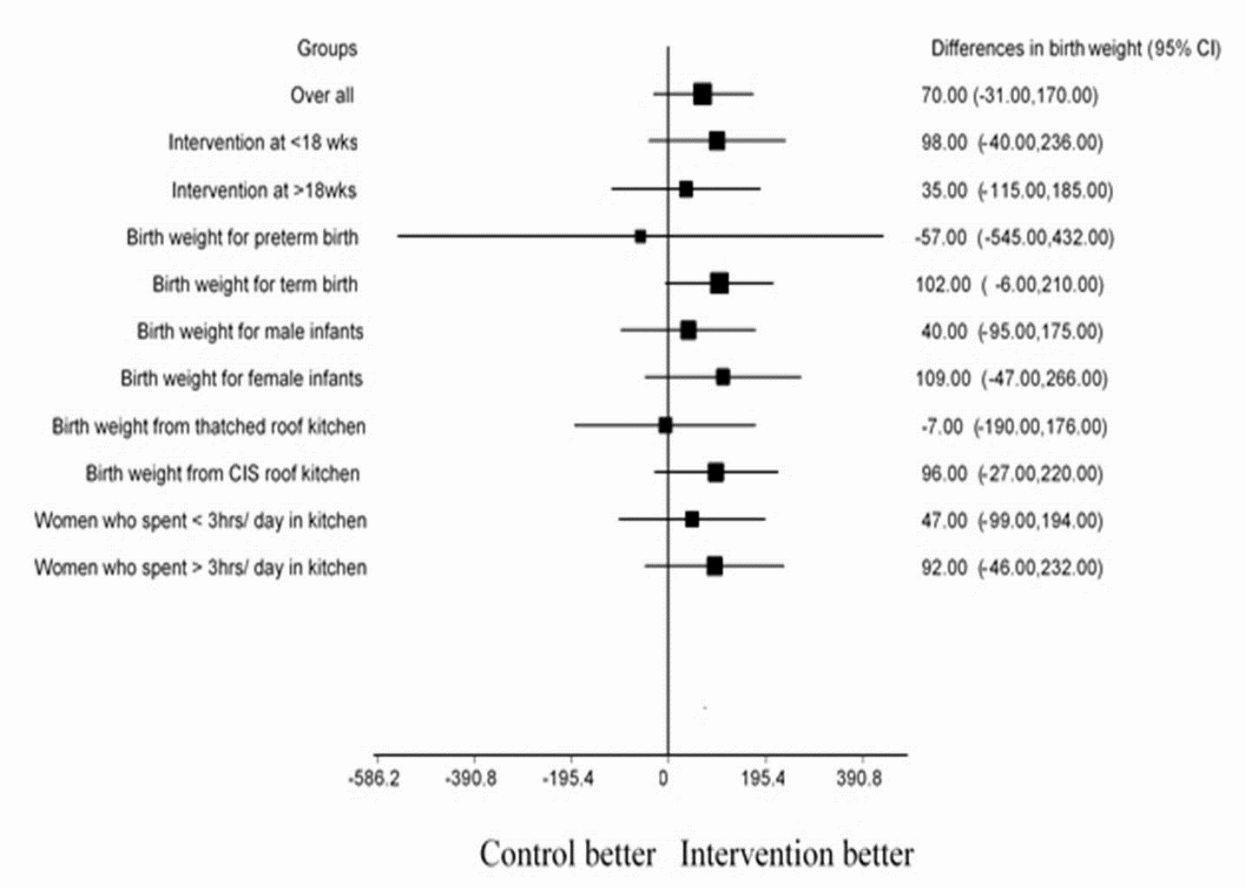


Figure 29: A forest plot showing subgroup analyses of the difference in birth weight between the intervention and control groups

5.4 Discussion

In this randomized control trial, a chimney-equipped Mirt stove intervention was initiated during the first and second trimesters of pregnancy in typical rural households of northwest Ethiopia. Birth weight is a well-established indicator of overall population health and is linked to long-term health outcomes (Wardlaw, 2004, Mahumud et al., 2017, McGovern, 2019). Given its association with exposure to biomass smoke (Jayaraj et al., 2019, Kaali et al., 2023a, Kaali et al., 2023b), it was selected as the primary outcome for this study. Additionally, we conducted secondary analyses of birth weight (low birth weight) and other secondary endpoints including stillbirth, miscarriage, gestational age, and maternal complications.

Though birth weight was slightly higher in the intervention group, the difference was not statistically significant. We found an effect size of 69 grams for average birth weight in the

intervention arm compared to the control arm. After accounting for potential influencing factors, the average birth weight difference further diminished to 55 grams. While previous primary studies (Ahmed et al., 2015, Epstein et al., 2013, Liu et al., 2019b, WHO, 2007, Obstetricians et al., 2021) and systematic reviews and meta-analyses (Younger et al., 2022, Amegah et al., 2014, Lee et al., 2020a) consistently linked household air pollution to increased risk of low birth weight, this study found no conclusive association between the improved biomass stoves intervention and birth weight.

Inconclusive mixed results have been also reported from previous studies (Thompson et al., 2011, Katz et al., 2020, Asante et al., 2019). For instance, similar results were reported from Guatemala, which demonstrated that unadjusted and adjusted birth weights were 68 grams and 89 grams higher, respectively, among the intervention group compared with the control group, although these differences were not statistically significant (Thompson et al., 2011). In Mongolia, the introduction of portable high-efficiency particulate air (HEPA) filters during pregnancy showed no association with birth weight, resulting non-significant 18 grams increment (Barn et al., 2018). While mothers who used LPG stoves in a separate large-scale study across four countries had babies with an average birth weight 19.6 grams higher than those born to mothers using open fires, the difference wasn't statistically significant (Clasen et al., 2022). Evidences from Nepal and Ghana indicated that introducing LPG or enhanced biomass cook stoves during pregnancy did not result in improved birth weight (Jack et al., 2021, Katz et al., 2020). The sole statistically significant birth weight increase came from an ethanol stove study in Nigeria, with an average gain of 128 grams after accounting for other factors (Alexander et al., 2018).

The subgroup analysis offered some promising indications that specific groups might have derived greater benefits from the intervention stove. Infants who were female, born from mothers with corrugated iron sheet roof kitchens, exposed to the intervention earlier (before 18 weeks of gestation), delivered at term, or whose mothers spent over three hours daily cooking displayed a trend towards higher birth weight compared to their counterparts in the control group. Similarly, a Mongolian study revealed that the use of HEPA filter air cleaners was associated with an 85-gram increase in mean birth weight among babies born at term in a subgroup analysis (Barn et al., 2018). Likewise, the difference in birth weight between the groups seemed to be slightly high

among infants born to women who received the intervention before 18 weeks of gestation (Clasen et al., 2022).

In contrast to our result, a meta-analysis of studies examining improved stove interventions during the third trimester of pregnancy found a significant increase in average birth weight (Quansah et al., 2017b). However, the ideal gestational window for introducing the intervention stove remains elusive. Existing studies report varying effectiveness across different timeframes, including mid and late gestation (Johnson et al., 2022b, Kaali et al., 2023a), the third trimester (Qiu et al., 2023), and early pregnancy/late first trimester (Miron-Celis et al., 2023). These mixed findings suggest that improved stoves alone might not provide comprehensive health protection. Nevertheless, by investigating which subgroups benefit most from the intervention, we can refine and optimize future interventions to maximize positive health outcomes (Grajeda et al., 2020, Shankar et al., 2014). It is also important to consider that women's exposure to air pollution, even before pregnancy, may pose health risks to their babies. Early intervention strategies are therefore advisable to mitigate these potential risks (Weber et al., 2020).

The secondary analysis of the primary outcome revealed insignificant reduction in low birth weight infants among women using improved stoves compared to traditional stove users. The result aligns with findings from comparable studies carried out in Nepal (Katz et al., 2020), Ghana (Jack et al., 2021), and Guatemala (Thompson et al., 2011), where the introduction of an improved stove during pregnancy did not demonstrate a statistically significant reduction in low birth weight compared to an open-burning stove. Though, another large-scale intervention study reported no significant effect on low birth weight with improved stoves (Younger et al., 2023), research results reported from Nigeria (Alexander et al., 2018) and Malawi (Best et al., 2022) suggests potential benefits. Pooled estimates from systematic reviews and meta-analyses also support this notion (Quansah et al., 2017a, Bruce et al., 2013). Furthermore, two recent studies provide additional evidence of the positive impact of improved stove interventions on reducing low birth weight (Best et al., 2022, Ahmed et al., 2024).

In this study, the lack of intervention impact also extended to secondary endpoints like stillbirth, miscarriage, and maternal complications which aligns with findings from systematic reviews conducted in LMICs, that reported inconclusive or null results for preterm birth and stillbirth reduction with improved stoves (Wastnedge et al., 2021, Quansah et al., 2017a, Thakur et al., 2018). A large scale multi-country study, using improved stoves during pregnancy also showed

no difference in miscarriage, high blood pressure problems, or severe bleeding after birth compared to open fires (Younger et al., 2023). Similarly, no statistically significant differences were observed for post-partum hemorrhage, pre-term birth, low birthweight, hypertensive disorders of pregnancy, or small for gestational age in the Ghanaian study (Weber et al., 2020). Neither the Guatemalan study (Thompson et al., 2011) nor the Ghanaian cohort study (Weber et al., 2020) found significant impacts on miscarriage rates. Though, the number of cases were small, and the difference was not statistically significant, an ethanol cook stove study in Nigeria showed a decrease in stillbirths and miscarriages among women who used the improved stoves compared to the control group (Alexander et al., 2018). But, in contradict to our result, risk reductions for stillbirth was reported from pooled estimates of previous systematic review and meta-analysis (Bruce et al., 2013).

This study uncovered a significant difference in gestational age between babies born to mothers using improved stoves during pregnancy and those born to mothers using traditional open fires. Consequently, babies in the improved stove group were delivered, on average, nearly a full week later. This finding align with a Nigerian study showing increased average gestational age among women using ethanol-burning stoves compared to those using traditional stoves (Alexander et al., 2018), although they reported a non-significant decrease in preterm births. A recent review report found that using gas stoves, compared to polluting fuels like wood or coal, was significantly lowered the risk of preterm birth (Puzzolo et al., 2024). A study in the United States reported a notable decrease in preterm birth rates during the COVID-19 pandemic compared to the pre-pandemic period (Berghella et al., 2020). While multiple factors, such as reduced travel and altered work patterns, likely contributed to the decrease in preterm birth rates during the pandemic, lessened exposure to air pollution may also have played a role.

In contrary, the large scale multi-country household air pollution intervention network trials found that switching to liquefied petroleum gas (LPG) stoves and fuel did not significantly reduce the risk of preterm birth (PTB) or increase the duration of pregnancy in participating women (Kirby et al., 2022, Younger et al., 2023). Another interventional study, focusing on improved biomass stoves in Nepal, did not demonstrate any evidence of reducing adverse birth outcomes, including preterm births (Katz et al., 2016). It was also reported that use of various improved stove or improved energy did not show any association with a decreased incidence of

preterm birth or small for gestational age in Mongolia (Barn et al., 2018) , in Nepal (Katz et al., 2020), and in Ghana (Jack et al., 2021).

The additional demands of Injera baking on traditional stoves in our study, including increased fuel needs, longer cooking times, and higher workload, could independently contribute to stress and potentially increase the risk of preterm birth in pregnant women. This hypothesis is supported by existing research, which has identified workload and stress as independent risk factors for preterm birth (Etil et al., 2023, Vrijkotte et al., 2021, Sepee and Tesfahun, 2023). In addition to pollutant reduction, improved stoves offered multiple benefits, including reducing biomass fuel consumption, saving time, and consequently, alleviating workload for users, as reported in other studies (Nazneen and Iqbal, 2018, UN, 2021, Mehrnoush et al., 2023).

As evidenced by our air quality data, the intervention stove offered some biomass smoke reduction as compared to open fires, but it failed to lower PM2.5 levels in kitchens below WHO safety thresholds (WHO, 2021b). This limited smoke reduction may explain the absence of statistically significant improvements on pregnancy outcomes as observed in this study. This aligns with findings from most prior research, where insufficient biomass smoke reduction is often cited as a reason for inconclusive results on stove interventions and pregnancy outcomes (Grajeda et al., 2020, Islam et al., 2022b, Koala et al., 2023a, Masera et al., 2007, Woolley et al., 2022b, Pope et al., 2017b).

It is also obvious that the success or failure, but mostly failure of improved stoves goes beyond just the technology itself. Several factors play crucial roles in their success, including cooking habits, lifestyle choices, consistent stove use by households, the presence of other pollution sources in the environment, and ensuring the stoves are well-suited to local needs (Schilmann et al., 2019, Adane et al., 2020c, Khandelwal et al., 2017, Thomas et al., 2015c). In our study, the chimney fitted Mirt design, optimized for the energy-intensive practice of Injera baking (done 2-3 times weekly), may have limited its impact on overall household air pollution, as other cooking activities likely involved different stoves and additional pollutant emissions (Jani et al.). Furthermore, the multifactorial nature of adverse pregnancy outcomes, influenced by factors like genetics, nutrition, and unknown etiologies, may further contribute to the null findings in our study (Abadiga et al., 2022, Getaneh et al., 2021).

5.5 Conclusion and recommendations

This study investigated the impact of improved stoves with chimneys on maternal and infant health outcomes. While the intervention did not yield statistically significant changes in birth weight or low birth weight rates, it demonstrated a positive association with increased gestational age and reduced preterm birth incidence. These findings suggest that the use of Mirt stoves equipped with chimneys may contribute to better pregnancy outcomes, potentially through reduced exposure to harmful indoor air pollutants. Future iterations of stove interventions should prioritize multi-functionality to accommodate a wider range of cooking practices and adaptability to utilize various fuel sources. Additionally, involving target communities in the design process can help ensure the stoves are culturally appropriate and meet user needs. Further research is warranted to explore the mechanisms underlying these associations and to determine the long-term health benefits of improved stove interventions. Additionally, larger-scale studies with longer follow-up periods are needed to confirm the observed effects on gestational age and preterm birth rates.

Chapter 6

Prenatal Exposure to Improved Stove and Infant Acute Respiratory Infections: Results from a Randomized Trial in Northwest Ethiopia

(Under Review)

Impact of Improved Stove Intervention during pregnancy on Infant Acute Respiratory Infections: Results from a Randomized Trial in Northwest Ethiopia

Journal: BMJ Open
Manuscript ID: bmjopen-2024-092108
Status: Assigning handling Editor
Submission date: 06 August 2024
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Abstract

Background: Every year, millions of young children affected by acute respiratory infections, which is the leading cause of serious illness and death among children globally. Indoor air pollution, primarily caused by traditional cooking practices, is a significant contributor to the infections in low income countries. Numerous strategies, including promoting improved stoves, have been implemented to address this critical public health challenge. But, only few studies have examined the impact of chimney-fitted improved stoves on acute respiratory infections incidence among newborns during early pregnancy, and evidences of a clear association remains limited. This study aimed to evaluate the impact of introducing chimney-fitted Mirt stoves initiated during pregnancy on the respiratory health of infants under six months old in rural Northwest Ethiopia

Method: All infants born to participating mothers were followed for a six-month period. Respiratory symptoms were assessed every two months in accordance with the Integrated

Management of Childhood Illness (IMCI) guidelines. The primary outcome of interest was the incidence of acute respiratory infections. To compare the occurrence of acute respiratory infections between the intervention and control groups, we employed Generalized Estimating Equations (GEE) statistical modeling, accounting for the correlated nature of repeated measurements within each infant.

Result: After excluding fetal loss and neonatal deaths prior to the initial assessment, a total of 343 infants (176 in the intervention and 167 in the control groups) were visited every 2 months for the first 6 months of life, resulting in 1029 visits throughout the study period. Of these, 43 infants (18 in the intervention group and 25 in the control group) encountered at least one episode of Acute Respiratory Infections (ARIs), yielding an overall prevalence rate of 12% (95% CI: 10, 14%). The prevalence rate in the intervention group was 11% (95% CI: 8, 13%), slightly lower than the control group's rate of 14% (95% CI: 11, 17%). While not statistically significant, the use of a statistical model (Generalized Estimating Equations, GEE) consistently indicated lower ARI incidence rate ratios in the intervention group compared to the control group both before (IRR= 0.80, 95% CI: 0.56, 1.15; p = 0.238) and after (IRR = 0.81; 95% CI: 0.56, 1.16; P=.252) adjusting for maternal age. Further stratified analysis highlighted promising reductions in acute respiratory infections among female infants (IRR = 0.59; 95% CI: 0.34, 1.04) and infants from smaller family size in the intervention group (IRR = 0.58; 95% CI: 0.32, 1.06) compared to the control group. These findings suggest potential benefits of improved stoves for specific demographic groups.

Conclusion: While the overall study did not demonstrate significant differences in acute respiratory infections risks during the initial six months, subgroup analyses revealed potential benefits for specific groups. These promising results warrant larger, long-term studies within households reliant on traditional stoves to explore these findings further.

6.1 Introduction

Infant mortality remains a pressing challenge globally with millions losing their lives in the first year of life (WHO, 2020) particularly in Sub-Saharan Africa where neonatal mortality rates remain high (Momtazmanesh et al., 2023, WHO, 2020). Despite significant progress in reducing child mortality rates, Ethiopia still faces challenges where 47 and 59 children per 1,000 live births die before their first and fifth birthdays, respectively (EPHI, 2021) with a slight increase in

neonatal mortality since 2016, rising from 29 to 33 deaths per 1,000 live births. According to world health organization report of 2020, Ethiopia is the 4th country next to India, Nigeria and Pakistan from the top 10 countries with the highest number of newborn deaths (WHO, 2020). Acute respiratory infections including pneumonia consistently stands as one of the leading causes of morbidity and mortality in young children on a global scale (Momtazmanesh et al., 2023, Troeger et al., 2017) which accounts for nearly 20% of all deaths in children under five years old.

Environmental exposures, including household air pollution during the prenatal period, pregnancy, and early life, can exert lasting negative effects on health, including heightened susceptibility to ARIs even in later stages of life (Lacagnina, 2019, Demelash et al., 2023, Holgate et al., 2016). Incomplete combustion of biomass fuels (wood, dung, and agricultural residues) in inefficient stoves releases various pollutants (Hasan et al., 2019a, Enyew et al., 2021a) and evidences across the globe demonstrate a strong association between these pollutants and increased risk of ARIs, especially pneumonia (Jary et al., 2016, Gordon et al., 2014, Kinney et al., 2021). The main health-damaging pollutants in this context are fine particulate matter (PM2.5) and carbon monoxide (CO) (Ranathunga et al., 2019, Rosenthal et al., 2018, Walker et al., 2020). The burden of ARIs associated with HAP is disproportionately high in certain regions of the world, including eastern, central, and western sub-Saharan Africa and Southeast Asia, where reliance on solid biomass fuels remains high(Gall et al., 2013, Newell and Raimi, 2020). The problem is highly affecting who spend most of their time near cooking areas, including women and children (Gupta and Muthukumar, 2018, LaFave et al., 2021).

In Ethiopia, where over 95% of households (almost all in rural households) rely on biomass fuels for cooking, heating, and lighting, the situation is closely similar to many low and middle-income countries (CSA, 2016, Geissler et al., 2013). Evidences from local studies suggests a strong link between biomass fuel use and child health outcomes, including ARIs (Adane et al., 2020b, Admasie et al., 2018b, Sanbata et al., 2014, Tefera et al., 2016, Addisu et al., 2021a). A pooled estimate of studies from different regions of the country found a nearly threefold increase in the risk of ARIs in children under five exposed to solid biomass fuel smoke (Enyew et al., 2021a). Similarly, a finding from further analysis of Ethiopian demographic and health surveys revealed an association between HAP and risk of respiratory infections among under-five children (Geremew et al., 2020).

This substantial increase in ARIs risk associated with HAP calls for immediate interventions (Thomas et al., 2015a, Bryden et al., 2015) and distributing improved stoves has been identified as a reasonable option for a safe transition to cleaner cooking in poor rural African settings, including Ethiopia (Dagnachew et al., 2019). This transition is expected to bring about a transformation in livelihoods, enhancing health by reducing respiratory illnesses, safeguarding the climate and the environment by lowering wood and charcoal consumption, empowering women through reduced cooking time and smoke exposure, and enabling consumers to save time and money on fuel purchases (Petrokofsky et al., 2021, Krishnapriya et al., 2021). In addition, improved stove use aligns with several sustainable development goals, including good health and well-being, gender equality, affordable and clean energy, and climate action (Rosenthal et al., 2018, WHO, 2016b, WHO, 2019c).

Despite the substantial health risks associated with household air pollution, there is a limited number of randomized controlled trial (RCT) evidence supporting the effectiveness of locally available improved stoves interventions in improving ARIs in young children which remains uncertain and lacks definitive quantifiable data (Pope et al., 2021a). Previous randomized controlled trials conducted in Ethiopia examined the impact of Mirt stoves on children under five years old. While these studies did not find significant reductions in ARI incidence, they demonstrated positive effects on child growth and household air quality (Adane et al., 2020b, LaFave et al., 2021) highlighting the need for further investigation into the impact of early intervention of chimney fitted improved stoves on ARIs in vulnerable populations.

This study distinguishes itself from previous randomized controlled trials in Ethiopia by specifically focusing on the impact of chimney-fitted Mirt stoves on pregnancy outcomes and newborn ARI rates. As the first Ethiopian study to evaluate the benefits of improved Mirt stoves in this context, we aimed to assess the effect of introducing the intervention stoves during the first and second trimester gestations of pregnancy and the subsequent six months on infant ARI rates in rural households of South Gondar zone, Northwest Ethiopia.

6.2 Methods and materials

6.2.1 Study design

This study is a follow-up to a randomized controlled trial (RCT), as illustrated in Figure 28. The initial RCT examined the effects of introducing chimney-fitted Mirt stoves during pregnancy on

birth outcomes in Northwest Ethiopia. Following the assessment of birth outcomes, all live-born infants without known health condition, undergoing follow-up visits to assess the incidence of respiratory symptoms. This design enabled us to compare the incidence of respiratory infections in infants exposed to improved stoves versus those continued using traditional stoves, while accounting for other potential factors influencing infant health including ARIs. Previous trials on childhood respiratory infections in Ghana are noteworthy for their use of similar designs (Abdo et al., 2021).

6.2.2 Participants

The study participants were infants born to mothers who participated in the trial on improved stoves during pregnancy. Mothers' consent to enroll their babies in the study was obtained during a prenatal visit, although enrollment of infants for this particular study occurred at birth. Infants with no known illnesses were followed from birth to six months of age. As respiratory symptoms are unlikely to occur in utero, we assumed minimal to no pre-existing respiratory infections in the infants at birth. Therefore, we calculated their follow-up period (person-time at risk) starting from birth and continuing until their final follow-up visit. The observation period for each infant was the number of days from birth until the final contact, which occurred either at the end of follow-up or loss to follow-up.

6.2.3 Sample size

The analysis included all live-born infants who participated in at least one ARI surveillance visit. Twelve infants were excluded from the study due to reasons outlined in the CONSORT flow diagram (Figure 28). These exclusions resulted in a final study population of 343 infants who were followed up for a total of six months.

6.2.4 Outcome assessment

The primary outcome of this particular analysis was the occurrence of acute respiratory infections (ARIs), measured as a count of episodes over time. It was defined as mother-reported sudden onset of cough, runny/stuffy nose or difficulty breathing on at least two consecutive days and at least two symptoms reported on at least one day, with at least one symptom present each day. Additional symptoms such as fever, poor feeding/decreased appetite, or hospitalization for breathing problems can confirm an ARI case if reported with symptoms in the main definition. Episodes were considered separate if there were at least seven days without symptoms between

them. The duration of an episode was determined by the number of days the symptom persisted, as reported by the mother. Exposure to household air pollution was assessed by stove type used during pregnancy as chimney stove (intervention) or traditional stove (control). Here, stove type is used as a surrogate for HAP exposure.

Trained data collectors asked mothers or care givers on the occurrence of ARIs following the definitions and protocols outlined in the Integrated Management of Childhood Illness (IMCI) module of WHO (WHO, 2005) and modified by the Federal Democratic Republic of Ethiopia Ministry of Health (FMoH) according to national guidelines and local terms (FMOH, 2011). This standardized approach ensures consistency with national guidelines for childhood illness management.

At birth, mothers were informed about the upcoming data collection process. They were instructed to record any significant events concerning their newborns, including the date of each vaccination and any respiratory illnesses that may occur. To enhance parental reporting of respiratory illnesses, field data collectors were provided ways on identifying symptoms consistent with ARIs in infants. Parents were instructed to contact the field data collectors, health extension workers, or local health development army leaders if their infants experience any of the symptoms. This recording should begin at birth and continue throughout the study period. ARI assessments follow-up visits were also integrated with existing infant vaccination schedule to reach more infants in the community residing remote areas. During birth weight measurement, field workers discussed the upcoming vaccination visits and their role in identifying potential ARIs. At each visit, the data collectors conducted a questionnaire to record the infant's symptoms over the past two months, as reported by the mother.

6.2.5 Data collection

Baseline data on sociodemographic, economic, housing, and cooking behaviors were collected using structured questionnaires, as detailed in Chapters Three and Four. A well-recognized approach which combines health promotion, disease prevention and management strategies to ensure early detection, effective treatment, and healthy habits within families and communities known as Integrated Management of Childhood Illness (IMCI) (FMOH, 2011) was used to track episodes of acute respiratory infections. Six midwives from three local health centers received refresher training on identifying ARI cases through symptom based assessment. They visited each infant's home every two months during the first six months of life. During these scheduled

active surveillance visits, they directly asked mothers about their infants' experience with fever, persistent cough, and wheezing/difficulty breathing (both before and during the current visit). Mothers were also encouraged to report any respiratory symptoms observed between visits. Additionally, data were collected on potential factors influencing ARIs, including age-appropriate vaccination status and exclusive breastfeeding status. Since data collection in remote rural areas is always challenging, various community platforms were utilized for case identification, including vaccination schedules. Vaccinations were offered at health posts, churches, and marketplaces to enhance accessibility and convenience for mothers. Some participants also received a trial sticker. When they or their babies required medical care, they showed the sticker to the health center midwives which allowed to collect valuable data.

6.2.6 Data quality assurance

To ensure data accuracy and consistency throughout the study, we implemented several key measures. First, all fieldworkers, regardless of prior training on the IMCI- respiratory illness algorithm, received refresher training. This training specifically focused on the consistent evaluation of the primary outcome variable, infant ARI, across both intervention and control groups. This minimized potential bias in identifying ARI cases. Second, supervisors conducted random duplicate home visits to independently verify the information collected by fieldworkers. This served as a cross-checking mechanism to ensure data fidelity and identify any discrepancies. Third, feedback sessions were regularly conducted with fieldworkers to address any challenges or inconsistencies encountered during data collection. This iterative approach helped refine the process and maintain data quality. Fourth, utilizing various local events, such as vaccination schedules, regular local meetings, and church activities, to maximize the number of infants accessible for ARI assessments. Finally, the longitudinal study design allowed us to track ARIs over time and capture potential changes in patterns. Additionally, collecting baseline data on relevant risk factors enabled statistical adjustments, further balancing for potential confounders in both study arms.

6.2.7 Statistical analysis

To ensure comparability between the intervention and control groups, we conducted a baseline descriptive analysis. This analysis compared the groups on relevant characteristics such as socioeconomic status, demographics, and kitchen and home environment. Independent sample t-

tests were used for continuous data, while chi-square tests were used for categorical data. This is mainly to ensured that any observed differences in ARI outcomes were likely due to the intervention, not pre-existing group imbalances.

The primary analysis focused on the intervention's impact on infant ARI incidence during the six-month follow-up period. Incidence was calculated by dividing the number of new episodes by the person-time at risk. Person-time at risk was defined as the number of days without a recorded respiratory infection. Given the longitudinal design with repeated infant visits, we employed Poisson regression with generalized estimating equations (GEEs) to account for this data structure. This approach allowed us to capture the dynamic changes in ARI risk throughout the study, providing a more comprehensive understanding of the burden of respiratory illness across different time points. Poisson regression is appropriate to model count data, which in our case is the number of ARI episodes per infant. GEEs further enhance this analysis by estimating how the risk of ARI changes over time, considering the potential correlation between repeated visits from the same infant. Following the intention-to-treat principle, all participants were included in the analysis regardless of adherence to the intervention. To calculate incidence rates (IR) and risk rate ratios (IRRs), we used infant-months at risk as the denominator. This metric takes into account the total time infants were followed and potentially susceptible to ARIs.

The initial step involved calculating the prevalence rate to give an overview of the overall prevalence of ARIs at specific time points during the study. This rate was obtained by dividing the number of infants with ARIs by the total number of infants studied at each time point. It aimed to provide a snapshot of ARI occurrence at particular intervals, offering insights into the overall burden of ARIs within the infant population. Following this, the study calculated the incidence rate to capture how frequently new ARI episodes occurred among the infants over the 6-month tracking period. This rate was computed as the number of new ARI episodes divided by the total infant-months observed. It provided a measure of the frequency of new ARI occurrences over time, highlighting how quickly infants experienced ARI episodes during the tracking period. Lastly, the investigation estimated the risk ratio to emphasize the relative risk of experiencing ARIs between the intervention and control groups. This calculation involved comparing the risk (probability) of ARI occurrence in the intervention group to that in the control group. The risk ratio offered insights into the comparative risk of ARIs in the two groups, presenting a clearer understanding of the potential impact of the intervention on ARI occurrence.

But, as respiratory infections are unlikely to occur in utero, at the enrolment (immediately at birth) we expected all infants free from ARI and assessment and adjustment for the baseline ARI value is not necessary. The incidence of ARIs was also assessed within subgroups stratified by newborn sex, gestational age, kitchen roof type, family size, exclusive breast feeding and vaccination status for age to identify potential variations in the intervention's effectiveness across different populations. All statistical analyses were conducted using SPSS version 25 (Pallant, 2020).

6.3 Results

6.3.1 Pregnancy and infant characteristics

A total of 422 eligible pregnant women were randomly allocated to equal-sized study arms at the beginning of the main trial, with birth outcomes known and assessed for 372 participants (189 interventions, 183 control). This resulted in 355 live births (183 interventions, 172 control). We observed 8 miscarriages (3 interventions, 5 control) and 9 stillbirths (3 interventions, 6 control). Out of the 355 live births enrolled in the postnatal study, 343 infants had complete follow-up data for ARI assessment. Reasons for exclusion (n=12) included lost to follow-up before the first visit (n=5), neonatal death (n=3), and refusal to participate (n=4) (Figure 28). The follow-up data showed that all participants in the intervention group continued to use the improved stoves exclusively and none of the participants in the control group switched to using the intervention stoves.

The baseline and infant characteristics of participants who remained in the study after exclusions was compared to ensure comparability between groups. As shown in Table 11, the participants in the intervention and control groups were well-matched in terms of most relevant pregnancy and newborn characteristics that could influence the occurrence of ARIs. The only notable statistically significant difference was observed in average maternal age at delivery between the intervention and control groups (28.6 and 29.3 years, respectively; $p = .023$) and infant vaccination completion status for their age (86.4% vs 82.5% for intervention and control group, respectively; $p = .048$). These differences might influence ARI, highlighting the importance of including them in adjusted analyses to account for their potential role in the intervention effectiveness.

Comparability checks were also conducted for housing and cooking-related characteristics across the intervention and control groups. As shown in supplemental table (supplemental table 1), household variables such as the number of rooms and windows able to open, and cooking characteristics including kitchen location, structure, primary fuel type, frequency of cooking per day, and Injera baking per week, were balanced across the groups to strengthening the internal validity of our subsequent analyses.

Table 11: Baseline characteristics of mothers and infants by intervention arms in south Gondar zone, northwest Ethiopia

Characteristics	**Overall (355)**	**Intervention (183)**	**Control (172)**	**p-value***
Maternal age at delivery, mean± SD	28.9 ±5.2	28.6±5.2	29.3±5.1	.023
Total family size, mean ± SD	4.8±1.6	4.7±1.6	4.9±1.6	.133
ANC complete (at least 4 visit), n(%)				
yes	97	49 (26.7)	48 (27.9)	
no	255	127 (72.2)	116 (70.6)	.313
missed	3	1	2	
current pregnancy order, n (%)				
prim gravida	23	12(6.6)	11 (6.4)	.514
multigravida	332	171 (93.4)	161 (93.6)	
Infant sex, n (%)				
male	174	90 (48.9)	84 (49.5)	.446
female	181	94 (51.1)	87 (50.5)	
Mean birth weight, in grams, ± SD	3050 ± 497	3045 ± 491	3043 ± 499	.944
range	1315 - 4200	1700 - 4200	1315 - 4162	
Gestational age at birth, weeks	39.4±1.9	39.3 ± 1.9	39.4 ± 1.8	.640
range	32-42	32-42	32-42	
Low birth weight, n(%)				
yes (<2500 grams)	26	13 (8.2)	13 (7.7)	
no (≥2500 grams)	304	159 (92.3)	145 (91.8)	.433
Preterm birth, n(%)				
yes (< 37 weeks)	18	10 (5.6)	8 (4.9)	
no (≥ 37 weeks)	298	154 (84.0)	144 (83.7)	.739
pentavalent and PCV				
completed	299	158(86.4)	141(82.5)	.048
not completed	43	18(9.8)	25(14.6)	
exclusive breast feeding				
yes	178	96(58.0)	82(47.2)	.669
no	165	69(42.0)	96(52.8)	
Place of delivery				
Home	35	16(8.7)	19(10.9)	.378
Institute	308	160(87.5)	148(86.2)	

Mode of delivery				
SVD	258	132 (72.2)	126 (73.2)	.243
instrumental assisted	16	7 (3.6)	8 (4.1)	
episiotomy	15	10 (5.6)	5 (3.1)	
Asset index				
poor	120	57 (31.0)	63 (36.8)	.114
middle	120	63 (34.7)	57 (36.8)	
rich	115	63 (34.3)	52(29.9)	
Drinking water source				
improved	179	95 (51.9)	84 (49.1)	.390
unimproved	175	88 (48.1)	87 (50.9)	
Toilet types				
improved	92	44 (23.5)	48 (27.6)	.139
unimproved	163	140 (76.5)	123 (72.4)	

*Compression for continuous variables (maternal age, birth weight and gestational age) were done using linear regressions whereas for all categorical variables, chi-square test was done.

6.3.2 Acute respiratory infection outcomes

Following the exclusion of miscarriages, stillbirths, those lost to follow-up, neonate deaths, and refusals before the first visit, 343 live births (176 vs 167 intervention and control group respectively) were tracked every two months for six months of life, resulting in a total of 1029 visits during the whole study period. Among the infants in the intention-to-treat (ITT) population, we identified 42 episodes of ARI from 2106 infant-month of follow-up among 355 infants.

The intervention group demonstrated a reduction in ARI episode duration, with an average of 4.97 days (SD=1.55) compared to 5.55 days (SD=1.86) in the control group indicating that the improved stoves may have contributed to a decrease in the severity or duration of respiratory infections (Figure 30). The observed average difference of 0.57 days between the two groups is statistically significant (t=2.14, p=0.034), suggesting a meaningful difference.

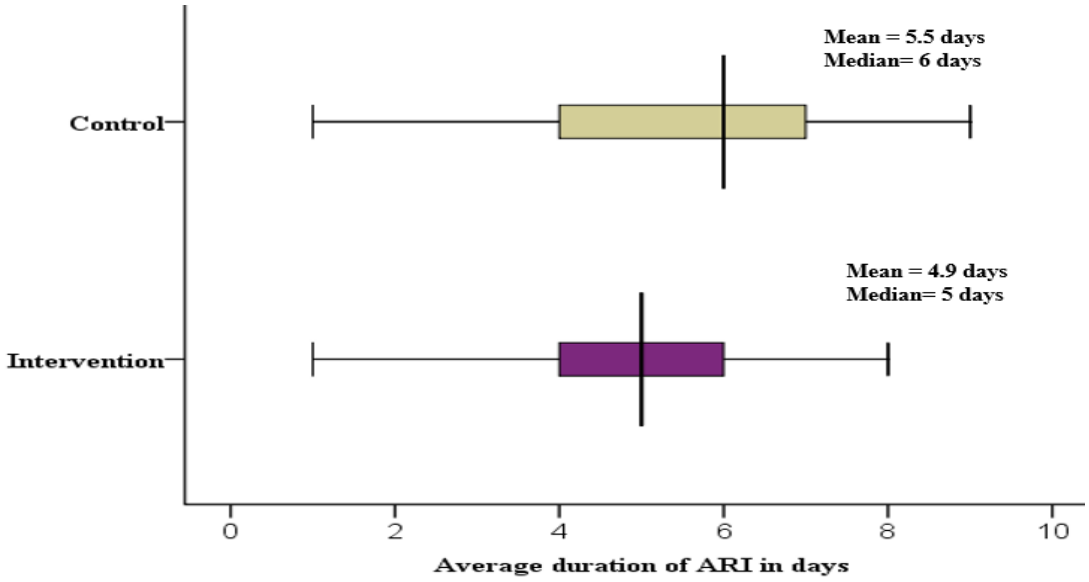


Figure 30: Comparison of average duration of acute respiratory infections (ARI) between control and intervention groups

Notably, recurrent ARI was relatively rare, with only 12 infants (8 from the control group and 4 from the intervention group) experiencing two ARI episodes throughout the follow-up period. This translates to the overall longitudinal prevalence of 11.8% (95% CI: 10.0, 14.0%) across the entire follow-up period. The prevalence of ARI within the intervention and control arms was 10.7% (95% CI: 8.0 ,13.0%) and 13.0% (95% CI: 10.0, 16.0%), respectively.

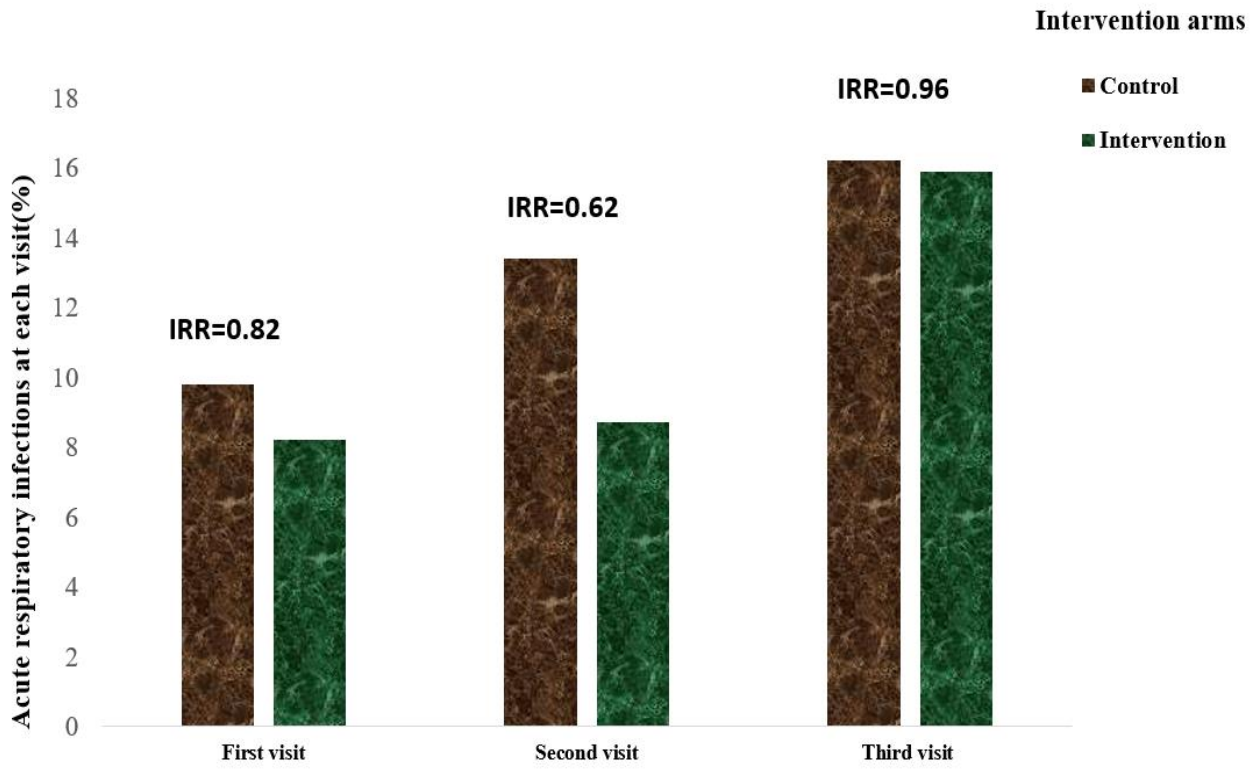


Figure 31: The point prevalence of infant acute lower respiratory infections and corresponding incidence rate ratios by study visits and arms in South Gondar Zone, Northwest Ethiopia

The point prevalence which reflecting the proportion of babies with at least one ARI episode at each visit, demonstrated a notable increase over time for both groups. At the first visit, 8.2% (95% CI: 4.0, 12.0%) of infants in the intervention and 9.9% (95% CI: 5.0 ,14%) in the control group had experienced an ARI episode. This increased to 15.9% (95% CI: 10.4, 21.3%) and 16.2 % (95% CI: 10.5, 21.8%) for the intervention and control arms, respectively, at the third visit. This indicates that while the number of ARI episodes increased with age of the infants in both groups, the control group exhibited a more pronounced increase over the follow-up time (Figure 31).

In addition to the longitudinal and point prevalence, an incidence rate (IR) was calculated to determine the average rate of new ARI episodes per unit of time (per infant-month) within the study population. The IR, based on the number of new episodes and total follow-up time, provides further insight into the dynamic pattern of ARI occurrence within the population. Across the six months of life, we observed an overall incidence rate of ARI of 6.76 episodes of

ARI (95% CI: 5.65, 7.87) per 100 infant-months. The control group had a slightly higher incidence rate 7.40 episodes of ARI (95% CI: 5.74, 9.05) per 100 infant-months compared to the intervention group 6.16 episodes of ARI (95% CI: 4.67, 7.64) per 100 infant-month.

Both groups exhibited a peak in incidence rates at the final visit (6 months of age). In the control group, the incidence rate was 5.45 episodes (95% CI: 2.96, 7.93) per 100 infant-months at the first visit, increasing to 8.72 episodes (95% CI: 5.67, 11.77) per 100 infant-months at the third visit. Similarly, the intervention group experienced an increase, with rates going from 4.48 episodes (95% CI: 2.29, 6.68) per 100 infant-months at the first visit to 8.42 episodes (95% CI: 5.52, 11.32) per 100 infant-months at the third visit.

6.3.3 Estimating the effect of the intervention

The potential impact of chimney-fitted Mirt stoves on ARI episode was estimated by comparing the probability of experiencing an ARI episode in the intervention group to that in the control group. We employed two models: generalized estimating equations (GEE) and Poisson regression models. Poisson regression captures the average rate of ARI episodes for each infant. GEE, on the other hand, can model the probability of having ARI at each visit while accounting for correlations between repeated visits on the same infant. Accordingly, the GEE model indicated a 20% lower risk of ARI in the intervention group compared to the control group (incidence rate ratio (IRR) = 0.80; 95% CI: 0.56, 1.15; P = .238). Similarly, the Poisson regression model showed an 18% reduction in ARI episodes in the intervention group compared to the control group (IRR = 0.82; 95% CI: 0.59, 1.14; P = .250). While these reductions were not reached to statistically significant, both incidence rate ratios (IRRs) suggest a protective effect of the intervention (improved stoves) on the incidence rate of ARI in infants.

GEE can model the probability of having ARI at each visit while accounting for correlations between repeated measures on the same infant. While this reduction was not statistically significant, the point estimates suggest a potentially protective effect of the improved stove, particularly at earlier time points. The intervention appeared to provide a greater protective effect at the second visit (4 months of age) (IRR = 0.62; 95% CI: 0.32, 1.22; P =.166) and the lowest protective effect at the third visit (IRR= 0.97 (95%CI: 0.55, 1.72; P =.918) (Figure 31).

While most relevant variables that could influence both the intervention (improved stoves) and the outcome (ARI episodes), were balanced between the study arms, we opted to include

adjustments for maternal age at delivery and vaccination status in the GEE model. Despite not reaching statistical significance (p = .252), the adjusted GEE model showed a promising 19% reduction in ARI incidence among infants exposed to improved stoves compared to the control group (incidence risk ratio (IRR) = 0.81; 95% CI: 0.56, 1.16; P=.252) after controlling maternal age.

Table 12: Effect of the intervention stove against fieldworkers assessed ARIs among infants in south Gondar zone, northwest Ethiopia

Characteristics	**Episodes of ARI**		**Unadjusted**	**P Value***	**Adjusted**	**P Value****
	yes	No	IRR (95% CI)		IRR (95% CI)	
Stove types						
Improved	20	163	0.80 [0.56, 1.15)	0.238	0.81 [0.56, 1.16]	.252
traditional	23	149	1	-	1	
Stratified analysis						
Infant sex						
female	18	162	0.58 [0.33, 1.03]	.062	0.59 [0.34, 1.04]	.071
male	24	151	1.04 [0.63, 1.71]	.887	1.03 [0.63, 1.70]	.894
Gestational age at birth						
preterm (< 37 weeks)	4	15	0.61 [0.16, 2.34]	.470	0.55 [0.14, 2.21]	.400
term (≥ 37 weeks)	35	263	0.79 [0.53, 1.19]	.267	0.80 [0.53, 1.20]	.278
Exclusive breast feed						
yes	18	163	1.01 [0.56, 1.80]	.977	1.00 [0.56, 1.80]	.989
no	24	138	0.73 [0.45, 1.17]	.194	0.74 [0.46, 1.19]	.218
pentavalent and PCV						
completed	37	163	0.84 [0.57, 1.25]	.398	0.85 [0.57, 1.26]	.417
not completed	5	38	0.59 [0.21, 1.64]	.314	0.58 [0.21, 1.61]	.297
Family size						
< 5 occupants			1.06 [0.66, 1.69]	.814	1.07 [0.67, 1.70]	.793
≥ 5 occupants			0.54 [0.30, 0.98]	.045	0.58 [0.32, 1.06]	.079
Kitchen roof type						
Thatched roof	10	91	0.80 [0.37, 1.71]	.569	0.80 [0.37, 1.71]	.566
Corrugated iron sheet	32	222	0.80 [0.53, 1.22]	.304	0.81 [0.53, 1.23]	.327
Kitchen location						
separated	29	216	0.80 [0.52, 1.23]	.316	0.81 [0.53, 1.25]	.351
Attached	12	94	0.92 [0.46, 1.82	.808	0.91 [0.46, 1.81]	.799
Injera baking per week						
once	7	56	0.82 [0.35, 1.92]	.644	0.85[0.36, 2.04]	.728
twice and more	35	257	.80 [0.52, 1.20]	.280	0.80[0.54, 1.19]	.281
Asset index						
poor	15	104	0.67 [0.35, 1.27]	.225	0.67 [0.35, 1.27]	.222
middle	11	109	1.78 [0.85, 3.76]	.128	1.71 [0.82, 3.59]	.154
rich	15	70	0.57 [0.31, 1.09]	.088	0.61 [0.32, 1.15]	.129

***** Differences for categorical variables come from Poisson regressions with robust estimates. Estimates shown represent risk ratios and 95% CIs as compared with the control group. Differences replicate unadjusted models and additionally adjust for covariates. **Abbreviations**: ARI, acute respiratory infection; IRR, incidence rate ratio

While GEE provides the average effect of the intervention (IRR) across the entire population, the effect might not be the same for everyone. Stratified analysis allows to explore whether the intervention's effectiveness (reduction in ARI) varies depending on certain characteristics. To assess potential variations in the intervention's effect, we also stratified our infant population based on nine characteristics identified from previous studies to be potentially associated with ARI risk (Cao et al., 2016b, Koala et al., 2023b). These characteristics include family size, kitchen location, kitchen roof type, frequency of "Injera" baking per week, wealth index, infant sex, maternal age, gestational age at birth, exclusive breastfeeding practices and vaccination status which are potentially related to ARI risk (Adane et al., 2021b, Anteneh and Hassen, 2020, Enyew et al., 2021a).

From our stratified analysis, being female and living in households with five or more permanent occupants revealed potential benefits from the intervention. However, the reduction in ARI incidence for females in the intervention group (IRR= 0.59; 95% CI: 0.34, 1.04, P=.071) was not statistically significant. In contrast, infants living in households with five or more occupants in the intervention group had a 46% reduction in ARI incidence (IRR=0.54; 95% CI: 0.30, 0.98) compared to the control group. While the unadjusted analysis suggested a statistically significant effect (P=.045), this effect became less pronounced after adjusting for maternal age at delivery (IRR= 0.58; 95% CI: 0.32, 1.06). Despite observing trends towards reduced ARI incidence in some subgroups following stratification, these findings did not reach statistical significance (Table 12).

6.4 Discussion

Evidences have consistently linked household air pollution from biomass fuel use to acute respiratory infections in Ethiopia (Admasie et al., 2018b, Adane et al., 2020b, Tamire et al., 2022, Sanbata et al., 2014). To address these concerns and explore the potential protective effect of improved stoves, a randomized controlled trial was conducted. The study evaluated whether introducing chimney-fitted Mirt stoves during pregnancy and continuing their use until infants reached 6 months of age could reduce ARI incidence. Participants were infants living in typical rural Ethiopian homes (earthen floors, wood/mud walls, corrugated iron sheet roofs) that relied

solely on biomass fuels, leading to high exposure to particulate matter (Enyew et al., 2023, Habtamu et al., 2023). The study compared the incidence of ARIs in households with intervention stoves versus those with traditional stoves.

In this study, although the intervention group experienced fewer ARIs incidence overall, the difference was not statistically significant. The null results were also reported from KidsAir study in rural U.S. households (Walker et al., 2022) and the cluster-randomized controlled trial in Rwanda (Kirby et al., 2019). But, the overall prevalence of ARIs observed in this study falls slightly below the result reported in a comparable study in Ethiopia (Adane et al., 2021b) and higher than the report from Mexico (Schilmann et al., 2015). The observed differences could potentially be attributed to the extended duration of follow-up, variations in the age range of the study children, the nature of the intervention stoves and the variations on the sample size as reported previously (Quansah et al., 2015, Woolley et al., 2022b, Quansah et al., 2017a). But, while improving health is a compelling reason to address household air pollution, the benefits extend far wider, driving economic growth and tackling climate change (Rees, 2016).

It was also observed that infants aged 4 to 6 months experienced the highest incidence of all ARIs, while infants younger than 2 months had the lowest incidence. The result aligns with the reported highest incidence rate for ARI and pneumonia occurring in the 9-12 months age group, compared to the lowest rate in infants under 3 months (Oktaria et al., 2021). The worldwide pattern also revealed that the highest number of new cases occurred within the 1– 4 years age groups (Safiri et al., 2023b). Similarly, the study found that the most common age for ARIs prevalence was between 6 months and 2 years, but the highest risk of death from ARIs was in infants less than 1 year old (Merera, 2021). The association between child age and the prevalence of ARIs was reported from additional literatures (Admasie et al., 2018c, Hasan et al., 2019b, Safiri et al., 2023a). This trend may be due to cultural practices such as mothers breastfeeding or carrying children while cooking, which could inadvertently expose them to high levels of household air pollution (HAP) (Aithal et al., 2023). Moreover, as infants gain strength, they tend to spend more time near their mothers and engage in play with their younger siblings, leading to an increased exposure to air pollution (Carroquino et al., 2013, Rees, 2016).

As confirmed by both unadjusted and adjusted incidence risk ratio, the GEE model did not reveal a statistically significant reduction in ARI incidences attributable to the intervention stove. Previously reported trials in Malawi (Mortimer et al., 2017), Gahanna (Jack et al., 2021) Ethiopia (Adane et al., 2021b, LaFave et al., 2021), Guatemala (Smith et al., 2011) and Nepal (Tielsch et al., 2016) also found no statistically significant evidences that stove and fuel interventions reduced the risk of respiratory infections in young children. Despite established links between household air pollution and respiratory problems (Shezi and Wright, 2018, Hendrina and Fauzi, 2023, Mondal and Paul, 2020, Addisu et al., 2021a, Lee et al., 2020b), the effectiveness of improved stoves in lowering exposures and ARI risk remains debatable, with research producing a range of inconclusive findings (Adane et al., 2021b, Abdo et al., 2021, Hartinger et al., 2016, Kirby et al., 2019, Mortimer et al., 2017).

Because the intervention stove was designed specifically for baking Injera, other food items were primarily cooked using the traditional stove. This may have influenced exposure levels and affected the intervention's effectiveness. Similarly, insufficient reductions in household air pollution levels were cited as a potential reason for the lack of observed improvements in respiratory health outcomes (UN, 2021) as the concentrations of the pollutants were well above both the WHO guideline values from previous studies (Quansah et al., 2017b, Singh et al., 2012b, Phillip et al., 2023b). As reported from chapter four, notably high PM2.5 concentrations were observed in both intervention (104 µg/m³) and control (449 µg/m³) households after the intervention (Enyew et al., 2024). These levels significantly exceed the WHO's recommended safe limit of 15 $\mu g/m^3$ for a 24-hour period (WHO, 2021a). Though low adoption or stove stacking behaviors were not observed in our study, limitations reported in previous intervention studies, such as insufficient adoption or stove stacking may have contributed to the absence of a notable effect on child respiratory health (Pope et al., 2021a, Khandelwal et al., 2017). Inconsistent use of the intervention, due to their complex maintenance and repair needs was also mentioned as one explanation for the limited effectiveness (UN, 2021, Pope et al., 2021b).

While our study found no significant impacts on ARI incidence, stove interventions in Rwanda (Kirby et al., 2019) and fuel intervention in Nigeria (Oluwole et al., 2013b) yielded protective impacts for respiratory health problems. Statistically significant reductions in persistent cough, wheeze and burn injury was also reported from rural Nepal (Tielsch et al., 2016) and a significant association was reported between Patsari stove intervention and a reduction of acute

respiratory symptoms in rural Mexico (Romieu et al., 2009). It was also reported that using solid fuels for cooking without a chimney or hood significantly increases the risk of acute lower respiratory infections (ALRI) among African children (Rehfuess et al., 2009b). Children under five in Kenyan homes using traditional three-stone stoves experienced significantly higher rates of ARIs compared to those with improved stoves (Wafula et al., 2000). A systematic review found that improved cook stoves showed a reduction in respiratory and ocular symptoms among women, but no detectable impact on child health (Thakur et al., 2018). In Ethiopia, it was reported that stove intervention is associated with improvement in height-for-age of young children compared with a control group (LaFave et al., 2021).

In our subgroup analysis, female infants and infants living in households with five and more occupants benefitted relatively more from the stove intervention. This is likely because larger family sizes can mean more exposure to cooking smoke (Atnafu et al., 2021) and a higher risk of respiratory infections for children, so the improved air quality from the intervention may have had a bigger effect in larger households (Addisu et al., 2021b, Addisu et al., 2019). However, the association between newborn sex and ARIs remains complex, with some studies suggesting higher rates in females and others in males. For instance, there were findings indicating a higher incidence of ARIs among female children (Adane et al., 2020b, Enyew et al., 2021a, Kinney et al., 2021, Enyew et al., 2021b). Similarly, studies from Bangladesh (Kurata et al., 2020) and a more detailed study from Ghana (Kinney et al., 2021) showed that female infants are particularly susceptible to respiratory infections. Based on recently published research, females globally bear a higher burden of morbidity-driven conditions, particularly for low back pain, depressive disorders, and headache disorders, when compared to males (Patwardhan et al., 2024). However, contradicted results have also been documented, suggesting that male fetuses may be more vulnerable to the effects of exposure to household air pollution in utero in Gahanna (Adjei-Mantey and Takeuchi, 2021) and in Bangladesh (Islam et al., 2022a, Hossain et al., 2022). Additionally, it was noted that females had a lower risk of hospitalization due to particulate matter compared to males (Shin et al., 2021). The global mortality rate from lower respiratory infections (LRI) was marginally higher in males (Safiri et al., 2023b).

6.5 Conclusion

An intervention that provided chimney-fitted Mirt stoves to pregnant women to replace traditional baking stoves did not lower the incidence of acute respiratory infections in their

infants living in rural Ethiopia which remains inconclusive. While the intervention did not yield statistically significant results, we observed promising trends suggesting a potential protective effect of the stove on ARI incidence. Further research with larger sample sizes and longer follow-up periods is warranted to confirm these trends and elucidate the underlying mechanisms.

Chapter 7

General Discussion, Conclusion and Future Research Perspectives

7.1 General discussion

Millions of lives in low-income countries are threatened by household air pollution, caused primarily by burning biomass fuels (Misganaw et al., 2023, Aemro et al., 2021, Bede-Ojimadu and Orisakwe, 2020). This critical public health issue is likely to persist due to the slow progress towards achieving universal access to clean cooking, a key component of the sustainable development goal seven (Nizami, 2023, Rosenthal et al., 2018, WHO, 2016b). Fortunately, advancements in stove technology and modifications of cooking fuels offer promising solutions for a safe transition to clean cooking practices (Nizami, 2023, Price et al., 2020, Program, 2021, WHO, 2018b). Though various global and local efforts have been made to reduce exposure to household air pollution, the related health burden still remains high in low income countries (HEI, 2019, Yigezu et al., 2023). This highlights the need for continued investment in research, development, and implementation of better cooking solutions to protect public health, particularly women and children in poor settings (Gall et al., 2013, Rosenthal et al., 2017).

This Ph.D. dissertation investigates three key aspects of household air pollution in rural Ethiopia. Firstly, assessment was done on how pregnant women perceive the health risks associated with household air pollution and the potential benefits of improved stoves. When perceptions of health risks and potential benefits are incorporated into intervention strategies, the likelihood of successful adoption and sustained use of improved stoves can be increased. Second, the study evaluates the effectiveness of chimney-fitted, locally produced Injera baking stoves in reducing kitchen PM2.5 concentrations. This involved comparing the air quality generated by these stoves to traditional methods. The assumption was that if the intervention stoves reduced PM2.5 to safe levels, it would benefit the health of mothers and their fetuses. Third, the study analyzes the impact of the intervention stoves on health outcomes, including both fetal health (pregnancy

outcomes) and the incidence of acute respiratory infections (ARIs) among newborns. The findings offer valuable insights into the potential benefits and challenges associated with this intervention.

Based on the findings from the mixed-method baseline assessment, pregnant women in the study area are concerned that HAP affects their health and wellbeing (63%) and even more so regarding the perceived benefits of improved stoves (74%) which has been reflected in high acceptance and adherence of intervention stove among the study participants. This high risk perception could be attributed to the increased awareness of pregnant women who might have additional concerns about the impact of air pollution on their unborn babies. However, previous practices to reduce HAP exposure was low (42%), suggesting that HAP did not compete sufficiently with other prioritized household issues as reported previously (Grajeda et al., 2020). High risk perception of HAP often coexists with low practices to reduce exposure. This discrepancy can be attributed to the long-term nature of HAP's effects, which often prioritizes more immediate life concerns in developing countries. In recognition of this potential challenge, the main trial incorporated close follow-up measures to prevent the potential stove abandonment (or "stove stacking") that affects the true effect of the intervention stove.

The observed PM2.5 reduction appears to be one of the largest reported from stove interventions in Ethiopia to date. The chimney design of the intervention stove likely played a significant role in venting out dark smoke, especially considering the often narrow construction of kitchens in the study area. While a significant reduction in kitchen PM2.5 concentrations with the intervention stove was demonstrated, post-intervention levels remained substantially above WHO safety guidelines (WHO, 2021b). Besides the intervention stove's limited combustion and venting capabilities, continued biomass use with traditional stoves for cooking other than Injera and heating contributed to indoor air pollution (Asefa and Mergia, 2022). Furthermore, smoke infiltration from neighboring households through kitchen openings may have negated the PM2.5 reduction benefits achieved by the intervention stoves. Previous study has indicated that achieving WHO-recommended air quality standards requires a near-complete transition from traditional to improved stoves (Islam et al., 2022b).

In this study, no significant difference in average birth weight was observed between the intervention and control groups. However, a crucial observation was that improved stove use was associated with a statistically significant increase in gestational age compared to the control group. This translates to babies born at an average of one week later in the intervention group. Additionally, the risk of preterm birth was significantly lower in the intervention group. While birth weight itself was not statistically impacted, these findings suggest potential benefits for infant health through a longer gestational period and a reduced risk of preterm birth. These observations, although not conclusive, warrant further investigation, particularly considering the positive perceptions towards improved stoves and the confirmed PM2.5 reduction achieved by the intervention stove.

The overall prevalence of ARIs remained relatively low (12%). This finding aligns with the PM2.5 reduction observed and suggests a potential link between reduced exposure to air pollution and a lower risk of ARIs in newborns. Furthermore, the subgroup analysis identified potentially greater benefits for specific populations within the intervention group. Female infants, those born to mothers with more frequent prenatal care visits, and those from smaller families experienced a more notable reduction in ARIs. These findings warrant further investigation to explore the potential mechanisms behind these observed trends. Although the difference in ARI rates was not statistically significant, the consistent trend observed across the analysis, combined with the positive findings from this study, provides encouraging preliminary evidence for the potential health benefits of improved stoves in reducing respiratory illnesses among newborns. In addition to limitations of intervention stove to reduce the level of PM2.5 to the permissible level and additional sources contributed to indoor air pollution, the study period might not have been long enough to observe a substantial impact on health outcomes, particularly for pregnancy outcomes as also reported from previous study (Thomas et al., 2015a). Because, birth defects or long-term health issues in newborns might require an extended periods of reduced exposure to manifest a statistically significant change.

In brief, this study highlights the alarming exposure of pregnant women in rural households to air pollution from biomass fuels. Despite their high awareness of health risks and the perceived benefits of improved stoves, traditional stoves remain in use due to affordability and availability constraints. While our intervention stove significantly reduced fine particulate matter ($PM_{2.5}$) in

kitchens, we did not observe a statistically significant improvement in health outcomes, particularly regarding pregnancy outcomes and acute respiratory infections. This lack of observed health impact could be due to the PM2.5 concentrations still exceeding the WHO's safety levels.

A key question arising from results of this analysis is why the observed reduction in PM2.5 did not meet the WHO safe level to translate into significant improvements in health outcomes. Several factors contributed to persistently high PM2.5 levels in the improved stove intervention group. The high baseline levels of kitchen smoke, resulting from the use of unclean energy sources, challenged the intervention stove's ability to achieve acceptable PM2.5 reductions. Incomplete combustion of fuel and ineffective chimney or ventilation systems, which trapped smoke within the dwelling, also contributed to higher emissions. Continuous development and implementation of improved stoves are essential to reduce indoor air pollutants to acceptable levels.

7.2 Overall messages

Improved stoves can significantly reduce household air pollution and have the potential to improve health outcomes. By promoting the use of improved stoves, policymakers and public health professionals can contribute to cleaner air and potentially lower respiratory illness rates in communities that rely on traditional cooking methods. This can lead to a healthier population and potentially reduced healthcare costs.

The observed high level of risk perception of household air pollution and perceived benefits of improved stove will help for future intervention. The intervention stove was well-received, with a high proportion of participants believing it would benefit their families, indicating a strong willingness to adopt these stoves. But, in addition to acute health problems manifested immediately when women exposed for biomass smoke, awareness and information should be given the chronic health problems to reinforce their implementation. The reported significant reduction of $PM_{2.5}$ is a promising finding for safe transition to clean cooking in the study area. In addition to pollutant reduction, the improved stove prevented from heat exhaustion due to its enclosed burning chamber. But still continuous modification is required based on the feedback of the local end user. Public health initiatives and government policies should encourage the

adoption of these stoves. The cost of improved stoves might be a barrier for some families. Subsidies or financing options could be explored to make them more accessible

Since different socioeconomic and household factors are identified to be associated with health risk perception, perceived benefits of improved stoves, public health programs should consider these factors when implementing interventions, potentially offering different stove models or educational materials depending on the specific needs of a household.

This study provides a foundation for future research on the health benefits of improved stoves. The observed reduction in PM2.5 alongside suggestive trends towards improving lower birth weight, preterm birth rates, and acute respiratory infections (ARIs) warrant further investigation. A larger, more robust study design with a significantly increased sample size is necessary to definitively confirm the health impacts of various improved stove models on a wider range of health outcomes in rural Ethiopian communities.

7.3 Strengths and limitation

7.3.1 Methodological strengths

The first strength is investigating the impact of air pollution on pregnant women and their infants who are considered as a vulnerable population. Testing the intervention stove in a real-world setting among disproportionally affected segment of the community increases the strength and generalizability of the findings. Another strength of this study lies in its utilization of a mixed-methods approach, employing both qualitative and quantitative data to comprehensively assess the perceived health risks of household air pollution and the perceived benefits of improved stoves.

The study also employed a randomized controlled trial (RCT), considered the gold standard for evaluating interventions. This rigorous approach strengthens the internal validity of the findings, allowing for a more confident attribution of the observed reduction in kitchen pollutants and potential health improvements to the intervention stove itself. The use before and after with control design strengthens the internal validity by allowing to isolate the effect of the intervention on the outcome variables. In addition, measures of air quality ($PM_{2.5}$) through air monitoring strengthens the study compared to relying solely on self-reported data. Using standardized tools for health outcomes (ARIs) allows for better comparison with other studies.

7.3.2 Methodological limitations

This research, while offering valuable insights, faced some methodological challenges that limit the generalizability and long-term conclusions we can draw. The study's follow-up period of six months is insufficient to definitively assess the sustained effectiveness of the improved stoves on air quality and health outcomes. Ideally, a longer study duration would allow for a more comprehensive evaluation. The research was conducted in a specific geographic location with a particular cultural context. This raises concerns about generalizing the findings to other populations with different settings or cultural practices. Replication in diverse settings would strengthen the generalizability of the results. The study relied on self-reported data for acute respiratory infections. This approach, while practical, can introduce bias due to potential inaccuracies in recall. Ideally, the study would be complemented by objective measures of respiratory health, such as lung function tests, to strengthen the findings.

The study employed a parallel individual-level randomization design, where the intervention was introduced at the household level. However, due to the potential infiltration of pollutants from neighbouring households using biomass fuel, through open spaces or ventilation systems, the study's design may be limited. To address this limitation, a community-level intervention or a quasi-experimental design could be considered. A community-level intervention would involve a broader intervention strategy targeting the entire community, rather than individual households. This approach could potentially reduce the impact of neighbouring households on the intervention group. A quasi-experimental design, on the other hand, could help control for potential confounding factors and provide a more robust assessment of the intervention's impact.

While area concentration measurements can provide valuable information about air pollution levels, personal exposure measurements offer a more accurate assessment of individual exposure to pollutants, particularly in the context of interventions aimed at reducing indoor air pollution. By directly measuring the concentration of pollutants inhaled by individuals, personal exposure measurements can better capture the impact of interventions on health outcomes. In addition, while PATS+ devices offer affordability, portability, and suitability for rural households in developing countries, they have limitations in accurately measuring particulate matter concentrations. These devices often overestimate concentrations, and their readings may require calibration or adjustment against more precise gravimetric air monitoring devices.

The analysis of PM2.5 concentrations only included baseline and post-intervention measurements. This limited data may not capture the dynamic nature of air quality and behavior changes over time. A more frequent monitoring schedule would provide a more complete picture of the intervention's sustained effectiveness. Background (ambient) air pollution data was not collected, making it impossible to determine its contribution to the overall kitchen PM2.5 concentrations measured.

This study focused on pregnant women, and the findings may not generalize to the broader population. This is because cooking habits might change significantly after childbirth. The estimation of gestational age mainly based on the last menstrual period could have led to misclassification of preterm births. Utilizing a more precise method for gestational age estimation would strengthen the study's conclusions. The sample size might not have been large enough to detect less frequent adverse pregnancy outcomes with statistical certainty. A larger sample size would allow for more robust analysis of these outcomes. The intervention stoves were distributed at an average of 18 weeks gestation, potentially limiting their impact on first-trimester exposure, a critical period for fetal development. Earlier stove distribution could be explored in future studies. Seasonal variations in food insecurity and exposure levels were not specifically analyzed, potentially overlooking their influence on pregnancy outcomes.

7.4 Conclusions

Despite household air pollution from traditional cooking methods remaining a major global health concern, particularly in low- and middle-income countries, this study offers promising solutions. The intervention group using improved chimney-fitted Mirt stoves experienced a significant reduction in kitchen PM2.5, demonstrating their effectiveness in combating indoor air pollution. This aligns with positive user reception and a suggestive trend towards lower acute respiratory infections rates in the intervention group. However, the study emphasizes the importance of considering household factors like education level and cooking practices when implementing such interventions.

The compelling evidence from this study supports promoting improved stoves as a key strategy for mitigating household air pollution. Public health initiatives and government policies should prioritize widespread adoption use. This can be achieved through awareness campaigns highlighting health risks and stove benefits, alongside subsidies or financing options to address

affordability concerns. Targeted programs offering different stove models or educational materials based on specific needs (less training for high-education households) can further enhance adoption rates. While health benefits are the primary focus, improved stoves offer additional advantages such as time and money savings, reduced risk of heat exhaustion and burns, and other notable benefits.

Future research should explore long-term health impacts through studies with longer follow-up periods, and evaluate the cost-effectiveness of improved stoves against healthcare cost savings from reduced respiratory illnesses. Additionally, a more detailed analysis of cooking habits and their interaction with different stove models can inform future stove design and usage recommendations. Overall, this study demonstrates the significant potential of improved stoves for the transition of cleaner cooking to improve health outcomes. By prioritizing widespread adoption through targeted policies and programs, public health efforts can make a substantial difference in the lives of communities burdened by traditional cooking methods. As cleaner air becomes a reality, improved stoves can play a pivotal role in fostering healthier homes and healthier communities.

7.5 Recommendations

There are some practical recommendations and future action perspectives stemming from this study on improved stoves. By considering these points, researchers, policymakers, and public health professionals can work together to optimize interventions and maximize the positive impact of improved stoves on household air quality and health outcomes in the communities. The following recommendations are forwarded for specific stakeholders based on the study results.

For policy action

- Despite perceiving HAP risks and improved stove benefits, this study found low rates of practical actions to reduce exposure at baseline survey. Because, households prioritize immediate needs over long-term health concerns associated with HAP. Therefore, subsidizing stoves can encourage up taking and exclusive use of the intervention stoves.
- Integrating improved stoves into health programs can accelerate the transition to clean cooking, reduce HAP, and support future clean energy options.
- Developing quality standards for improved stoves can ensure their effectiveness and safety which can help consumers identify reliable and high-performing stove models.

- Build partnerships with local stakeholders, including businesses, NGOs, community leaders, and women's groups, to ensure culturally appropriate and sustainable intervention stoves.

For stove producers

- Since technologies are in continuous change to accommodate public interest, updating the existing improved stove design is necessary. One of the potential reasons for the null impact of the improved stove on health endpoints is the parallel use of biomass fuel with traditional stoves for cooking food items other than Injera. Therefore, improving the design of the Mirt stove to accommodate other cooking methods could be an important step forward.

For community health workers

- A critical challenge lies in effectively translating awareness of household air pollution's health risks into tangible behavior change. To bridge this gap, awareness creation strategies should be refined to emphasize the severe, long-term health consequences of HAP exposure.
- Another possible reasons for the insignificant impact of the improved stove on targeted health outcomes is the infiltration of biomass smoke from neighboring households through openings in the kitchen. Therefore, public health intervention strategies should include all households in a given location to achieve effective outcomes.

For future research work

- The current research on improved stove faces a challenge in data comparability. The absence of standardized protocols tailored to local settings for PM2.5 measurements in kitchens across diverse geographical and socioeconomic landscapes poses a substantial challenge. Often different indoor air monitoring devices with varying degrees of accuracy and calibration procedures were employed. Therefore, it is essential to specify a limited set of reliable indoor air quality monitors suitable for kitchen environments and establish standardized calibration procedures to enhance data comparability across studies.
- Conducting longitudinal studies with longer follow-up periods is crucial to definitively assess the impact of improved stoves on various health problems associated with HAP exposure.
- Future studies could investigate the effectiveness of improved stoves in reducing other harmful pollutants like carbon monoxide (CO) and nitrogen oxides (NOx).

- Given the limitations of area concentration measurements and the potential for exposure misclassification, future research should prioritize personal exposure assessment using validated devices. This will provide a more accurate estimation of individual exposure to air pollutants and allow for a more precise evaluation of the impact of improved cookstove interventions on health outcomes.
- Additionally, it is crucial to explore the effects of multiple improved cookstove technologies. In many households, multiple stoves may be used for different cooking purposes. To effectively address these diverse needs, it is essential to evaluate the impact of different types of improved stoves designed for specific cooking activities.

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Annexes

Annex_1: Curriculum Vitae (CV)

I. Personal information

First name	**Habtamu Demelash**
Surname	Enyew
Date of birth	08/11/1986
Place of birth	Zemene Birhan, West Gojjam
Nationality	Ethiopian
Marital status	Married
Address	Debre Tabor
Mobile	+251931590256
E-mail	Enyew29@gmail.com
Working place	Debre Tabor University

II. Education

2019 - 2024	PhD student in environmental health at Jimma University
2009- 2011	Master of public health in general public health at Addis Abab

	University
2005 -2007	BSC in environmental health at Jimma University
2001-2004	Secondary and preparatory school
1994-2000	Primary school

III. Training attended

In person

1. December 13-17,2021	Certificate on Evidence Based Public Health, Stellenbosch University and Armauer Hansen Research Institute (AHRI), Addis Ababa Ethiopia
2. January,27-31, 2020	Certificate on Complex Survey Analysis Course, Addis continental institute of public health and Harvard T.H. Chan School of Public Health, Addis Ababa Ethiopia,
3. May 19-20, 2018	Certificate on Leadership in action, center for African Leadership studies(CALS), Debre Tabor University with collaboration CIRHT Ethiopia
4. December 28-31,2017	Certificate on Systematic Review With Its Statistical Soft Ware, Debre Tabor University, Debre Tabor, Ethiopia
5. May 5-7,2017	Certificate on Research Methodologies and Statistical Analysis Debre Tabor University ,Debre Tabor, Ethiopia
6. June11-16,2015	Methods and Procedures of Data Analysis Using SAS, Madawalabu University, Bale Goba, Ethiopia
7. July 15-19,2013	Evaluation And Data Collector Skill Inventory, Research Ethics And Informed Consent, Family Health International(FHI360), Hawasa, Ethiopia
8. July ,2012	Higher Diploma Program, Madawalabu University, Ethiopia
9. **Septembers19-21,2010**	Reproductive health commodity Security and Advocacy, UNFPA and Addis Ababa University, Adama, Ethiopia

Virtual

1. June 9, 2022	Certificate on global burden of diseases (GBD) Online Training, the Institute for Health Metrics and Evaluation
2. July 7, 2021	Certificate on Global Career Opportunities in Public Health organized by Faculty of Management Studies, Ganpat University
3. May 25, 2020	Certificate on the Covid_19 infection prevention and control (IPC) online course Ethiopian ministry of health
4. December 14-16, 2021	Certificate on the international conference on public health in Africa (CPHIA 2021)
5. August ,23,2022	Certificate on the Nigeria One Health Awareness Virtual Conference: A call to action towards building a One Health Community-based Network, Global Implementation Solutions,
6. Nov 21, 2022	online training on Impact evaluation (IE)

IV. Scientific contribution

1. March 12, 2024	– Effect of a chimney-fitted improved stove on pregnancy outcomes in Northwest Ethiopia: a randomized controlled trial. *BMC Pregnancy*

Childbirth. 2024; 24: 192.

2. February 20, 2024 – The effect of chimney fitted improved stove on kitchen fine particulate matter (PM2.5) concentrations in rural Ethiopia: Evidence from a randomized controlled trial. *Environ Res. 2024 Feb 20:250:118488. doi: 10.1016/j.envres.2024.118488.*
3. October17, 2023 – Kitchen fine particulate matter (PM2.5) concentrations from biomass fuel use in rural households of Northwest Ethiopia. *Front Public Health. 2023 Oct 17:11:1241977. doi: 10.3389/fpubh.2023.1241977*
4. March 23, 2023 – Aflatoxin contamination of animal feeds and its predictors among dairy farms in Northwest Ethiopia: One Health approach implications. Front. Vet. Sci., 23 March 2023 Sec. Veterinary Epidemiology and Economics Volume 10 – 2023 https:// doi.org/ 10.3389/ fvets.2023.1123573
5. August 14, 2023 – Health risk perceptions of household air pollution and perceived benefits of improved stoves among pregnant women in rural Ethiopia: a mixed method study. *BMJ Open 2023;13:e072328. doi:10.1136/ bmjopen-2023-072328*
6. June 20, 2023 – Safety Practices and Associated Factors among Healthcare Waste Handlers in Four Public Hospitals, Southwestern Ethiopia. *Safety 2023, 9, 41. https://doi.org/10.3390/ safety9020041*
7. December, 2023 – Magnitude and associated factors of post Dural puncture headache after spinal anesthesia in surgical patients at comprehensive specialized referral hospital, 2021: A multi-center cross-sectional study. *Interdisciplinary Neurosurgery Volume 34, December 2023, 101817*
8. Jully 12, 2023 – Environmental exposures and adverse pregnancy outcomes in Ethiopia: A systematic review and meta-analysis. *PLoS One. 2023 Jul 12;18(7): e0288240. doi: 10.1371/journal.pone.0288240*
9. June 6, 2022 – Factors associated with sexual violence among waitresses working in Bahir Dar City, Ethiopia: a mixed-method study. *BMC Women's Health (2022) 22:209 https://doi.org/10.1186/s12905-022-01806-x*
10. March 10, 2021 – Biomass fuel use and acute respiratory infection among children younger than 5 years in Ethiopia: a systematic review and meta-analysis. *Public Health.2021 Apr: 193:29-40. doi: 10.1016/j.puhe.2020.12.016.*
11. Jully 1, 2021 – Intestinal parasitic infections and associated factors among pregnant women in Ethiopia: a systematic review and meta-analysis. *BMC Pregnancy Childbirth. 2021 Jul 1;21(1):474. doi: 10.1186/s12884-021-03908-0.*
12. August 26, 2020 – Determinants of obstructed labor among women attending intrapartum care in Amhara Region, Northwest Ethiopia: A hospital-based unmatched case–control study. *Womens Health (Lond). 2020; 16: 1745506520949727*

13. April 22, 2020 – Diarrheal Diseases in Under-Five Children and Associated Factors among Farta District Rural Community, Amhara Regional State, North Central Ethiopia: A Comparative Cross-Sectional Study. *Hindawi Journal of Environmental and Public Health Volume 2020, Article ID 6027079, 7 pages https://doi.org/10.1155/2020/6027079*

14. October 16, 2019 – Fluoride concentration in ground water and prevalence of dental fluorosis in Ethiopian Rift Valley: systematic review and meta-analysis. *BMC Public Health (2019) 19:1298 https://doi.org/10.1186/s12889-019-7646-8*

15. April 1, 2019 – Predictive Values of Preoperative Tests for Difficult Laryngoscopy and Intubation in Adult Patients at Tikur Anbessa Specialized Hospital. *Anesthesiol Res Pract. 2019 Apr 1:2019:1790413. doi: 10.1155/2019/1790413*

16. September 18, 2019 – Magnitude of maternal near misses and the role of delays in Ethiopia: a hospital based cross-sectional study. *BMC Res Notes (2019) 12:585*
– *https://doi.org/10.1186/s13104-019-4628-y*

17. Jully 7, 2019 – Magnitude and Associated Factors of Awareness with Recall under General Anesthesia in Amhara Regional State Referral Hospitals. *Hindawi Anesthesiology Research and Practice Volume 2019, Article ID 7043279, 6 pages https://doi.org/10.1155/2019/7043279*

18. December 24, 2018 – Utilization and Associated Factors of Insecticide Treated Bed Net among Pregnant Women Attending Antenatal Clinic of Addis Zemen Hospital, North-Western Ethiopia: An Institutional Based Study. *Hindawi Malaria Research and Treatment Volume 2018, Article ID 3647184, 9 pages* https://doi.org/10.1155/2018/3647184

19. August 21, 2017 – The prevalence of tuberculosis among prisoners in Ethiopia: a systematic review and meta-analysis of published studies. *Archives of Public Health (2017) 75:37 DOI 10.1186/s13690-017-0204-x*

20. October 7,2016 – Predictors of Treatment Failure among Adult Antiretroviral Treatment (ART) Clients in Bale Zone Hospitals, South Eastern Ethiopia. *https://doi.org/10.1371/journal.pone.0164299*

21. May 2, 2016 – Height for age z score and cognitive function are associated with Academic performance among school children aged 8–11 years old. *Arch Public Health. 2016 May 2:74:17. doi: 10.1186/s13690-016-0129-9*

22. December ,2016 – Cognitive function and associated factors among school age children in Goba Town, South-East Ethiopia. *https: //doi.org/ 10.1016 /j.cogdev.2016.09.002*

23. December 20, 2015 – A Case-Control Study on Intimate Partner Violence during Pregnancy and Low Birth Weight, Southeast Ethiopia. *Hindawi Publishing Corporation Obstetrics and Gynecology International Volume 2015, Article ID*

394875, 6 pages http://dx.doi.org/10.1155/2015/394875

24. October 13, 2015 – Risk factors for low birth weight in Bale zone hospitals, South-East Ethiopia: a case–control study. *BMC Pregnancy and Childbirth (2015) 15:264 DOI 10.1186/s12884-015-0677-y*

25. September 25, 2013 – Assessment of Sexual and Reproductive Health Status of Street Children in Addis Ababa. *Hindawi Publishing Corporation Journal of Sexually Transmitted Diseases Volume 2013, Article ID 524076, 20 pages http://dx.doi.org/10.1155/2013/524076*

V. Under review manuscript

Submitted on February 06 , 2024 – Impact of Improved Stove Intervention during pregnancy on Infant Acute Respiratory Infections: Nested Cohort Study in Northwest Ethiopia. *Respiratory Research Submission ID 6cc43ae6-a9d6-4f12-bfc4-0dfb472268ae*

VI. Collaboration projected delivered

Assessment Of Professional Ethics Among Health Care Workers In Public Hospitals Found In South Gondar Zone, Amhara ,North Central Ethiopia

Fetal, Neonatal and Maternal Outcomes of Obstructed Labor in Amhara Regional State Referral Hospitals: A Prospective Cohort Study

"Diarrheal disease in under-five children and associated factors among open defection free and none open defecation free households of Farta district rural community, Amhara, North west Ethiopia: A comparative cross- sectional study"

Evidence Based Intervention For Common Infectious Diseases In Guna-Tana

Integrated Field Research And Development Center Catchment Area Community

June 11-14,2017 Provided training on prevention and control of acute watery diarrhea in three woredas of south Gondar zone from June 11-14,2017

May ,2018 Provide training on Strengthening Household Vegetable Production For Diversification and Enrichment Of Meal for Having a Better Health of the Community in Debre Tabor University with Collaborating University of Gondar, Kosoye Development Program, May, 2018

VII. Oral and poster presented articles

From March 17-19, 2024 – The effect of chimney fitted improved stove on kitchen fine particulate matter (PM2.5) concentrations in rural Ethiopia: Evidence from a randomized controlled trial. Presented at the 35th EPHA Annual Conference, at the Inter Luxury Hotel in Addis Ababa.

From March 14-16, 2021 – Biomass fuel use and acute respiratory infection among children younger than 5 years in Ethiopia: a systematic review and meta-analysis. Presented at the 32nd EPHA Annual Conference, at intercontinental

Addis hotel in Addis Ababa.

From May 18-19,2017 – Presenting of a research project in the Guna Tana integrated field research and development center national conference on quality education and ecology sustainability held at Debere Tabor University

From February 26-28, 2015 – Risk factors for low birth weight in Bale zone hospitals, South-East Ethiopia: a case–control study, presented at 26th annual conference of Ethiopian public health association, Bahir Dar Ethiopia

May 30 - 31,2013 – Assessment of Sexual and Reproductive Health Status of Street Children in Addis Ababa. Presented at 1st Annual Symposium Organized By College of Medicine and Health Sciences of Arbaminch University, Ethiopia

VIII. Review of articles & proposals, participation in institutional publications editorial work

- Certificate awarded for 5 reviews between September 2021 and June 2023 contributed to Public Health Journal
- Certificate awarded for 6 reviews between 12/04/2023 and 08/11/2023 contributed to Frontier Public Health Journal
- Certificate awarded for 5 reviews between May 8, 2023 and 4 Oct 2, 2023 contributed to PLOS ONE journal
- Peer reviewer for research and community service proposals, in the college of health sciences, Debre Tabor university from 2016 to 2019

IX. Membership in Professional Associations

- Lifetime member of Ethiopian Public Health Association
- A lifetime member of the Ethiopian red cross society

Annex II: Information Sheet and Consent

1. English Version Participants Information Sheet and Consent

1.1 Information Sheets in English

Title: Effect of Improved Stove on Kitchen Air Quality, Pregnancy Outcomes, and Acute Respiratory Infections in South Gondar Zone, Ethiopian: *Randomized Control Trial*

1.1.1 Introduction

Greeting; this is _____ and I am here to collect information for the study being conducted by Mr. Habtamu Demelash (PhD candidate at Jimma University, Institute of Health, Faculty of Public Health, Department of Environmental Health Science and Technology). He is conducting the research to quantify the impact of improved stove intervention on pregnancy outcomes and infant acute respiratory infections. I will give you some information on how to participate on the basis of which you will decide on whether or not you will participate in the study.

1.1.2 Rationale of the Study

Burning biomass fuels in open fires with traditional stoves creates smoke that can damage health. To reduce exposure to biomass smoke, we need to develop effective and affordable ways of burning these fuels. One way of doing this is to use improved stoves instead of open fires or other ineffective stoves. Different types of improved stoves are in use in Ethiopia, and they have the potential to improve both health and the environment. However, it is unclear whether these improved stoves, such as the Mirt stove, can reduce the incidence of acute respiratory infections in infants and improve pregnancy outcomes through reducing kitchen area air pollutant concentration. Therefore, the aim of this study is to investigate the effectiveness of the Mirt stove in achieving these goals

1.1.3 Why have you been chosen?

Because, you are pregnant woman residing in the six kebeles of Guna-Tana integrated field research and development center catchment area of south Gondar zone and meet the eligibility criteria to participate in this study.

1.1.4 Do I have to take part in the study?

Your participation in this study is entirely voluntary. You are under no obligation to participate, even if other members of your community are involved. Your decision to participate or decline will not affect your eligibility for any benefits or services you may be entitled to. You may withdraw from the study at any time, for any reason, without penalty.

1.1.5 What will be involved if I agree to take part in this study?

You will be randomly assigned to either the intervention or control group. This means you will be placed in one of these groups by chance, without your knowledge or influence. All households in the intervention group will be given improved stoves to replace the traditional baking stove. It is very important that the improved stove is used for Injera baking tasks and that open fires and any other stoves are no longer used. Stove use monitoring will be done through self-report and direct observation by trained field data collectors during home to home visiting and interview with primary cook to record information about how much the stove is used over the course of the trial. This information is needed to help us understand how much these improved stoves are used in a real life setting. We will provide training about how the improved stoves work and how to use these to the best possible effect.

All households in the control group will be asked to continue to bake in their usual way until the end of the trial when each control household will also receive the improved one (if the stove reduces the concentration significantly). We will give the pregnant women a new health passport and we will put a sticker in the passport about the trial. We will ask you to show this sticker to the staff at the health center if you or your infant requires medical attention during the trial since this will help the staff collect the information we need for the trial. After any attendance at the health center we will ask you to contact the trial team using the phone.

We will collect some basic information about you and your family at the beginning of the study using paper format. Then every three months during pregnancy and every two months for your infant fieldworkers will visit your home to review your and your infants health passports in the trial to collect information about health condition of pregnant women and episodes of acute respiratory infection for new born babies. We will also collect information about any infant who die.

We will measure levels of air pollution in your kitchen at the beginning of the study and two times before the end of the trial using small monitors which will be huged in your kitchen for 24 hours. In a small sample of households, we will conduct some additional monitoring which will help us understand how much smoke the pregnant women in the trial and their new born babies are exposed to. You can decide whether or not to participate in this part of the study without affecting your participation in the main trial. These are non-intrusive monitors that will not stop you going about your day-to-day activities.

1.1.6 Will there be any risks involved in the study?

You may be inconvenienced by the time commitment involved in taking part in the study, the information we need to record and the measurements we need to take. All of the study procedures are routine and involve minimal risks.

1.1.7 Will there be any benefits involved in being in the study?

All households will receive improved stoves either at the beginning (intervention group) or end (control group) of the study. We will ensure that supplies of antibiotics for the treatment of acute respiratory infections are available for participants through the local health centers.

1.1.8 Who will know what we find out?

We will record the information we collect about you using paper format and small exposure measuring devices. This information will be transferred to a computer database but without using your name or address so that you could not be identified from this information. This database will be analyzed only by researchers. We will share the results of this study with you and your community, at research meetings and will present the findings at national and international conference and in journals. We will not share any information that would allow you to be identified.

1.1.9 Whom to contact?

If you have any questions about this study, please contact our research project manager, Habtamu Demelash on +2519-31-59-02-56.

1.2 Consent Form

With the due understanding of the aforementioned information, would you be willing to participate in the study?

☐ Yes (proceed to sign and interview ☐ No (Thank and terminate the interview)

I, _____here by give my consent to participate in this survey. I have been given the necessary information about the research in a language I understand. I have also understood that I can withdraw my consent any time without penalty of loss of benefits.

Signature/Finger print of the participant

Signature/Finger Print _____Date _____

Signature of the Interviewer

Name _____Signature _____ Date _____

Supervisors/Researcher Remark and Signature

_____

_____

Name _____ Signature _____ Date _____

Annex- III: Baseline Questionnaire

General information

Household ID: /_____/
Kebele :/_____/
Sub Kebele (Got):/_____/
Name interviewer:/ _____/
Date of interview: /_____/
Season of the year: /_____/

- Rainy (it has rained in the last two weeks) :/_____/
- Dry (it has not rained in the last two weeks) :/_____/

አጠቃላይ መረጃ

የቢቱ መለያ ቁጥር: /_____/
የቀበሊዉ ስም/_____/
የለዩ ቦታዉ/ጎጥ ስም/_____/
የጠያቂዉ ስም :/ _____/
የተጥየቀበት ቀን: /_____/
የተጥየቀበት ወቅት: /_____/

- ዝናባማ (ባልፉት ሁለት ሳምንት ዉስጥ ዘንቦ ነበር) :/_____/
- ደረቃማ (ባልፉት ሁለት ሳምንት ዉስጥ አልዘነበም:/_____/

English Version					
Part-I: Socio Demographic and Economic Status of the Respondents					
No	**Questions**	**Responses**	**ተ. ቁ**	**ጥያቄዎች**	**ምላሾች**
1	Age of the woman in complete years	/_____/ Years	1. 1	የእናትዮዋ ዕድሜ በተጠናቀቀ አመት	/_____/ ዓመት
2	Marital status of the woman	1. Married 2. Single 3. Widowed 4. Divorced 5. Separated	2. 2	የእናትዮዋ የትዳር ሁኔታ	1. ያገባች 2. ያላገባ ች 3. የሞተባት 4. የተፋታች 5. የተለያይተዉ ይሚኖሩ
3	LMP (Last Menstrual Period):	___/___/_____ (dd/mm/yyyy)	3.	የመጨረሻው የወር አበባ ጊዜ	ቀን/ወር /አመት
4	EDD (Expected Delivery Date):	___/___/_____ (dd/mm/yyyy)	4.	የሚጠበቀዉ የመዉለጃ ቀን	ቀን/ወር /አመት
5	Religion of the woman	1. Orthodox 2. Protestant 3. Muslim 9. Other /_____/	5. 3	የእናትዮዋ ሃይማኖት	1. ኦርቶዶክስ 2. ፕሮቴስታንት 3. ሙስሊም 9. ሌላ /_____/
6	Educational status of the woman	1. Unable to read and write 2. Read and write only 3. /_____/ Grade	6.	የእናትዮዋ የትምህርት ሁኔታ	1. ማንበብ እና መጻፍ የማትችል 2. ማንበብ እና መጻፍ ብቻ 3. /_____/ ክፍል
7	Educational status of the husband	1. Unable to read and write 2. Read and write only 3. /_____/th Grade completed	7.	የአባት የትምህርት ሁኔታ	1. ማንበብ እና መጻፍ የማይችል 2. ማንበብ እና መጻፍ ብቻ 3. /_____/ ኛ ክፍል አጠናቃልች
8	Occupation of the woman	1. Housewife 2. Farmer 3. Merchant 9. Other /_____/	8. 8	የእናት የሥራ ሁኔታ	1. የቤት እመቤት 2. አርሶ አደረ 3. ነጋዴ 9. ሌላ /_____/

9	Total family size of the household in number	1. Male /_____/ Female/_____/ Total /_____/ 2. U_5 years old /_____/	9.	አጠቃላይ የቤተሰብ ብዛት	1. ጠቅላላ / _____ / ወነድ/_____/ ሲት/_____/ 2. ከ5 አመት ብታች /_____/
10	Monthly/yearly income of the family-- *(in cash or in kind) write all mentioned*	/_____ _____ /	10.	የቤተሰቡ ወርሃዊ/ ዓመታዊ ገቢ *(በጥሬ ገንዘብ ወይም በአይነት) የተጠቀሱትን ሁሉ ይጻፉ*	/_____ _____/
11	Are you a member of any women groups?	1. Yes 2. No	11.	የማንኛውም የሴቶች ቡድን አባል ነዎት?	2. አዎ 2. አይደለሁም
12	if yes,the name of the group	/_____/	12.	መልሱ አዎ ከሆነ ይቡድኑ ስም	/_____/
13	Are you registered for community based health insurance?	1. Yes 2. No	13.	ለማህበረሰብ አቀፍ የጤና መድን ተመዝግበዋል?	3. አዎ 2. አይደለሁም
14	Do you have or own any of the following? (if yes,write the number of each property type)	Bicycle 1. Yes 2. No Television 1. Yes 2. No Radio 1. Yes 2. No Cows 1. Yes 2. No Chickens 1. Yes 2. No Horses 1. Yes 2. No chair 1. yes 2 No goat/sheep 1. yes 2. No	14.	ከሚከተሉት ውስጥ አንዳች አለዎት ወይም ባለቤት ነዎት?	ብስክሌት 1. አዎ 2. የለም ቴሌቪዥን 1. አዎ 2. የለም ሬዲዮ 1. አዎ 2. የለም ላሞች 1. አዎ 2. የለም ዶሮዎች 1. አዎ 2. የለም ፈረሶች 1. አዎ 2. የለም ወንበር 1. አዎ 2 የለም ፍየል/በግ 1. አዎ 2. የለም
	Part-II: Housing Condition			**ክፍል-II: የቤቱ ሁኔታ**	
15	When the house is constructed?	Before /_____/ years	15.	ይህ ቤት ከተሰራ ስንት ዓመት ሆነው?	ከ/ _____ / ዓመት በፊት
16	Floor material of the house	1. Earthen/Mud 2. Plastic cover 3. Cement/Tiles 4. Others (Specify) /_____/	16.	የቤቱ ወለል የተሠራበት ቁሳቁስ	1. የጭቃ 2. የፕላስቲክ ሽፋን 3. ሲሚንቶ / ሰድሮች 4. ሌሎች (ይግለጹ) /_____/
17	Wall material of the house	1. Grass/wood/bamboo 2. wood/Mud 3. Blocks/Bricks/stones 4. Others (Specify) /_____/	17.	የቤቱ ግድግዳ የተሠራበት ቁሳቁስ	1. ሣር / እንጨት / የቀርከሃ 2. እንጨት/ጭቃ 3. ጡቦች / ድንጋዮች

					4. ሌሎች (ይግለጹ) / _____ /
18	Roof material of the house	1. Thatch roof 2. CIS/ metal sheet 3. Concrete/Tiles 4. Others (Specify) /_____/	18.	የቤቱ የጣሪያ የተሠራበት ቁሳቁስ	1. የ ሣር ጣሪያ 2. ቆርቆሮ 3. ሌሎች (ይግለጹ) / _____ /
19	What is the number of rooms at your home?	1. One room 2. Two rooms 3. More than three rooms	19.	በቤትዎ ውስጥ ያሉት ክፍሎች ብዛት ስንት ነው?	1. አንድ ክፍል 2. ሁለት ክፍሎች 3. ከሶስት ክፍሎች በላይ
20	How many doors are there in the house? (able to open)	/_____/	20.	በቤቱ ውስጥ ስንት በሮች አሉ? (መከፈት የሚችሉ)	/_____/
21	How many windows are there in the house? (able to open)	/_____/	21.	በቤት ውስጥ ስንት መስኮቶች አሉ? ((መከፈት የሚችሉ)	/_____/
22	Are there any openings between wall and roof in the house?	1. Yes 2. No	22.	በቤቱ ውስጥ በግድግዳ እና ጣሪያ መካከል ክፍተት አሉ?	1. አዎ 2. የለም
	Part- II: Kitchen and Stove Condition			**ክፍል-III: ኩሽና ቤት እና ምድጃ ሁኔታ**	
23	Location of kitchen	1. Separate building 2. Separate room attached to main house 3. Main living area in house 4. Other, specify /_____/	23.	የኩሽና ቤቱ የሚገኝበት ቦታ	1. ከዋናው ቤት የተለየ ሌላ ቦታ 2. ከዋናው ቤት ተያይዞ የተለየ ክፍል 3. ከዋናው የመኖሪያ ቤት ውስጥ 4. ሌላ ፣ይገለጽ /_____/
24	What does the kitchen structure consist of?	1. Four walled structure 2. Three walled structure 3. Two walled structure 4. No walls, but a covered roof 5. In the open 'courtyard' 6. Other (please write in) /____/	24.	የኩሽና ቤቱ መዋቅር ምን ይመስላል?	1. አራት ግድግዳ ያለው 2. ሶስት የግድግዳ ያለው 3. ሁለት የግድግዳ ያለው 4. ግድግዳ የሌለዉ፣ጣሪያ ብቻ 5. ግቢው ውስጥ ክፍት ቦታ 6. ሌላ (እባክዎን ይፃፉ) /_____/
25	Size of the kitchen area	1. Narrow 2. Medium 3. Wide	25.	የኩሽና ቤቱ ስፋት	1. ጠባብ 2. መካከለኛ 3. ሰፊ
26	Where did most of the cooking practice would be done during the dry season?	1. Outside in a separate structure with walls and a roof 2. Outside in a separate structure with a roof only 3. Outside in the open air	26.	በደረቅ ወቅት አብዛኛው የማብሰል ተግባር የት ይከናወናል?	1. ከቤት ውጭ ግድግዳ እና ጣሪያ ያለው ኩሽና ቤት ውስጥ 2. ከቤት ውጭ ጣሪያ ብቻ ያለዉ ኩሽና ቤት ውስጥ

		4. Inside in a separate room (kitchen) 5. Inside in a living room			3. ከቤት ውጭ ባዶ ቦታ ላይ 4. ቤት ዉስጥ በተለየ ክፍል 5. ቤት ዉስጥ ሳሎን ውስጥ
27	Where did most of the cooking practice would be done during the rainy season?	1. Outside in a separate structure with walls and a roof 2. Outside in a separate structure with a roof only 3. Outside in the open air 4. Inside in a separate room (kitchen) 5. Inside in a living room	27.	በዝናባማ ወቅት አብዛኛው የማብሰያ ተግባር የት ይደረግ ነበር?	1. ከቤት ውጭ ግድግዳ እና ጣሪያ ያለው ኩሽና ቤት ውስጥ 2. ከቤት ውጭ ጣሪያ ብቻ ያለዉ ኩሽና ቤት ውስጥ 3. ከቤት ውጭ ባዶ ቦታ ላይ 4. ቤት ዉስጥ በተለየ ክፍል 5. ቤት ዉስጥ ሳሎን ውስጥ
28	Does the kitchen has a chimney?	1. Yes 2. No	28.	ኩሽና ቤቱ የጭስ ማውጫ አለው?	1. አዎ 2. የለዉም
29	How many stoves are actively in use in your home	1. One only 2. Two 3. Three	29.	በቤትዎ ውስጥ ስንት ምድጃዎች ጥቅም ላይ ናቸው?	1. አንድ ብቻ 2. ሁለት 3. ሶስት
30	Which types of stove do you use most frequently to cook your meals	1. Three stone stove 2. Other local stove type 3. Other (specify) /_____/	30.	ምግብዎን ለማብሰል በብዛት የሚጠቀሙት ምን ኣይነት ምድጃ ነዉ?	1. የሶስት ጉልቻ ምድጃ 2. ሌላ የአከባቢ ምድጃ ዓይነት 9. ሌላ (ይገለጥ) / _____/
31	What do you like about this primary stove?	1. Uses little firewood 2. Cooks food quickly 3. Emits little smoke 4. Easy to light; wind not affect 5. Safe to use while cooking 9. Other (specify) /_____/	31.	የምድጃዉን ምን ወደዱለት?	1. አነስተኛ የማገዶ ይጠቀማል 2. ምግብ በፍጥነት ያበስላል 3. የጭስ መጠን ይቀንሳል 4. ለማቀጣጠል ቀላል ነው 5. በነፋስ ኣይጠፋም 6. ኣደጋ የለዉም 9. ሌላ (ይግለጹ) /_____/
32	What do you NOT like about this primary stove?	1. Uses lots of firewood 2. Takes a long time to cook 3. Emits lots of smoke 4. Difficult to light 5. Not safe while cooking 9. Other (specify) /_____/	32.	ስለዚህ ምድጃ የማይወዱት ምንድን ነው ?	1. ብዙ የማገዶ እንጨት ይጠቀማል 2. ለማብሰል ረጅም ጊዜ ይወስዳል 3. ብዙ ጭስ ያስወጣል 4. ለማቀጣጠል ከባድ ነው 5. አደጋ ያስከትላል 9. ሌላ (ይፃፉ) /_____/
33	Do you know about improved stoves? Have you ever heard of the	1. Yes 2. No	33.	ስለ የተሻሻሉ ምድጃዎችያውቃሉ?	1. አዎ 2. አላውቅም

	improved fuel wood stove?				
34	if yes, why haven't you acquired an improved stove?	1. No interest 2. No money 3. Don't know where to find 4. No kitchen 9. Other (specify	34.	አዎ ከሆነ-ለምን አይጠቀሙም?	1. ፍላጎት የለኝም 2. ገንዘብ የለኝም 3. የት እንደምገኝ አላውቅም 4. ወጥ ቤት የለም 9. ሌላ (ይግለጹ)
35	Have you ever owned a different new type of stove in the past?	1. Yes 2. No	35.	ከዚህ በፊት የተለየ አዲስ ዓይነት ምድጃ ነበራችሁ?	2. አዎ 2. አልነበረኝም
36	Are you planning on buying an improved stove in the future?	1. Yes 2. No	36.	ለወደፊቱ የተሻሻለ ምድጃ ለመግዛት አቅደዋል?	1. አዎ 2. አላቀድኩትም
37	If your household wanted to buy a new improved stove, who would make the decision?	1. Self 2. Husband 3. Other/_____/	37.	ቤተሰቦችዎ አዲስ የተሻሻለ ምድጃ መግዛት ቢፈልጉ ውሳኔውን የሚወስነው ማን ነው?	1. ራሴ 2. ባለቤቴ 3. 3. ሌላ / _____ /
	Part-IV: Type of Fuel Use and Cooking Practice			**ክፍል-IV: የነዳጅ ዓይነት እና የማብሰል ባህል**	
38	Type of main food most frequently cooked	/_____/	38.	ብዙውን ጊዜ ቢት ዉስጥ የሚበስለዉ ዋና ምግብ ዓይነት	/_____/
39	What type of fuel does your household mainly used for cooking?	1. Wood, cow dung, crop residue 2. Charcoal 3. Biogas/LPG stove 4. Kerosene 5. Other (specify)/_____/	39.	ቤተሰቦችዎ በዋናነት ለማብሰያ የሚጠቀሙበት ምን ዓይነት ነዳጅ ነው?	1. እንጨት ፣ ኩበት ፣ የሰብል ቅሪት 2. ከሰል 3. ባዮጋዝ / LPG ምድጃ 4. ኬሮሴን 9. ሌላ (ይግለጹ) /_____/
40	Who collects wood?	1. Boys 2. Girls 3. Women 4. Men	40.	እንጨት የሚሰበስብ ማነው?	1. ወንዶች ልጆች 2. ሴት ልጆች 2 እናቶች 4. አባቶች
41	How much time was spent on fuel collection? (Estimate in hours/days/weeks)	/_____/ hours per day /_____/days	41.	ለነዳጅ ማሰባሰብ ምን ያህል ጊዜ ፈጅቷል? (በሰዓታት / ቀናት)	/ _____ / ሰዓታት በቀን / _____ / ቀናት
42	What is the frequency of wood collection per week?	/_____/ times/week	42.	በሳምንት የእንጨት መሰብሰብ ድግግሞሽ ስንት ነው?	/ _____ / ጊዜያት / ሳምንት
43	Do you dry the firewood prior to using the firewood?	1. Yes 2. No	43.	የማገዶ እንጨት ከመጠቀምዎ በፊት የማገዶ እንጨት ያደርቃሉ?	1. አዎ 2. አላደርቅኩም

44	Have you use more than one fuel per cooking?	1. Yes 2. No	44. 4 2	ለማብሰል ከአንድ በላይ ነዳጅ ይጠቀማሉ?	1. አዎ 2. አልጠቀምም
45	When did the worst-scenario of emissions happen in the kitchen?	1. During the lighting, 2. Extinguishing 3. During moving of fuel 9. Other /_____/	45. 4 3	በኩሽና ውስጥ በጣም የከፋ ልቀት ሁኔታ መቼ ነው የሚከሰተዉ?	1. ብማቀጣጥልበት ጊዜ ፣ 2. በማጠፋበት ጊዜ 3. ማገዶዉን በማንቀሳቅስበት ጊዜ 9. ሊላ /_____/
46	How many times a day do you light the stove for cooking?	1. Once 2. Twice 3. Three and above times	46. 4 4	በአንድ ቀን ውስጥ ምግብ ለማብሰል ምን ያህል ጊዜ እሳት ያቃጥላሉ?	1. አንዴ 2. ሁለት ጊዜ 3. ሶስት እና ከዚያ በላይ ጊዜ
47	How many meals a day do you prepare?	1. One meal 2. Two meal 3. Three and more meals	47.	በቀን ስንት ምግብ ያዘጋጃሉ?	1. አንድ ምግብ 2. ሁለት ምግብ 3. ሶስት እና ከዚያ በላይ ምግቦች
48	What is the average time spent per day in cooking? (in Hours)	/_____/ hours	48.	ምግብ ለማብሰል በየቀኑ አማካይ ስንት ሰዓታት ነው? (በሰዓታት)	/ _____ / ሰዓታት
49	How often times you cook Injera in a week?	1. Once 2. Twice 3. Three and above times	49.	በሳምንት ውስጥ ስንት ጊዜ እንጀራ ይጋገራሉ?	1. አንዴ 2. ሁለት ጊዜ 4. ሶስት እና ከዚያ በላይ ጊዜ
50	Do you keep the windows or doors open when you cook?	1. Yes, always 2. Yes, most of the times 3. Sometimes (<80% of the time) 4. No at all	50.	ምግብ በሚበስሉበት ጊዜ መስኮቶቹን ወይም በሮቹን ክፍት ያደርጋሉ?	1. አዎ ፣ ሁል ጊዜ 2. አዎ ፣ ብዙ ጊዜ 3. አንዳንድ ጊዜ (<80% ጊዜ) 4. በፍፁም
51	What did you do to prevent/reduce exposure from smoke?	1. Increased Ventilation 2. Adopt cleaner stove 3. Dry fuel before using 4. Adopt cleaner fuel 5. Cooking Outside	51.	ከጭስ ተጋላጭነትን ለመከላከል/ለመቀነስ ምን አደረጉ?	1. የአየር ማናፈሻ መጨመር 2. የተሻሻለ ምድጃ ገዛሁ 3. ማገዶዉን ማድረቅ 4. ጭስ ያልበዛባቸዉን ማገዶ ምጥቀም 5. ከቤት ውጭ ምግብ ማብሰል
52	Is a child usually present in the kitchen during cooking?	1. Yes 2. No	52.	ምግብ በሚበስልበት ጊዜ ልጅ አብዛኛውን ጊዜ በኩሽና ውስጥ ይገኛል?	1. አዎ 2. የለም
53	Is there a habit of carrying a child by a mother while cooking?	1. Always 2. Sometimes	53. 5 1	ምግብ በሚበስልበት ጊዜ ልጅን	1. ሁል ጊዜ

		3. Never		በእናት የመያዝ ልማድ አለ?	2. አንዳንድ ጊዜ 3. 3. በጭራሽ
54	When you are cooking, where are your children who are still too young to walk?	1. On my back 2. Near me in the kitchen 3. in the same building, 4. in a separate building 5. Coming in and out in kitchen 6. Playing in the open courtyard 7. Not Applicable	54. 5 2	ምግብ በሚያበስሉበት ጊዜ ገና ለመራመድ ያልበቁ ልጆችዎ የት ይቆያሉ?	1. ጀርባዬ ላይ 2. በኩሽና ውስጥ በአጠገቤ 3. በተመሳሳይ ሕንፃ ውስጥ 4. በተለየ ሕንፃ ውስጥ 5. ወደ በኩሽና መግባትና መውጣት 6. ግቢ ውስጥ መጫወት 7. ተፈጻሚ አይሆንም
55	where are the children under 5 who can walk?	1. On my back 2. Near me in the kitchen 3. in the same building, 4. in a separate building 5. Coming in and out in kitchen 6. Playing in the open courtyard 7. Not Applicable	55. 5 3	ዕድሜያቸው ከ 5 ዓመት በታች የሆኑ ልጆች የት ሊቆዩ ይችላሉ?	1. ጀርባዬ ላይ 2. በኩሽና ውስጥ በአጠገቤ 3. በተመሳሳይ ሕንፃ ውስጥ 4. በተለየ ሕንፃ ውስጥ 5. ወደ በኩሽና መግባትና መውጣት 6. ግቢ ውስጥ መጫወት 7. ተፈጻሚ አይሆንም
56	Apart from cooking, are you exposed to any other sources of smoke (check all that apply)	1. Burning rubbish 2. Making beer 3. Making bricks 4. Kerosene lamps 5. Not exposed 9. Others (specify) /_____/	56. 5 4	ከማብሰያ ውጭ ሌሎች የጭስ ምንጮች ይጋለጣሉ? (የሚመለከታቸውን ሁሉ ምልክት ያድርጉ)	1. የሚቃጠል ቆሻሻ 2. መጠጥ መሥራት 3. ሸክላ መሥራት 4. ኬሮሲን መብራቶች 5. አልተጋለጡም 9. ሌሎች (ይግለጹ) / _____ /
57	During the past 12 months has anyone suffered a burn injury?	1. Yes 2. No	57. 5 5	ባለፉት 12 ወራቶች ዉስጥ የቃጠሎ ጉዳት የደረሰበት ሰው ይኖር ይሆን?	1. አዎ 2. የለም
58	If yes, how did he/she get burned?	1. Fell in the fire 2. Burned by a hot object 3. Hot liquid was spilled 9. Other (specify)/_____/	58. 5 6	አዎ ከሆነ ፣ እሱ / እሷ እንዴት ተቃጠለ/ች?	1. በእሳት ውስጥ በመዉደቅ 2. በሞቃት ነገር መቃጠል 3. ሙቅ ፈሳሽ ፈሰሰ 9. ሌሎች (ይግለጹ) / _____ /
59	If yes , how serious was the burn?	1. Light (there is no scar) 2. Moderate (scar smaller than a birr coin)	59. 5 7	አዎ ከሆነ ቃጠሎው ምን ያህል ከባድ ነበር?	1. ቀላል (ምንም ጠባሳ የለም) 2. መካከለኛ (ከብር ሳንቲም ያነሰ ጠባሳ)

		3. Serious (scar larger than a birr coin)							3. ከባድ (ከብር ሳንቲም የሚልቅ ጠባሳ)				
Part-V: Perception of the Respondents on health risk of household air pollution and health Benefits of improved stove. *(for the questions below, kindly state if you agree or disagree)*							**ክፍል-V: የጥናት ተሳታፊዎች የቤት ውስጥ የአየር ብክለት በጤና ላይ ያለው ተጽዕኖ እና የተሻሻለው ምድጃ ጥቅሞች ያለው ግንዛቤ** *(ከዚህ በታች ላሉት ጥያቄዎች ፣ እርስዎ ከተስማሙ ወይም ካልተስማሙ ይግለጹ)*					
	Questions	**SA**	**A**	**N**	**DA**	**SDA**		**ጥያቄዎች**	**በእ**	**እ**	**ገ**	**አ**	**በአ**
60	Indoor smoke is bad for your health?						60.	የቤት ውስጥ ጭስ ለጤናዎ መጥፎ ነው?					
61	Indoor smoke can affect children's health						61.	የቤት ውስጥ ጭስ በልጆች ጤና ላይ ተጽዕኖ ሊያሳድር ይችላል					
62	Indoor smoke leads to respiratory problems						62.	የቤት ውስጥ ጭስ የመተንፈሻ አካላት ችግር ሊያስከትል ይችላል					
63	I bothered by smoke emitted when cooking						63.	ምግብ በሚዘጋጅበት ጊዜ የሚወጣው ጭስ ያሳስበኛል					
64	The smoke from the kitchen causes stinging eyes, headache, Cough and difficulty in breathing						64.	ከኩሽና ውስጥ ያለው ጭስ አይን የሚያቃጥል ፣ራስ ምታት ፣ ሳል እና የመተንፈስ ችግር ያስከትላል::					
65	Having a cleaner cook stove is important to you?						65.	የተሻሻለ የማብሰያ ምድጃ መኖሩ ለእርስዎ አስፈላጊ ነው?					
66	I'm readily welcome any technology of improved stove which reduces smoke emission for use in my house						66.	በቤት ውስጥ አዲስ የማብሰያ ምድጃ ቴክኖሎጂን ለመጠቀም በደስታ ይቀበላሉ?					
67	Most people think that cooking with improved stove is good for their family						67.	ብዙ ሰዎች በተሻሻለ ምድጃ ምግብ ማብሰል ለቤተሰባቸው ጥሩ ነው ብለው ያስባሉ					
68	the smoke the stove produced is helpful to heats the house, for curing foods to Dries clothes and to keeps insects away						68.	የምድጃው ጭስ ቤቱን ለማሞቅ ፣ ምግቦችን ለደረቅ ልብስ ለማከም እና ነፍሳትን ለማስወገድ ይረዳል					
SA= Strongly Agree , A= Agree N=Neutral, DA=Disagree SDA=Strongly Disagree								በእ=በጣም እስማማለሁ, እ=እስማማለሁ, ገ =ገለልተኛ, አ=አልስማማም					

				በአ=በጣም አልስማማም	
	Part-VI : WASH Related Questions			**ክፍል-VI : የውሃ እና የንፅህና አጠባበቅ ጥያቄዎች**	
69	Can you please show me where members of your household most often wash their hands?	1. Observed, fixed place 2. Observed, mobile place 3. Not observed, no permission 4. No response	69. 6 7	የቤተሰብዎ አባላት ብዙውን ጊዜ እጃቸውን የሚታጠቡበትን ቦታ እባክዎን ሊያሳዩኝ ይችላሉ?	1. የተመለከተ ፣ ቋሚ ቦታ 2. የተመለከተ ፣ ተንቀሳቃሽ ቦታ 3. አልታየም ፣ ፈቃድ የለም 4. ምላሽ የለም
70	At the place where the household washes their hands, observe if: Check all that apply.	1. Soap or detergent is present 2. Stored water is present 3. Running water is present 4. Handwashing area is near a sanitation facility 5. None of the above	70. 6 8	ቤተሰቡ እጆቹን በሚታጠብበት ቦታ ላይ የሚከተሉትን ይመልከቱ: ያሉትን ሁሉ ያረጋግጡ።	1. ሳሙና ወይም ሌላ አጣቢ አለ 2. ንጹህ የተከማቸ ውሃ ይገኛል 3. የእጅ ማጠቢያ መጸዳጃ ቤት አጠገብ ነው 4. ከላይ ከተዘረዘሩት ውስጥ አንዳቸውም አይገኝም
71	What is the main source of drinking water for members of your household?	1. Dug well: protected well 2. Dug well: unprotected well 3. protected spring 4. Unprotected spring 5. Rainwater 6. Surface water (River / Dam / Lake / Pond / Stream / Canal	71. 6 9	ለቤተሰብዎ አባላት የመጠጥ ውሃ ዋና ምንጭ ምንድነው?	1. በደንብ የተጠበቀ የጉድጓድ ውሃ 2. በደንብ ያልተጠበቀ የጉድጓድ ውሃ 3. በደንብ የተጠበቀ ምንጭ ውሃ 4. በደንብ ያልተጠበቀ ምንጭ ውሃ 5. የዝናብ ውሃ 6. የገፀ ምድር ውሃ (ወንዝ / ግድብ / ሐይቅ / ኩሬ / ዥረት / ቦይ)
72	What is the main source of water used by your household for other purposes such as cooking and handwashing?	1. Dug well: protected well 2. Dug well: unprotected well 3. protected spring 4. Unprotected spring 5. Rainwater 6. Surface water (River / Dam / Lake / Pond / Stream / Canal	72. 7 0	ቤተሰቦችዎ እንደ ምግብ ማብሰል እና እጅን መታጠብን ላሉት ሌሎች ዓላማዎች የሚጠቀሙበት ዋና የውሃ ምንጭ ምንድነው?	1. በደንብ የተጠበቀ የጉድጓድ ውሃ 2. በደንብ ያልተጠበቀ የጉድጓድ ውሃ 3. በደንብ የተጠበቀ ምንጭ ውሃ 4. በደንብ ያልተጠበቀ ምንጭ ውሃ 5. የዝናብ ውሃ 6. የገፀ ምድር ውሃ (ወንዝ / ግድብ / ሐይቅ / ኩሬ / ዥረት / ቦይ)
73	How long does it take to get water, and come back?	/_____/ minutes /_____/ km	73.	ውሃ ለመቅዳት እና ለመመለስ ምን ያህል ጊዜ ይወስዳል?	/ _____ / ደቂቃዎች / _____ / ኪ.ሜ.
74	What is the main toilet facility used by members of your household?	1. Ventilated improved pit latrine 2. Pit latrine with slab 3. Pit latrine without slab	74.	የቤተሰብዎ አባላት የሚጠቀሙበት የመፀዳጃ ቤት ዓይነት ምንድነው?	1. አየር ማስወጫ ያለው የተሻሻለ መፀዳጃ ቤት 2. የጉድጓድ መፀዳጃ ከንጣፍ ጋር

		4. Composting toilet 5. No facility / bush / field			3. መጸዳጃ ቤት ያለ ንጣፍ 4. መጸዳጃ ቤት ማዳበሪያ 5. ሽንት ቤት የለም/ ቁጥቋጦ / ሜዳ
	Part- VII : Health and Pregnancy-Related Characteristics			ከጤና እና ከእርግዝና ጋር የተዛመዱ ባህሪዎች	
75	Date of Last Menstrual Period (dd/mm/yyyy)	/_____/_____/_____	75. 7 3	የመጨረሻው የወር አበባ ጊዜ (ቀን / ወር / ዓመት)	/_____/_____/_____
76	Woman Anthropometric	Wt/_____/Kg , Ht/_____/Mtr	76. 7 4	ሴትየዋ antropometry	ክት/_____/ኪግ, ቁት/ _____ / ሜ
77	Mother's BMI	/_____/kg/m^2	77. 7 5	የሴትየዋ BMI	/_____/ኪግ/ሜ^2
78	Can you tell me the order of the current pregnancy?	/_____/ Current pregnancy /_____/ Total pregnancy	78. 7 6	የአሁኑን የእርግዝና ቅደም ተከተል ሊነግሩኝ ይችላሉ?	/_____/የአሁኑ እርግዝና / _____ / ጠቅላላ እርግዝና
79	How many times have you attended ANC since the start of this pregnancy?	/_____/ times	79.	ይህ እርግዝና ከጀመረበት ጊዜ አንስቶ የቅድመ ወሊድ ክትትል ስንት ጊዜ አድርገዋል?	/_____/ ጊዜያት
80	What was your previous pregnancy outcome?	1. Normal birth 2. Low birth weight 3. Still birth 4. Preterm birth 5. Miscarriage 6. Other/_____?	80. 7 8	ያለፈው የእርግዝና ውጤትዎ ምን ነበር?	1. መደበኛ ህፃን 2. ዝቅተኛ ክብደት ያለው ህፃን 3. የሞተ መወለድ 4. ያለጊዜው መወለድ 5. የፅንስ መጨንገፍ 6. ሌላ / _____/
81	Have you ever been diagnosed with the following diseases before this pregnancy?	1. Cardiac Disease 2. Diabetes Mellitus 3. Hypertension 4. Asthma or COPD 5. Sexually Transmitted Diseases	81. 7 9	ከዚህ እርግዝና በፊት በሚከተሉት በሽታዎች ተመርምረው ያውቃሉ?	1. የልብ በሽታ 2. የስኳር ህመም 3. የደም ግፊት 4. አስም ወይም COPD 5. በግብረ ሥጋ ግንኙነት የሚተላለፉ በሽታዎች
82	Are you currently using alcohol?	1. Yes 2. No	82. 8 0	በአሁኑ ጊዜ አልኮል እየተጠቀሙ ነው?	1. አዎ 2. አልጠጣም
83	Please indicate the box that best describes your symptoms WHEN	Eye irritation: 1. Yes 2. No Blurred vision: 1. Yes 2. No Nose irritation: 1. Yes 2. No	83. 8 1	ምግብ በሚያበስሉበት ጊዜ	የአይን ማሳከክ: 1. አዎ 2. የለም ደብዛዛ እይታ: 1. አዎ 2. የለም

	COOKING:	Headache: 1. Yes 2. No Chest wheezing: 1. Yes 2. No Throat irritation: 1. Yes 2. No Cough: 1. Yes 2. No Shortness of breath: 1. Yes 2. No		የሚከተሉትን ምልክቶች እየተመለከቱ ከሆነ እባክዎን በተሻለ የሚገልፅበትን ያመልክቱ	የአፍንጫ ማሳከክ: 1. አዎ 2. የለም ራስ ምታት: 1. አዎ 2. የለም የደረት አተነፋፈስ: 1. አዎ 2. የለም የጉሮሮ መቆጣት: 1. አዎ 2. የለም የጉሮሮ መቆጣት: 1. አዎ 2. የለም ሳል: 1. አዎ 2. የለም የትንፋሽ እጥረት: 1. አዎ 2. የለም የትንፋሽ እጥረት : 1. አዎ 2. የለም
84	Which illness (es) in your opinion is/are associated to smoke inhalation?	1. Asthma Bronchitis 2. Pneumonia Lung Cance 3. Tuberculosis 4. Cataract (blindness) 5. Cardiovascular disease 6. Adverse pregnancy outcomes	84. 8 2	በአንተ አስተያየት የትኛውን በሽታ/በሽታ/ከጭስ እስትንፋስ ጋር ይዛመዳል?	1. የአስም ብሮንካይተስ 2. የሳንባ ምች የሳንባ ካንሰር 3. ሳንባ ነቀርሳ 4. የዓይን ሞራ ግርዶሽ (ዓይነ ስውር) 5. የካርዲዮቫስኩላር በሽታ 6. አሉታዊ የእርግዝና ውጤቶች
85	Which indoor air pollution illness (es) is frequent in your household? .	1. Asthma Bronchitis 2. Pneumonia Lung Cancer 3. Catarrh Convulsion 4. Tuberculosis 5. Cataract (blindness) 6. Cardiovascular disease Adverse pregnancy outcomes	85.	በቤተሰብዎ ውስጥ የትኛው የቤት ውስጥ የአየር ብክለት በሽታ (በሽታዎች) ተደጋጋሚ ነው?	1. የአስም ብሮንካይተስ 2. የሳንባ ምች የሳንባ ካንሰር 3. ሳንባ ነቀርሳ 4. የዓይን ሞራ ግርዶሽ (ዓይነ ስውር) 5. የካርዲዮቫስኩላር በሽታ 6. አሉታዊ የእርግዝና ውጤቶች
	Part -VIII: Dietary Diversity Status			**ክፍል -VIII: - የአመጋገብ ሁኔታ**	

86	Please describe the foods (meals and snacks) that you ate or drank yesterday during the day and night, whether at home or outside the home. Start with the first food or drink eaten in the morning. *[Write down all food and drinks mentioned. When composite dishes are mentioned, ask for the list of ingredients. When the respondent has finished, probe for meals and snacks not mentioned]*	Breakfast:_____ _____ Lunch:_____ _____ Snack:_____ _____ Dinner:_____ _____	86. ፩ ፮	እባክዎን ትናንት በቤት ውስጥም ሆነ ከቤት ውጭ በቀን እና በምሽት የበሉትን ወይም የጠጡትን ይግለጹ ። ጠዋት ላይ በሚበላው ይጀምሩ ። [የተጠቀሱትን ምግቦች እና መጠጦች ሁሉ ይጻፉ ። የተቀናጁ ምግቦች ሲጠቀሱ የንጥረ ነገሮችን ዝርዝር ይጠይቁ ። ተጠሪ ከጨረሰ በኋላ ለምግብነት ምርመራ ያድርጉ እና ያልተጠቀሱ መክሰስ]	ቁርስ:_____ _____ _____ ምሳ:_____ _____ _____ መክሰስ:_____ _____ _____ እራት:_____ _____ _____

Annex IV: Follow-up Questionnaire

Pregnancy, delivery and ARIs follow-up

No	Questions	Responses	ተ.ቁ	ጥያቄዎች	የ ተሰጡ ሜልሶች
1.	Household ID	/_____/_____/	**1.**	የ ቤተሰብ ሜላ ያ ቁጥር	/_____/_____/
2.	Visiting date , (dd/mm/yyyy)	/____/_____/_____/	**2.**	የ ጉብኝት ቀን ፣ (ቀን /ወር /ዓ ሜት)	/____/_____/_____/
3.	Assigned stove usage	1. using the assigned stove 2. shifted to another stove	**3.**	የ ተሜ በ ውምድጃ አ ጠቃቀ ም	1. የ ተሜ በ ውን ምድጃ በ ሜከቀ ም ላ ይ 2. ወደ ሌላ ምድጃ ተለ ወጠ
4.	Health conditions of the women	1. healthy 2. faced health problems	**4.**	የ ሴቶቹ የ ጤፍ ሁኔ ታ	1. ጤፍ ማ 2. የ ጤፍ ችግሮች አ ጋ ጥሟቸ ዋል
5.	Birth outcome (circle all relevant)	1. Term birth 2. Preterm (< 37 wks.) 3. Stillborn 4. Miscarriage 5. Birth defect	**5.**	ስ ለ ተወለ ደ ዉህ ጻ ን የ ሚሜላ ከ ተዉን ሁሉ ይከ በ ብ	1. በ ጊ ዜ ዉ የ ተወለ ደ 2. ያ ለ ጊ ዜ ዉ የ ተወለ ደ 3. ጡፍ ቶ የ ተወለ ደ 4. Miscarriage 5. Birth defect
6.	If delivery visit, Date of birth, dd/mm/yyyy	/____/____/____/	**6.**	የ ወሊድ ጉብኝ ት ከ ሆነ ፣ የ ዉል ድ ቀን ፣ (ቀን /ወር /ዓ ሜት)	/____/____/____/
7.	Mod of delivery	1. Normal 2. CS	7.	ህ ጻ ኑ የ ተወለ ደ በ ት ሜን ገ ድ	1. በ ኖ ር ሜል 2. በ ቀ ዶ ጥ ገ ና
8.	Month of birth	Name the month /_____/	8.	የ ተወለ ደ በ ት ወር	ወሩ ይጣፍ /- _____/
9.	Place of delivery,	1. Hospital or clinic 2. Home	9.	የ ዉል ድት ቦ ታ	1. ሆ ስ ፒ ታ ል ወይ ም ክ ሊ ኒ ክ 2. ቤት
10.	Gender of the new borne	1. Male 2. Female	10.	አ ዲ ስ የ ተወለ ዱ ሕፃ ና ት ጾ ታ	1 ወን ድ 2. ሴት
11.	Gestational age (weeks)	/_____/wks	11.	የ እ ር ግ ዝ ና ጊ ዜ (ሰ ምን ታት)	/_____/ሰ ምን ት
12.	Birthweight (gm)	/_____/gm	12.	የ ል ደ ት ክ ብ ደ ት (ግ ራ ም)	/_____/ግ ራ ም
13.	The birth weight was measured	1. Within 24 hours 2. Within 48 hours	13.	የ ል ደ ት ክ ብ ደ ት	1. በ 24 ሰ ዓ ታ ት ዉስ ጥ ተ ለ ካ 2. በ 48 ሰ ዓ ታ ት ዉስ ጥ
14.	Month of birth		14.		
15.	Birth outcome *(circle all relevant)*	1. Term birth 2. Preterm (< 37 wks.) 3. Stillborn 4. Miscarriage	15.	የ ስ ለ ተወለ ደ ዉህ ጻ ን የ ሚሜላ ከ ተዉን ሁሉ ይከ በ ብ	1. በ ጊ ዜ ዉ የ ተወለ ደ 2. ያ ለ ጊ ዜ ዉ የ ተወለ ደ 3. ጡፍ ቶ የ ተወለ ደ

		5. Birth defect			4. Miscarriage 5. Birth defect
16.	Was your child kept in hospital because of health problems after his/her birth?	1. No 2. Yes, fewer than 8 days 3. Yes, 8 to 30 days	16.	ልጅዎ ከተወለደ በኋላ ባሉት የጡ ቻግሮች ምክንያት ሆስፒታል ቆይቷል?	1. አይ 2. አዎ፣ ከ8 ቀናት በታች 3. አዎ, ከ 8 እስከ 30 ቀናት
17.	Has the infant had an illness with cough at any time in the last two weeks?	1. Yes 2. No	17.	ህፃኑ ባለፉት ሁለት ሳምንታት ውስጥ በማናቸውም ጊዜ በሳል ህመም አጋጥሞታል?	1. አዎ 2. አይደለም
18.	When infant had an illness with a cough, did he/she have trouble breathing or breath faster than usual, with short, fast breaths?"	1. Yes 2. No	18.	ጩቅላ ሕፃን በሳል ሲታመም የ ሙ ንፈስ ችግር ነ በረበት ወይምከ ወትሮውበበለጠ ፍጥነ ት የ ሙ ንፈስ ችግር አጋጥሞ ት ነ በር፣ በአ ጭር እና ፈጣን ትንፋሾች?"	1. አዎ 2. አይደለም
19.	If yes for how long? Main Symptom(s)	Fever /__/ days ago Runny nose /__/ days ago Cough /__/ days ago Fast breathing /__/ days ago Wheeze /__/ days ago Others,_____/___/ days ago	19.	አዎ ከሆነ ለምን ያህል ጊዜ? ዋና ዋና ምልክቶች	1. ትኩሳት /__/ ቀናት 2. የ አፍንጫፍሳሽ /__/ ቀናት 3. ሳል /__/ ቀናት በፊት 4. ፈጣን ሙ ንፈስ /__/ ቀናት 5. ጩኸት /__/ ቀናት 6. ሌሎች፣ /__/ ቀናት
20.	Did you seek advice or treatment for the cough/fast breathing?	1. Yes 2. No	20.	ለሳል/ፈጣን አተነ ፋፈስ ምክር ወይምህክምና ፈልገ ዋል?	1. አዎ 2. አልፈለ ኩም

Annex V: Focus Group Discussion Study Guiding Questions

Introduction

Hello, thank you for coming in today. We appreciate you taking the time to discuss cooking and air pollution with us. My name is _____, and I'm a researcher working with Mr. Habtamu Demelash, a PhD candidate at Jimma University, Institute of Health, Faculty of Public Health, Department of Environmental Health Science and Technology.

This discussion is part of a research study led by Mr. Habtamu to explore the community's understanding of the health risks associated with cooking smoke and potential benefits of improved stoves. We are specifically interested in understanding your perception of the health risks associated with cooking smoke and benefits of improved stoves.

Your participation in this study is completely voluntary. You can ask questions at any time and have the right to decline to answer any question. Your responses will not be linked to your name or any identifying information. All your responses will be kept confidential. Your views and answers will not be shared outside of this interview.

To ensure we capture all the important information, we will be recording this discussion. You have the right to withdraw your consent to the recording at any time. Please feel free to ask any questions you may have about the study or your participation.

Before we begin, I would like you to confirm your understanding of these points. Are you willing to participate in this study with the understanding that you can withdraw at any time?

1. Yes, I understand and agree to participate 2. No, I do not wish to participate.

Date	
Woreda	
Kebele	
Time started	
Time finished	

Respondent	Age	Education	Religion	Family size
P1				
P2				
P3				
P4				
P5				
P6				
P7				
P8				

Domains	English guiding questions	Amharic version
Main cooking fuels	**1. What is the main cooking fuel used?** a. Variation across different season. b. do you use start fuel for burning? c. is there Smokey fuel? Do you try not to use it?	**1. ዋና ውየ ማብሰያ ማ ዶ ምን ድነ ው?** a. በተለያዩ ወቅቶች በ ማ ዶ አጠቃቀምላይ ልዩነ ት አለ? b. ለ ማቃጠል የ ማ ሻ ማቋጣጪያ ይጠቀማሉ? c. ጭል የ ሚያ ባብስ ማ ዶ ኣለ? ላለ ማከቀም ይሞክራሉ?
Perceived health risk	**2. What do you feel about the health effects of kitchen smoke?** a. Do you feel you have health issues due to kitchen smoke – what are these? b. Are your children affected by kitchen smoke? c. What are health problems the community associated with HAP d. Do you think majority of the community members agree with the health risk of HAP? Why? e. Do pregnant women reduce their exposure intentionally?	**2. የ ኩሽና ጭል በጤ ላይ ስላለው ጉዳት ምን ይሰ ሟ ታል?** *a.* በ ኩሽና ጭል ምክ ን ያት የ ጤ ፕ ግሮች እ ን ዳሉዎት ይሰ ሟ ታል - *እ ነ ዚህ ምን ድን ና ቸው?* b. ል ጆ ቻ ችሁ በ ኩሽና ጭል ተጎ ድተ ዋ ል ብለ ዉ ያ ስ ባ ሉ? c. ህ ብ ረ ተ ሰ ቡ ከ ኩሽና ጭል ጋ ር የ ሚያ ገ ና ኝ ው የ ጤ ፕ ግሮች ምን ድን ና ቸው? d. አ ብዛ ኛ ው የ ሚህ በ ረ ሰ ቡ አ ባ ላ ት በ ኩሽና ቤት ጭል ምክ ኒ ያ ት የ ጤ ፕ አ ደ ጋ አ ን ዳ ለ የ ሚ ክ ሞ ው ይሞክ ላ ች ኋ ል? ለ ምን? e. ነ ፍ ሰ ጡ ር እ ና ቶ ች በ ተ ለ የ የ ኩሽና ጭል ተ ጋ ላ ጭ ፅ ታ ቸ ውን ለ ማ ቀ ነ ስ ይሞክ ራ ሉ? በ ምን ሜ ል ኩ?
Perceived benefit of ICS	**3. What do you feel about the importance of improved stove?** a. what types of cooking stove in use b. Do you like your current stove? c. what is your ideal stove? d. Do most people think that cooking with improved stove is good for their family? e. Are you readily welcome any technology of improved stove which reduces smoke emission for use in your house	**3. ስ ለ የ ተ ሻ ሻ ለ ምድ ጃ አ ስ ፈ ላ ጊ ነ ት ምን ይሰ ሟ ታል?** a. ምን ዓ ይ ነ ት የ ማ ብሰ ያ ምድ ጃ ዎ ች ን ነ ዉ የ ሚ ጠ ቀ ሙ ት? b. የ አ ሁ ኑ ን ምድ ጃ ዎ ን ይ ወ ዳ ሉ? ለ ምን ? ካ ል ወ ደ ዱ ት ሰ ለ ምን ? c. የ እ ር ስ ዎ ተ ስ ማ ሚ ምድ ጃ ምን ዓ ይ ነ ት ሞ ድ ጃ ነ ዉ ነ ው? d. ብ ዙ ሰ ዎ ች በ ተ ሻ ሻ ለ ምድ ጃ ማ ብ ሰ ል ለ ቤ ተ ሰ ባ ቸ ው ጤ ቃ ሚ ነ ው ብ ለ ው ያ ስ ባ ሉ? e. ባ ሁ ኑ ጊ ዜ የ ጭል ል ቀ ት የ ሚ ቋ ን ስ ማ ን ኛ ው ን ም የ ተ ሻ ሻ ለ ምድ ጃ ለ ማ ከ ቀ ም ያ ለ ዎ ት ዝ ግ ጅ ት ምን ይ ሞ ክ ላ ል?

Perceived Barriers to own ICS	**4. What barriers do you faced when trying to own improved stove?** a. Are there circumstances or incidences that forced you not to use improved stove? b. Do people think that cooking with improved stove is a sign of higher social status ▪ In your opinion, what can be done to improve the utilization of improved stove community? ***Financial,*** *accessibility, affordability, husband dominancy…. Probe for; festivity, food item, etc...* *Would you say the structure of the house influence people improved stove utilization? How?* *Would you say the family size influence people improved stove? How?* *Taste of food cooked with improved stoves*	**4. የተሻሻለ ምድጃ ባለቤት ለሚሆን ሲሞክሩ ምን ማነና ክሎች አጋጥሞዎታል?** a. የተሻሻለ ምድጃ እንዳይጠቀሙ ያስገደድዎት ሁኔታዎች ወይምአጋጣሚዎች አሉ? b. ሰዎች በተሻሻለ ምድጃ ማብሰል የቅንጦት ምልክት ነ ውብለውያስባሉ? c. በእርስዎ አስተያየት የተሻሻለ የምድጃ ሚህበረሰብን አጠቃቀም ለማሻሻል ምን ሊደረግ ይገባል ይላሉ? ▪
Cooking Behavior	**5. Where should cooking take place?** ▪ do pregnant women reduce their exposure intentionally? ▪ Do you know of any other behaviours you could change to reduce you or your children's exposure to cooking smoke?	**5. አሁን የሚየበስሉበት ቦታየት ነ ዉለምን?** a. የማብሰያ ቦታበወቅቶች ይለያያል?ለምን? b. ሌላ የማብሰያ ቦታ ሊያስቀይር የሚችል ነገር ካለ?? c. ከቤት ዉስጥና ከቤት ውጭሲያበስሉ ምን ይሰማዎታል?ለምን? d. ልጆች ምግብብሚሰልበት ጊዜ ከናታቸዉጋር ኩሽና ቤት የመቆየት ነገር አለ?ለምን?
Traditional Beliefs	**6. Are there traditional beliefs related with HAP and improved stove use? If yes, what are they?** a. What kind of information is easily available in the community about improved stove? b. How do the community treat an individual or household use improved stove in all the seasons? What about those who do not use?	**6. <u>ከኩሽና ቤት ጭስ እና ከተሻሻለ ምድጃ አጠቃቀም ጋር የተያያዙ ባህላዊ እምነ ቶች አሉ? አዎ ከሆነ ፣ ምን ድና ቸው?</u>** **a.** ቤት ሞቅ ሞቅ ለማድረግ ፣ አህል ለማድረቅ፣ ልብሰ ለማድረቅ፣ ነፍሳት ለማገረር ሌላም ካለ--- **b.** ስለ ተሻሻለ ምድጃ ማህበረሰቡ ያለዉ አመለካከት ምን ይማስላል?ለምን?
Experiences on ICS	**7. Have you ever been given or asked to use a different cooking stove?**	**7. የተለየ የማብሰያ ምድጃ ተሰጥተው ወይም እንዲጠቅሙተጠይቀዉታውቃለህ?** a. ምን ተሞክሮ አለዎት?

Advise/support on improved stove use	**8. Do you think seeking advice about improved stove utilization or any other thing related to HAP and improved stove is important? Why?**	▪ ስለ የተሻሻለ ምድጃ አጠቃቀም ወይም ከHAP እና ከተሻሻለ ምድጃ ጋር የተያያዘ ሌላ ነገር ምክር ሚፈለግ አስፈላጊ ነውብለውያስባሉ? ለምን?

9. ስለ ምግብ ማበሰል እና የአየር ብክለት አስተያየት ማከል የሚፈልጉት ሌላ ነገር አለ?

END – Thank you for participation and for your time

Annex VI: Kitchen Air Sampling Form

General information

Household ID: /_____/

Kebele :/_____/

Sub Kebele (Got):/_____/

Sampling Conducted by:/ _____/

Season of the year: /_____/

Rainy (it has rained in the last two weeks) :/_____/

Dry (it has not rained in the last two weeks) :/_____/

Sampling Date: ddd/mm/yyyy	/_____/_____/___'____/
Air monitoring device ID:	
Monitoring Phase:	1. Baseline 2. End line
Sampling Start Date (dd / mon/ yyyy)	/_____/_____/___'____/
Sample Start Time (hh:mm) Fine	/_____:_____/
Sample Stop Date(dd / mon/ yyyy)	/_____/_____/___'____/
Sample Stop Time (hh:mm)	/_____:_____/
Elapsed Time (hh:mm)	/_____:_____/

Declaration Form

I, the under signed, declared that this thesis is my original work and has not been submitted in whole or in part for any other degree or diploma at this or any other university. All sources and materials used for this thesis have been fully acknowledged

Name: Habtamu Demelash

Signature: _____

Date: _____

Place: Jimma University, School of Graduate Studies

Date of submission: _____

This dissertation has been submitted for examination with my approval as a university supervisor

Candidate's First Supervisor

Name: Professor Seid Tiku

Signature: _____

Date: _____

Candidate's Second Supervisor

Name: Dr. Abebe Beyene

Signature: _____

Date: _____