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HOUSEHOLD AIR POLLUTION EXPOSURE IN SUB-SAHARAN AFRICA AND ASSESSMENT OF DISEASE BURDEN ATTRIBUTABLE TO RISK FACTOR

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If ever we had proof that our nation's pollution laws aren't working, it's reading the list of industrial chemicals in the bodies of babies who have not yet lived outside the womb.

Louise Slaughter

We've got to pause and ask ourselves: How much clean air do we need?

Lido Iacocca

ABSTRACT

BACKGROUND: One of the major environmental threats to human health is air pollution. It contributes to premature deaths of millions of people worldwide. Air quality issues are growing exponentially in developing countries (West et al. 2016). More specifically, household air pollution that results from indoor cooking with solid fuels is damaging to the human health in LMIC. About 54% of global population in low and middle income countries (LMIC) relies on polluting fuel (including wood and dung) for cooking (WHO, 2016). Very high emissions of particulate matter (PM), short-lived climate forcers and polycyclic aromatic hydrocarbons (PAHs) result from inefficient combustion of solid fuel in household stoves (Ramanathan, 2008). While outdoor and household air pollution can be detrimental to everyone, a subpopulation particularly at risk is that including pregnant women.

METHODS: 2114 pregnant women were surveyed regarding their cooking habits and fuel-type use for cooking purposes in Adama of Ethiopia, Africa; an area of 600 000 inhabitants. AirQ+ software was used to assess health impact of household air pollution through estimating disease burden (including Acute Lower Respiratory Infections, Chronic Obstructive Pulmonary Disease, Ischemic Heart Disease, Lung Cancer, and Stroke) attributable to risk factor.

RESULTS: Fifty-nine per cent of the cohort group of Adama, Ethiopia, use solid fuel (such as coal) for cooking purposes. As a result, the BoD estimation of mortality rate per 100 000 Adama women, using age-standardized mortality rates of women of Ethiopia is 33 for ALRI, 9 for COPD, 23 for IHD, 12 for LC, and 11 for stroke. Burden of Disease DALYs estimation per 100 000 women of Adama is using DALYs per 100 000 Ethiopian women of ages 15-49 is 4,265 DALYs for ALRI, 629 DALYs for COPD, 1,123 DALYs for IHD, 53 DALYs for LC, and 753 DALYs for stroke. While 95.2% of Adama population have electricity at home, 42.8% use if for cooking, the rest using solid fuel or a combination of electricity and solid fuel. Other factors, such as education level, location of cooking, and presence of running water at home have shown to impact fuel-type use in the cohort population.

CONCLUSION: This health impact assessment leads to the knowledge that household air pollution due to solid fuel use (such as charcoal) among pregnant women in Adama, Africa, leads to mortality rates and disease-adjusted life years that could be avoided by decreasing or eliminating solid fuel use for cooking purposes.

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CHAPTER ONE

INTRODUCTION

One of the major environmental threats to human health is poor air quality or air pollution. Air pollution contributes to premature deaths of millions of people worldwide. Air quality issues are growing exponentially in developing countries (West et al. 2016). In addition, over the last twenty years, data have shown a dramatic growth for adverse health effects of ambient air pollution (USEPA 2009 & 2013). Further, household air pollution that results from indoor cooking with solid fuels is damaging to the human health in low- and middle-income countries. About 54% of global population in low and middle income countries (LMIC) relies on polluting fuel (including wood and dung) for cooking (WHO, 2016). Very high emissions of particulate matter (PM), short-lived climate forcers (such as methane, fluorinated gases, tropospheric ozone, and black carbon) and polycyclic aromatic hydrocarbons (PAHs) result from inefficient combustion of solid fuel in household stoves (Ramanathan, 2008). While outdoor and household air pollution can be detrimental to everyone, a subpopulation particularly at risk is that including pregnant women.

Rationale for the study

In Africa, estimating the effect of air pollution exposure is harder due to lack of monitoring and high-resolution outdoor air pollution modelling. In addition, household air pollution is also a major factor of pollution exposure and as a result, additional knowledge is needed of how different fuels that are used, cooking habits, and cooking stoves affect exposure to air pollution. To date, no high-quality study of the Global Burden of Disease (GBD) of indoor air pollution exposure on pregnant women in Africa has been done.

The purpose of this study was to investigate exposure of pregnant women to household air pollution, by identifying type of biomass exposure, frequency of exposure per day, and using these data to determine the Global Burden of Disease (GBD), in Adama of Ethiopia, Africa. This chapter provides a detailed description of the overall aim of the study, significance of the study, and importance of the study and the study topic.

Overall aim of the study

This study will enrich the knowledge of estimation of health impact of household air pollution exposure on pregnant women, including source characteristics, which will lead to principal knowledge for suitable policy making. Detailed research questions and analytical approaches are shown in the methods section.

Specific study aims:

1. Model household air pollution exposure by combining measurements with fuel use.
2. Perform Health Impact Assessments on association of indoor air pollution exposure and burden of disease attributable to risk factor.
3. Assess correlation between level of fuel – type use and education level, location of cooking, and availability of running water and electricity at home.

Significance of the study

In this multidisciplinary study exposure to air pollution from household sources was assessed. The methods developed could be used in a wider framework, however, here were used in health impact assessments utilizing a well characterized cohort of pregnant women in Adama, Ethiopia. The knowledge gained from this study could have great implications for preventive actions in order to protect health especially for pregnant women and their future children.

Importance of the study

The study cohort will be representative of pregnant women seeking antenatal care (ANC) at public health facilities in a low-income setting with high exposure to air pollution. In addition, this cohort of pregnant women gives the opportunity to create another cohort of children born to women that are characterized with regard to air pollution exposure and child development.

This research study will also strengthen the research collaboration between Lund University and Africa as part of the goal set by LU in 2014.

CHAPTER TWO
LITERATURE REVIEW

Pollution, which has been identified as one of the great existential confrontations of the Anthropocene epoch, endangers the continuing survival of human societies, like ocean acidification, depletion of world's fresh water supply, desertification, biodiversity loss, and climate change do (Rockström et al. 2009). Industrial emissions, toxic chemicals, as well as vehicular exhausts have caused pollution to rise significantly in the past two-hundred years. Even though today most significant increases in pollution are noticed in low- and middle-income countries, chemical, as well as industrial and vehicular exhaust is highly overlooked in developing countries in global health agendas and in international development. As a result, pollution, now a weighty obstacle that threatens the health of billions, compromises the economic stability of nations, atrophies ecosystems of Earth, and is at fault for a vast global burden of disease, premature death, and disability (Landrigan et al. 2017).

European Union defines pollution as material that is unwanted and often dangerous and that is introduced to the environment by human activity, harming ecosystems of the Earth and threatening the health of humans (EU, 2010). Geographically, as seen in figure 1, the highest mortality due to all forms of pollution occurred in southeast Asia (including India) of approximately 3.2 million deaths, and the western Pacific (including China) of approximately 2.2 million deaths. The highest mortality rate from diseases related to pollution occur in industrializing and rapidly developing low-income and middle-income countries, accounting for 92 per cent of pollution-related deaths worldwide. In addition, worldwide, regardless of level of country income, detrimental health effects of pollution affect mostly the marginalized and the poor of the population, as well as the very old and the very young, where number of deaths from all types of pollution peaks amidst children less than five years old, and the highest number of deaths related to pollution happens amidst people over the age of sixty years. Resulting disease-adjusted life years (DALYs) from diseases related to pollution are fixed towards the very young (infants and children), echoing the years of life lost from each child lost or disabled (GBD, 2016).

While there are different forms of pollution, including air, water, soil, and occupational pollution, it is air pollution that is especially considered in this study, more specifically household air pollution. Household and air pollution are comprised of many of the same pollutants and they often co-exist; in low-income and middle-income countries, the household air pollution accumulated from cooking practices contributes to the overall ambient air pollution (Balakrishnan et al. 2014; Chafe et al. 2014). Besides indoor air pollution contributing to outdoor air pollution, it has been found that airborne pollutants are able to travel across countries and even oceans. Conversely, outdoor air pollution contributes to indoor air pollution, especially in LMIC, where there is no filtration of the outdoor air, upon it travelling indoors. Lin et al found that Chinese manufacturers emissions had travelled all the way to the USA due to winds blowing across the Pacific Ocean; more specifically, 11% of black carbon, 12-24% of sulphate, 4-6% carbon monoxide and up to 2-5% of ozone that were detected in the west of USA had an origin from China; in addition, while the manufacturing occurred in China, the consumption and use of the products can be attributed to other places (2014).

Cost of pollution

While pollution is eminently costly to the society, its full cost is not recognized and is unavailable to rebuke an argument that is one-sided and economically based against pollution control/restraint. Despite it being responsible for healthcare costs, productivity losses, costs resulting from damaged ecosystems, these costs end up being unrecognized as results of pollution (National Academy of Science, 2010). These costs end up being accounted for elsewhere, for example, healthcare costs of pollution end up buried in hospital budgets and pollution-caused disease-related productivity losses are hidden in labor statistics (Landrigan et al. 2015).

Currently, expanded industrialization of low- and middle-income countries, increased energy consumption worldwide, uncontrolled growth of cities by an increased population movement from rural to urbanized areas, global spread of toxic chemicals by increased application of herbicides and insecticides, increased deforestation, smelting and mining, and increased use of buses, trucks and cars powered by petroleum are all factors contributing to a worsening nature of pollution. Combined they cause an increase in all pollution types, including ambient air, chemical and soil pollution (Smith et al. 2005). Furthermore, the increase in overall pollution over the past half of a century is a direct characteristic of the actual economic archetype that focuses relentlessly on GDP, where human capital and natural resources are viewed and expansive and substantial, and where the consequences of their impertinent exploitation are given little thought. This economic archetype is conclusively unsustainable as it fails to associate maintenance of Earth's resources and social justice to the economic development of humanity (McMichael et al. 2017, Rockström et al. 2009, Whitmee et al. 2015).

Pollution prevention

Paradoxical to repeated claims that pollution control and economic growth cannot go hand-in-hand, it is now understood that pollution control is cost-effective. Inasmuch, USA has been able to decrease six air pollutants (sulfur dioxide, carbon monoxide, lead, nitrogen dioxide, particles and ozone) by approximately seventy per cent since 1970, when the Clean Air Act was passed. During this time, it has been estimated that GDP increased by about two hundred and fifty per cent (Samet et al. 2017). To put the case of USA in perspective, every dollar that was invested towards air pollution control, it returned thirty US dollars in economic growth (US Environmental Protection Agency). Additionally, the intervention of removing lead from gasoline which began in 1975 in the USA, turned out to be another example of an economic benefit while addressing pollution. The correlation of the consumption of leaded gasoline and the average air lead concentrations in the USA, for the period of 1975 to 2016 can be seen in figure 2. This intervention decreased the mean blood concentration of lead in the US population by more than ninety per cent, it aided in increasing children's cognitive capacity (those born since 1980) by 2-5 IQ points and almost entirely eliminated lead poisoning in children (Grosse et al. 2002). As a result, the increase in intelligence of the generation born since 1980 in the USA, it is estimated that it will lead to national economic benefit of about 200 billion US dollars (over lifetime of each annual cohort of that generation (Grosse et al. 2002). To date, that benefit is estimated to approximate 6 trillion US dollars (Pirkle et al. 1998).

However, notwithstanding the evidence of poor health effects of pollution and its negative consequences on the environment and the economy, as well as the evidence that pollution control can be cost-effective when done right, pollution control has been largely neglected, more specifically chemical, industrial, and vehicular pollution control by low-income and middle-income countries (Nugent, R. 2016). While work has been done to curb indoor or household air pollution that is released by cookstoves that are poorly ventilated (Chafe et al. 2014, Balakrishnan et al. 2014, Yadama 2013), as well as to control biological contamination of drinking water, along with antibiotic treatment protocols and administration of vaccinations, leading to a decrease in morbidity and mortality that is linked to traditional types of pollution, there has been a lack of international attention and resources to curb the problems that are caused by water, soil and air pollution due to electricity generation, mining, modern industry, petroleum-powered vehicles, smelting, mining, and chemical pesticides in low-income and middle-income countries (Nugent, R. 2016). It is also worth mentioning that Prevention and Control of Non-Communicable Diseases of the Global Action Plan scarcely mentions mediation in opposition to pollution.

Factors contributing to neglect of pollution

Numerous factors have led to neglect of pollution. A constant barrier has been the false belief that disease and pollution are the inevitable aftermath or repercussion of economic development. This phenomenon has been referred to as the 'environmental Kuznets hypothesis' (Kuznets, 1955), a claim which Landrigan et al label as antiquated and flawed as it was formulated many decades ago, a time when urban centers and populations were smaller than today, modern production technologies as well as cleaner fuel was not available at that time, and sources, health effects and the nature of pollution were quite different (2017).

Another factor that has contributed to neglect of pollution control is the dissolution of plans for environmental health and pollution management. While the obligation of dealing with pollution-related disease resides in ministries of environment and ministries of health, oftentimes it ends up belonging to neither. As a result, different research groups and agencies regulate water, air, soil, and chemical pollution, leading to a repercussion where contribution of pollution to global burden of disease as well as the full scale of pollution are not identified (Landrigan et al. 2017). In addition, more specifically in low-income countries, the presence of many pressing socio-economic problems may lead to the issue of air pollution simply to not be prioritized.

Neglect of pollution can also be traced back to World War II, when development assistance programs were launched and when more than fifty per cent of the countries were categorized as low-income. Their aims were to improve child and maternal health as well as combat infectious diseases, which were the predominant health problems at that time (Hill et al. 2012). While their efforts were lucrative for their set goals, they were not designed to address the more contemporary forms of pollution.

Lastly, the resistance of authoritative vested interests, both internationally and within countries, is a continual barrier to management and control of pollution. These interests not only have an influence in government policy, but also contradict the scientific knowledge that links disease to pollution, downplay efficacy of interventions, as well as demolish governmental efforts to establish standards, appoint pollution taxes, and administer regulations and laws (Michaels, 2008).

Pollution and health

Effects of pollution on health have markedly advanced through scientific research and understanding (National Academy of Sciences 2012, Brauer et al. 2012). A major contribution to this understanding has been the contribution of advanced technologies, such as satellite imaging (Sorek-Hamer et al. 2016), ability to map, measure and identify sources of pollution, as well as trail physical or earthly trends remotely (Brauer et al. 2012, Sorek-Hamer et al. 2016). Additionally, advanced chemical analyses have contributed to understanding the composition of pollution, as well as expounded associations between pollution and disease (Valavanidis et al. 2008). In particular, the link between pollution and a wide range of non-communicable diseases was shown by multi-year and large prospective epidemiological studies, such as the Harvard Six-Cities study (Dockery et al. 1993) and Utah's studies on respiratory diseases associated with community air pollution by Pope and comrades. (Pope, C. 1989).

Air pollution is now understood and identified as an important causative factor in multiple non-communicable diseases, such as cancer, neurodevelopmental disorders, asthma and birth defects in children, as well as stroke, chronic obstructive pulmonary disease, heart disease and cancer in adults (Cacciottolo et al. 2017, Casanova et al. 2016, Chen et al, 2017, Cohen et al. 2017, Cosselman et al. 2015, Heusinkveld et al. 2016, Krewski et al. 2009, Kioumourtzoglou et al. 2016, Loomis et al. 2013, Malley et al. 2017, Meo et al. 2015, Perera et al. 2014, and Thurston et al. 2015). In addition, it is estimated that, should there be no aggressive intervention to pollution, mortality due to ambient air pollution is likely to increase by fifty per cent or more by year 2050 (Lelieveld et al. 2015).

While knowledge in understanding pollution and its effects on health has advanced, there remains much to be researched and understood. For example, many countries lack country-specific pollution levels and prevalence of pollution-related health issues. In addition, there is still missing knowledge on the scope of exposures and disease burden linked to toxic pollution exposures in polluted areas (Pure Earth, TSIP). Information is also incomplete on the possible delayed effects of toxic exposures sustained early in life or before birth (Heindel et al. 2015), and additional knowledge is needed regarding toxic effects of commonly used chemicals, as well as newer chemical classes now in use (Landrigan et al. 2011, Grandjean et al. 2014). Further, the dose-response function curve that is used to estimate the relative risk (RR) of disease linked to pollution is not currently known. For example, the shape of the exposure-response link of fine-particulate air pollution, both at very high and very low exposure levels that are used to estimate relative risk (RR) of exposure to fine particulate matter of magnitude of 2.5 μm ($PM_{2.5}$) in World Health Organizations analysis (Cohen et al. 2017) and in Global Burden of Disease studies (GBD 2015) are not strictly established.

While the gap between current knowledge regarding health effects of pollution, as well as environmental effects of it, the good news is that pollution itself has been shown to be preventable. Some middle-income and high-income countries have already issued regulations and enacted legislation that use new scientific evidence about health effects of pollution. These regulations and laws have banned hazard pollutants, such as DDT, lead, asbestos; they have mandated clean air and water at levels that prevent disease and have incorporated policies for chemical safety. In addition, these control strategies, that have been shown to be cost-effective, are ready to be adopted at city and country levels and at every income level. Application of these strategies can enable industrializing and developing countries to escape detrimental consequences of pollution at both ecological and human levels, overall improving human wellbeing and health (Landrigan et al. 2017).

Global burden of disease

Air pollution is a colossal and expanding global problem. The pollution effect on the health of humans is poorly understood and the contribution of pollution to the overall global burden of disease is inexorably undervalued. Since the 1950s, there have been more that 140,000 novel pesticides and chemicals synthesized, and more that 5,000 of those chemicals have been spread onto the environment worldwide. In addition, only less than half of the chemicals that have been synthesized have been tested for their effects on potential human health, including safety and toxicity. New chemical testing and pre-market evaluations have only become mandatory in some high-income countries and in the past decade, leaving a lot to questions regarding the effect of these synthesized chemicals in human health and safety. While their effect on the environment and human health was not tested, these new chemicals have been responsible for disease, environmental degradation, and death. Some factual examples of chemicals that have been around for decades and that have caused detriment to the environment and human health include lead, polychlorinated biphenyls (PCBs), asbestos, dichlorodiphenyltrichloroethane (DDT) and chlorofluorocarbons (CFCs). Newer emerging chemicals (such as herbicides, new insecticides, novel pharmaceuticals wastes, and nanomaterials), that have entered the market in the past two decades also have almost no pre-market assessment and as little is known about their effect on human health, are bound to repeat the history of the aforementioned, older chemicals. Of particular concern are low-income and middle-income countries where public health protection is usually insufficient and where it is likely to increase the production of chemicals (Landrigan et al. 2017).

When it comes to the disease burden caused by pollution, it is non-communicable diseases that account for most of the diseases due to pollution (about 71%) (GBD, 2016). More specifically, data from 2015 release that deaths reported from cardiovascular disease (21%), stroke (23%), chronic obstructive pulmonary disease (51%), lung cancer (43%), and cardiovascular disease (21%) we all due to all forms of pollution; the risk of death increases as the exposure to pollution increases (GBD, 2016). However, it is air pollution (both ambient and household) that aggregate the biggest category of welfare damages for countries of all income levels (Landrigan et al. 2017).

Household air pollution and lack of data in sub-Saharan Africa

Biomass burning in inefficient cooking stoves, forest and agresic burnings, and open fires in low-income countries, as well as fossil fuel combustion in middle- and high-income countries show grounds for almost all pollution by oxides of nitrogen and sulfur, and for approximately 85% of airborne particulate pollution (Guavea et al. 2015; Johnston et al. 2012). Additionally, fossil fuel combustion is also a significant source of greenhouse gases and climate pollutants that are, in turn, the main anthropogenic driver of global climate change, making pollution closely linked to global climate change (McMichael et al. 2017).

Health effects of household air pollution have been considered and suspected for many years, a few studies appearing even more than sixty years ago (Padmavati & Pathak, 1959). However, it is only recent research that has been marshaled to make a systematic case for the health effects of household air pollution across a range of illnesses. Globally, where half of the households rely on solid fuel, such as biomass burning, for cooking and heating purposes (Bonjour et al. 2013), indoor or household air pollution is assessed to cause 3.5 million premature deaths every year (Lim et al, 2012). In Ethiopia, 95% of energy is supplied by biomass sources, where it was estimated in 2007 that household air pollution caused approximately 5% of the national global burden of disease and more than 50 000 deaths annually (WHO, 2006). Additionally, inhalation rates during pregnancy are enhanced by 50% due to an increased oxygen demand by the pregnancy, leading to an increased inhalation of the polluted air (Hackley, 2007). Studies contributing to the knowledge and understanding of the effect of household air pollution on pregnant women have crude exposure assessments and lack detail on cooking habits, such as fuel type used and/or stove types (Amegah et al.

2014). The exposed population in Sub-Saharan Africa has increased by 100% since 1980, however, intervention in the continent has failed (Bonjour et al. 2013). Due to lack of technical and financial resources, high air quality measurements and population exposure assessment are deficient especially in Sub-Saharan Africa (Gebreab et al, 2015), and quality of air is not measured and/or monitored at all in that part of the world, as seen in figure 3. This lack in data makes it difficult to develop health statistics, adequate policies, as well as health impact assessments.

While we have come to understand some of the specifics of air pollution of the human physiology, such as exposure to ultra-fine particles (< 1 μm) inducing inflammation and oxidative stress (Terzano et al. 2010), we are only beginning to understand the effect that air pollution has on pregnant women and unborn children. For example, it has been found that air pollution particles smaller than one hundred nanometers, when inhaled, can penetrate the alveolar wall into the maternal bloodstream. This way, inflammatory mediator could reach the placenta, and eventually the foetus (Al-Gubory 2014, Erickson et al. 2014).

Currently, Ethiopia has one of the highest maternal mortality rates worldwide (420/100,000), where preeclampsia accounts for 25% of neonatal deaths and stillbirths and 16% of maternal deaths (Gaym et al. 2011). Despite the fact that the cause of preeclampsia is not yet known, scientific evidence suggests that in placenta, oxidative stress disrupts vascular functioning, which can result in inflammation and insufficient blood perfusion. In addition, recent studies and meta-analysis suggest that exposure to ambient air pollution increases risk of preeclampsia (Malqvist et al. 2013, Pedersen et al. 2014). As for household air pollution exposure during pregnancy, there has been one study done in India, which indicated a doubled risk for preeclampsia symptoms for pregnant women that used solid fuels for cooking purposes (Agrawal and Yamamoto, 2015).

Besides preeclampsia, low birth weight has been linked to maternal exposure to air pollution during pregnancy (Kuhn et al. 2016, Backes et al. 2013). In addition, birth weight has been identified as a major risk factor for mortality as well as adverse health later in the life of those children. This phenomenon is also referred to as 'Barker hypotheses' or 'fetal programming' (Barker et al. 2002). While the link between maternal household air pollution exposure and low birth weight has been strongly evidenced (Amegah et al. 2014), a need for assessments of previous outcomes exposure is there and needs improvement.

Albeit the evidence is inadequate to precisely link the risk of household air pollution to all of the diseases that are characterized to exposure to indoor air pollution specifically, it is clear that household air pollution will continue to be classified as a severe health risk impacting the world's poorest population (Smith & Pullarisetti, 2017).

World Health Organization has developed household air quality guidelines describing the great health risks of burning coal, wood, and kerosene indoors. It has also established capacity building training programs in order to address indoor (household) pollution as a risk to human health. While these efforts have filled an important gap for household energy interventions, more immediate research is needed in understanding current indoor energy use and cooking practices among women in Africa, including specific sub-populations, such as pregnant women, effecting both pregnant women as well as unborn children. Pregnant women are a vulnerable population whose health could be significantly jeopardized by pollution. Foetuses are also especially susceptible to neurotoxic pollutants, which can result from combustion of fossil fuels (Heusinkveld et al. 2016).

In addition, there have been other efforts in reducing air pollution from cookstoves, including China's National Improved Stove Program, Indian National Program on Improved Chulha, and the Gyapa Stoves Program in Ghana, as well as major advances in making clean fuel available in the past few years,, such as the Indian liquefied petroleum gas program and Equador's electric induction stove program (Landrigan et al. 2017). While these programs have been labeled as partially successful, they lead by good example and enrich the knowledge regarding long-term practices of indoor cookstoves in different countries around the world.

Summary

This chapter provided an extensive literature review on the effect of all forms of pollution on human health, and more specifically focused on the health effects of household air pollution. In addition, it explained the need to further investigate the health effects of indoor air pollution in pregnant women. Household air pollution exuding from cook stoves is detrimental to human health and more prominently shown in low-income and middle-income countries. However, more research is needed in understanding how cooking habits of those exposed can affect the exposure to pollution. As pregnant women are among the part of the population that is exposed to household air pollution the most, the need for high quality studies in LMIC is urgently needed.

This review also included brief summaries of the pollution effect on climate change, cost of pollution, ways to prevent pollution, and main factors that contribute in the neglect of pollution prevention implementation. Understanding all concepts of pollution and how they relate to one another is important when both trying to understand pollution implications on health as well as taking measures to mitigate pollution, whether by policy change and development or community/county program implementations.

Despite the extensive research and measures taken to understand, combat and mitigate the implications of pollution in human health and to there is still much left to explore and understand when it comes to extent of exposure to air pollution, more specifically household air pollution exposure among pregnant women and its global burden of disease, especially in Africa.

Chapter 3 describes the research methodology of the present study as well as tools and software programs used to obtain measurements and analyze data.

CHAPTER THREE
METHODS

The purpose of this study was to investigate exposure of pregnant women to household air pollution, by identifying type of biomass exposure, frequency of exposure per day by cooking practices, and using these data to determine disease burden attributable to the risk factor, in Adama of Ethiopia, Africa. This chapter provides a detailed description of methods used to examine the study objectives, including setting and participants, sampling methods, inclusion criteria, data collection procedures, data analysis and burden of disease from household air pollution description of method, research measures, human subject concerns, and threats to validity.

Preliminary results

While in Adama, the Lund University research team assessed air pollution through time-resolved measurements in two households before, during, and after cooking events. Results of analysis declared that the women cooking were exposed to average pollution $PM_{2.5}$ levels between 600 and 800 μg/m^3, with peak level high enough to overload the instrument. Indoor, the preliminary study found that the air pollution accumulated rather than diluted inside the house, with levels reaching to 5,000 μg/m^3.

Participants and study setting

This study was conducted in a peri-urban, low-income setting in the city of Adama, Ethiopia, and its surrounding area, with a population of approximately 600,000 inhabitants. Participants were recruited and followed up at antenatal care (ANC) clinics at the Adama regional hospital and two public health centers, where about 8,000 women register annually.

Sampling procedure

At inclusion, structured information on socio-demographic conditions, such as housing and cooking facilities, occupation, education, and poverty indications were collected. In addition, medical history (particularly gynecologic, obstetric and Tuberculosis-related details) was collected. Apart from study conduct, which also included physical and obstetric examinations, participants received care according to current Ethiopian antenatal care guidelines.

Inclusion criteria

The final sampling frame consisted of 2000 pregnant women living in Adama, Ethiopia. Participants were recruited during pregnancy at Ethiopian public health facilities, including two public health centres and the Adama regional hospital. Data collection began in November 2015 until a total of 2114 pregnant women were reached. Participants were of different levels of education, income, marital status, employment, and living condition.

Data collection

Validated questionnaires were used to assess indoor air pollution exposure, by assessing different variables, such as the type of cooking fuel used (charcoal, wood, gas, kerosene, cylinder, or electricity), the frequency of women cooking while pregnant (times per day or times per week), location of cooking (indoor, outdoor, in the same room as sleeping or separate room, etc), and the ventilation system – if any - in the living and/or cooking space. In addition, variables such as education level were assessed and categorized as 'illiterate,' meaning no formal education was attained by participants, 'less than 6 years of education,' meaning participants have attended one up to 6 grades of formal education, and '6 years or more of education,' meaning participants have attended more than 6 years of formal education. At the aerosol laboratory at Lund University emission factors from different fuels and cooking methods, as well as particle characteristics, are being assessed experimentally. The data on pregnancy outcomes have been extracted from public health facilities in Ethiopia.

Data analysis and burden of disease from household air pollution description of method

Air pollution in some homes of the study area has been assessed in a pilot study, which has concluded that the largest source of indoor air pollution is the cooking stove. The exposure to pollution from cook stoves was assessed by detailed measurements at a number of different representative settings based on the information collected from socio-demographic variables. Participants were stratified with regard to air pollution exposure (ordinal), type of fuel used (ordinal), location of cooking (ordinal) and presence of ventilation in location of cooking (ordinal) for comparison analysis. Frequencies and descriptive statistics were assessed using SPSS software and data were portrayed in APA style tables.

Upon determination of percentage of exposed population to indoor pollution caused by use of solid or other fuels for cooking, quantitative research analyses on disease burden attributable to risk factor exposure of pregnant women were assessed. WHO's AirQ+ software tool was used for health risk assessment of air pollution.

In order to quantify burden of disease (BoD) attributable to household air pollution, the population attributable fractions (PAF or AF_p) was used by AirQ+. AF_p represents the proportional devaluation in population mortality and population disease that would arise if the risk factor exposure (in this case exposure to household air pollution) were to decline to a different optimal exposure scenario (for example, no exposure to household air pollution). Health risks estimates that were used in the AF_p calculations were established by using the methods developed by the Institute for Health Metrics and Evaluation (IHME). Household air pollution attributable burden was acquired using the AF_p equation (shown below with equation A), where P_e represents the population percentage exposed to household air pollution by using polluting technologies and fuels for cooking practices. AF_p's were applied to each individual disease (ALRI, LC, COPD, Stroke and IHD), in a manner as shown in figure 4 (Ezzati et al. 2002, Lim et al. 2010, Balakrishnan et al. 2013, and Smith et al. 2014).

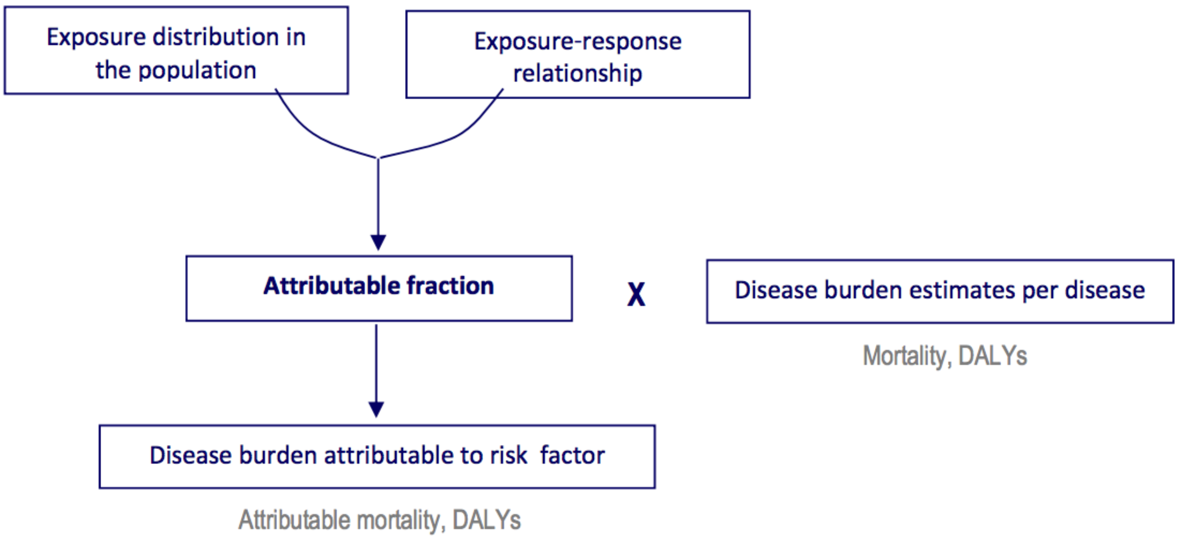

Figure 4. Method utilized for estimating burden of disease attributable to risk factor. DALYs: disease-adjusted life years (WHO, 2018).

(A) Population Attributable Factor (AF_p or PAF) mathematical formula:

$$AF_p = \frac{P_e(RR-1)}{1+P_e(RR-1)}$$

In order to decipher the proxy of the polluting fuel used for cooking into an individual-level exposure estimate, a systematic review of literature regarding epidemiological studies for women was done by the World Health Organization and was used and assumed in the burden of disease calculations by the AirQ+ software. The $PM_{2.5}$ exposure level value for women assumed for households relying mainly on polluting technologies and polluting fuels used for cooking was estimated to be 337 μg/m^3. (Balakrishnan et al. 2013, and Smith et al. 2014).

The relative risks values used with 95% confidence intervals for each disease analyzed can be seen in table 1. In order to estimate the relative risk for diseases caused by air pollution exposure (table 1), the Global Burden of Disease Study (Lim et al. 2012, Forouzanfar et al. 2015, Forouzanfar 2016, and Burnett et al. 2014) and WHO (WHO 2014, WHO 2016) developed an Integrated Exposure Response (IER), which was used to estimate and approximate the relative risk for diseases caused by exposure to air pollution from $PM_{2.5}$. The IER merges evidence from epidemiological studies for household air pollution, active smoking, second-hand smoking, and outdoor air pollution in order to estimate the risk of disease (e.g. IHD) at different concentrations of $PM_{2.5}$. To put into perspective, the system uses the same mathematical measure or relationship to estimate the risk of stroke from outdoor air pollution as that of household air pollution, or second-hand smoke.

Table 1. Relative risks (RR) for women, by cause

Disease	RR (95% CI)	Reference
Acute lower respiratory infection	2.3 (1.8 – 2.8)	Burnett et al. 2014, GBD 2016, GBD 2017.
Chronic obstructive pulmonary disease	2.3 (1.7 – 3.1)	Smith et al. 2014
Ischemic heart disease	1.5 (1.3 – 1.9)	Burnett et al. 2014, GBD 2016, GBD 2017.
Lung cancer	2.4 (2.0 – 2.8)	Burnett et al. 2014, GBD 2016, GBD 2016.
Stroke	1.3 (1.2 – 1.8)	Burnett et al. 2014, GBD 2016.

The percentage of the population exposed to $PM_{2.5}$ via household air pollution was attained from the study data collected in Adama, Ethiopia, for which the AirQ+ system provided increments of 1μg/m^3, and the counterfactual concentration for air pollution was selected between 2.4μg/m^3 and 5.9μg/m^3. The country population attributable fractions for stroke, LC, COPD, IHD, and ALRI were calculated using the mathematical formula shown above (equation A). The Integrated Exposure Response function was used to estimate the burden of disease (mortality and DALYs) due to household air pollution for five different causes: ALRI, COPD, LC, IHD, and stroke.

The AirQ+ model is executed using Markov chain Monte Carlo (MCMC) and similar to other Bayesian analysis, results are a set of full posterior distributions of point estimates of the proportions (of the fuel type usage, by year and by country). As a result, summaries of these distributions can be used to provide means or point estimates, as well as uncertainty (e.g. 95% Confidence Intervals) (WHO, 2018). The relative risks for women by cause (ALRI, COPD, IHD, LC and stroke) as portrayed in table 1, the age – standardized and crude mortality rates, and estimated DALYs of women of all ages and women of ages 15 – 49 by cause per 100,000 women in Ethiopia, as portrayed in tables 2 and 3, were used to estimate hypothetical effects of household air pollution impact in the cohort group.

Table 2. Age-standardized and crude mortality rates per 100 000 population of women in Ethiopia, Africa.

Disease	Age-standardized mortality rates	Crude mortality rates
Acute lower respiratory infection	75.4	57.8
Chronic obstructive pulmonary disease	19.7	8.7
Ischemic heart disease	98.9	42.2
Lung cancer	33.6	31.9
Stroke	75.6	33.9

- Data obtained from the World Health Organization Department of Information, Evidence and Research. Data originally collected on 2016; published on April 2018; accessed on April 2020, and WHO's International Agency for Research on Cancer Globocan, 2018.
- LC rates obtained from USstatscancer.gov.

Table 3. Estimated DALYs by cause per 100 000 population of women of all ages and of ages 15-49, in Ethiopia, Africa.

Disease	Disease-adjusted life years All ages	Disease-adjusted life years Ages 15 – 49
Acute lower respiratory infection	18,368	9,825
Chronic obstructive pulmonary disease	13,880	1,450
Ischemic heart disease	48,300	4,930
Lung cancer	12,435	141
Stroke	44,470	5,010

- Data obtained from the World Health Organization Department of Information, Evidence and Research. Data originally collected on 2016; published on April 2018; accessed on April 2020, WHO's International Agency for Research on Cancer Globocan, 2018 and Research Gate, 2018.

Attained analysis were expressed as burden of disease attributable to risk factor. Detailed research questions and analytical approaches of this assessment are shown in table 4 below.

Research measures

Table 4. Analytical Approach Used to Answer Research Questions

Research Questions	Analytical Approach
1. What percentage of Adama's pregnant women population use solid fuels for cooking purposes?	Frequency Analysis using SPSS
2. What is the mortality number of attributable cases using age-standardized versus crude mortality rates per 100 000 women in Ethiopia?	Burden of Disease (BoD) Assessment using AirQ+
3. What is the mortality number of attributable cases per 100 000 population at risk using age-standardized versus crude mortality rates per 100 000 women in Ethiopia?	Burden of Disease (BoD) Assessment using AirQ+

4. What is the number of DALYs of attributable cases using all-ages versus ages 15 – 49 rates per 100 000 women in Ethiopia?	Burden of Disease (BoD) Assessment using AirQ+
5. What is the number of DALYs of attributable cases per 100 000 women using all-ages versus ages 15 – 49 rates per 100 000 women in Ethiopia?	Burden of Disease (BoD) Assessment using AirQ+
6. Is there a correlation between fuel-type use and level of education, location of cooking, presence of electricity and/or presence of water at home, among the cohort group?	Crosstabulations using SPSS

Threats to validity

Exposure to household air pollution in this study only considers exposure to cooking fuel(s) use. Heating and lighting fuels have not been included, both of which could increase the overall exposure of study participants to household air pollution. In addition, the IER function assumes the toxicity of $PM_{2.5}$ from household air pollution and ambient air pollution to be approximately the same.

Human subjects concerns

No risks of human subject concerns of participating in this study were identified. Review Board approval was obtained from Lund University prior to data collection and conducting research.

CHAPTER FOUR
RESULTS

The main purpose of this study was to assess the health impact of household air pollution in pregnant women in Adama, Africa, by their exposure through cooking habits and fuel-type use for cooking purposes. More specifically the health impacts assessed included Acute Lower Respiratory Infections (ALRI), Chronic Obstructive Pulmonary Disease (COPD), Ischemic Heart Disease (IHD), Lung Cancer (LU), and Stroke. This chapter presents the results of the health impact assessment. The first part describes the characteristics of the sample and the second part of the chapter presents the main results of the health impact assessment.

Characteristics of the sample

The final sample comprised of 2044 participants, between ages 14 and 40, living in Adama of Ethiopia and associated territories, representing a population of 600,000 inhabitants. More specifically, the majority of the cohort was between ages 21 and 25 (39.4%), followed by the age group of 26 – 30 (32.8%), 18.9% of ages 15 – 20, 6.3% of ages 31 – 35, 1.9% of ages 36 – 40, and 0.1% younger than 15 years old. Additionally, 56% of the cohort had a level of education ranging from 6 – 12 grade and 10.9% had an education level higher than 12^{th} grade. The rest, 19.4% had an education level less than 6^{th} grade, and 13.2% were illiterate. The dominant occupation was Housewife, representing 63% of the cohort group.

Regarding cooking practices and fuel – type use, 59.4% of the participants reported using solid fuel (including Charcoal, with or without additional use of wood, gas, kerosene, electricity, and cylinder), and 40.6% reported using electricity for cooking. In addition, 72.1% reported cooking twice a day, 12.6% reported cooking 1 – 3 times per weeks, and 9.4% cooking once a day. Regarding the location of cooking, 31% reported cooking in the same room that is used for sleeping purposes, 37.1% reported cooking in a separate room in the house, and 7.2% reported cooking outdoors or not at home. 54.5% of the participants lived in a one-room home and 44.9% in a home with more than one room. 86.5% used window for ventilation while 10.7% had no ventilation available, and 0.1% had a stove with hood or chimney. 95.2% of the participants reported having electricity at home and 89.6% reported having running water at home.

Regarding health and pregnancy characteristics of the cohort, over 99% of the participants reported not having previously been diagnosed with hypertension, cardiac disease, Asthma/COPD, or diabetes mellitus; 10.2% reported having headaches. Over 98% reported not smoking and not having a smoker present in the house. Tables 5, 5a and 5b represent more details of the cohort population regarding the socio – demographic characteristics, cooking practices and fuel – type use, and health and pregnancy – related characteristics of the sample, respectively.

Burden of Disease (BoD) assessments attributable to risk factor, AirQ+

Disease burden mortality estimations of attributable cases for the study representative population using age – standardized mortality rate per 100,000 women in Ethiopia is 116 for ALRI, 30 for COPD, 80 for IHD, 54 for LC and 40 for stroke; whereas the mortality number of attributable cases per 100,000 population at risk using age – standardized mortality rate per 100,000 women in Ethiopia is 33 for ALRI, 9 for COPD, 23 for IHD, 15 for LC and 11 for stroke.

Burden of disease mortality estimations of attributable cases for the study representative population using crude mortality rate per 100,000 women in Ethiopia is 89 for ALRI, 13 for COPD, 34 for IHD, 51 for LC and 18 for stroke; whereas the mortality number of attributable cases per 100,000 population at risk using crude mortality rate per 100,000 women in Ethiopia is 25 for ALRI, 4 for COPD, 10 for IHD, 14 for LC and 5 for stroke.

Disease burden DALYs estimations of attributable cases for the study representative population using DALYs per 100,000 women of all ages in Ethiopia is 28,224 for ALRI, 21,328 for COPD, 38,950 for IHD, 19,913 for LC and 23,674 for stroke; whereas DALYs number of attributable cases per 100,000 population at risk using DALYs per 100,000 women of all ages in Ethiopia is 7,973 for ALRI, 6,025 for COPD, 11,003 for IHD, 5,625 for LC and 6,688 for stroke.

Burden of disease DALYs estimations of attributable cases for the study representative population using DALYs per 100,000 women of ages 15 – 49 in Ethiopia is 15,907 for ALRI, 2,228 for COPD, 3,976 for IHD, 225 for LC and 2,667 for stroke; whereas DALYs number of attributable cases per 100,000 population at risk using DALYs per 100,000 women of ages 15 – 49 in Ethiopia is 4,265 for ALRI, 629 for COPD, 1,123 for IHD, 64 for LC and 753 for stroke.

The numbers provided for BoD assessments attributable to risk factors for mortality and DALYs values represent the central levels estimated by AirQ+. In addition, minimum and maximum possible values for each situation can be viewed in table 6 for mortality values and in table 7 for DALYs values.

The difference in the estimated mortality number for attributable cases and number of attributable cases per 100,000 population at risk using age – standardized versus crude mortality rates per 100,000 women in Ethiopia are portrayed in figures 5 and 6. Also, the difference in estimated DALYs number for attributable cases and number of attributable cases per 100,000 population at risk using women of all ages versus using Ethiopian women of ages 15 – 49 DALYs rates per 100,000 women in Ethiopia are portrayed in figures 7 and 8.

Crosstabulations, SPSS

Thirty-nine per cent of the cohort population with any level of education, or lack thereof, reported to use solid fuel for cooking purposes. In addition, 40.6% reported to use electricity, and 20.4% reported use of both solid fuel and electricity for their cooking needs, as seen in table 8.

Study participants that self – identified as illiterate reported 52.9% use of solid fuels, 10.2% use of a combination of solid fuel and electricity, and 36.8% use of electricity for cooking purposes. Participants with a level of education less that 6th grade reported 38.0% use of solid fuels, 45% use of electricity, and 16.9% of a combination of electricity and solid fuel, and those with more than 6 grades of education reported 34.1% use of solid fuels, 24.3% use of a combination of solid fuels and electricity, and 41.4% use of electricity.

Participants that slept and cooked in the same room reported 38.7% use of solid fuels, 51.6% use of electricity and 9.7% use of combination of both, for cooking. Those who cooked at home but in a separate room from that used for sleeping reported 34.8 % use of solid fuels, 31.4% use of combination of electricity and solid fuel, and 33.7% use of electricity. Lastly, those who cooked outside or their homes or in an entirely different building from their homes reported 54.2% use of solid fuels, 26.7% use of electricity and 19.1% use of a combination of both.

Study participants that had running water at home reported 35.7% use of solid fuels, 38.3% use of electricity and 25.8% use of both for cooking. In contrast, those who did not have running water reported 45.0% use of solid fuels, 44.6% use of electricity and 10.3% use of both.

Lastly, those that had electricity at home reported 37.1% use of solid fuels, 42.0% use of electricity and 20.9% use of combination of both. Those that did not have electricity at home reported 56.8% use of solid fuels and 17.0% use of both electricity and solid fuels. In addition, those with no electricity reported 26.1% use of electricity for cooking.

Summary

This chapter presented the main outcomes of the study. Descriptive and frequency analyses as well as crosstabulation analysis revealed that of the cohort group comprised of women of Adama between the ages of 14 and 40, 59.4% of them use solid fuel such as charcoal for their cooking purposes (either alone, or in combination with electricity). Using this statistic, along with other data obtained from the study questionnaire regarding cooking practices and living conditions, BoD estimations attributable to risk factors (ALRI, COPD, IHD, LC and stroke) and crosstabulations (fuel-type use, education level, cooking location, and presence of running water and electricity at home) were used to undergo a Health Impact Assessment to understand the impact of household air pollution on health of pregnant women.

The next chapter offers a discussion of the study implications and limitations.

CHAPTER FIVE

DISCUSSION

This study assessed exposure to household air pollution exposure of pregnant women on Adama, specifically to solid fuel, and estimated the disease burden (BoD) attributable to risk factor. In addition, it investigated correlations between fuel – type use and other factors, such as level of education, location of cooking, and presence of electricity and running water at home.

Summary and analysis of key findings

The results of the study showed that 59.4% of the cohort group of pregnant women of Adama chose solid, such as charcoal, for cooking purposes, 72.1% of them cooking twice a day. In addition, 33.9% of them used the same room for sleeping and for cooking, and 37.1% of the participants cooked in another room of the house. This shows that the presence of burned solid fuel is present in the air that pregnant women breathe all day. The calculated aforementioned 59.4% accounts for solid fuel use for cooking purposes only. The level of exposure of pregnant women to household fuel may be higher as the study did not assess for solid fuel use for heating and lighting purposes.

An interesting statistic that emerged from this study is the fact that 95.2% of the cohort group reported having electricity at home, however 40.6% reported using electricity for cooking purposes. While use of electricity is healthier than that of solid fuel, and presence of electricity was not an issue for this cohort group, this finding could be a marker for the economic situation for the pregnant women of Adama. In addition, it could also be linked to study participants' knowledge of health effects and impacts of household air pollution in pregnant women. Further analysis of the relationship between fuel – type use and presence of electricity at home showed that 58.0% of participants used solid fuel either alone or in combination with electricity for cooking purposes, while 73.8% of those that did not have electricity at home used solid fuel (table 8). The percentages of the two groups are quite close in value considering the difference between having and not having electricity at home. A possible reason could be that charcoal is cheaper than electricity, however further analysis is needed to reach conclusion.

Considering education level of the cohort group, it was found that as education level increased from illiterate, to <6 grades, to >6 grades, the use of solid fuels decreased, 52.9%, 37.9%, and 34.2%, respectively (table 8). While correlation does not mean causation, it enhances the importance of further researching the relationship between education and fuel – type use for cooking.

The age – standardized and crude mortality rates and estimated DALYs by cause (ALRI, COPD, IHD, LC and stroke) per 100,000 women in Ethiopia are portrayed in tables 2 and 3, respectively. Using those core values and AirQ+ hypothetical effects of household air pollution impact have been estimated in the cohort group.

Burden of disease mortality estimations of attributable cases per 100,000 population at risk using age – standardized mortality rate per 100,000 women in Ethiopia and disease burden mortality estimations of attributable cases per 100,000 population at risk using crude mortality rate per 100,000 women in Ethiopia, as portrayed in figures 5 and 6, respectively, give a representation of lives that would be spared by decreasing or eliminating exposure to household air pollution.

Disease burden DALYs estimations of attributable cases per 100,000 population at risk using DALYs per 100,000 women of all ages in Ethiopia and burden of disease DALYs estimations of attributable cases per 100,000 population at risk using DALYs per 100,000 women of ages 15 – 49 in Ethiopia are portrayed in figures 7 and 8, respectively. While there is a difference between burden of disease DALYs estimations between results when using DALYs of women of all ages versus DALYs of women of ages 15 – 49, it is still clear by DALYs estimations that household air pollution affects women of ages that pertain to the young age of our cohort group.

Implications of the study

This study adds to the existing limited literature on effect of household air pollution on health of pregnant women. While research has shown the detrimental effects that particulate matter of air pollution has on human body, this study focused on the issue from an additional approach, targeting and analyzing pregnant women and their daily practices and choices of solid fuel use for cooking purposes. By approaching the research this way, the study was able to not only estimate the burden of disease due to risk factor, but it was also able to understand the practices of the cohort group that lead to that exposure. This knowledge is beneficial as it leads to possible steps that can be taken in order to deter the issue, apart from estimating its impact on health. Understanding that the level of education may impact decision making on fuel type use open the door to possibilities of further, more detailed studies, as well as implementing preventive care strategies, such as increasing the level of education, more particularly the knowledge of detrimental effects of pollution on health of mothers and children.

Researchers, specialists, policy makers, and non – governmental organizations (NGOs) may want to focus on the importance of public education and public awareness that solid fuel use has on the health of pregnant women. In addition, besides educating on health effects, strategies on fuel use, such as stepping away from the area while food is cooking, or cooking in a separate area from the room that is used for sleeping (which this study found that 33.9% of the cohort population cooked in the same area where they slept), may be simple and conceivable steps that can be taken by pregnant women even in LMIC.

The findings of this research can be used to develop public policies and programs, which should be a major focus of current efforts to improve public health. In addition, in terms of public implications, these results may aid the development of programs and policies that improve how daily – practices and habits of pregnant women effect exposure of pregnant women to pollution, in low, middle, and high – income countries.

Limitations of the study

This study is among few studies that assess household air pollution exposure due to solid fuel use in sub – Saharan Africa, specifically due to cooking practices. It also serves as the first study of this type to take place in the peri – urban city of Adama, which is one of the few areas in Ethiopia to have such a high percentage of population with electricity and running water available at home. As a result, this study cannot be claimed as representative of other cities of Ethiopia and the entire country, as the availability of electricity is different, depending of the region of Ethiopia.

Exposure to household air pollution in this study only considers exposure to cooking fuel(s) use. Heating and lighting fuels have not been included, both of which could increase the overall exposure of study participants to household air pollution. In addition, the IER function assumes the toxicity of $PM_{2.5}$ from household air pollution and ambient air pollution to be approximately the same.

The age – standardized and crude mortality rates and estimated DALYs for women of all ages and women of ages 15 – 49 for Lung Cancer (LC) were not available from WHO data of Ethiopia. As a result, they had to be adopted form other sources, representing global and US lung cancer mortality rates and DALYs, respectively, obtained from Research Gate and USstatscenter.gov. The results estimated for LC are not representative per 100,000 women of Ethiopia specifically but for women globally in mortality rates, and US women for DALYs.

Lastly, the study did not assess for the cohort groups awareness and knowledge of the health implications of solid fuel use and more specifically while pregnant, as well as their family economic impact on choice of fuel use. This knowledge would be useful when utilizing study results for health system and environmental policy building. Knowing the causes of cohort group's reasons for choosing solid fuel over electricity would more directly help construct country policies that directly impact the cause of the choice, be it lack of knowledge regarding health implications of solid fuel use on mother and child, or inability to afford electricity as the healthier choice of fuel use.

Recommendations for future research

Based on this study, we recommend that future researchers assess for use of coal not only for cooking purposes, but also for use of heating and lighting purposes in order to estimate the percentage of population using and being exposed to solid fuel. This will offer a more realistic figure of the percentage of population that is exposed to household air pollution caused by use of solid fuel use, such as charcoal.

While the results of this study showed that level of education shows a correlational impact on the choice Adama population makes when it comes to use of solid fuels, in future research studies it would be beneficial to directly assess the cohort group's awareness and understanding of health implications of household air pollution caused by solid fuels, as well as the ability to afford other fuels, such as electricity. This information and knowledge would lead to understanding of what impacts the decision-making when it comes to choosing fuel type utilization. In addition, assessing reasons why those who choose to use solid fuel use it, instead of fuels that are considered healthier for overall health, such as electricity, would lead to more conclusive statements regarding choice and decision making of cohort. This type of information would also help policy makers consider how public knowledge and economic status of the population impact decision making, and in turn, population health.

This study included a cohort of pregnant women, 59.4% of which used solid fuels for cooking purposes, 72.1% of them used it twice a day, leading to the knowledge that their unborn children were exposed to detrimental household air pollutants while still in the womb. Future studies should strongly consider follow – up research on the impact of household air pollution health impact on children who were exposed while still in fetal stages, as well as impact of household air pollution exposure on the health of children, of different ages and stages of development, who live in homes that use solid fuel to fulfill their daily needs of food preparation, heating and lighting.

As there is lack of air pollution monitoring all over continental Africa, as seen in figure 3, while mortality rates due to all forms of pollution are the highest in Africa (151 – 316 per 100,000) as seen in figure 1, we recommend urgently replicating this study in other regions of Africa, particularly in regions where there is a higher lack of availability of electricity at home, so that there is a better understanding of the level of exposure of pregnant women and unborn children to household solid fuel use. This knowledge on pollution exposure can lead to an urgency of action that needs to be taken by country leaders in order to educate the population, both on health implications of indoor solid fuel use and steps that can be taken to decrease exposure, or ideally eliminate it.

Last, there is specific lack of data regarding Lung Cancer (LC) mortality rates and DALYs for Ethiopia by WHO's Department of Information, Evidence and Research. The closest disease covered through these data is Mesothelioma, but not Lung Cancer. Considering the detrimental health effects that pollution has in human lungs, it is recommended that LC is included in WHO's Department of Information, Evidence and Research database for both men and women of Africa.

CHAPTER SIX

CONCLUSION

This study enriches the knowledge of health impact of household air pollution exposure of pregnant women, including source characteristics, which leads to principal knowledge for suitable policy making.

Household air pollution is a major risk factor for ill health and will endure as a major risk factor while billions of households use solid fuels all over the world. The question is no longer whether household air pollution is detrimental to health, but how significantly it is affecting populations, more specifically in Africa, as there is lack of data. In addition, it is important to approach this issue, whose impact is significant, operates in low – income countries, and demands engineering and behavioral interventions and innovations. Current research on household air pollution needs to focus on what works on a large(r) scale, for example, applying natural and alternate interventions (e.g. provide health impact of solid fuels education and awareness to exposed populations, or even offer switching to clean fuels, such as liquefied petroleum gas) while executing precise monitoring and evaluations and using exposure outcomes as endpoints. Combining potentially successful natural interventions and monitoring exposure – response through health research could help to find ways to create healthy households with less pollution and better health. This is, however, an ambitious goal as proving cost – effectiveness of these interventions may be inconceivable.

This research provides crucial knowledge that can already be used in the proposed approach. It shows that even availability of a cleaner fuel, such as electricity, is not effective in decreasing or eliminating the use of solid fuels for cooking purposes. Hence, other interventions, such as increased population awareness and others, may be the next step.

To conclude, on the issue of household air pollution, the ultimate goals would be to bring education and awareness to affected populations, bring clean fuels to even the poorest populations, and improve stoves (biomass), while at the same time attempt to change conventional and behavioral practices of solid fuel use and cooking habits.

CHAPTER SEVEN

POLICY IMPLICATIONS

Burden of disease estimations are a critical and crucial resource for informed policymaking. Human life is valuable, and everyone deserves to live a long and healthy life. In order to reach this objective, an exhaustive depiction is needed of what kills, and disables people, across time, age, sex, and across countries. Burden of disease attributable to risk factors, such as that calculated through the AirQ+ software, helps quantify the effects of long-term exposure to air pollution, including estimates of the reduction in life expectancy, which is a critical component in policy discussion and formulation. This study in particular has provided quantification of health and life loss in terms of quality-adjusted life years and mortality rates, more specifically from four diseases, including acute lower respiratory infections, ischemic heart disease, chronic obstructive pulmonary disease, stroke and lung cancer. Additionally, this study provided specific information regarding pregnant women and their exposure to household or indoor air pollution through cooking practices and fuel-type use while cooking.

In order to coordinate health systems and the populations they assist, policymakers need to first be able to understand the true nature of the challenges that their country's health faces, as well as how those health challenges are shifting over time. This means that more knowledge is required besides only knowing disease prevalence estimates, such as the number of people with hypertension or asthma in a population. Burden of disease estimations incorporate not only knowledge regarding disease prevalence or risk factor, but also the relative harm that the disease causes in terms of quality-adjusted life years and mortality rates. This type of information gives decision-makers the ability to compare the effects of different diseases, such as ischemic heart diseases versus chronic obstructive pulmonary disease and enables them to use such information at home. The final results of burden of disease estimations are portrayed in terms of number of deaths per 100 000 population or daily-adjusted life years per 1000 population, which is an incredibly useful way to depict the facts that policy and decision makers can visualize, regardless of their healthcare of medical science backgrounds.

The results of this study serve not only for health systems policy implications but also for environmental policy considerations and development.

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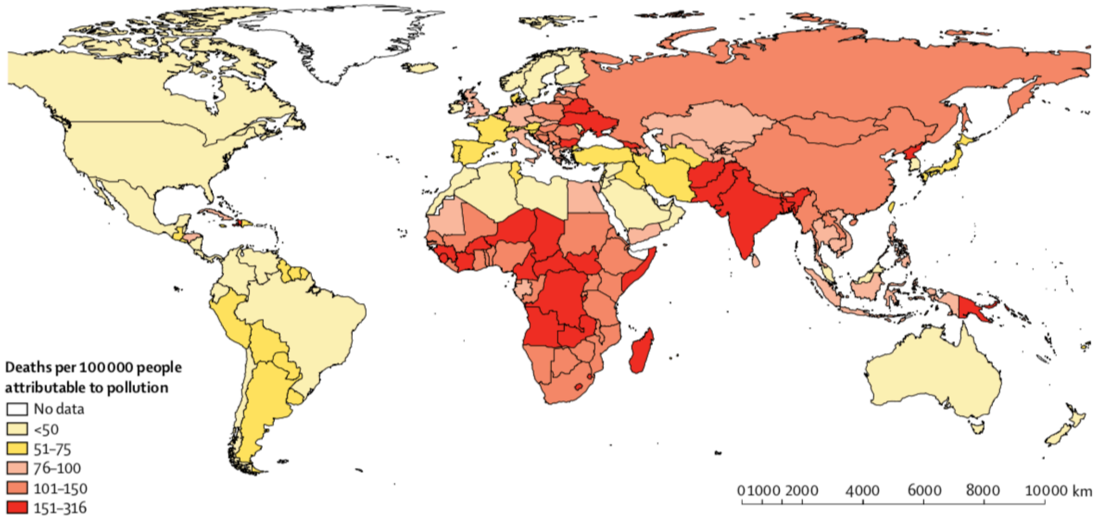
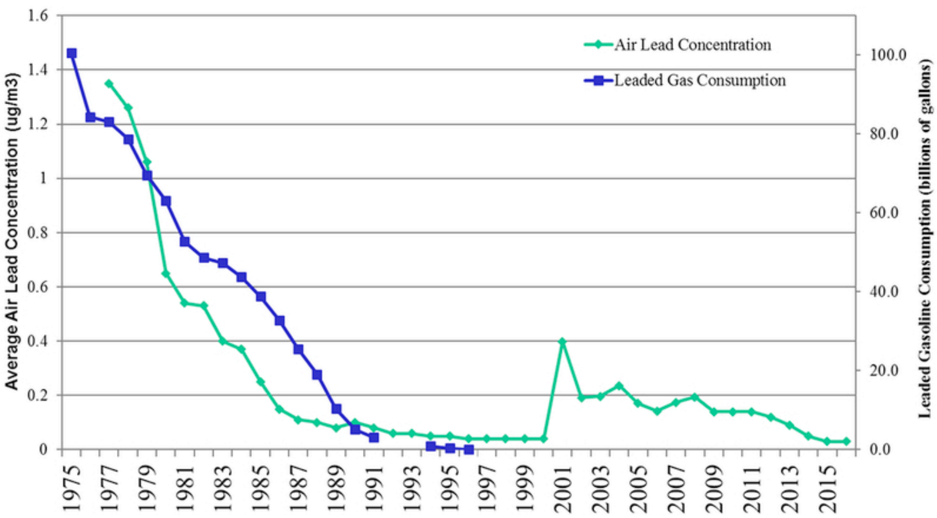
APPENDICES

APPENDIX A – FIGURES



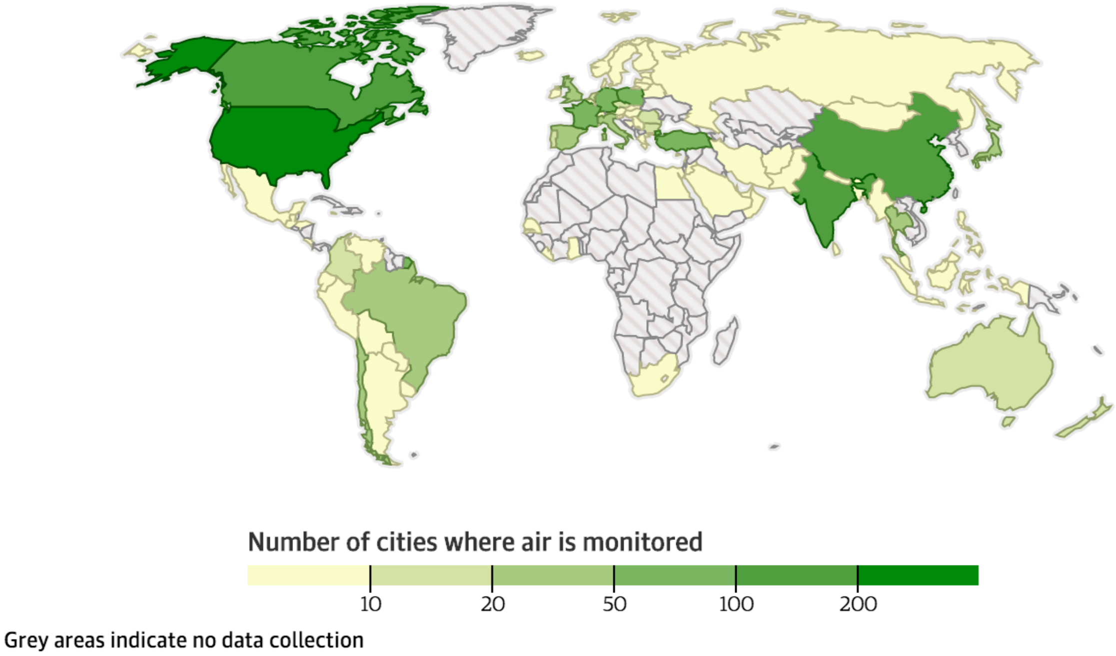
- Taken from the GBD study, 2016.

Figure 1: Mortality due to all forms of pollution, in number of deaths per 100 000 people, 2015.



- Taken from data that is publicly available from the Centers for Disease Control (Dignam et al. 2019).

Figure 2: Correlation between average air lead concentrations and consumption of leaded gasoline in USA, 1975-2016.



- Taken from the Guardian; Source: WHO

Figure 3: Lack of air pollution monitoring by area, 2015.

APPENDIX B – TABLES

Table 5. Socio-Demographic Characteristics of the Sample (n = 2114).

Characteristic	***N***	**Percentage**
Age		
Below 15	3	0.1
15 – 20	401	18.9
21 – 25	833	39.4
26 – 30	694	32.8
31 – 35	134	6.3
36 – 40	41	1.9
Marital status		
Single	66	3.1
Married	2022	95.6
Divorced	17	0.8
Widowed	3	0.1
N/A	6	0.3
Education		
Illiterate	279	13.2
< 6 grades	411	19.4
6 – 12 grade	1189	56.2
Higher education	231	10.9
N/A	4	0.2
Occupation		
Daily laborer	255	12.1
Housewife	1332	63.0
Student	42	2.0
Self-employed	166	7.9
Permanent job	278	13.1
Unemployed	32	1.5

Table 5 (a). Cooking Practices and Fuel-Type Use Characteristics of the Sample (n = 2114).

Characteristic	*N*	Percentage
Frequency of cooking while pregnant		
One time / day	199	9.4
2 times / day	1524	72.1
1 – 3 times / week	267	12.6
4 – 6 times / week	94	4.4
No	14	0.6
N/A	16	0.7
Location of cooking		
Outdoors	92	4.3
In the room used for sleeping	657	31.0
Outdoors & in room used for sleeping	62	2.9
In a separate room	786	37.1
In a separate building	175	8.3
Not cooking at home	14	0.7
N/A	328	15.5
Type of fuel used for cooking		
Charcoal/Wood	729	34.5
Charcoal/Wood/Electricity	420	19.9
Electricity	868	41.0
Charcoal/Wood/Gas/Kerosene	36	1.7
Gas/Kerosene	19	0.9
Electricity/Gas/Kerosene	7	0.3
Cylinder/Gas/Kerosene/Electricity/Charcoal	30	1.4
N/A	5	0.2
Number of rooms at home		
One	1153	54.5
More than one	949	44.9
N/A	12	0.6
Presence of ventilation in location of cooking		
Stove has hood/chimney	21	0.1
Window used for ventilation	1829	86.5
No ventilation	227	10.7
N/A	37	1.7
Electricity at home		
Yes	2013	95.2
No	84	4.0
N/A	17	0.8
Running water at home		
Yes	1894	89.6
No	214	10.1
N/A	6	0.3

Table 5 (b). Health and Pregnancy-Related Characteristics of the Sample (n = 2114).

Characteristic	*N*	Percentage
Previous diagnosis of Hypertension		
Yes	11	0.5
No	2096	99.1
N/A	6	0.3
Previous diagnosis of Cardiac Disease		
Yes	1	0.0
No	2107	99.7
N/A	6	0.3
Previous diagnosis of Asthma/COPD		
Yes	5	0.2
No	2103	99.5
N/A	6	0.3
Previous diagnosis of Diabetes Mellitus		
Yes	5	0.2
No	2102	99.4
N/A	6	0.3
Headaches		
Yes	216	10.2
No	1895	89.6
N/A	3	0.1
Previous (history of) high-risk pregnancy		
Pre – Eclampsia	13	0.6
Rh – Negative	6	0.3
Diabetes Mellitus	1	0.0
Abortion	1	0.0
Other	8	0.4
None	928	43.9
N/A	1157	54.7
Smoking		
Yes	2	0.1
Yes, but stopped during this pregnancy	2	0.1
Smoked previously	2	0.1
No	2075	98.2
N/A	33	1.6
Smoker present in the house		
Yes	25	1.2
No	2078	98.3
N/A	11	0.5

Table 6. Burden of Disease (BoD) estimations by AirQ+ as total mortality number of attributable cases and mortality number of attributable cases per 100 000 population at risk, using age-standardized and crude mortality rates per 100 000 women in Ethiopia, Africa.

	Burden of Disease	**ALRI**	**COPD**	**IHD**	**LC**	**Stroke**
Utilizing age-standardized mortality rates per 100 000 women in Ethiopia	Number of Attributable Cases	116 (86-137)	30 (20-39)	80 (53-121)	54 (44-61)	40 (28-86)
	Number of Attributable Cases per 100 000 Population at Risk	33 (24-39)	9 (6-11)	23 (15-34)	15 (12-17)	11 (8-24)
Utilizing crude mortality rate per 100 000 women in Ethiopia	Number of Attributable Cases	89 (66-105)	13 (9-17)	34 (22-52)	51 (42-58)	18 (13-38)
	Number of Attributable Cases per 100 000 Population at Risk	25 (19-30)	4 (3-5)	10 (6-15)	14 (12-16)	5 (4-11)

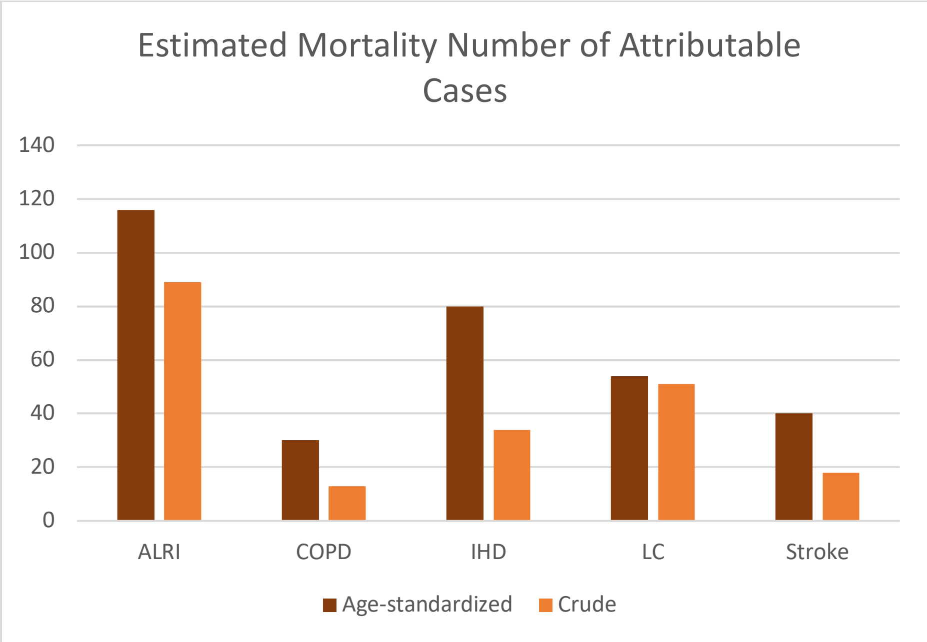


Figure 5. Estimated mortality number of attributable cases using age-standardized versus crude mortality rates per 100 000 women in Ethiopia, Africa.

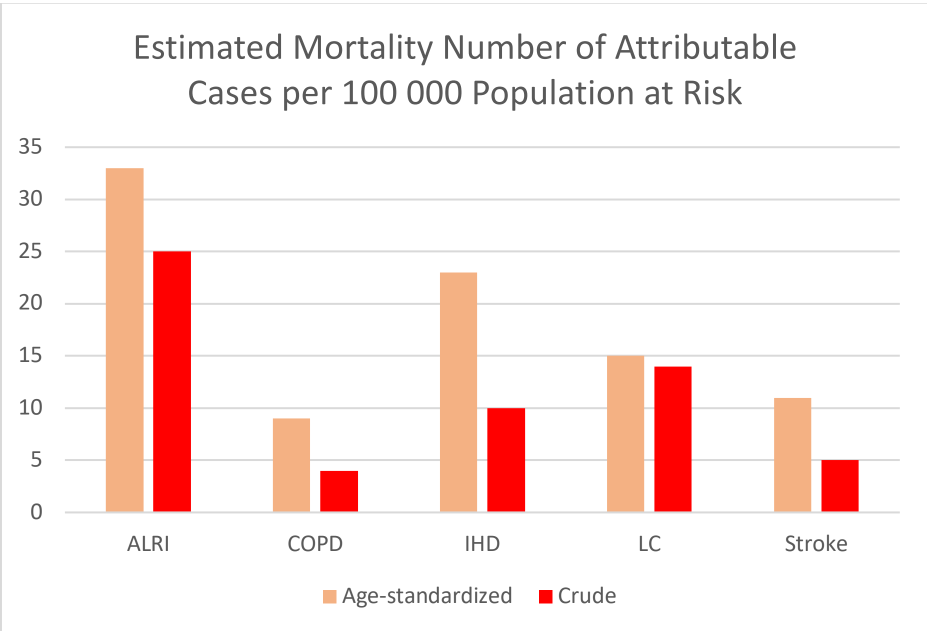


Figure 6. Estimated mortality number of attributable cases per 100 000 Population at risk, using age-standardized versus crude mortality rates per 100 000 women in Ethiopia, Africa.

Table 7. Burden of Disease (BoD) estimations by AirQ+ as total number of DALYs of attributable cases and number of DALYs of attributable cases per 100 000 population at risk, using DALYs of all ages and DALYs of ages 15-49 per 100 000 women of all ages in Ethiopia, Africa.

	Burden of Disease	**ALRI**	**COPD**	**IHD**	**LC**	**Stroke**
Utilizing disease-adjusted life years for all ages of women in Ethiopia	Number of Attributable DALYs	28,224 (20,850-33,489)	21,328 (14,362-27,190)	38,950 (25,713-59,302)	19,913 (16,334-22,672)	23,674 (16,615-50,478)
	Number of Attributable DALYs per 100 000 Population at Risk	7,973 (5,890-9,460)	6,025 (4,057-7,681)	11,003 (7,263-16,752)	5,625 (4,614-6,404)	6,688 (4,694-14,259)
Utilizing disease-adjusted life years for ages 15-49 for women in Ethiopia	Number of Attributable DALYs	15,097 (11,152-17,913)	2,228 (1,500-2,840)	3,976 (2,625-6,053)	225 (185-257)	2,667 (1,872-5,687)
	Number of Attributable DALYs per 100 000 Population at Risk	4,265 (3,150-5,060)	629 (424-802)	1,123 (741-1,710)	64 (52-73)	753 (529-1,606)

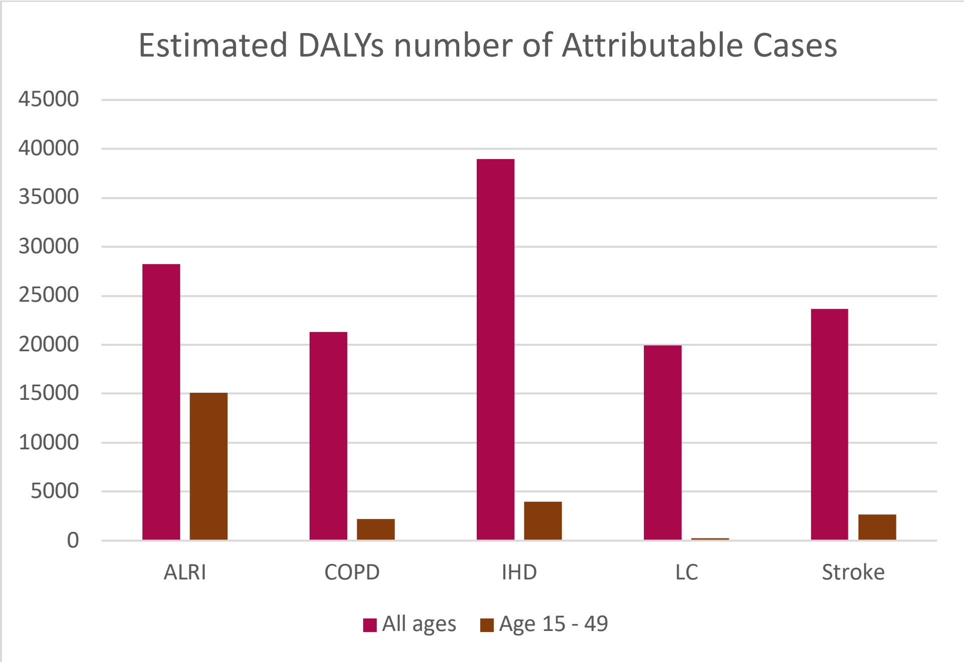


Figure 7. Estimated number of DALYs of attributable cases using all-ages versus ages 15-49 rates per 100 000 women in Ethiopia, Africa.

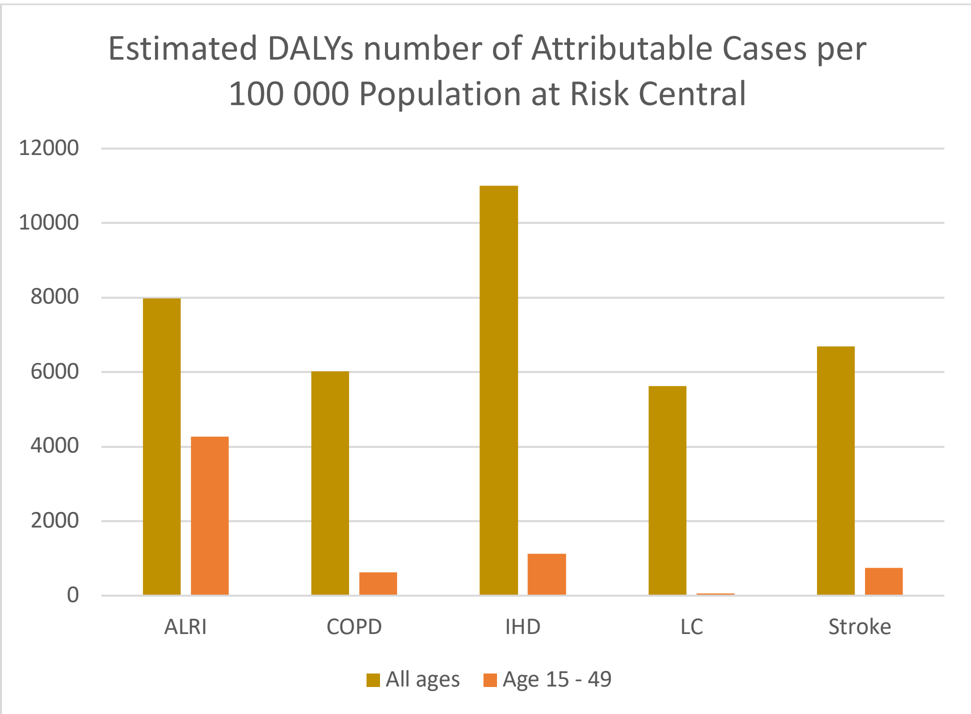


Figure 8. Estimated Number of DALYs of Attributable Cases per 100 000 women, using All-Ages versus Ages 15-49 DALYs per 100 000 women in Ethiopia, Africa.

Table 8. Crosstabulation between the type of fuel use among the cohort population and the cohort education level, location of cooking, and presence of running water and presence of electricity at home.

				Type of fuel use for cooking		
Location of cooking	**Running water at home**	**Electricity at home**		*Solid fuels*	*Electricity*	*Both electricity and solid fuels*
Indoor/in same room used for sleeping	*No*	*No*	**Education history**			
			Illiterate	2	1	0
			<6 grades	4	1	1
			6-12 grades	2	1	1
			Higher education	0	0	0
		Yes	**Education history**			
			Illiterate	29	18	0
			<6 grades	24	23	0
			6-12 grades	16	60	0
			Higher education	11	60	0
	Yes	*No*	**Education history**			
			Illiterate	1	1	1
			<6 grades	0	1	0
			6-12 grades	1	1	1
			Higher education	0	0	0
		Yes	**Education history**			
			Illiterate	41	17	6
			<6 grades	50	63	7
			6-12 grades	151	148	50
			Higher education	11	62	19
Indoor/not in the same room that is used for sleeping	*No*	*No*	**Education history**			
			Illiterate	4	0	1
			<6 grades	9	4	1
			6-12 grades	9	1	0
			Higher education	2	1	0
		Yes	**Education history**			
			Illiterate	15	23	7
			<6 grades	22	29	7
			6-12 grades	62	33	31
			Higher education	13	51	15
	Yes	*No*	**Education history**			
			Illiterate	1	0	2
			<6 grades	1	1	0
			6-12 grades	2	1	0

			Higher education	0	0	0
		Yes	**Education history**			
			Illiterate	28	38	7
			<6 grades	35	35	37
			6-12 grades	91	40	115
			Higher education	18	45	59
Outdoor/ separate building	*No*	*No*	**Education history**			
			Illiterate	1	2	2
			<6 grades	1	2	1
			6-12 grades	2	0	0
			Higher education	0	0	0
		Yes	**Education history**			
			Illiterate	22	1	0
			<6 grades	36	1	1
			6-12 grades	26	7	6
			Higher education	10	0	0
	Yes	*No*	**Education history**			
			Illiterate	6	1	2
			<6 grades	0	1	1
			6-12 grades	2	2	1
			Higher education	0	1	0
		Yes	**Education history**			
			Illiterate	1	3	1
			<6 grades	10	12	9
			6-12 grades	16	25	25
			Higher education	9	12	1
Total				797	829	418
				39.0%	40.6%	20.4%
						N = 2044

APPENDIX C – ACRONYMS

AF_p – Attributable Fraction of the Population

ANC – Antenatal Care

ALRI – Acute Lower Respiratory Infection

APA – American Psychological Association

ASDR – Age Standardized Death Rate

BoD – Burden of Disease

CDC – Center for Disease Control

CFCs – Chlorofluorocarbons

CI – Confidence Interval

COPD – Chronic Obstructive Pulmonary Disease

DALYs – Disease Adjusted Life Years

DDT – Dichlorodiphenyltrichloroethane

EU – European Union

GBD – Global Burden of Disease

GDP – Gross Domestic Product

IER – Integrated Exposure Response Function

IHD – Ischemic Heart Disease

IHME – Institute for Health Metrics and Evaluation

IQ – Intelligence Quotient

LC – Lung Cancer

LMIC – Low-Income and Middle-Income Countries

MCMC – Markov chain Monte Carlo

N/A – Not Applicable

$PM_{2.5}$ & PM_{10} – Particulate Matter 2.5 µm and Particulate Matter 10 µm

PAF – Population Attributable Fraction

PAHs – Polycyclic Aromatic Hydrocarbons

P_e – Percentage of Population Exposed to Household Air Pollution

PE – Preeclampsia

PCBs – Polychlorinated Biphenyls

RR – Relative Risk

SPSS – Statistical Package for Social Sciences

USEPA – United States Environmental Protection Agency

WHO – World Health Organization

YLDs – Years of Life Lived with Disability

YLLs – Years of Life Lost

APPENDIX D – ADAMA SURVEY

PART I

Socio-Demographic Characteristics of the Sample

1. What is your age?
    a. 15 or younger
    b. 15 – 19
    c. 20 – 24
    d. 25 – 29
    e. 30 – 34
    f. 35 – 39
    g. 40 or older

2. What is your weight? _________

3. What is your current marital status?
    a. Married
    b. Divorced
    c. Widowed
    d. Single
    e. Other
    f. N/A

4. What type of residence area do you live in?
    a. Urban

b. Rural
c. Other
d. N/A

5. How many family members live in your household? ________________

6. What is your current living situation?
    a. Permanent residence
    b. No permanent residence
    c. Other
    d. N/A

7. Will you stay at the same address during pregnancy?
    a. Yes
    b. No
    c. I don't know
    d. Other
    e. N/A

8. What is the number of rooms at your home?
    a. None
    b. One
    c. Two
    d. Three
    e. More than three
    f. Other

g. N/A

9. What is your educational history?

    a. Illiterate
    b. Less than 6 grades
    c. 6 – 12 grades
    d. More than 12 grades

10. What is your employment situation/occupation?

    a. Self – employed
    b. Employed
    c. Permanent job
    d. Daily laborer
    e. Housewife
    f. Student
    g. Unemployed
    h. Other
    i. N/A

11. What are your religious beliefs?

    a. None
    b. Muslim
    c. Orthodox Christian
    d. Protestant Christian
    e. Other
    f. N/A

PART II

Cooking Practices and Fuel-Type Use Characteristics of the Sample

12. Where does your cooking take place?

    a. In the room used for sleeping/living

    b. In a different room than that used for sleeping

    c. In a separate building

    d. Outside

    e. Indoors, at various locations

13. How often do you cook?

    a. Once a day

    b. Two times a day

    c. Twice a week

    d. One to three times a week

    e. Three times a week

    f. Four to six times a week

    g. Other

    h. N/A

14. What type of cooking fuel do you use for cooking?

    a. Electricity

    b. Charcoal/Wood

    c. Gas

    d. Kerosene

    e. Cylinder

15. Do you have ventilation at the location of cooking?

    a. Window(s) used for ventilation
    b. Stove has chimney/hood
    c. No ventilation
    d. Other
    e. N/A

16. Do you have electricity at home?

    a. Yes
    b. No
    c. Other
    d. N/A

17. Do you have running water at home?

    a. Yes
    b. No
    c. Other
    d. N/A

PART III

Health and Pregnancy-Related Characteristics of the Sample

18. Is the actual pregnancy your first pregnancy?
    a. Yes
    b. No
    c. Other
    d. N/A

19. How many previous pregnancies have you had?
    a. None
    b. One
    c. Two
    d. Three
    e. Four
    f. More than four
    g. Other
    h. N/A

20. How many previous deliveries have you had?
    a. None
    b. One
    c. Two
    d. Three
    e. Four
    f. More than four

g. Other

h. N/A

21. How many children do you have?

a. None

b. One

c. Two

d. Three

e. Four

f. More than four

g. Other

h. N/A

22. What was your previous pregnancy outcome? ______________

23. Have you ever been diagnosed with Diabetes Mellitus before this pregnancy?

a. Yes

b. No

c. Other

d. N/A

24. If yes, when? _________________

25. Have you ever been diagnosed with Cardiac Disease(s) before this pregnancy?

a. Yes

b. No

c. Other

d. N/A

26. If yes, when? _________________

27. Have you ever been diagnosed with Hypertension before this pregnancy?

a. Yes

b. No

c. Other

d. N/A

28. If yes, when? _________________

29. Have you ever been diagnosed with Asthma or COPD before this pregnancy?

a. Yes

b. No

c. Other

d. N/A

30. If yes, when? _________________

31. Have you ever been diagnosed with Sexually Transmitted Diseases before this pregnancy?

a. Yes

b. No

c. Other

d. N/A

32. If yes, when? ________________

33. Do you have persistent cough?

    a. Yes

    b. No

    c. Other

    d. N/A

34. Have you had a productive cough in the past four weeks?

    a. Yes

    b. No

    c. Other

    d. N/A

35. Have you had blood-stained sputa in the past four weeks?

    a. Yes

    b. No

    c. Other

    d. N/A

36. Have you experienced any chest pain in the past four weeks?

    a. Yes

    b. No

    c. Other

    d. N/A

37. Have you experienced any blurred vision during current pregnancy?

a. Yes

b. No

c. Other

d. N/A

38. Have you experienced any seizures during current pregnancy?

a. Yes

b. No

c. Other

d. N/A

39. Does any household member have persistent cough?

a. Yes

b. No

c. Other

d. N/A

40. Were you using family planning before the current pregnancy?

a. Yes

b. No

c. Other

d. N/A

41. If yes, what method? _______________

42. Was your current pregnancy planned?

a. Yes

b. No

c. Other

d. N/A

43. Are you currently taking any medications regularly?

a. Yes

b. No

c. Other

d. N/A

44. If yes, please specify ________________________

45. Are you currently using alcohol?

a. Yes

b. No

c. Other

d. N/A

46. If yes, please specify ________________________

47. Do you chew khat during pregnancy?

a. Yes

b. No

c. Other

d. N/A

48. Are you currently smoking?

a. Yes

b. No

c. Other

d. N/A

49. If yes, please specify ___________________________

50. Is anyone in your household currently smoking?

a. Yes

b. No

c. Other

d. N/A

51. Do you currently have a headache?

a. Yes

b. No

c. Other

d. N/A

52. Have you had headaches in the past four weeks?

a. Yes

b. No

c. Other

d. N/A

POPULAR SCIENCE SUMMARY

One of the major environmental threats to human health is air pollution. It contributes to premature deaths of millions of people worldwide. Air quality problems are growing in poorer countries. Household air pollution that comes from cooking indoors by using solid fuels is damaging to the human health. More than half of the world's population relies on polluting fuel for cooking. While both outdoor and indoor air pollution can be bad for everyone's health, a part of population especially at risk includes pregnant women.
In order to understand the health effect of using solid fuel (such as charcoal) in pregnant women, 2114 pregnant women were surveyed regarding their cooking habits and fuel-type use for cooking purposes in Adama of Ethiopia. Then a software program was used to estimate health impact of household air pollution through looking at the pollution effect on different diseases, such as lung infections and disease, heart disease, lung cancer, and stroke.

We found that fifty-nine per cent of the cohort group of Adama, Ethiopia, use solid fuel (such as coal) for cooking purposes. As a result, we calculated the number of women that would die per 100 000, and the healthy life years that would be lost due to the use of solid fuel for cooking purposes. Also, while most of Adama population (95.2%) have electricity at home, less than half (42.8%) use if for cooking, the rest using solid fuel or a combination of electricity and solid fuel. Other factors, such as education level, location of cooking, and presence of running water at home have shown to impact fuel-type use in the cohort population.

The results of this study help us understand that household air pollution due to solid fuel use (such as charcoal) among pregnant women in Adama, Africa, leads to number of deaths and healthy years lost that could otherwise be avoided by decreasing or getting rid of solid fuel use for cooking purposes.