Distribution Agreement

Cooking-Related Determinants of Respiratory Irritation Symptoms: A Cross-Sectional Study in Rwanda

By

Tamara Lambert
Master of Public Health

Global Environmental Health

____
Thomas Clasen, PhD, JD, MSc
Committee Chair

____
Miles Kirby, PhD
Committee Member

____
Paige Tolbert, PhD
Committee Member

Cooking-Related Determinants of Respiratory Irritation Symptoms: A Cross-Sectional Study in Rwanda

By

Tamara Lambert

B.S.
Cornell University
2016

Thesis Committee Chair: Thomas Clasen, PhD, JD, MSc

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Environmental Health
2018

Abstract

Cooking-Related Determinants of Respiratory Irritation Symptoms: A Cross-Sectional Study in Rwanda

By Tamara Lambert

Household air pollution (HAP) exposure produced by the combustion of solid fuels (e.g. wood, charcoal, plant waste, animal feces, etc.) contributes to the deaths of 5.5 million people each year, including 500,000 children under 5 year of age. HAP is linked to the development of non-communicable respiratory illnesses that lead to premature deaths among those exposed such as chronic obstructive pulmonary disease (COPD) and lung cancer. This is particularly concerning for children under 5, because about half of the pneumonia deaths among young children are linked to HAP exposure. There is currently a large body of research that has confirmed the link between $PM_{2.5}$ produced from burning solid fuels and the increase in the odds of developing chronic conditions such as lung adenocarcinomas 1.55 (95%CI: 1.05–2.29). However, research that explores the interconnectedness of the type of stove used to cook, the type of fuel to cook, and the location of where meals are prepared in relation to respiratory health outcomes is more limited. Moreover, there are a limited amount of studies that evaluate the relationship of these factors to the prevalence of respiratory irritation symptoms (RIS) that are potentially indicative of chronic disease development. Through this study, our main aim was to establish if the above cooking determinants significantly predicted the survey respondent's and children under-five's odds of reported RIS. Our analysis indicates that the cooking determinants were not as influential to respondents and children experiencing acute and chronic RIS as other factors such as age, sex, lighting used in the home, and smoking status of the respondent. This study faces several limitations that hinders the validity of the results, including low sample size and because it was cross-sectional, lack of follow-up with survey respondents. Although we did not find that cooking behaviors were associated with increased health risk in our survey population, these behaviors have been shown to increase risk in other settings, and this study has identified modifiable risk factors which can be targeted in addition to transitioning to cleaner cooking options.

Cooking-Related Determinants of Respiratory Irritation Symptoms: A Cross-Sectional Study in Rwanda

By

Tamara Lambert

B.S.
Cornell University
2016

Thesis Committee Chair: Thomas Clasen, PhD, JD, MSc

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Environmental Health
2018

Acknowledgements

First and foremost I would like to thank Dr. Thomas Clasen and Dr. Miles Kirby for affording me the opportunity to work on this project with them. Their continual support, guidance, patience, and encouragement has made this experience positive and worthwhile. I would like to thank Dr. Paige Tolbert for her guidance in the initial stages of this journey, and her constructive feedback during the writing process. I would also like to thank Ariadne Switchenberg for her support, guidance and encouragement from the beginning to the end of my time at Rollins. I would not have been able to make it to this point without their help.

Acronym Dictionary

ALRI = Acute Lower Respiratory Infections
COPD = Chronic Obstructive Pulmonary Disease
CI = Confidence Interval
HAP = Household Air Pollution
OR = Odds Ratio
$PM_{2.5}$ = Particulate matter (PM) with a diameter <2.5 micrometers
PR = Prevalence Ratio
RIS = Respiratory Irritation Symptoms
RR = Relative Risk
SES = Socioeconomic status
Ref= Referent Category

Table of Contents

1. Background

1.1. Introduction

Each year, exposure to household air pollution (HAP) due to the use of solid fuels (wood, animal dung, crop wastes, charcoal, and coal) for cooking, heating, and other household purposes contributes to the premature deaths of 5.5 million people worldwide [1]. The incomplete combustion of these solid fuels often leads to the production of toxic byproducts such as carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter (PM), which have detrimental environmental and human health effects [2]. Solid fuels usage contributes to the presence of chronic respiratory disease symptoms, eye irritation symptoms, and other illnesses [3]. Levels of $PM_{2.5}$ (particulate matter that are ≤ 2.5 μm) in houses using solid fuels are about 10 to 50 times above the WHO annual average Air Quality Guideline level of 10 $\mu g/m^3$ [4, 5].

1.2. Contribution of Solid Fuel Combustion to HAP

In addition to solid fuel use, stove type (inefficient stoves such as simple cookstoves, open flames, and fire pits) and lack of proper ventilation contribute to the high levels of HAP. Many of the byproducts produced by combustion of solid fuels are toxic to human health, however the most notable ones are $PM_{2.5}$, carbon monoxide, nitrous oxides, sulphur oxides (principally from coal), formaldehyde, and polycyclic organic matter containing carcinogens such as benzo[a]pyrene [6]. $PM_{2.5}$ is especially of great concern, having the ability to lodge deep into the lung tissue due to its small size [6], and contributing to reduced immune function and blood oxygen-carrying capacity [7, 8]. Carbon monoxide, a colorless, tasteless, and odorless gas is linked to headache dizziness, flu-like symptoms, and death [9, 10]. In countries such as India where 90% of impoverished households use solid fuels to cook, primary household cooks had an average CO reading of 7.77ppm. Children had an average reading of 6.48ppm, indicative of individuals who smoke 7 cigarettes per day [11]. Exposure to nitrous oxides and sulfur dioxide primarily results in respiratory irritation, and exacerbation of respiratory illness [12-14]. Formaldehyde is also linked to respiratory irritation, and like exposure to some forms of polycyclic organic matter (benzo[a]pyrene) may lead to the development of certain cancers [15-17].

1.3. Factors Associated with Elevated HAP in Rwanda

HAP is a serious concern for families living in developing countries, especially those that are low income, located in rural and urban areas [18]. Rwanda is one such country [19], where close to 100% of households in rural areas use solid fuels for cooking [20]. High income-countries have shifted away from the use of biomass fuels to the use of cleaner energy such as electricity and liquefied petroleum gas. However, for families in low-income countries, combustion biomass fuels remain the primary method for cooking and heating households due to high cost and lack of access[6].

The contrast in biomass fuel usage among regions of the world containing wealthier nations and regions of the world containing nations with a lower socioeconomic status (SES) is stark. In European and Central Asian Countries, biomass usage is <20% compared to Sub-Saharan Africa and South Asia, where biomass usage is >80% [21]. Although globally solid fuel usage has experienced a massive decline (50% in 1900 to 13% in 2000) [6], solid fuel usage among the world's most vulnerable populations has remained steady, and is expected to increase [21]. One reason for this is due to the stagnant, and even negative economic growth in some low-income countries.

Poverty is the primary factor that determines the usage of biomass fuels since cleaner fuels are usually more expensive and less readily available due to distribution challenges and poor infrastructure. Poverty contributes to the cycle of using biomass fuels for energy purposes, leading to a higher risk of health ailments, decreasing the likelihood of attaining a higher SES, contributing to the continued use of biomass fuels [21]. The type of fuel used to light the homes influences the presence of HAP because they are typically biomass fuels. For example, Muyanja et al. concluded that the use of kerosene lighting contributes to the increase of $PM_{2.5}$ in Uganda. The majority of homes using solar lighting met WHO Air Quality Standards (75%), compared to those using kerosene lighting (27.6%) [22]. Additionally, there is evidence that lack of access to fuel efficient cookstoves contribute to elevated levels of $PM_{2.5}$ [23, 24]. According to Rosa et al., the use of EcoZoom Dura improved wood burning stoves contributed to the 48% reduction of $PM_{2.5}$ in cooking areas over a 24 hour timeframe compared to the use of traditional stoves [25].

1.4. Risk Factors for HAP Exposure and Related Illness

Women and children are known to be at the highest risk for HAP exposure and respiratory illnesses due to the norm of women being the homemakers and preparing meals, and children <5 spending the majority of their time at home [4]. Women in developing countries may spend anywhere between 3-7 hours per day cooking, thereby inhaling toxins produced by solid fuel combustion during this time [26]. Children are often carried on their mother's back while she goes about her daily activities, including cooking or are kept close to inefficient stoves for warmth. As a result, children inhale the toxins produced by the stove, which are especially detrimental to developing lungs. Therefore, children under five years of age account for 56% of deaths related to HAP exposure [26]. They are also at high risk of developing acute lower respiratory infections (ALRI) [4], a leading cause of death for this age group [27]. Gender is another factor to be considered when examining HAP related deaths among children. In India, girls were more likely to die and contract pneumonia due to HAP exposure compared to boys [28]. The primary cause of death attributable to HAP for adults is chronic respiratory disease (e.g. chronic obstructive pulmonary disease (COPD)), which may be measured by proxy using symptoms such as coughing, wheezing, and congestion [4]. Women tend to have a higher odds of developing COPD when exposed to HAP: odds ratio (OR) = 2.80 (95%CI: 1.85-4.00) [29], while men exposed to HAP still have a significant odds of developing COPD (OR 1.90, 95%CI: 1.15-3.13) [30].

1.5. Other Related Potential Health Effects

HAP contributes to other major illnesses such as lung cancer, heart disease, low birthweight, tuberculosis, and cataracts [8]. HAP contributes to 46 disability adjusted life years per 1000 people per year (DALYs/1000 cap/year) [31]. HAP ranks number 5 out of 84 in Global Burden of Disease 2016 risk factors [32], number 2 among women [4], and 8th in preventable risk factors associated with loss in DALYs [18]. HAP exposure also poses a quality of life concern, because studies have indicated potential links between HAP and minor health ailments such as headache [33], cough, wheezing [34], and eye irritation due to the pollutants contained in smoke produced from solid fuel combustion [35]. According to a study conducted by Díaz el at., use of the plancha, an improved stove that reduced the cook’s exposure to solid fuel exhaust compared to the open fire significantly reduced the odds of the cook developing eye irritation and headache

(OR 0.18, 95%CI 0.11-0.29 and OR 0.63, 95%CI 0.42-0.94, respectively) [18]. Rural Mexican woman who used the improved Patsari stove to cook had a significantly lower risk of experiencing cough and wheezing symptoms (relative risk (RR) 0.77; 95%CI 0.62–0.95; RR 0.29; 95%CI 0.11–0.77 for wheezing) compared to those who cooked over an open fire [34].

Minor health ailments are a concern, because they may be predictors of future chronic respiratory ailments down the line and also symptoms of chronic respiratory disease, and therefore is a critical area of research. For example, chronic coughing and phlegm production may be indicative of developing lung cancer [36]. Respiratory distress characterized by symptoms such as chronic cough and wheezing also have the potential to reduce the quality of life of the individual sufferer [37]. Daily routine activities become more arduous to perform due to HAP irritants increasing the mucous production of those exposed, promoting respiratory irritation symptoms (RIS) and ultimately negatively impacting the sufferer’s ability to breathe [37]. Chronic RIS such as wheeze and phlegm is an indicator of lung morbidity and can lead to increased hospitalizations, reducing the time the sufferer has to work and care for household duties [38]. Severe RIS may also prevent those exposed to HAP from maintaining consistent employment due to illness, decreasing household income, thereby increasing dependence on solid fuels because of their affordability compared to cleaner fuels such as natural gas [39].

1.6. Study Aims and Hypotheses

Statistical analysis of cross-sectional data collected from a survey of households in Rwanda will be conducted to answer the following primary research question:

Is stove type, cooking location, or fuel type predictive of reported RIS and non-RIS among primary cooks and children <5 in Rwanda?

We examined the following RIS in the primary household cook as outcomes: cough, wheeze, phlegm, and chest pressure. The following non-RIS was also analyzed for the primary cooks: headache, dizziness, and chest pressure. For children, we examined the following RIS: constant cough, congestion, and wheezing.

We explored cooking location in addition to stove type and fuel type, because the association between cooking fuels and higher prevalence of RIS may be confounded by fuel usage indoors compared to outdoor locations, where there is increased ventilation and less exposure to cooking smoke. We explored whether RIS are more prevalent during cooking or non-cooking periods to characterize the chronic nature of these symptoms, and if cook and child symptoms are associated with each other.

We hypothesized that those who cook with plant fuel (grass, straw, agricultural crops, and wood) and inefficient stoves indoors will have higher odds of RIS than those cooking with charcoal because charcoal is known to produce less pollution compared to the other fuel types mentioned [40]. According to Ellegard et al., wood burning stoves produced a greater than two fold increase of respirable particles (1,260 $\mu g/m^3$) compared to charcoal burning stoves (540 $\mu g/m^3$) [41]. In addition, crop residues are known to produce a higher amount of endotoxin [42] (toxins encased in bacterial cells that can induce illness when released during crop burning [43]) and smoke that contains more $PM_{2.5}$ compared to other solid fuel types [40]. We also hypothesized that RIS will be more prevalent during and immediately after cooking periods compared to non-cooking periods because we expected the level of survey respondent's exposure to solid fuel pollutants to be higher during this time and be the main driver of adverse symptoms.

The specific aims of this study are listed below:

1. Determine the prevalence of each fuel type and stove type used for cooking, specified in the Baseline Stove and Water Practices Survey.
2. Determine the primary and secondary cooking locations used, and the associations between cooking location (indoor vs. outdoor) on fuel/stove type.
3. Determine the prevalence of cooks and children <5 experiencing RIS and the types of symptoms presented by age group.
4. Examine the prevalence of RIS during cooking periods and non-cooking periods in the primary household cook.
5. Determine the crude and adjusted odds ratios for the association between fuel type, stove type and cooking location on primary cooks' reported acute and chronic respiratory and non-respiratory symptoms.
6. Determine crude and adjusted odds ratios for the association between fuel type, stove type and cooking location on care-taker reported child acute respiratory symptoms, and compare to crude and adjusted odds ratios of cook symptoms to examine if there is a correlation.

7. Determine the crude and adjusted odds ratio for the association between fuel type, stove type and cooking location, and the cook's eye irritation, dizziness, and headache as a secondary analysis.

2. Study Design and Methodology

2.1. Study Population

In 2013, the GAP1 National Cross-Sectional Survey was designed and administered by Dr. Miles Kirby and his field team in Rwanda. The primary purpose of the national cross-sectional survey was to determine the fuel use, cooking practices, and drinking water practices at the district, province, and national level in Rwanda [44]. The funder for this study was Del Agua Health, a social enterprise that in 2013 was planning for a large-scale distribution of fuel-efficient cookstoves and drinking water filters in cooperation with the Rwanda Ministry of Health [45, 46]. DelAgua, requested for the sampling to be conducted nationally in all 30 districts for programmatic purposes to obtain behavioral and water quality estimates relevant for carbon financing of the intervention program [44]. The survey was administered to 476 households in the poorest tertile (*ubudehe* 1 and 2 households) from 120 villages in all 30 districts of Rwanda based on government designation [44]. The survey respondent was the primary cook (the female head of household), and respiratory symptoms were collected for each child <5 residing in the household (n=~ 200 children) [44].

2.2. Variables

The survey included questions regarding household demographics, socioeconomic status, cooking, lighting, drinking water practices, and self-reported respondent and child health [44].

The predictor variables and outcome variables of interest to be analyzed for the aims below are as follows:

AIM 2:

Predictor Variables: fuel type and stove type

Outcome Variables: Cooking location

AIM 4:

Predictor variables: age of household cook

Outcome Variables: RIS during and non-cooking periods

AIM 5-6:

Predictor Variables: fuel type, stove type and cooking location

Outcome Variables: Child and adult RIS

AIM 7:

Predictor Variables: fuel type, stove type and cooking location

Outcome Variables: Adult non-RIS

2.3. Sample Size Calculation

The sample size for this study was based on deriving a national estimate of households with contaminated drinking water, and was determined by the following calculation below:

$$n = \frac{1.96^2 pq}{d^2}$$

where p is the proportion of interest with $q = 1\text{-}p$ and d=margin of error. The proportion of interest is the percentage of households without a water filter that were free of thermotolerant coliforms, which was determined to be 21% according to previous household water quality sampling by the London School of Hygiene and Tropical Medicine (LSHTM) [44]. The margin of error was 5%. According to the equation above, n = 255 household water samples were needed for an estimate of households with contaminated drinking water. Investigators increased the sample size to 476 households to increase the precision, representation, and power of the study [44].

2.4. Sampling Strategy and Data Collection Methods

Two villages were randomly selected from each district using a random number generator, with the requirement that the villages be from non-adjacent cells (administrative cluster of 2-16 villages) to increase geographic representation of sampling. One additional village within each of these cells was randomly selected for the purposes of increasing the number of water sampling sites and easing transport-related logistical requirements, increasing the number of villages selected to four villages per district [44]. Households were included in the survey if they were considered to be in *ubudehe* groups 1 and 2, in which are the two lowest SES categories according to the Government of Rwanda's designation. Within each village, specific households from a government-provided list of *ubudehe* 1&2 households were selected using a mobile-phone based random number generator. If the head of household was not present or was under the age of 18, survey collectors selected another household in the village using the random number generator until 3-5 households were surveyed in each village equating to 12-20 households sampled per district [44].

2.5. Ethics

Survey respondents were required to be 18 years or older to participate, and were de-identified in the study. Survey participation was voluntary, and those who chose to participate were required to give consent by signing a consent form to complete the interview. Personal identifying information was only viewed by the LSHTM research staff, and was not included in any of the results published as a result of the study [44]. The study was authorized by the LSHTM ethics committee (Reference 6457 and amendment number A461), by the Rwanda National Ethics Committee (460/RNEC/2013), and by the Rwanda National Institute of Statistics (Visa approval No. 0274/2013/10/NISR).

2.6. Data Analysis Methods

For this study, we undertook the analysis of the survey data. The analysis of the data was primarily quantitative, using descriptive statistics and reporting odds ratios. We developed an overall analysis plan with details for each specific aim of the study. Statistical analysis was done using SAS Institute Inc. version 9.4 (Cary, NC).

A descriptive analysis was done using frequency and univariate procedures. As part of the descriptive analysis, a cross-tabulation was used to determine the relationship between the survey respondent and the partner of the survey respondent's level of schooling. If survey respondents did not have a partner, they were not included in this part of the analysis. Though not included in the univariate and multivariate procedures since most of the respondents did not report an educational level for partners, this information can be informative to determine if the partner's level of education could potentially impact SES, and may be a factor necessary to include in future analysis. Single and multiple logistic regression was used to determine odds ratios and relationships between the health outcomes and predictor variables. Predictor variables were analyzed with the following potential confounding variables to determine the true significance of the crude odds ratios; age, sex, the type of lighting used in the home, the respondent's smoking status, SES, and if respondent's smoked inside of the house. Separate models were constructed for each respiratory outcome, with covariates including cooking location, stove type, fuel type. Data analysis methods for each aim are as follows:

AIM 1: A frequency procedure was performed to determine the prevalence of each fuel type and stove type used for cooking.

AIM 2: A frequency procedure was performed to determine the primary and secondary cooking locations used by survey respondents. A chi-square test of independence was performed to measure if primary and secondary fuel types were dependent on cooking location. Cooking location variables were grouped by whether the cooking took place outdoors, indoors, or in a separate kitchen, and fuel type variables were grouped depending on whether plant material, charcoal, or wood was used to cook. The null and alternative hypotheses are the following:

Null Hypothesis: Cooking location and fuel type are independent of each other at the $p<0.05$ level.

Alternative Hypothesis: Cooking location and fuel type are dependent of each other at the $p<0.05$ level.

AIM 3: A single variate logistic procedure was performed to examine the relationship between the children and survey respondent's age, and RIS symptoms, using age as the predictor and symptom as the outcome. A frequency procedure was also used to examine the frequency and percent of children and adults experiencing RIS by age group.

AIM 4: Self-reported cook symptoms were analyzed using a logistic regression model, with age groups being the predictor variable (18-35 year olds being the reference group), and RIS being the outcome.

AIM 5 & 7: Cooks were surveyed to determine if they experienced RIS and non-RIS over the past week and over the last six months before the survey was taken. We assumed symptoms reported over the past week to be acute, and over the past six months to be chronic. Cooks were also surveyed to determine the acute RIS of children living in their household under age 5. Chronic and acute classifications were based on the American College of Chest Physicians Clinical Practice Guidelines [47]. Responses were analyzed using a logistic regression to determine if stove type, fuel type, and cooking location had an influence on the symptoms experienced by the cooks. The categories for the predictor variables were as follows: stove type (efficient v. inefficient), fuel type (plant vs. charcoal), and cooking location (outside vs. inside). Stoves were determined to be inefficient if they were traditional stoves that did not that did not completely combust the fuel used, based on the household air pollution literature. Fuel type was categorized into plant vs. charcoal based on if the fuel was combusted as raw plant matter (ex: straw, shrubs, agricultural crop, wood), or if it was charcoal. Primary fuel type used during the dry season was the fuel type variable used for analysis because the majority of survey respondents (98.2%) reported that the survey was administered during the dry season. Cooking location was categorized based on whether survey respondents reported cooking outdoors or indoors. Separate kitchen for the purposes of this analysis was considered to be an indoor location so each cooking determinant would contain two categories. First, the predictor variables stove type, fuel type, and cooking location were assessed separately in a univariate analysis to determine if each individual variable significantly increased the odds of a survey respondent experiencing RIS and non-RIS. Then, predictor variables were added to a single multivariate model (Model 1) to determine if the combination of the three variables significantly influenced the respondent's and children's odds of reported RIS and non-RIS.

To check for confounding factors, potential confounding variables that may influence the occurrence of RIS were added to the model containing fuel type, stove type, and cooking location (Model 2) which include; age, sex, and SES. Age was included in the model as a continuous variable. Potential influential variables such as respondent's smoking status, the type of lighting used in the home, and if respondents smoked inside of the house were also included because increased prevalence of respiratory illness is often associated with these factors [48, 49]. A backwards elimination logistic regression was performed on Model 2 to determine which variables were the most significant to the model. Type of lighting was divided into two categories, efficient (doesn't use the combustion of inefficient fuels resulting in elevated HAP, such as battery or solar-powered lighting) vs. inefficient (dependent on the combustion of inefficient fuels such as kerosene, candles, and wood).

SES was divided into 5 categories, low, lower-middle, middle, upper-middle, and high based off the household's access to the following 11 goods; household electricity, a radio, a phone, a mattress, transportation vehicle, land ownership, ownership of a cow not provided by the government, ownership of other farm animals not provided by the government, improved wall material (more expensive material such as bamboo, bricks and cement (high quality) as opposed to mud (low quality)), improved floor material (cement, ceramic, etc.(high quality) as opposed to mud and animal dung (low quality)), and a toilet [50]. A household received one point for each item that they were in possession of or had a higher quality of in comparison to their survey counterparts, and a 0 for items that they were not in possession of or had a lower quality. The points were added up for each household, and these point values were used to split the households into five SES categories determined according to the BG Prasad socioeconomic classification for 2016 [51]. A SAS univariate procedure was used to determine the quintile cut points for class classifications. Lower class households scored a 2 or lower on the ownership scale, lower-middle class households scored between a 2 and a 3, middle class scored between a 3 and a 4, upper-middle class scored between a 4 and a 5, and upper class households scored a 5 or greater.

AIM 6: Crude and adjusted odds ratios for child and adult cough, as well as child congestion and adult phlegm were compared to see if an increase in adult RIS was indicative of an increase in child RIS. A chi-square test for independence was used to examine the correlation between children and adults experiencing RIS.

3. Results

3.1. Descriptive analysis

3.1.1. Household and Survey Respondent Characteristics

The majority of households had a family size of 5 or below and did not have any children under 5 (see Table 1). Formal education was limited, with 95.8% of survey respondents having a primary school education or below. The average age of survey respondents was 50 years old. Females comprised the larger part of the study population (91.4%).

Table 1: Household and Survey Respondent Characteristics

	N (# of survey respondents) or mean(SD)	**%**
Mean Family Size (per household (SD))	3.9 people (2.1)	
# of children <5 (per household)		
0	312	65.6
1	125	26.7
2	35	7.4
3	4	0.8
Educational Level of Respondent*		
No Schooling	211	44.3
Preschool	19	4.0
Primary School	226	47.5
Secondary	17	3.6
Beyond Secondary	3	0.63
Educational level of Partner*		
No Schooling	55	30.1

Preschool	4	2.2
Primary School	113	61.7
Secondary	8	4.4
Beyond Secondary	3	1.6
Sex		
Female	435	91.4
Male	41	8.6
Mean Age (in years(SD))	50 (18.6)	
Age Categories		
18-35	130	27.7
36-50	124	26.4
51-65	90	19.2
66-80	78	16.6
81+	47	10.0

*Educational levels include those who initiated but did not complete the specified level of schooling, and those who have completed the specified level of schooling.

On average, households with fewer children under 5 tended to have a smaller number of people per household, with about 3.3 people per household compared to households with a greater number of children under 5. Households containing 2 and 3 children under 5 had about the same family size of 5.6 people per household. However, the households with no children under 5 also contained the most outliers for family size (See Figure 1.).

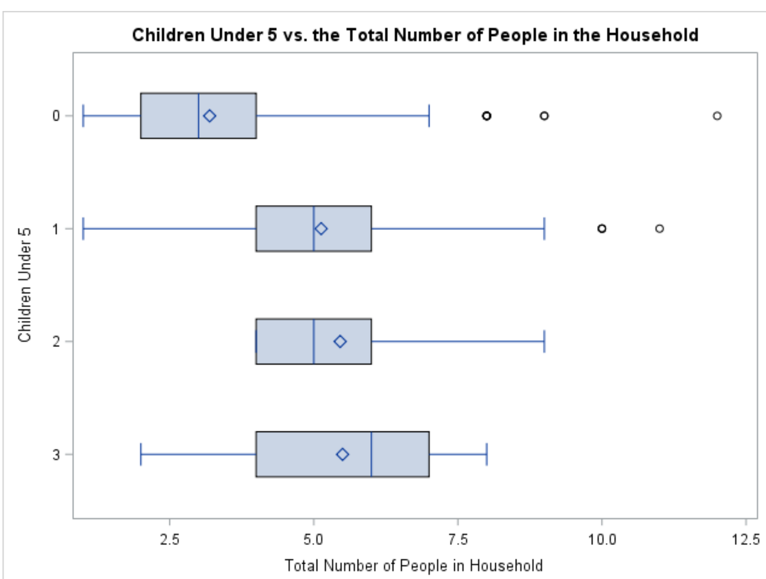

Figure 1: Boxplot of the number of children under 5 vs. the total number of people per household

3.1.2. Method Used to Light Homes

The most common form of lighting for survey respondents was the torch (battery-powered flashlight) and kerosene lamp. The torch had the highest percentage of use with 38.2% of respondents (n = 182) using a torch to light their living areas, while the kerosene lamp had the second highest percentage of use with 36.7% of survey respondents (n = 175) using kerosene lamps to light their living spaces. Other forms of lighting homes included candles, electric lamps, three-stone fires, and burning wood. A little over a third of survey respondents (n = 175, 36.7%) did not have a method of lighting their home (see Table 2).

Table 2: Methods survey respondents use to their homes, categorized by efficient fuel combustions vs. inefficient fuel combustion.

Efficient	**N (# of Households)**	**%**	**Inefficient**	**N (# of Households)**	**%**
Electric Lamp	24	5.0	Candle	32	6.7
Solar Powered Lights	2	0.4	Kerosene Lamp	175	36.7
Torch (battery-powered flashlight)	187	39.2	Three-Stone Fire	10	2.1
Telephone	2	0.4	Grass	2	0.4
			Wood	2	0.4

3.1.3. Educational levels of Survey Respondents and Partners

Partners of survey respondents tended to have a slightly higher educational level on average (Table 1). A higher percentage of survey respondents did not have a formal education compared to their partners (44.3% vs. 30.1%). In addition, 61.7% of partners received a primary school education, while only 47.5% of respondents received a primary school education. It is important to take into consideration that the amount of partners that were surveyed (n=476) was not equivalent to the amount of partners that were surveyed (n=182), so the sample distribution of education among partners may not accurately reflect the true sample distribution of the total number of partners in the sample.

Among respondents with partners who responded to the survey, it was most common for both the respondent and partner to have some form of primary education (n=37). The second most common combination was for the respondent to have no formal education while the partner had some primary education (n=29), followed by both partners having no formal education (n=23).

3.1.4. Wealth Indicators

The majority of survey respondents did not have access to household electricity, a radio a mattress, farm animals, improved floor material, and a mode of transportation (Table 3). Most survey respondents did have access to a phone, their own plot of land, and sturdy wall material for their homes.

Table 3: Ownership of goods among survey respondents

Indicators	Yes		No	
	Frequency	Percent	Frequency	Percent
Household Electricity	36	7.6	440	92.4
Radio	185	39.0	290	61.1
Phone	333	70.1	142	29.9
Mattress	157	33.0	319	67
Transportation (includes boat, bicycle, and Motorcycle)	26	5.5	450	94.5
Own Land Plot	425	89.3	51	10.7
Owns at least 1 cow (not government provided)	55	11.5	422	88.5
Owns at least 1 pig, sheep, chicken or goat (not government provided)	143	30.0	334	70
Improved Flooring Type (includes bricks, cement, ceramic tiles, palm, bamboo, and wood planks)	40	8.4	437	91.6
Improved Wall Material (includes mud bricks covered with cement, real bricks, block cement covered with cement, and wood planks)	249	52.2	228	47.8
Toilet	444	93.1	33	6.92

3.1.5. Fuel Type and Stove Type Descriptive Statistics

Wood was the primary fuel of choice for 69.8% of survey respondents during the rainy season, followed by straw, shrubs, and grass (21.6%). Most survey respondents did not use a second fuel type during the rainy season (72.3%). If the survey respondents had a secondary fuel type, wood was the most common used, followed by straw, shrubs, and grass (Table 4).

The primary fuel used during the dry season was also wood (68.7%), followed by straw, shrubs, and grass (25.0%). As with fuel during the rainy season, the majority of survey respondents did not use a secondary fuel type (70.5%). Secondary fuel types that were most common were the same for the dry season as the rainy season.

Survey respondents primarily used a 3-stone stove to prepare their food (71.9%), followed by a *rondereza* stove (21.0%). Nearly all of the survey respondents did not have a secondary means of preparing their food. If they did, a 3-stone stove would primarily be used (49.0%), followed by an imbabura charcoal stove (32.7%).

3.1.6. Primary and Secondary Cooking Locations

Survey respondents primarily prepared their meals in a separate kitchen (39.2%). Indoor food preparation was the second most common location, followed by outdoor food preparation (28.5%). None of the survey respondents reported a secondary cooking location. Survey respondents were classified as cooking indoors if they cooked inside of their bedrooms, in a designated kitchen room within the household, in a sitting room, or in a designated storing room. Respondents were classified as outdoors if they prepared meals outside, and as separate kitchen if they prepared meals in a separate kitchen in a structure separate from the building containing the sleeping room (Table 4).

Table 4: Cooking determinants used during the rainy and dry seasons

	N (# of households utilizing cooking determinant)	%
Primary Fuel Type (Rainy)		
Agricultural crop	1	0.2
Charcoal	39	8.2
Straw, shrubs, and grass	103	21.6
Wood	333	69.8
None	1	0.2
Secondary Fuel Type (Rainy)		

Charcoal	15	3.1
Straw, shrubs, and grass	34	7.1
Wood	82	17.2
None	346	72.5
Primary Fuel Type (Dry)		
Agricultural crop	1	0.2
Charcoal	29	6.1
Straw, shrubs, and grass	119	25.0
Wood	327	68.7
Secondary Fuel Type (Dry)		
Agricultural crop	2	0.4
Charcoal	20	4.2
Straw, shrubs, and grass	42	8.8
Wood	76	16.0
None	335	70.5
Primary Stove Type		
Three-Stone	342	71.9
Ceramic woodstove	2	0.4
Imbabura charcoal stove	28	5.9
Mud woodstove	3	0.6
Rondereza (built-in) woodstove	100	21.0
Secondary Stove Type		
Three-Stone	24	49.0
Imbabura charcoal stove	16	32.7
Mud woodstove	1	2.0
Rondereza (built-in) stove	8	16.3
Primary Cooking Location		
Indoors	153	32.3
Outdoors	135	28.5
Separate kitchen	186	39.2

A further breakdown of cooking location is below. A separate kitchen was the most frequently used area for cooking (39.2%), followed by cooking outside of the house (28.5%) exhibited by **Figure 2**.

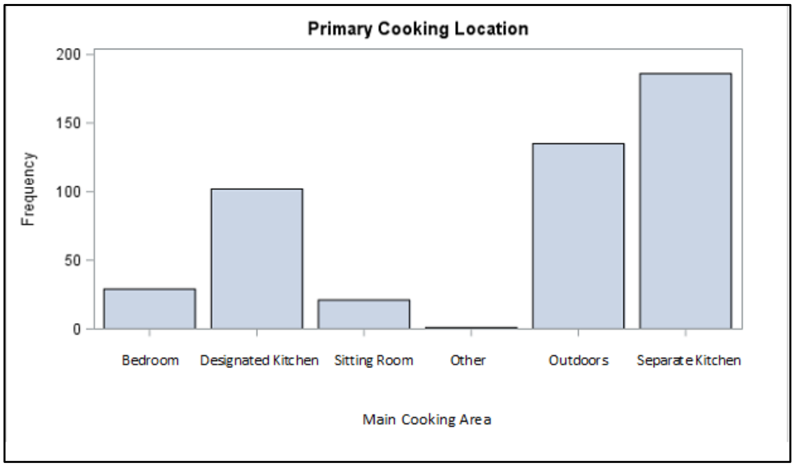

Figure 2: Breakdown of primary cooking location for survey respondents

3.2. Univariate Analysis

3.2.1. Association between Cooking Location (Indoor vs. Outdoors vs. Separate Kitchen) and Fuel Type (Plant vs. Wood vs. Charcoal)

The chi-square test for independence was conducted to demonstrate if the fuel type used is dependent on where the survey respondent chooses to cook. The resulting statistic illustrated a dependence between primary fuel used by survey respondents and cooking location, regardless of season at α=0.05 (p <0.0001). One limitation to the association between primary fuel used during the rainy season and primary location used to cook is that two of the cells had counts less than 5, so the association may not be as strong as the results indicate (Table 5). The p-value of the chi-square test statistic was above α =0.05 for the association between the secondary fuel used during the dry season and the primary cooking location used (p=0.0735) (See Table 6). This indicates that we cannot reject the null hypothesis, and therefore there is a possibility that there is no association between the aforementioned variables, and that they are independent of one another. There was no secondary fuel used during the rainy season, therefore no analysis was performed for that variable.

3.2.2. Association between Primary Stove Type (3-stone stove, Imbabura charcoal stove, and the Rondereza stove) and Cooking Location (Indoor vs. Outdoors vs. Separate Kitchen)

The chi-square test for independence was conducted to demonstrate if the stove type used is dependent on where the survey respondent chooses to cook. The chi-square test statistic exhibited an association between primary stove type and cooking location, and proved the variables to be dependent at the $p<0.05$ level ($p<0.0001$). However, secondary stove type and cooking location were not associated, and were shown to have a potentially independent relationship at the $p<0.05$ level ($p=0.0859$) (See Table 5). It is important to take into account that 44% of the cells contained counts less than 5, which may have impacted the significance of the result [52].

Table 5: Fuel and stove type used according to location.

	Indoors *N(%)*	**Outdoors** *N(%)*	**Separate Kitchen** *N(%)*
Primary Fuel Type (Rainy Season)			
Charcoal	9(1.9)	23(4.9)	7(1.5)
Plant	35(7.4)	36(7.6)	33(7.0)
Wood	109(23.0)	76(16.0)	146(30.8)
Primary Fuel Type (Dry Season)			
Charcoal	7(1.5)	19(4.0)	3(0.6)
Plant	37(7.8)	44(9.3)	39(8.2)
Wood	109(23.0)	72(15.2)	144(30.4)
Secondary Fuel Type (Dry Season)			
Charcoal	2(1.4)	10(7.2)	8(5.8)
Plant	14(10.1)	16(11.5)	14(10.1)
Wood	24(17.3)	17(12.2)	34(24.5)

Primary Stove Type			
3-Stone Stove	115(24.5)	95(20.3)	130(27.5)
Imbabura	8(1.7)	19(4.1)	1(0.2)
Rondereza	19(6.2)	16(3.4)	55(11.8)
Secondary Stove Type			
3-Stone Stove	11(22.9)	7(14.6)	6(12.5)
Imbabura	1(2.1)	7(14.6)	8(16.7)
Rondereza	2(4.2)	4(8.3)	2(4.2)

Table 6: Chi-Square test of independence; comparing fuel type used during the season specified vs. cooking location, and stove type vs. cooking location

Fuel Type	Season	p-value	Stove Type	p-value
Primary	Rainy	<0.0001	Primary	<0.0001
Primary	Dry	<0.0001	Secondary	0.0859
Secondary	Rainy	0.0035		
Secondary	Dry	0.0735		

3.2.3. Acute RIS Experienced by Children

Constant Cough

Children under 1 years old had the highest percentage of constant cough (66.7%) the day the survey was taken and over the last seven days before the survey was taken (Table 7). It is important to note that children under 1 had a smaller sample size than the other categories, particularly the age category that contained the next highest percentage of cough (1 year olds, 12 to 23 month olds), so this may impact the significance and generalizability of the results. 4-year-old children had the lowest percentage of cough the day the survey was taken and over the past seven days. Running a logistic regression model, with the child's age being the predictor variable, and cough (today and over the last seven days) the outcome variable, the age of the child was a significant predictor of cough today at the $p<0.05$ level ($p=0.0175$), and was a significant predictor of cough over the past seven days ($p=0.0050$).

Congestion

One-year-old children experienced the highest percentage of congestion the day the survey was taken (55.9 %). Two-year-old children had the lowest percentage of congestion (31.0%) (Table 7). Age was not a significant predictor of current congestion at the $p<0.05$ level ($p = 0.2134$). In the week before the survey was taken, one-year-old children experienced the highest percentage of congestion (69.2%), followed by three-year-old children. Two-year-old children had the least amount of congestion (24.1%). Age was a significant predictor of congestion in the previous 7 days at the $p<0.05$ level ($p= 0.0360$).

Wheezing

Children under one had the highest percentage of wheezing (33.3%) the day the survey was taken, followed by one-year-olds. No two-year-old was reported to experience wheezing (Table 7). Age was not a significant predictor of wheezing over the past day ($p= 0.2337$). In the seven day period before the survey was taken, children under one have the highest percentage wheezing (33.3%), followed by one-year-olds. None of the survey respondents reported wheezing for the two-year-olds. Age was found to be a significant predictor of wheezing over the past 7 days ($p= 0.0124$).

Table 7: Frequency and percent of children who experienced RIS the day the survey was taken and over the previous seven days before the survey was taken, by age and for all ages.

Symptom	Duration	Age	Yes *(N)*	No *(N)*	Yes *(%)**	No *(%)**	p-value
Cough	Today	0	2	1	66.7	33.3	0.0175
		1	14	12	53.9	46.1	
		2	10	19	34.5	65.5	
		3	10	23	30.3	69.7	
		4	5	16	23.8	76.2	
		All	41	71	36.6	63.4	
Cough	Past 7 days	0	2	1	66.7	33.3	0.0050
		1	16	10	61.5	38.5	
		2	10	19	34.5	65.5	
		3	10	23	30.3	69.7	
		4	5	16	23.8	76.2	
		All	43	69	38.4	61.6	
Congestion	Today	0	1	2	33.3	66.7	0.2134
		1	14	12	53.9	46.1	
		2	9	20	31.0	69.0	
		3	11	22	33.3	66.7	
		4	7	14	33.3	66.7	
		All	42	70	37.5	62.5	
Congestion	Past 7 days	0	1	2	33.3	66.7	0.0360
		1	18	8	69.2	30.8	
		2	7	22	24.1	75.9	
		3	13	20	39.4	60.6	
		4	6	15	28.6	71.4	
		All	45	67	40.2	59.8	
Wheeze	Today	0	1	2	33.3	66.7	0.2337
		1	5	21	19.2	80.8	
		2	0	29	0	100	
		3	3	30	9.1	90.9	
		4	2	19	4.8	95.2	
		All	11	101	9.8	90.2	

Wheeze	Past 7 days	0	1	2	33.3	66.7	0.0124
		1	8	18	30.8	69.2	
		2	0	29	0	100	
		3	3	30	9.1	90.9	
		4	1	20	4.8	95.2	
		All	13	99	11.6	88.4	

*Percentages are according to age group, not total sample size

3.2.4. RIS Experienced by Survey Respondents over the Past Day and Past 6 Months

Cough

RIS for cooks were analyzed according to the following age groups: 18-35 years of age, 36-50 years of age, 51-65 years of age, 66-80 years of age, and 81years of age and older (Table 8). The percentage of respondents reporting cough generally increased with age. Among adults who responded to the survey, 66-80 year-olds had the highest percentage of those experiencing coughing the day the survey was administered, and over the past 6 months (63.6% and 29.5% respectively), followed by 81+ year-olds and 36-50 year-olds. The youngest age group had the lowest percentage of those experiencing coughing the day the survey was administered and in the 6 month period prior (34.9% and 6.2% respectively). Age was a significant predictor of coughing over the past six months at the $p<0.05$ level ($p= 0.0002$).

Phlegm

Self-reported phlegm on the day the survey was administered exhibited the highest percentages among older age categories ages 66-80 (69.2%) and 81+ (Table 8). Younger age categories, particularly ages 36-50 (55.3%) had lower percentages of phlegm on the day of survey administration. Age was not a significant predictor of chronic phlegm for the day of survey administration ($p = 0.2077$). The percentage of respondents reporting chronic phlegm generally increased with age. The highest reported percentage of phlegm over the past 6 months was among 66-80 year-olds (21.8%). The eldest age category (81+) reported the next highest percentages of those producing chronic phlegm. The lowest percentage of reported chronic phlegm was among 36-50 year-olds (8.1%). Age was a significant predictor phlegm over the past 6 months at the $p<0.05$ level ($p= 0.0386$).

Wheeze

In general, the percent of those experiencing wheezing increased among the age groups as the age of the groups increased (Table 8). Those 66-80 years old experienced the highest percentage of self-reported wheezing among the age groups (26.9%) followed by 51-65 year olds (17.8%). Those 18-35 years old had the lowest percentage of self-reported wheezing among the age groups. Age was a significant predictor of wheezing over a six-month period at the $p<0.05$ level ($p = 0.0074$).

Chest Pressure

Similar to wheezing, the percent of those reporting waking up with a sensation of pressure on their chests increased with age, except for the group ages 81 and over, of which 63.8% experienced chest pressure (Table 8). The highest percent of self-reported chest pressure was among 66-80 year-olds (71.8%), followed by 51-65 year olds. The youngest survey respondents (18-35 years old) had the lowest percentage of those feeling chest pressure in the morning. Age was a significant predictor of chest pressure at the $p<0.05$ level ($p = 0.0050$).

Table 8: Frequency and percent of cooks who experienced RIS the day the survey was taken and over the past six months before the survey was taken, by age group and for all age groups.

Symptom	Duration	Age Group	Yes *(N)*	No *(N)*	Yes *(%)*	No *(%)*	p-value
Cough	Today	18-35	45	84	34.9	65.1	0.0029
		36-50	59	65	47.6	52.4	
		51-65	39	51	43.3	56.7	
		66-80	49	28	63.6	36.4	
		81+	23	24	48.9	51.1	
		All	215	252	46.0	54.0	
Cough	6 months	18-35	8	121	6.2	93.9	0.0002
		36-50	12	111	9.8	90.2	
		51-65	13	77	14.4	85.6	
		66-80	23	55	29.5	70.5	
		81+	8	39	17.0	83.0	
		All	64	403	13.7	86.3	
Phlegm	Today	18-35	84	43	66.1	33.9	0.2077
		36-50	68	55	55.3	44.7	
		51-65	53	37	58.9	41.1	
		66-80	54	24	69.2	30.8	
		81+	31	15	67.4	32.6	
		All	290	174	62.5	37.5	
Phlegm	6 months	18-35	12	117	9.3	90.7	0.0386
		36-50	10	113	8.1	91.9	
		51-65	14	76	15.8	84.4	
		66-80	17	61	21.8	78.2	
		81+	8	39	17.0	83.0	
		All	61	406	13.1	86.9	
Wheeze	6 months	18-35	9	120	7.0	93.0	0.0074
		36-50	19	104	15.4	84.6	
		51-65	16	74	17.8	82.2	
		66-80	21	57	26.9	73.1	
		81+	8	39	17.0	83.0	
		All	73	394	15.6	84.4	

Chest Pressure	6 months	18-35	61	68	47.3	52.7	0.0050
		36-50	73	51	58.9	41.1	
		51-65	60	30	66.7	33.3	
		66-80	56	22	71.8	28.2	
		81+	30	17	63.8	36.2	
		All	280	188	59.8	40.2	

3.2.5. RIS and Non-RIS Symptoms Experienced During Cooking and Non-Cooking Periods

RIS and Non RIS Symptoms during Cooking Periods

Self-reported cook symptoms were analyzed using a logistic regression model, with age groups being the predictor variable, RIS and non-RIS being the outcome, and 18-35 year olds being the reference group (Appendix A). Generally, the percentage of a survey respondents within an age group experiencing RIS and non-RIS increased with age. The youngest age group, 18-35 year olds typically had the lowest percentage of individuals experiencing RIS and Non-RIS on the day the survey was taken and in the week before (22.5% for bad cough the day the survey was administered, 40.3% for eye irritation the day the survey was administered). The eldest age groups (66-80 and 81+) tended to have the highest percentages of RIS and non-RIS (56.5% for bad cough the day the survey was administered (81+) year olds, 69.2% for eye irritation the day the survey was administered (66-80)). Age was a significant predictor for RIS and non-RIS for symptoms reported the day of survey administration ($p<0.05$), but was not a significant predictor for RIS and non-RIS symptoms reported in the week before survey administration ($p>0.05$). Odds Ratios were significantly elevated for all RIS and non-RIS the day of survey administration, particularly bad cough among 81+ year olds (OR: 4.48, 95%CI: (2.19, 9.16), $p<0.0001$) and eye irritation for 66-80 year olds (OR: 3.33, 95%CI: (1.84, 6.04), $p<0.0001$). In the week before survey administration, the only symptom that displayed a significant elevation was bad cough among 66-80 year olds (OR: 3.44, 95%CI: (1.11, 10.68), p= 0.0322).

RIS and Non RIS Symptoms during Non-Cooking Periods

As with cooking periods, the percentage of survey respondents experiencing RIS and non-RIS generally increased with age (Appendix A). The majority of the older age groups had a significantly increased odds of self-reported RIS and non-RIS compared to ages 18-35, with the exception of ages 36-50 for most symptoms except bad cough over the past 7 days. For this particular symptom, ages 36-50 was the only group that had a significantly increased odds (OR: 3.31, 95%CI: (1.02, 10.79), p = 0.0468). Unlike cooking periods, eye irritation was significantly elevated among the age groups in the week before the survey was taken for non-cooking periods (p=0.0006), but no other symptom was significantly elevated.

3.3. Multivariate Analysis

3.3.1. Survey Respondent Acute and Chronic RIS Symptoms

RIS (Past Week)

A single variate analysis using fuel type *(ref. plant matter)*, stove type *(ref. inefficient)*, and cooking location *(ref. indoors)* as the predictor and RIS (cough and phlegm) as the outcome displayed a slight increase in prevalence of phlegm but decrease in the prevalence of cough for all predictors (See Appendix B). None of the results were significant at the $p<0.05$ level. A multivariate analysis including fuel type, stove type, and cooking location into a single model (Model 1) revealed that survey respondents still had slightly elevated and insignificant odds of cough for all covariates except stove type, which was slightly protective but insignificant. Phlegm still had a slightly increased and insignificant odds across all covariates.

When stove type, fuel type, and cooking location variables were entered into the model along with potential confounders (Model 2), stove type, fuel type, and cooking location were still found to be insignificant predictors of cough over the past week (Appendix B). Cooking with plant matter, cooking outdoors, and cooking with an inefficient stove were shown to be semi-protective for cough symptoms, but increased odds of experiencing phlegm symptoms, though the results were insignificant at the $p<0.05$ level. Using backwards elimination to determine the most significant variables to the model, age was the only factor that was statistically significant (OR: 1.01, $p = 0.0114$) for cough, and smoking was the only statistically significant factor for phlegm production over the past week (OR: 1.85, 95%CI (1.06, 3.21)). SES was determined to be influential to cough in the model, but was not significant at the $p<0.05$ level.

RIS (Past 6 Months)

A single variate analysis revealed mixed results, showing slightly increased, but insignificant odds of chronic cough and chest pressure, but decreased and insignificant odds of chronic phlegm and wheezing across all predictors (Appendix B). A Model 1 analysis displayed the same results across all outcomes. A Model 2 analysis displayed a decreased and insignificant odds ratio for most symptom types and predictors, with the exception of inefficient stove usage for cough, wheeze, and chest pressure respectively (OR: 1.01, $p=0.9854$; OR: 1.19, $p=0.6359$; OR: 1.25, $p=0.3830$), and plant fuel usage for chest pressure (OR: 1.56, $p=0.3583$). Using backwards elimination to determine the variables most significant to the models, age was the most significant predictor for all RIS ($p < 0.05$). Chronic chest pressure was the only model having two significant predictors, which were age and cooking location. Older survey respondents displayed an increased and significant odds of reporting chest pressure (OR: 1.02, 95%CI: (1.004, 1.027), $p = 0.0068$), while cooking indoors displayed a significantly reduced odds of chronic chest pressure compared to cooking outdoors (OR: 0.53, 95%CI: (0.33, 0.85), $p = 0.0078$). Using inefficient fuel to light the household increased the odds of chronic wheezing compared to age, but this value was insignificant at the $p<0.05$ level (OR: 1.70, 95%CI: (0.95, 3.03), $p = 0.0739$).

3.3.2. Child Acute RIS

Cough (Past Week)

A single variate analysis of the predictor variables compared to cough revealed plant fuel and inefficient stoves had elevated, but insignificant odds when assessing their impact on children experiencing cough over the past week. Cooking indoors had a protective, but also insignificant odds of a child having a persistent cough over the past week. A Model 1 analysis of the predictor variables displayed the same results. Running Model 2, revealed that age was the only significant variable at the $p<0.05$ level. As the age of the child increased, the odds of experiencing acute cough symptoms decreased (OR: 0.64, 95%CI: (0.410, 0.998), $p = 0.0490$). Cooking indoors and with inefficient stoves showed a decrease in child acute cough that was insignificant at the $p<0.05$ level. Using plant matter showed a substantial increase in the odds of the child experiencing acute cough when all predictors and confounders were included in the model (OR: 21.83, 95%CI: (1.272, 374.850), $p = 0.0335$), but as the effects of other variables were removed through backwards elimination, it was eventually found to be insignificant (Appendix B).

Wheeze (Past Week)

A single variate analysis revealed an increased and insignificant odds of a child experiencing wheezing. A Model 1 analysis displayed the same association among all three variables, particularly using an inefficient stove type (OR: 2.42, $p = 0.2060$). A Model 2 analysis exhibited a fairly elevated, but insignificant effect on children wheezing when survey respondents cooked indoors (OR: 5.77, $p = 0.1853$), while using an inefficient stove had a slightly decreased and insignificant effect on children wheezing. The interval for fuel type did not converge, and therefore was excluded from analysis. Using the backwards elimination, age was the only covariate that sufficiently modeled acute wheezing symptoms in children. Older children had a decreased, but insignificant odds of experiencing acute wheezing symptoms at the $p<0.05$ level (OR: 0.55, 95%CI: (0.27, 1.10), $p = 0.0893$) (Appendix B).

Congestion (Past Week)

A single variate analysis revealed an insignificantly decreased odds of reported child congestion for survey respondents who cooked indoors and used an inefficient stove, but an increased and insignificant odds among those using plant fuel (Appendix B). A Model 1 analysis displayed similar results, insignificantly decreased odds while cooking indoors and using an inefficient stove ($p = 0.4566$ and $p = 0.6292$ respectively), but insignificantly increased odds while using plant fuel (OR: 1.58, $p = 0.4869$). Model 2 displayed similar patterns for the three predictors, with the exception that plant fuel usage was initially determined to be a significant predictor of child congestion (OR: 16.11, $p = 0.0490$). However through the use of backwards elimination, it was eventually determined to be insignificant and eliminated through the model. All predictors were removed through backwards elimination, except for household members smoking inside of the house. Smoking inside of the house showed an increased, but insignificant odds of children under 5 experiencing acute congestion symptoms (OR: 2.93, $p = 0.0710$).

3.3.3. Correlation between Child and Adult Acute RIS

Examining the influence of fuel type, stove type, and cooking location on the prevalence of acute coughing symptoms among children and adults, there seems to be some variability in the data when comparing how these factors impact the occurrence of this symptom in both populations (Appendix B). Using plant matter as fuel increases the prevalence of cough among both children and adults, however cooking indoors and using an inefficient stove have differing results among both populations. Cooking indoors shows a slight increase in coughing among survey respondents, but a slight decrease among children. Using an inefficient stove to cook shows a slight increase in coughing among children, but decrease among adults. Models including all predictors and cofounders showed that age was the only statistically significant factor in both children and adults experiencing acute cough. However this variable had opposite effects on both populations. The odds of acute coughing decreased as children aged, while the odds for adults increased as they aged. A chi-square test examining the correlation between children and adults experiencing cough displayed an association between children and adult's acute cough ($p = 0.0261$).

The use of plant fuel for cooking showed an increase in child congestion and adult phlegm. Cooking indoors decreased the prevalence of congestion among children and phlegm among adults. Inefficient stove usage slightly increased the prevalence of phlegm among adults, but decreased the prevalence of congestion among children. Models that included predictors and confounders showed that the most influential variable to adults having acute phlegm was the respondent's smoking status, while age was the most influential factor to children, although insignificant. A chi-square test examining the correlation between children and adults experiencing phlegm displayed an association between children and adult's acute phlegm ($p = 0.0094$).

3.3.4. Acute non-RIS Symptoms for Cooks

A multivariate analysis revealed that cooking indoors had a slight reduction on the crude odds ratios pertaining to eye irritation symptoms among survey respondents, insignificant at the $p<0.05$ level. Cooking with plant fuel exhibited a two-thirds reduction in survey respondents reporting eye irritation, but this result was insignificant ($p = 0.2705$). Cooking with an inefficient stove showed an increase in reported eye irritation, insignificant at the $p<0.05$ level (OR: 1.38, $p = 0.5380$). A single variate analysis show the same effects. The backwards elimination model, including confounders and covariates, showed that none of the variables significantly influenced the prevalence of eye irritation among the respondents. Examining the adjusted odds ratios showed the same patterns present in the crude odds ratios.

The crude odds ratios for fuel type and cooking location exhibited a decrease in headache when using plant fuel and cooking indoors, however both values were insignificant. Inefficient stove usage exhibited an increased odds of headache among survey respondents, but this result was also insignificant. The variables exhibited the same trends when analyzed separately. Including all covariates into one model and adjusting for confounding, stove type, fuel type, and cooking location were still insignificantly associated with the occurrence of headache among the respondents. While plant fuel usage and cooking indoors still exhibited a decrease in headache, inefficient stove usage also exhibited a decreased in the prevalence of headache. Backwards elimination eliminated the majority of the variables from the model, except for the sex of the respondent and the type of lighting used in the survey respondent's home. Using solid fuels to light the home (OR: 1.65, $p = 0.0113$) and being a female (OR: 2.15, $p = 0.0384$) survey respondent was associated with a significantly increased odds of experiencing acute headache over a week's timeframe.

The crude odds ratio for cooking location exhibited a protective effect on survey respondents experiencing acute dizziness symptoms when cooking indoors compared to outdoors, although this effect was insignificant. The crude odds ratio for using a fuel inefficient stove showed an increase in the survey respondent's dizziness, although this effect was also insignificant. The association between fuel type and dizziness was inconclusive. An analysis of the effect of each variable on the model, introducing each variable into the model separately, showed the same results. Including all covariates and confounders into a logistic model and performing a backwards elimination eliminated all variables from the model. None of the variables were significant at the $p<0.05$ level. Adjusted odds ratios for stove type, fuel type, and cooking location showed the same associations compared to the variables being placed into the single and multivariate models. See Appendix B for further results.

4. Discussion and Limitations

According to the results, stove type, fuel type, and cooking location were not reliable predictors for the majority of RIS and non-RIS among survey respondents and their children under 5. Cooking indoors was determined to be a significantly protective predictor determining the respondent's development of chronic chest pressure. This was unexpected because the results show a decrease in chronic chest pressure among those cooking indoors, when we expected the opposite effect because toxic bi-products typically build up indoors compared to outdoor cooking which would normally exacerbate RIS [19, 53-56]. While we expected that cooking indoors, using plant matter as fuel, and using and inefficient stove would yield higher odds of RIS among children and adults [40, 57, 58], the results produced by this study were at best mixed, sometimes yielding higher odds of RIS and other times not. Cooking indoors was associated with a reduction in many of the RIS, which was unexpected. This may be because cooking in a separate kitchen was also classified as cooking indoors. Those who have a separate kitchen may have a higher SES, which could be a confounding factor in our measurement [40] although we did control for SES. A differing association may have been seen if cooking location was modeled using three variables (indoors, outdoors, and separate kitchen) instead of two (indoors vs. outdoors). This association may also be due to additional exposures to pollution outdoors, such as burning trash, smoke from their neighbor's fires, close proximity to household fires, and road traffic.

Survey respondents had similar odds of experiencing RIS and non-RIS during cooking and non-cooking periods. On average, the older age groups (66-80 and 81+) had the highest odds of experiencing RIS and non-RIS the day the survey was taken, as well as in the week and six-month period prior. Ages 66-80 year olds tended to have a higher prevalence of RIS and non-

RIS, but this is most likely due to a smaller sample size of 81+ year olds compared to 66-80 year olds. This indicates that age is a potential risk factor to developing RIS, consistent with many other studies [59, 60]. The occurrence of RIS among survey respondents and children were statistically significant at the $p<0.05$ level, indicating that RIS among respondents and children are highly dependent. The factors that influence RIS among both groups were fairly similar for the RIS symptoms they had in common according to the models (e.g. age for cough and smoking status for congestion/phlegm), indicating that these factors are of greater concern for the respiratory health of survey respondents and children compared to stove type, fuel type, and cooking location. Comparing the odds of experiencing RIS and non-RIS during cooking and non-cooking periods over the past day vs. the past week reveals that survey respondents had a higher odds of experiencing both types of symptoms during non-cooking periods. The odds of bad cough and headache were consistently higher during non-cooking periods among survey respondents, increasing as age increased. The only symptom that showed an elevated odds of occurrence during cooking periods compared to non-cooking periods was eye irritation over a seven day period, but these results were not significant. This indicates that HAP may have a persistent and enhanced effect on the individual exposed even in the periods of non-exposure, which emphasize the critical nature of reducing prolonged exposure to HAP. This may also indicate that exposures to other pollutants such as cigarette smoke and household lighting fuel may contribute to RIS and non-RIS in the absence of cooking determinant exposures.

We find that the most reliable predictors for RIS and non-RIS were the confounding factors, such as age, sex, and SES. Smoking status, the type of fuel the survey respondents used to light their homes, and if someone smoked in the home were also more influential to the model compared to the predictors we analyzed. Age was the most common variable that was included in the model after the backward elimination method, indicating that this variable is perhaps the most influential in the development of RIS and non-RIS in children and adults [28, 60]. There may be confounding factors involved in age that influence the development of RIS that we did not take into account into our model because the data is not available at this time, such as immune function, body mass, height, health history (if they have an illness that affects their respiratory system), etc. Children were found to be more susceptible to RIS at younger ages while adults were more susceptible as they aged. Some of the reasons children may be more susceptible to RIS at younger ages is due to lower body mass and underdeveloped immune system [61]. Older adults may be more susceptible due to chronic exposure to toxicants produced by smoke from burning solid fuels [60], and lowered immune functions resulting from age [62]. However, more research is required before we can conclude the mechanisms behind why age is so influential, considering that the majority of the odds ratios calculated for the cooking determinants were found to be insignificant or inconclusive.

Sex was expected to be influential because women typically do the cooking in the household and are more likely to stay home with the children, so it is expected that they would have an elevated risk of certain RIS [63] and non-RIS. Unexpectedly, sex was only a significant predictor for acute headache among adults. It is not clear why it was not significant for other non-RIS as well as RIS, although the large difference in sample size between women and men may be the reason (435 out of 476 survey respondents were women), and most respondents were the primary household cooks. Smoking had an influence on the increase in acute phlegm symptom in survey respondents as well as children, which was expected because smoking is known to be associated with an increase in phlegm production [64].

The type of lighting was also fairly influential compared to other variables analyzed, included in the chronic wheezing and headache models for adults. It was expected that lighting would be influential to an increase in RIS because many of the lighting methods used by the survey respondents depend on combustion of fuels known to be associated with an increased risk in respiratory illness such as kerosene [49]. It is interesting to note that lighting methods had more of an effect on RIS development compared to fuel type used for cooking, although fuels used to light the home were similar to the fuels used to cook. At this time, we are uncertain as to why lighting was influential when fuel type was not. One hypothesis for this finding is that survey respondents may be exposed to the pollution from their lighting methods for longer periods of time during the evening and night since the fuel would be burning continuously to enable them to see the indoors and outdoors. If they are cooking, they may be able to walk away from their cooking duties and perform other household duties, reducing exposure.

Although we had two fuel type classifications, plant fuel considered slightly more inefficient, none of the fuel types are considered efficient or clean compared to electricity and LPG. Though plant fuel may produce more PM, it is possible that once PM reaches a saturation level within the blood and lungs, there is no true difference between the effects of one inefficient fuel type on the body vs. the other, or it is difficult to detect in a single cross-sectional study with a small sample size. More research needs to be conducted to determine the validity of this hypothesis. SES was not as influential as expected, although influential for acute cough. As discussed earlier, SES is associated with access to higher quality fuels, which typically results in a lower prevalence of RIS and non-RIS due to the decreased exposure HAP [40]. However, our results show that SES had little impact on the majority of RIS and non-RIS. It is possible that although some of the households have more belongings than the others, there is no significant difference between household SES, or the variables used to measure SES were not the most accurate indicator of household wealth. In addition, the survey respondents were already classified as the poorest in their community according to defined government standards, so this study is potentially confirming the accuracy of the government classifications and we wouldn't expect much SES variability.

This study has a number of limitations. One limitation of our study is that no data was collected for acute wheezing and chest pressure symptoms for survey respondents, so we cannot be sure if stove type, fuel type, and cooking location would have an influence on these symptoms. We did not collect data on the children's sex, so we cannot be sure if that confounding factor would be more influential to the development of RIS symptoms in children, or affect the validity of our results. This study relies on self-report, which may introduce misclassification bias, therefore limiting the reliability of the results. Some of the acute and chronic symptoms may have been misclassified because some survey respondents reported cough over the last 7 days, and not the last 6 months. At this time, there is no way to know if this cough is chronic in nature unless the survey respondent is followed over time. Due to this study being cross-sectional, data was only collected at one point in time, making chronic symptoms more difficult to categorize.

There were limitations in data collection, as the original dataset did not measure if there were other individuals who smoked in or around the home, which could be a potential confounder. Some of our measures for HAP exposure were fairly simplistic such as type of lighting. We did not take into account the amount of hours the lighting was used for per night or the location, which is potentially impactful to the development of RIS and non-RIS in addition to lighting quality. Data was collected during the dry season, so all data analysis was performed within this context. If data was collected during the wet season, there may have been more notable differences in the results, particularly in the relationship between RIS/non-RIS and fuel type. We expect that the plant fuels would be wet because they are collected outside, which would produce more smoke when combusted compared to charcoal , which theoretically should lead to a stronger, more direct association between plant fuel usage and RIS/non-RIS. Indeed, there is evidence that higher production of PM occurs during the rainy season [65].

Our sample sizes were fairly small, especially for children under 5 and older adults (66 and up), which has the potential to limit accurate representation of the population. The sampling strategy over-sampled from cells and did not take into account population in geographic areas, and is therefore not representative of the Rwandan population or self-weighted. The aim of the sampling strategy was to collect household survey data and water samples for carbon financing purposes. The survey therefore was designed to primarily address the population and geography of interest to the implementer, and not the population and geography of Rwanda as a whole [44]. Village and cell-level census data was not made available at the time of sampling or analysis, preventing weighting the sample by population and unevenly distributing the probability of selection into the study among the villages, introducing possible bias into the sampling strategy.

If survey respondents were not home on the day of visitation, another household was chosen at random and that household was not revisited. In addition, the government designations for *ubudehe* 1&2 households may not have been accurate due to the transient nature of certain households, which may result in the poorest households being overlooked. However, this survey is the first water quality, cooking practices, and adult health study conducted in all 30 districts of Rwanda. Data from this study can be used to guide future research and implementation of policies regarding cooking practices, such as governmental provision of efficient stoves and fuel to low-income populations [44].

5. Conclusion and Recommendations

Based on the results from our study population, we conclude that the observed differences in stove type, fuel type, and cooking location are not as influential to the development of RIS compared to age, sex, smoking status, and the type of fuel used to provide light for the house. We recognize that these conclusions may not be an accurate representation of the effect of the predictors due to the numerous limitations in this study, as there are several papers that demonstrate that these factors are indeed significant in similar low-income settings [4, 18, 19, 54]. For future studies, we may consider collecting a larger sample size that is more representative of the population, collecting more data from children and older adults, and within the context of a study that is geared towards cooking practices. The data collected in this study was primarily tailored towards water quality, so key factors that may impact cooking practices and RIS/non-RIS may have been overlooked. The results revealed that certain age categories (81+) had a much lower sample size compared to other age categories (18-35), which can impact the power and reliability of the results. We plan to account for cell-level clustering of survey observations [66], and calculate cluster-robust standard errors for future analyses, as this was not included in out models due to time constraints. We plan to tailor the study questions for future research towards cooking practices because missing information that was not available which is crucial to the understanding of the study results. For example, we did not know how long the survey respondents cooked outdoors vs. indoors, so this could have introduced misclassification of exposure to the results. It is possible that survey respondents may have cooked indoors for most of their life, and then switched to outdoor cooking (and vice versa), which can impact the occurrence of RIS and non-RIS. Classification of “efficient” vs. “inefficient” fuel in this study was somewhat of a misnomer because none of the fuel types used in this study are considered efficient. If we have the opportunity to do a future study, we will look at fuels used by a larger sample size reflective of the Rwanda population that are actually considered efficient and clean, such as electricity and LPG. We will then compare it to the fuel types within the study to examine the difference in the prevalence of RIS and non-RIS.

We may consider using other cooking determinants to see if they are more influential to RIS, and consider collecting information other potential confounders to see if they are influencing RIS more than the ones already included in the model. We may follow up with our survey respondents to determine if the presence of RIS correlated with the development of chronic respiratory illness in the future. Collecting thorough information on the survey partner’s status may be done for future studies to inform SES, which may be helpful to explain why certain groups within the survey population are at higher risk for RIS compared to others within the same population. We did not consider the marital status of the survey respondents due to the lack of information collected on survey respondents, which may influence income and therefore the type of fuel, stove, and cooking location the families are able to afford. This variable may be considered as a confounding factor for future analysis. In addition, family size may be considered as a confounding factor for a later analysis because it not only impacts SES but can lead to a greater production of HAP in the household and longer cook times due to the need to prepare more food for the family. As mentioned previously, some of the variables require further characterization to determine their significance to reported RIS such as type of lighting. Factors that may influence this such as amount of time the lighting method is used for in and around the household will be taken into account for future studies.

References

[1] IHME. (2016, March 30, 2018). *Global Burden of Air Pollution*. Available: http://www.healthdata.org/infographic/global-burden-air-pollution

[2] L. P. Naeher *et al.*, "Woodsmoke health effects: a review," (in eng), *Inhal Toxicol*, vol. 19, no. 1, pp. 67-106, Jan 2007.

[3] D. Chakraborty, N. K. Mondal, and J. K. Datta, "Indoor pollution from solid biomass fuel and rural health damage: A micro-environmental study in rural area of Burdwan, West Bengal," *International Journal of Sustainable Built Environment*, vol. 3, no. 2, pp. 262-271, 2014/12/01/ 2014.

[4] D. Pope *et al.*, "Exposure to household air pollution from wood combustion and association with respiratory symptoms and lung function in nonsmoking women: results from the RESPIRE trial, Guatemala," (in eng), *Environ Health Perspect*, vol. 123, no. 4, pp. 285-92, Apr 2015.

[5] WHO. (2016). *Ambient (outdoor) air quality and health*. Available: http://www.who.int/mediacentre/factsheets/fs313/en/

[6] N. Bruce, R. Perez-Padilla, and R. Albalak, "Indoor air pollution in developing countries: a major environmental and public health challenge," (in eng), *Bull World Health Organ*, vol. 78, no. 9, pp. 1078-92, 2000.

[7] Q. Li *et al.*, "Effects of Ambient Fine Particles PM2.5 on Human HaCaT Cells," (in eng), *Int J Environ Res Public Health*, vol. 14, no. 1, Jan 12 2017.

[8] WHO. (2016). *Household air pollution and health*. Available: http://www.who.int/mediacentre/factsheets/fs292/en/

[9] CDC. (2018, March 30, 2018). *Carbon Monoxide Poisoning*. Available: https://www.cdc.gov/co/faqs.htm

[10] EPA. (2017, March 30, 2018). *Carbon Monoxide's Impact on Indoor Air Quality*. Available: https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality

[11] E. G. Dulfo, M.; Hanna, R., "Cooking Stoves, Indoor Air Pollution and Respiratory Health in Rural Orissa," *Economic & Political Weekly*, vol. 43, pp. 71-76, 2008.

[12] DEE, "Sulfur dioxide (SO2)," 2005.

[13] EPA. (2016, March 30, 2018). *Nitrogen Dioxide (NO2) Pollution*. Available: https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects

[14] J. Gillespie-Bennett, N. Pierse, K. Wickens, J. Crane, and P. Howden-Chapman, "The respiratory health effects of nitrogen dioxide in children with asthma," (in eng), *Eur Respir J*, vol. 38, no. 2, pp. 303-9, Aug 2011.

[15] CDC. (2015, March 30, 2018). *ToxFAQs – for Formaldehyde*. Available: https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=219&tid=39

[16] N. Mathur and S. K. Rastogi, "Respiratory effects due to occupational exposure to formaldehyde: Systematic review with meta-analysis," (in eng), *Indian J Occup Environ Med*, vol. 11, no. 1, pp. 26-31, Jan 2007.

[17] J. A. Swenberg, B. C. Moeller, K. Lu, J. E. Rager, R. C. Fry, and T. B. Starr, "Formaldehyde Carcinogenicity Research:30 Years and Counting for Mode of Action, Epidemiology, and Cancer Risk Assessment," *Toxicologic Pathology*, vol. 41, no. 2, pp. 181-189, 2013.

[18] E. Diaz *et al.*, "Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomised stove intervention trial," (in eng), *J Epidemiol Community Health*, vol. 61, no. 1, pp. 74-9, Jan 2007.
[19] I. Das, J. Pedit, S. Handa, and P. Jagger, "Household air pollution, microenvironment and child health: Strategies for mitigating HAP exposure in urban Rwanda," *Environemental Research Letters*, 2018.
[20] DHS, "Rwanda Demographic and Health Survey," in "Demographic and Health Survey," Republic of Rwanda, Rockville, Maryland2016, Available: https://dhsprogram.com/pubs/pdf/FR316/FR316.pdf.
[21] N. R. Bruce, E; Mehta, S; Hutton, G; Smith, K, *Indoor Air Pollution*, 2nd edition. ed. (Disease Control Priorities in Developing Countries.). Bethesda: Oxford University Press, 2006.
[22] D. Muyanja *et al.*, "Kerosene lighting contributes to household air pollution in rural Uganda," *Indoor Air*, vol. 27, no. 5, pp. 1022-1029, 2017.
[23] F. Yip *et al.*, "Assessment of traditional and improved stove use on household air pollution and personal exposures in rural western Kenya," *Environment International*, vol. 99, pp. 185-191, 2017/02/01/ 2017.
[24] T. Pilishvili *et al.*, "Effectiveness of Six Improved Cookstoves in Reducing Household Air Pollution and Their Acceptability in Rural Western Kenya," *PLOS ONE*, vol. 11, no. 11, p. e0165529, 2016.
[25] G. Rosa *et al.*, "Assessing the Impact of Water Filters and Improved Cook Stoves on Drinking Water Quality and Household Air Pollution: A Randomised Controlled Trial in Rwanda," *PLOS ONE*, vol. 9, no. 3, p. e91011, 2014.
[26] WHO, "Indoor Air Pollution, Health, and the Burden of Disease," Available: http://www.who.int/indoorair/info/briefing2.pdf, Accessed on: April 1, 2018.
[27] PMNCH. (2011, April 1, 2018). *Child mortality*. Available: http://www.who.int/pmnch/media/press_materials/fs/fs_mdg4_childmortality/en/
[28] D. G. Bassani, P. Jha, N. Dhingra, and R. Kumar, "Child mortality from solid-fuel use in India: a nationally-representative case-control study," (in eng), *BMC Public Health*, vol. 10, p. 491, Aug 17 2010.
[29] O. P. Kurmi, S. Semple, P. Simkhada, W. C. Smith, and J. G. Ayres, "COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis," (in eng), *Thorax*, vol. 65, no. 3, pp. 221-8, Mar 2010.
[30] K. R. Smith *et al.*, "Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution," (in eng), *Annu Rev Public Health*, vol. 35, pp. 185-206, 2014.
[31] WHO. (2009, April 1, 2018). *Country profile of Environmental Burden of Disease : Rwanda*. Available: http://www.who.int/quantifying_ehimpacts/national/countryprofile/rwanda.pdf?ua=1
[32] E. Gakidou *et al.*, "Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016," *The Lancet*, vol. 390, no. 10100, pp. 1345-1422, 2017.
[33] WHO. (2008, April 1, 2018). *INDOOR AIR POLLUTION* Available: http://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf

[34] I. Romieu, H. Riojas-Rodriguez, A. T. Marron-Mares, A. Schilmann, R. Perez-Padilla, and O. Masera, "Improved biomass stove intervention in rural Mexico: impact on the respiratory health of women," (in eng), *Am J Respir Crit Care Med,* vol. 180, no. 7, pp. 649-56, Oct 1 2009.
[35] S. K. West *et al.*, "Is household air pollution a risk factor for eye disease?," (in eng), *Int J Environ Res Public Health,* vol. 10, no. 11, pp. 5378-98, Oct 25 2013.
[36] J. Polanski, B. Jankowska-Polanska, J. Rosinczuk, M. Chabowski, and A. Szymanska-Chabowska, "Quality of life of patients with lung cancer," (in eng), *Onco Targets Ther,* vol. 9, pp. 1023-8, 2016.
[37] F. L Ramos, J. S Krahnke, and V. Kim, "Clinical issues of mucus accumulation in COPD," *International Journal of Chronic Obstructive Pulmonary Disease,* vol. 9, pp. 139-150, 2014.
[38] P. A. Mahesh, B. S. Jayaraj, A. K. Prabhakar, S. K. Chaya, and R. Vijayasimha, "Prevalence of chronic cough, chronic phlegm & associated factors in Mysore, Karnataka, India," (in eng), *Indian J Med Res,* vol. 134, pp. 91-100, Jul 2011.
[39] S. B. Gordon *et al.*, "Respiratory risks from household air pollution in low and middle income countries," (in eng), *Lancet Respir Med,* vol. 2, no. 10, pp. 823-60, Oct 2014.
[40] A. Sood, "Indoor fuel exposure and the lung in both developing and developed countries: an update," (in eng), *Clin Chest Med,* vol. 33, no. 4, pp. 649-65, Dec 2012.
[41] A. Ellegard, "Cooking Fuel Smoke and Respiratory Symptoms among Women in Low-Income Areas in Maputo," *Environ Health Perspect,* vol. 104, pp. 980-5, 1996.
[42] O. P. Kurmi, K. B. Lam, and J. G. Ayres, "Indoor air pollution and the lung in low- and medium-income countries," (in eng), *Eur Respir J,* vol. 40, no. 1, pp. 239-54, Jul 2012.
[43] H. Heine, E. T. Rietschel, and A. J. Ulmer, "The biology of endotoxin," (in eng), *Mol Biotechnol,* vol. 19, no. 3, pp. 279-96, Nov 2001.
[44] M. Kirby, "Assessing use, exposure, and health impacts of a water filter and improved cookstove distribution program in Rwanda– Upgrading Report," 2013.
[45] C. K. Barstow, C. L. Nagel, T. F. Clasen, and E. A. Thomas, "Process evaluation and assessment of use of a large scale water filter and cookstove program in Rwanda," (in eng), *BMC Public Health,* vol. 16, p. 584, Jul 16 2016.
[46] C. K. Barstow *et al.*, "Designing and piloting a program to provide water filters and improved cookstoves in Rwanda," (in eng), *PLoS One,* vol. 9, no. 3, p. e92403, 2014.
[47] R. S. Irwin *et al.*, "Diagnosis and Management of Cough Executive Summary," *CHEST*, vol. 129, no. 1, pp. 1S-23S.
[48] I. Urrutia, A. Capelastegui, J. M. Quintana, N. Muniozguren, X. Basagana, and J. Sunyer, "Smoking habit, respiratory symptoms and lung function in young adults," (in eng), *Eur J Public Health,* vol. 15, no. 2, pp. 160-5, Apr 2005.
[49] J. Y. Choi *et al.*, "Increased risk of respiratory illness associated with kerosene fuel use among women and children in urban Bangalore, India," (in eng), *Occup Environ Med,* vol. 72, no. 2, pp. 114-22, Feb 2015.
[50] USAID. (2013, April 3, 2018). *Rwanda Malaria Indicator Survey* Available: https://www.dhsprogram.com/topics/wealth-index/Wealth-Index-Construction.cfm

[51] M. Khairnar, U. Wadgave, and P. Shimpi, "Updated BG Prasad socioeconomic classification for 2016," *Journal of Indian Association of Public Health Dentistry,* Letter to Editor vol. 14, no. 4, pp. 469-470, Oct 1, 2016 2016.
[52] M. L McHugh, *The Chi-square test of independence* (Biochemia Medica). 2013, pp. 143-9.
[53] J. Langbein, "Firewood, smoke and respiratory diseases in developing countries-The neglected role of outdoor cooking," (in eng), *PLoS One*, vol. 12, no. 6, p. e0178631, 2017.
[54] A. F. Akunne, V. R. Louis, M. Sanon, and R. Sauerborn, "Biomass solid fuel and acute respiratory infections: The ventilation factor," *International Journal of Hygiene and Environmental Health*, vol. 209, no. 5, pp. 445-450, 2006/09/25/ 2006.
[55] E. A. Rehfuess, L. Tzala, N. Best, D. J. Briggs, and M. Joffe, "Solid fuel use and cooking practices as a major risk factor for ALRI mortality among African children," *Journal of Epidemiology and Community Health,* vol. 63, no. 11, pp. 887-892, 2009.
[56] H. Buchner and E. A. Rehfuess, "Cooking and Season as Risk Factors for Acute Lower Respiratory Infections in African Children: A Cross-Sectional Multi-Country Analysis," *PLOS ONE,* vol. 10, no. 6, p. e0128933, 2015.
[57] T. Smith-Sivertsen *et al.*, "Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala," (in eng), *Am J Epidemiol,* vol. 170, no. 2, pp. 211-20, Jul 15 2009.
[58] K. C. Piddock *et al.*, "A cross-sectional study of household biomass fuel use among a periurban population in Malawi," (in eng), *Ann Am Thorac Soc,* vol. 11, no. 6, pp. 915-24, Jul 2014.
[59] M. Dherani, D. Pope, M. Mascarenhas, K. R. Smith, M. Weber, and N. Bruce, "Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis," *Bulletin of the World Health Organization*, vol. 86, no. 5, pp. 390-398, 11/22/received. 03/11/revised. 03/12/accepted 2008.

[60] M. A. Alim, M. A. B. Sarker, S. Selim, M. R. Karim, Y. Yoshida, and N. Hamajima, "Respiratory involvements among women exposed to the smoke of traditional biomass fuel and gas fuel in a district of Bangladesh," (in eng), *Environmental health and preventive medicine,* vol. 19, no. 2, pp. 126-134, 2014/03// 2014.
[61] J. Y. T. Po, J. M. FitzGerald, and C. Carlsten, "Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis," *Thorax,* vol. 66, no. 3, pp. 232-239, 2011.
[62] E. Montecino-Rodriguez, B. Berent-Maoz, and K. Dorshkind, "Causes, consequences, and reversal of immune system aging," (in eng), *J Clin Invest,* vol. 123, no. 3, pp. 958-65, Mar 2013.
[63] M. A. Desai *et al.*, *Indoor smoke from solid fuels*. 2018.
[64] C. A. Brown, M. Woodward, and H. Tunstall-Pedoe, "Prevalence of chronic cough and phlegm among male cigar and pipe smokers: results of the Scottish Heart Health Study," (in eng), *Thorax,* vol. 48, no. 11, pp. 1163-7, Nov 1993.
[65] M. Zuk *et al.*, "The impact of improved wood-burning stoves on fine particulate matter concentrations in rural Mexican homes," *Journal Of Exposure Science And Environmental Epidemiology,* Research Article vol. 17, p. 224, 05/24/online 2006.

[66] C. Bottomley, M. J. Kirby, S. W. Lindsay, and N. Alexander, "Can the buck always be passed to the highest level of clustering?," *BMC Medical Research Methodology*, journal article vol. 16, no. 1, p. 29, March 08 2016.

Appendix A: RIS experienced by cooks during cooking and non-cooking periods in the last 24 hours and 7 days.

Symptom	Period	Duration	Age Group	Yes *(N)*	No *(N)*	Yes *(%)*	No *(%)*	p-value	OR	CI	p-value
Bad Cough	Cooking	Today	18-35	29	100	22.5	77.5	<.0001	*ref. group*		
			36-50	31	93	25.0	75.0		1.149	(0.64, 2.05)	0.6378
			51-65	34	56	37.8	62.2		2.094	(1.16, 3.79)	0.0147
			66-80	43	34	55.8	44.2		4.361	(2.37, 8.03)	<.0001
			81+	26	20	54.5	43.5		4.483	(2.19, 9.16)	<.0001
Bad Cough	Cooking	Past 7 Days	18-35	7	93	7.0	93.0	0.0948	*ref. group*		
			36-50	10	82	10.9	89.1		1.62	(0.59, 4.45)	0.3493
			51-65	2	54	3.6	96.4		0.49	(0.10, 2.45)	0.3870
			66-80	7	27	20.6	79.4		3.44	(1.11, 10.68)	0.0322
			81+	1	19	5.0	95.0		0.70	(0.08, 6.02)	0.7446
Bad Cough	Non-Cooking	Today	18-35	25	103	19.5	80.5	<.0001	*ref. group*		
			36-50	30	94	24.2	75.8		1.32	(0.72, 2.40)	0.3711
			51-65	37	53	41.1	58.9		2.88	(1.57, 5.27)	0.0006
			66-80	42	36	53.9	46.1		4.81	(2.58, 8.97)	<.0001
			81+	24	22	52.1	47.8		4.50	(2.18, 9.28)	<.0001
Bad Cough	Non-Cooking	Past 7 Days	18-35	4	100	3.9	96.1	0.3665	*ref. group*		
			36-50	11	83	11.7	88.3		3.31	(1.02, 10.79)	0.0468
			51-65	4	49	7.6	92.4		2.04	(0.49, 8.51)	0.3273
			66-80	4	32	11.1	88.9		3.13	(0.74, 13.22)	0.1214
			81+	0	22	0.0	100.0		N/A*	N/A*	N/A*

Headache	Cooking	Today	18-35	61	68	47.3	52.7	0.0207	*ref. group*		
			36-50	63	61	50.8	49.2		1.15	(0.70, 1.89)	0.5757
			51-65	55	35	61.1	38.9		1.75	(1.01, 3.03)	0.0445
			66-80	48	30	61.5	38.5		1.78	(1.01, 3.12)	0.0475
			81+	33	13	71.7	28.3		2.83	(1.36, 5.86)	0.0052
Headache	Cooking	Past 7 Days	18-35	10	58	14.7	85.3	0.8735	*ref. group*		
			36-50	13	48	21.3	78.7		1.57	(0.63, 3.90)	0.3301
			51-65	6	29	17.1	82.3		1.20	(0.40, 3.63)	0.7467
			66-80	5	25	16.7	83.3		1.16	(0.36, 3.74)	0.8040
			81+	3	10	23.1	76.9		1.74	(0.41, 7.45)	0.4552
Headache	Non-Cooking	Today	18-35	50	79	38.8	61.2	0.0004	*ref. group*		
			36-50	55	69	44.4	55.6		1.26	(0.76, 2.08)	0.3669
			51-65	49	41	54.4	45.6		1.89	(1.09, 3.26)	0.0224
			66-80	49	29	62.8	37.2		2.67	(1.50, 4.77)	0.0009
			81+	32	14	69.6	30.4		3.61	(1.76, 7.42)	0.0005
Headache	Non-Cooking	Past 7 Days	18-35	53	76	41.1	58.9	0.0006	*ref. group*		
			36-50	53	71	42.7	57.3		1.07	(0.65, 1.76)	0.7895
			51-65	48	42	53.3	46.7		1.64	(0.95, 2.82)	0.0744
			66-80	51	27	65.4	34.6		2.71	(1.51, 4.86)	0.0008
			81+	31	15	67.4	32.6		2.96	(1.46, 6.82)	0.0027
Eye Irritation	Cooking	Today	18-35	52	77	40.3	59.7	0.0006	*ref. group*		
			36-50	60	63	48.8	51.2		1.41	(0.86, 2.32)	0.1767

			51-65	48	40	54.6	45.4		1.78	(1.03, 3.07)	0.0396
			66-80	54	24	69.2	30.8		3.33	(1.84, 6.04)	<.0001
			81+	30	16	65.2	34.8		2.78	(1.38, 5.60)	0.0043
Eye Irritation	Cooking	Past 7 Days	18-35	7	70	9.1	91.1	0.4106	*ref. group*		
			36-50	8	56	12.5	87.5		1.43	(0.49, 4.18)	0.5149
			51-65	8	33	19.5	80.5		2.42	(0.81, 7.25)	0.1131
			66-80	1	23	4.2	95.8		0.44	(0.05, 3.72)	0.4472
			81+	2	14	12.5	87.5		1.43	(0.27, 7.61)	0.6760
Eye Irritation	Non-Cooking	Today	18-35	32	97	24.8	75.2	<.0001	*ref. group*		
			36-50	38	96	30.7	69.3		1.34	(0.77, 2.33)	0.3000
			51-65	40	50	44.4	55.6		2.43	(1.36, 4.32)	0.0026
			66-80	44	34	56.4	43.6		3.92	(2.15, 7.15)	<.0001
			81+	28	18	60.9	39.3		4.72	(2.31, 9.63)	<.0001
Eye Irritation	Non-Cooking	Past 7 Days	18-35	8	89	8.3	91.7	0.9977	*ref. group*		
			36-50	8	78	9.3	90.7		1.141	(0.41, 3.18)	0.8010
			51-65	5	45	10.0	90.0		1.236	(0.38, 4.00)	0.7233
			66-80	3	31	8.8	91.2		1.077	(0.27, 4.32)	0.9170
			81+	0	18	0	100		N/A*	N/A*	N/A*

N/A = Confidence interval did not converge, therefore odds ratios and p-values are not available

Appendix B: Acute and chronic RIS and non-RIS experienced by cooks in the last 7 days and 6 months.

Symptom Type	Variable Type	Reference Group	Comparison Group	Crude Odds Ratio	p-value	Model 1 Odds Ratio	p-value	Model 2 Odds Ratio	p-value
Survey Respondents									
Acute Cough	Fuel	Plant Matter	Charcoal	0.973 (0.452, 2.092)	0.9434	1.113 (0.475, 2.610)	0.8057	0.860 (0.336, 2.200)	0.7522
	Cooking Location	Indoors	Outdoors	0.979 (0.656, 1.462)	0.9175	1.024 (0.673, 1.559)	0.2934	0.961 (0.599, 1.542)	0.8684
	Stove	Inefficient	Efficient	0.816 (0.542, 1.229)	0.3304	0.788 (0.506, 1.229)	0.9109	0.735 (0.444, 1.216)	0.2308
Chronic Cough	Fuel	Plant Matter	Charcoal	1.320 (0.387, 4.505)	0.6575	1.026 (0.266, 3.954)	0.9702	0.950 (0.224, 4.022)	0.9441
	Cooking Location	Indoors	Outdoors	1.361 (0.735, 2.521)	0.3270	1.307 (0.693, 2.463)	0.4077	0.992 (0.491, 2.002)	0.9817
	Stove	Inefficient	Efficient	1.253 (0.675, 2.324)	0.4746	1.258 (0.647, 2.444)	0.4991	1.007 (0.477, 2.127)	0.9854
Acute Phlegm	Fuel	Plant Matter	Charcoal	1.252 (0.578, 2.711)	0.5694	1.175 (0.496, 2.782)	0.7134	1.117 (0.436, 2.862)	0.8177
	Cooking Location	Indoors	Outdoors	1.006 (0.666, 1.520)	0.9760	1.045 (0.680, 1.606)	0.8410	1.012 (0.624, 1.641)	0.9624
	Stove	Inefficient	Efficient	1.066 (0.701, 1.619)	0.7661	1.022 (0.649, 1.609)	0.9268	1.144 (0.691, 1.892)	0.6017
Chronic Phlegm	Fuel	Plant Matter	Charcoal	0.661 (0.241, 1.808)	0.4195	0.631 (0.198, 2.008)	0.4355	0.755 (0.197, 2.895)	0.6825
	Cooking Location	Indoors	Outdoors	0.869 (0.485, 1.557)	0.6374	0.885 (0.483, 1.622)	0.6923	0.649 (0.328, 1.286)	0.2157
	Stove	Inefficient	Efficient	1.055 (0.573, 1.943)	0.8643	1.183 (0.597, 2.341)	0.6301	0.969 (0.449, 2.093)	0.9366
Chronic Wheeze*	Fuel	Plant Matter	Charcoal	0.871 (0.320, 2.367)	0.7865	0.903 (0.294, 2.780)	0.8594	0.794 (0.215, 2.926)	0.7284
	Cooking Location	Indoors	Outdoors	0.888 (0.519, 1.520)	0.6662	0.862 (0.494, 1.504)	0.6017	0.768 (0.328, 1.286)	0.4201
	Stove	Inefficient	Efficient	1.038 (0.594, 1.811)	0.8968	1.045 (0.567, 1.925)	0.8874	1.190 (0.579, 2.445)	0.6359
Chronic Chest Pressure*	Fuel	Plant Matter	Charcoal	1.525 (0.710, 3.277)	0.2791	1.591 (0.675, 3.750)	0.2885	1.561 (0.604, 4.035)	0.3583
	Cooking Location	Indoors	Outdoors	0.796 (0.527, 1.202)	0.2780	0.693 (0.447, 1.074)	0.1010	0.508 (0.308, 0.835)	0.0076
	Stove	Inefficient	Efficient	1.328 (0.879, 2.005)	0.1775	1.215 (0.776, 1.902)	0.3940	1.249 (0.758, 2.060)	0.3830
Acute Eye Irritation	Fuel	Plant Matter	Charcoal	0.409 (0.083, 2.006)	0.2705	0.332 (0.051, 2.162)	0.2486	0.500 (0.065, 3.862)	0.5064
	Cooking Location	Indoors	Outdoors	0.878 (0.363, 2.120)	0.7719	0.973 (0.382, 2.479)	0.9548	0.779 (0.285, 2.127)	0.6255
	Stove	Inefficient	Efficient	1.108 (0.445, 2.760)	0.8255	1.384 (0.492, 3.891)	0.5380	1.245 (0.415, 3.735)	0.6957

Acute Headache	Fuel	Plant Matter	Charcoal	0.804 (0.368, 1.755)	0.5834	0.679 (0.284, 1.622)	0.3836	0.750 (0.299, 1.880)	0.5397
	Cooking Location	Indoors	Outdoors	0.791 (0.530, 1.180)	0.2508	0.830 (0.545, 1.264)	0.3860	0.775 (0.491, 1.224)	0.2743
	Stove	Inefficient	Efficient	1.314 (0.872, 1.980)	0.1919	1.434 (0.919, 2.239)	0.1123	1.377 (0.847, 2.239)	0.1963
Acute Dizziness	Fuel	Plant Matter	Charcoal	N/A	N/A	N/A	N/A	N/A	N/A
	Cooking Location	Indoors	Outdoors	0.621 (0.284, 1.358)	0.2328	0.587 (0.261 1.323)	0.1991	0.638 (0.271, 1.503)	0.3043
	Stove	Inefficient	Efficient	1.764 (0.690, 4.512)	0.2363	1.400 (0.541 3.626)	0.4879	1.520 (0.542, 4.269)	0.4263
Children <5 years old									
Acute Cough	Fuel	Plant Matter	Charcoal	1.747 (0.515, 5.922)	0.3705	1.645 (0.428, 6.327)	0.4691	21.832 (1.272 374.850)	0.0335
	Cooking Location	Indoors	Outdoors	0.805 (0.427, 1.515)	0.5005	0.777 (0.400, 1.508)	0.4554	0.485 (0.136, 1.728)	0.2644
	Stove	Inefficient	Efficient	1.400 (0.685, 2.860)	0.3559	1.292 (0.597, 2.792)	0.5154	0.458 (0.132, 1.587)	0.2184
Chronic Wheeze	Fuel	Plant Matter	Charcoal	1.846 (0.228, 14.980)	0.5660	1.010 (0.102, 10.037)	0.8594	N/A	N/A
	Cooking Location	Indoors	Outdoors	1.357 (0.516, 3.571)	0.5363	1.251 (0.464, 3.370)	0.6017	5.773 (0.431 77.287)	0.1853
	Stove	Inefficient	Efficient	2.424 (0.677, 8.686)	0.1739	2.420 (0.615, 9.522)	0.8874	0.920 (0.118, 7.190)	0.9370
Acute Congestion	Fuel	Plant Matter	Charcoal	1.311 (0.410, 4.192)	0.6481	1.583 (0.434, 5.778)	0.4869	16.107 (1.013, 256.165)	0.0490
	Cooking Location	Indoors	Outdoors	0.789 (0.420, 1.483)	0.4613	0.778 (0.402, 1.506)	0.4566	0.456 (0.128, 1.626)	0.2260
	Stove	Inefficient	Efficient	0.927 (0.462, 2.861)	0.8315	0.830 (0.389, 1.769)	0.6292	0.561 (0.164, 1.924)	0.3583

*Only chronic symptom data is available

N/A = Confidence interval did not converge, therefore odds ratios and p-values are not available