Effects of Household Air Pollution on Pulmonary Function and Respiratory Symptoms of Women in Bhaktapur, Nepal

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ABSTRACT

This project aims to quantify level of household air pollution (HAP) and its effects on pulmonary function of women in Nepal who do most of the cooking. I carried out a cross-sectional study of women in households that used biomass and non-biomass fuel types for cooking. To quantify the level of HAP, I measured the level Nitrogen Dioxide (NO_2) across households that use various fuel types. To evaluate the respiratory health effects of HAP, I did pulmonary function testing (PFT) using EasyOne Spirometer. And, I used standard questionnaire to evaluate the respiratory symptoms. Of the 383 study participants, 170 (44.39%) used biomass solid fuel (wood and agricultural residues) and 209 (54.57%) used non-biomass fuel (electricity and liquefied petroleum gas), respectively. The mean 24-h indoor NO_2 concentration was significantly higher in households that used biomass fuels for cooking compared to the non-biomass users (mean NO_2 of 74.33 ug/m3 in biomass cooking households vs. mean NO_2 of 53.38 ug/m3 in non-biomass users). Pulmonary Function indices (FEV_1 (forced expiratory volume in one second) and FEV1/FVC ratio) were significantly lower among women that cooked with biomass fuels in comparison to women that cooked with non-biomass fuels. In this study, 9.6% of the total sample size in the randomly chosen sample represented had airflow obstruction and were diagnosed as COPD sufferers. This study found cooking using biomass fuel types as a single great risk factor for elevated concentration of NO_2, reduced pulmonary function, and prevalence of increased respiratory health symptoms among women that do most of the cooking.

KEYWORDS

Agricultural and residues, indoor air pollution, airflow obstruction, spirometry, cross-sectional study

INTRODUCTION

Household Air Pollution (HAP) due to cooking is a leading cause of death in developing countries. It is significantly associated with various respiratory symptoms and degrading pulmonary health (Smith et al. 2003, Padilla et al. 2010). More than 4.3 million premature deaths occur every year as the result of high level of exposure to HAP (Adamkiewicz et al. 2010, Kurmi et al. 2008, Pokhrel et al. 2013, and Kim 2011). Health risks associated with exposure to HAP are more severe in developing countries and in communities with lower socioeconomic status, demographic sectors in which an estimated 3 billion people rely on solid fuel (wood, coal, dung, and crop or agricultural residue), through which they are exposed to a variety of health-degrading pollutants (Rai 2013, Baxter 2007, Zhang et. al 2003). Elevated concentrations of HAP in developed countries are linked to increased incidence of respiratory symptoms such as chronic bronchitis, chronic cough, chronic phlegm, wheezing, breathlessness, chest pain, and reduced pulmonary function or airflow obstruction (Kurmi et al. 2104, Kurmi et al. 2013, Umoh et al. 2014, Diaz et al. 2007, Ranabhat et al. 2015, Desalu et al. 2010, Ng et al. 1993, Arbex et al. 2007, Stankovic et al. 2011, Pandey 1984). The progressive manifestation of these respiratory symptoms usually leads to a life threatening and non-reversible condition known as chronic obstructive pulmonary disease (COPD) (Mutunayagam et al. 2010). COPD is a progressive disease that makes it hard to breath, and is marked by airflow limitation that is irreversible and usually life threatening when it progresses beyond Stage II (Mutunayagam et al. 2010). The early diagnosis of the risk of COPD is usually confirmed by conducting a pulmonary function testing (PFT) (Manzar et al. 2010, Mutunayagam et al. 2010). However, under utilization of important diagnostic device such as spirometry for diagnosing airflow obstruction is very common in developing countries and associated with degrading respiratory health condition of individual in developing countries like Nepal (Manzar et al. 2010). Globally, COPD is the 4th leading cause of death, and, in Nepal, it is ranked second and third in terms of the number of death- and disability-adjusted life years, respectively (Sharma et al. 2012). HAP is the number one risk factor associated with disease burden in Nepal. Several studies conducted in Nepal have pointed towards HAP as a being the chief risk factor of COPD, particularly in women (Rinne et al. 2007, Sharma et al. 2012, Bhandari et al. 2012, Ko et al. 2011, Kurmi et al. 2010). Common HAP that are associated with the increase of respiratory health symptoms and reduced pulmonary function are $PM_{2.5}$, NO_2, environmental tobacco smoke, and volatile organic compounds (KO et al. 2011, Zhang et al. 2003).

Nitrogen dioxide (NO_2) is a well-studied marker of respiratory symptoms and reduced pulmonary function that usually leads to the risk of development of COPD (Smith et al. 2000, Braga et al. 2007, Ng et al. 1993, Zhang et al. 2003, Kim et al. 2011, Burnett et.al 2014). NO_2 is a ubiquitous and strong oxidant, and primarily an indoor air pollutant resulting from smoking, incomplete combustion of solid fuel and natural gas, and from intrusion of nitrogen from vehicles and industrial activities outdoor (Adamkiewicz et al. 2010). Dose-response studies on animals show significant association between acute and chronic exposure to NO_2 and pulmonary degradation, including alteration of pulmonary structure and function, and increased susceptibility to respiratory infections like pneumonia, but only at levels exceeding concentration of 2 parts per million (ppm) (Adamkiewicz et al. 2010). In several dose-response studies among healthy adults with concentrations less than 1ppm, significant degradation of pulmonary function were reported with decrease of force vital capacity and forced expiratory volume in 1 seconds (FEV1), and increasing airflow obstruction (Adamkiewicz et al. 2010). In subjects with COPD & asthma, respiratory symptoms were aggravated at lower exposure of 560 µg/m3 (Adamkiewicz et al. 2010). However, other studies have shown no effects on asthmatics even at the dose exposure of more than 1880–7520 µg/m3, and yields mixed results (Adamkiewicz et al. 2010).

The types of stoves mainly used in Nepal for household cooking are biomass stoves, which use coal, wood, dung, straw, and agricultural or crop residue as fuel; non-biomass stoves, such as liquefied petroleum gas (LPG), kerosene, and biogas; and electric stoves that uses electricity (Pokhrel et al. 2013). Especially in biomass cooking Nepali households poor ventilation is associated to elevated concentration of HAP during periods of cooking (Pokhrel et al. 2013). Higher prevalence of exposure to NO_2 during the cooking period in rural parts of developing countries was observed when using solid fuel and natural gas such as LPG in poorly ventilated kitchens (Nicole 2013, Reid et al. 1986). In a systematic review and meta-analysis of the burden of disease in developing countries, exposure to HAP was significantly associated with an increased risk of COPD. In particular, HAP from the use of traditional biomass cookstoves put women at greater risk of development of COPD (Kurmi et al. 2010). With significant portion of their time spent in the cooking in a poorly vented kitchen, and being exposed to HAP for 3-7 hours daily, there is an increasing trend of the prevalence rates of respiratory symptoms that causes COPD in Nepal (Pandey 1984, Burnett et al. 2014, Ranabhat et al. 2015).

Gap Statement:

There is dearth of studies in Nepal looking at the association between HAP and respiratory health in women (Gurung et al. 2013). The potential of diagnostic tools such as spirometry to diagnose early COPD marked by airflow obstruction is underused in many developing countries (Manzar et al. 2010). Evidence on the impact of NO_2 on pulmonary function of non-smoking women is mostly limited to the developed countries. To date, no study has examined the respiratory health impacts from exposure to NO_2 as potential indoor pollutants with large sample size. By conducting a large scale quantitative measurement of NO_2 and diagnosing COPD by evaluating respiratory systems and pulmonary function of the women cooks, this study will try to fill the gap in evidence that exists on relationship between the exposure to NO_2 and pulmonary function and respiratory symptoms in women.

Epidemiological studies simply relying on stove types as surrogates of exposure might overestimate or underestimate the actual personal exposure to pollutants and over or under estimate the associated risk for respiratory health (Adamkiewicz et al. 2010). To overcome the limitation of using surrogates measures of HAP levels, and to avoid any measurement biases resulting from exposure misclassification, this study conducted an objective measurement of $NO_{2.}$ Covariates such as tobacco smoking and socioeconomic status (SES) are a known confounder of respiratory symptoms. To do best in controlling the effect of tobacco smoking, I exclusively sampled the non-smoking population of women that cook. I captured their SES through a structured questionnaire. Furthermore, by utilizing spirometry as a diagnostic tool, I evaluated the risk and severity of the COPD among women that spend most of their lives cooking and exposed to higher concentration of HAP.

Objective:

The main objective of this study was to investigate the relationship between the HAP exposure and respiratory symptoms and pulmonary function in women using different fuel types in the vicinity of Bhaktapur municipality, Nepal.

Central Research Question:

How different levels of NO_2 associate with respiratory symptoms and pulmonary function in non-smoking women that use biomass stoves, electric stoves, and LPG stoves during periods of cooking?

Sub-questions:

- How does the level of NO_2 vary between households that use biomass stoves, electric stoves, and LPG stoves during periods of cooking?
- How is the varying level of NO_2 associated respiratory health effects are prevalent on women who do most of the cooking?
- How NO2 levels vary by season (the winter and summer) in household that use different fuel types for cooking?

METHODS

To conduct this study, human subjects` approval was obtained from the institutional review boards at the University of California, Berkeley at United States of America, and from the Nepal Health Research Council at Nepal.

Site description

This study was conducted in Bhaktapur municipality, Nepal. Bhaktapur is a semi-urban city located about 8 miles away from the capital city, Kathmandu and occupies a space of 119 sq km. According to the Nepal population census report from 2011, Bhaktapur had a population of 304,651 people with majority of them belonging to Newari ethnicity. There is a total of 68,636 households in Bhaktapur (Government of Nepal 2011). It is a densely populated city with the average household size of 4.44 per houses. Bhaktapur is also rich in cultural heritage with temples and monuments that are more than 5000 years old, and is listed in the World Heritage Sites by UNESCO. Majority of people in Bhaktapur are engaged in farming. In the outskirts of the Bhaktapur city brick factories are spread and mostly operate during the winter and summer and contribute significantly to the outdoor air pollution.

Research design

A total of 383 participants were enrolled in this cross-sectional study to investigate a relationship between the HAP, respiratory symptoms, pulmonary function among participants in households that were stratified by use of different stove types such biomass, electricity, and LPG during the winter and summer season. The 383 participants were all women and cooked presently for their families. A simple random sampling was used to create a sampling frame that includes households in Bhaktapur that use different stove types. These households were part of the nutritional study conducted by Siddhi Memorial Hospital in the Bhaktapur municipality. Second, I used stratified sampling method to sub-sample the households by stove types. Only participants that met the following inclusion criteria were enrolled into the study: at least 18 years of age, currently cook and do not smoke, not pregnant, currently do not suffer from Tuberculosis, and no fever. The field interviewer and research staff from the Siddhi Memorial Hospital verified the inclusion criteria. And, only after meeting the inclusion criteria, consent were obtained from the participants.

Study period

I conducted exposure and health questionnaires interview, pulmonary function testing, and air pollution monitoring of NO_2 in the participants households during the summer (June-August 2014) and winter (December 2014-February 2015) in Nepal.

Data collectors

I recruited 15 students in Nepal to conduct field interviews, pulmonary function testing, and air pollution monitoring for NO_2. The students were trained to follow protocols adhering to the ethical requirements for conducting interviews and air pollution measurement. Volunteers obtained consent from the study participants. Volunteers were lead by a research staff member hired from the hospital.

Interview

I conducted field interviews to gather information on respiratory symptoms, data on smoking, socioeconomic status, duration of time spent cooking, and literacy through questionnaire during the air pollution monitoring for NO_2 and pulmonary function measurement. The respiratory symptom questionnaire were adapted from Dr. Amod`s tuberculosis study in Nepal (Pokhrel et al. 2010) and American Thoracic Society. The trained bilingual interviewer administered questionnaire to the participants in their native language.

Exposure measurement

I measured NO_2 concentration to see how the concentration level of HAP in households varied across biomass, LPG, and Electric stove users. To determine household NO_2 concentration, I used passive sampling device Rapid Air Monitor (RAM) for Nitrogen Dioxide (Gradko International Limited, Hamisphere, England). The sampling was conducted for 24 hours to capture a time-weighted average concentration of NO_2 throughout the cooking period. The samplers in each household were placed at least 2m away from the stove, away from windows and doors. On average, the distance 0.5-1m is the usual distance maintained from the stove during cooking.

Respiratory symptoms questionnaire

To identify the respiratory health outcome from the use of different stove types, I conducted thorough medical examination using a structured health interview in households that collected data on the following respiratory symptoms. I obtained information on the prevalence and frequency of cough, phlegm, wheezing, difficulty breathing, chest pain, palpitations, nighttime cough, and headaches among the non-smoking women within the period of last 12 months. Participants with the presence of persistence coughing and production of phlegm for periods more than 3-4 months were classified as a suffering from chronic case (Kurmi et al. 2014). Grades for difficulty in breathing was assessed and reported based on the following dyspnea scale that participants reported: with no dyspnea except with strenuous exercise, with dyspnea when walking up an incline or stops after 15 minutes of walking on the level, stops after a few minutes of walking no the level, and dyspnea at rest and too difficult to leave the house.

Pulmonary function measurement

I conducted pulmonary function testing (PFT) of the women using an EasyOne spirometer (ndd Medical Technologies, Inc. Massachusetts). The procedure of spirometry usually requires utmost cooperation between the examiner and the participants. After piloting extensively for several times by conducting spirometry, it was found that the women participants were more comfortable with women volunteers as their examiners. Therefore, volunteers that spoke the native language and were female were deemed necessary and chosen to conduct the PFT. The volunteers were trained intensively to meet the American Thoracic Society (ATS) guidelines for conducting PFT. Following the administering of respiratory symptoms questionnaire, I measured the standing height and weight of the women participants before conducting the PFT. The PFT were conducted only after the women participants met the inclusion criteria. After meeting the inclusion criteria, informed consent was administered to all the women participants that undergo the PFT. To conduct the PFT procedure, participants were seated down in a chain and asked to hold their body in an upright position, and then asked draw in as much air their pulmonarys could hold. Then after receiving a to-go signal, the participants were asked to release all the air as quickly as possible inside the mouthpiece of the spirometer for a total of 6 seconds. This procedure was repeated until at least three satisfactory blows were recorded by the spirometer and deemed acceptable as per the ATS ERS task force acceptability and reproducibility criteria. Within the EasyOne spirometer, an algorithm judged for the acceptability and reproducibility of expiratory maneuvers. FVC (forced vital capacity), FEV_1 (forced expiratory volume in one second) and FEF_{25-75} (forced expiratory flow 25-75%) were used as parameters to access the degree of airflow obstruction and diagnose for the risk of COPD (stage-0) and severity of COPD (stage-1 and greater) among the women participants. Participants with $FEV_1/FVC < 0.70$ were diagnosed as COPD sufferers. The spirometric readings of the participants were reviewed and approved through visual examination by an experienced pulmonary physician, Dr. John R. Balmes.

Covariates

Variables known to confound with the respiratory symptoms and pulmonary function such as presence of environmental tobacco smoke (ETS) were captured through the respiratory symptoms questionnaire. Socioeconomic information obtained from the exposure questionnaire were obtained and indexed by yes/no response about their educational attainment. Additionally, information on past smoking habit was captured through the exposure questionnaire. Height and weight of the participants were also taken into consideration as potential confounders.

Data management and analysis

I created Questionnaire database using a SQL Microsoft database system (Microsoft® SQL Server® 2008). The data from the exposure and health questionnaire was entered in an application that was designed especially for this project. I created a unique ID was created for each household in the database. The data entered on the application were transmitted to the main server in encrypted form via a secure VPN tunnel. I analyzed the data using the STATA (version 13.0; STATA Corp LP, College Station, TX, USA).

I conducted descriptive analyses of the demographics, exposure measurement, PFT measurement, and respiratory symptoms of the population under study. The results from the descriptive analyses were divided by use of different fuel types. Seasonal difference in NO_2 concentration is reported for summer season and winter season. The exposure concentration was reported in micrograms (ugm3), and the pulmonary function indices were reported in liters (L). Linear regression models were built to analyze for the relationship between kitchens NO_2 concentration, respiratory symptoms, and PFT indices. A level of p-value <0.05 was recognized as statistically significant.

RESULT

Of the 383 study participants, 170 (44.39%) used biomass solid fuel (primarily wood and agricultural residues) and 209 (54.57%) used non-biomass fuel (primarily LPG), respectively. A total of 4 participants did not report the type of fuel used, and therefore were removed from the analysis. Participants that cooked on biomass weighed less and were illiterate relative to those who used electricity and LPG for cooking (Table 1). There were higher numbers of past and present smoker among the biomass users (Table 1)

Table 1. Demographic characteristics of study participants using different fuel types.

Characteristic	N	n	Electricity	n	LPG	n	Biomass
Age (years); mean (SD)	247	**6**	**28.6 (5.92)**	**129**	**39.4 (10.61)**	**112**	**41.3 (12.4)**
Height (m); mean (SD)	247	**6**	**1.485 (0.07)**	**129**	**1.489 (0.05)**	**112**	**1.487 (0.05)**
Weight (kg); mean (SD)	247	**6**	**47.5(3.271)**	**129**	**57.98 (9.05)**	**112**	**55.49 (7.92)**
BMI (kg/m^2); n (%)	247						
<18		**1**	**1 (25)**	**1**	**1 (25)**	**2**	**2 (50)**
18-24.99		4	4 (3.74)	49	49 (45.79)	54	54 (50.47)
>25		1	1 (0.75)	78	78 (58.21)	55	55 (41.04)
Literate; n (%)	216	**10**	**10 (4.63)**	**124**	**124 (57.41)**	**82**	**82 (37.96)**
Illiterate; n (%)	130	**3**	**3 (2.29)**	57	57 (43.51)	**70**	**70 (53.44)**
ETS exposure; n (%)	24	**1**	**1 (4.17)**	**12**	**12 (50)**	**11**	**11 (45.83)**
Smoking status; n (%)	345						
Past		**0**	**0**	**3**	**3 (27.27)**	**8**	**8 (72.73)**
Never		13	13 (3.99)	173	173 (53.07)	139	139 (42.64)
Now		0	0	4	4 (44.44)	5	5 (55.56)

Exposures

The geometric mean 24-h indoor NO_2 concentration was significantly higher in households that used biomass for cooking compared to LPG and electricity during both the summer and winter season (Table 2).

Table 2. Time weighted average mean values of HAP pollutants in μg/m^3 in the summer and winter season by fuel types.

Pollutants	ΣN	n	Electricity	n	LPG	n	Biomass
NO_2 (Summer); mean (SD)	166	**10**	**42.27 (30.54)**	**80**	**53.38(62.75)**	**76**	**74.33 (57.51)**
NO_2 (Winter); mean (SD)	122	**1**	**43.97 (0)**	**64**	**39.54 (39.48)**	**57**	**56.33 (54.17)**

The 24-hr indoor concentration of NO_2 was significantly higher during the summer season than in the winter season (Table 3). The total time spent cooking in the households was also significantly higher during the summer season compared to the winter season (Table 3).

Table 3. Total time weighted mean values by season.

Pollutants	ΣN	n	Summer	n	Winter	p
NO_2; mean (SD)	289	167	62.10(59.62)	122	47.42 (47.32)	0.02
Total time spent cooking	349	209	130 (64)	140	119 (20)	0.03

Respiratory symptoms questionnaire

In general most of the respiratory symptoms were more prevalent in women that used biomass fuel for cooking than in the non-biomass users (Table 4). Table 4 presents the general prevalence of respiratory symptoms reported by women that used biomass and non-biomass fuel types for cooking. Similarly, cough, wheezing, and phlegm were more common among women that used biomass compared to the non-biomass fuel (p <0.01). The prevalence of difficulty in breathing was also reported highly among the biomass users compared with the non-biomass users (p <0.01). There were also significant numbers of biomass users that reported having night cough (p <0.02). On the other hand, headaches and chest pain were more prevalent in women that use non-biomass fuel compared with biomass, but it was not statistically significantly different. The reporting of chronic phlegm was evenly distributed among the biomass and the non-biomass users.

Table 4. Respiratory symptoms reported by women according to types of fuel used for cooking.

Respiratory symptoms	**Biomass fuel** ΣN= 281	**Non-biomass fuel** ΣN= 281	**p**
Cough; n (%)	100 (35.6)	95 (33.8)	0.009
On most days	16 (5.7)	12 (4.3)	0.02
Night Cough; n (%)	61 (21.7)	49 (17.4)	0.02
Phlegm; n (%)	107 (38.1)	97 (34.5)	0.001
On most days	44 (15.6)	40 (14.2)	0.28
Chronic Phlegm; n (%)	19 (6.8)	19 (6.8)	0.485
Chest pain; n (%)	26 (9.2)	33 (11.7)	0.25
Palpitation; n (%)	25 (8.9)	21 (7.5)	0.104
Difficulty Breathing; n (%)	69 (24.5)	59 (20.1)	0.013
Headaches; n (%)	107 (38.1)	122 (43.4)	0.544
Wheezing; n (%)	61 (21.7)	47 (16.7)	0.003
On most days	61 (21. 7)	47 (16.7)	0.01

Pulmonary function measurement

Of the total of 381 participants, 281 participants underwent the spirometry after meeting the inclusion criteria. Overall, 27 (9.6%) participants were diagnosed with COPD and suffering from airflow obstruction. In general, univariate analysis suggested poor pulmonary function indices among women that used biomass fuel types for cooking. During the summer season, the FEV1, FVC, and FEV1/FVC were found to be significantly lower among biomass users compared to the non-biomass users (Table 5). Similarly in the winter season, FEV1 and FVC were lower among biomass users compared to the non-biomass users but were not significantly different. In general, mean FEV1, FVC, and FEV1/FVC were also significantly lower during the summer compared to the winter season ($p < 0.03$). In general, the amount of time spent cooking was also significantly associated with lover pulmonary function indices during the summer season compared to the winter season ($p < 0.005$).

Table 5. Mean values of pulmonary function indices by fuel types and season

Parameters	**Biomass**		**Non-biomass**	
	Summer	**Winter**	**Summer**	**Winter**
Time spent cooking	134 (69)	130.5 (13)	137 (65)	109 (19)
FEV1 (Liters)	2.00 (0.54)	2.23 (0.55)	2.22 (0.55)	2.32 (0.49)
FVC (Liters)	2.58 (0.62)	2.77 (0.58)	2.73 (0.59)	2.82 (0.56)
FEV1/FVC	0.788 (0.075)	0.793 (0.126)	0.805 (0.091)	0.820 (0.064)

Multivariate regression analysis (adjusted for age, smoking status, education, season, total cooking time in minutes) results in Table 6 shows mean adjusted differences of NO_2 concentration in quartiles 2 to 4 (Q2 to Q4) relative to the reference quartile Q1. Overall, results from the multivariate analysis show some trends of decreasing pulmonary function with increasing NO_2 concentration, but they were not statistically significant (Table 6). On the other hand, there is a significant trend of increasing risk of respiratory symptoms such as phlegm, nighttime cough, and wheeze with an increasing level of NO_2 when adjusted for the same covariates described above (Table 6).

Table 6. Multivariate linear regressions between pulmonary function parameters, respiratory symptoms and time weighted NO_2 concentrations

Parameters	Time weighted mean exposure			
	Q1 (0-28ug.m3) Mean	Q2 (28-38 ugm3)	Q3 (38-60 ugm3)	Q4 (60 + ugm3)
		Difference from Q1 (95% confidence interval)		
FEV1 (Liters)	Ref	-0.2 (-0.42, 0.006)	-0.02 (-0.22, 0.18)	-0.19 (-0.40, 0.01)
FEV1 (adjusted)*	Ref	-0.08 (-0.26, 0.10)	0.01 (-0.16, 0.18)	-0.09 (-0.28, 0.1)
FEV1/FVC	Ref	0.05 (-0.07, 0.16)	-0.008 (-0.12, 0.10)	-0.001 (-0.12, 0.11)
FEV1/FVC (adjusted)	Ref	0.04 (-0.08, 0.15)	-0.01 (-0.12, 0.10)	-0.003 (-0.12, 0.11)
Cough	Ref	0.03 (-0.15, 0.21)	0.02 (-0.16, 0.19)	0.17 (-0.01, 0.35)
Cough (adjusted)	Ref	-0.01 (-0.19, 0.17)	0.02 (-0.16, 0.19)	0.07 (-0.11, 0.26)
Phlegm	Ref	0.18 (0.01, 0.36)	0.19 (0.02, 0.36)	0.26 (0.09, 0.43)
Phlegm (adjusted)	Ref	0.15 (-0.03, 0.32)	0.19 (0.03, 0.36)	0.18 (0.004, 0.36)
Chest Pain	Ref	-0.22 (-0.56, 0.12)	-0.14 (-0.47, 0.18)	-0.15 (-0.46, 0.15)
Chest Pain (adjusted)	Ref	-0.24	-0.17	-0.12

		(-0.59, 0.11)	(-0.51, 0.17)	(-0.45, 0.21)
Palpitation	Ref	-0.18	-0.18	-0.13
		(-0.49, 0.11)	(-0.47, 0.11)	(-0.40, 0.14)
Palpitation (adjusted)	Ref	-0.19	-0.2	-0.07
		(-0.50, 0.12)	(-0.51, 0.10)	(-0.37, 0.22)
Difficulty Breathing	Ref	0.16	0.16	0.14
		(-0.02, 0.35)	(-0.02, 0.34)	(-0.05, 0.32)
Difficulty Breathing (adjusted)	Ref	0.12	0.17	0.11
		(-0.07, 0.31)	(-0.01, 0.35)	(-0.08, 0.30)
Nighttime Cough	Ref	0.05	0.12	0.25
		(-0.14, 0.23)	(-0.06, 0.29)	(0.06, 0.43)
Nighttime Cough (adjusted)	Ref	0.006	0.09	0.19
		(-0.18, 0.19)	(-0.09, 0.27)	(-0.00, 0.39)
Headaches	Ref	0.003	0.03	0.07
		(-0.14, 0.15)	(-0.10, 0.17)	(-0.06, 0.22)
Headaches (adjusted)	Ref	0.02	0.04	0.06
		(-0.12, 0.17)	(-0.10, 0.18)	(-0.09, 0.22)
Wheeze	Ref	0.03	0.18	0.18
		(-0.15, 0.21)	(0.00, 0.36)	(0.00, 0.37)
Wheeze (adjusted)	Ref	0.02	0.2	0.17
		(-0.17, 0.21)	(0.02, 0.38)	(-0.02, 0.36)

*Adjusted for age (<30, 30-39, 40-49, >49), smoking status (never smoked vs. smoked in the past), education (read and write vs. no read and no write), season (summer and winter), and total cooking time in minutes.

DISCUSSION

As far as I know, this is the first study that investigated the exposure relationship between level of NO_2 and the respiratory symptoms and pulmonary function of women in Nepal that cooked using biomass or non-biomass fuels. There were several important findings in this study. The level of NO_2 was significantly higher during the summer season in the biomass-cooking households. This study showed that risk of reporting respiratory symptoms such as phlegm and wheeze were significantly higher among women exposed to elevated concentration of NO_2. Pulmonary function indices were lower among the biomass users compared to the non-biomass users, and were significantly lower during the summer season.

Overall, the mean level of NO_2 in the biomass and non-biomass cooking households were significantly above the WHO guidelines of indoor air pollution for NO_2 (40 ug.m3) during both the summer and winter season (Adamkiewicz et al. 2010). In general, NO_2 concentration was significantly higher in the summer season. In a study conducted in Korea, similar trend of higher NO2 levels were found during the summer season indoor (Lee et al. 2013). Other studies, however, found higher concentration of NO_2 during the winter season especially in the households that cooked on LPG or gas appliances (Lambert et al. 1993, Garrett et al. 1999).

Level of NO_2 concentration was significantly higher in households that used biomass fuels for cooking during both the summer and winter season. In a study conducted in rural Ethiopia significantly higher concentration of NO_2 (97 ug.m3) was found in households that used biomass fuel (Kumie et al. 2009). This study also found significant trends in the prevalence of respiratory symptoms with increasing concentration of NO_2. In general, the prevalence of respiratory symptoms such phlegm, wheeze, and nighttime cough were significantly higher among women that were exposed to the higher concentration of NO_2 concentration. When the exposure level of NO_2 were adjusted for different biomass (wood, dung, straw) and non-biomass (LPG and electricity) fuel types, a significantly higher number of LPG users reported of having various respiratory symptoms ($p <0.001$). In a large study comprising of 888 non-smoking women, no association was found between NO_2 level and respiratory symptoms when NO_2 was treated as a continuous variable (Trishe et al. 2005). However, when the NO_2 concentration was dichotomized and compared with the reference quartiles, a higher level of NO2 was associated with chest tightness, wheezing, and other acute respiratory symptoms (Trishe et al. 2005, Simoni et al. 2004). This study also found trends in the increase in the prevalence of cough, chest tightness, wheeze, phlegm, and nighttime cough but only the phlegm, wheeze, and nighttime cough was found to be significant with exposure to NO_2 in higher quartiles. One study however reports different findings and draws a different picture on relationship between NO_2 concentration and respiratory symptoms. Keller et al. (1979), found no association of any respiratory illness with measured level of NO_2. Majority of the other studies that has investigated the impact of NO_2 has been mostly limited to children exposure study.

In general, women in the biomass-cooking households spent significantly longer period of time than their non-biomass counterpart. In our study, women cooking with biomass fuel reported spending longer time cooking during winter season. Perhaps, spending more time in front of the biomass cookstoves could result in a higher risk of prevalence of respiratory symptoms. One study found increase in the prevalence of respiratory symptoms among women with duration of time spent per day near the fireplace (Pandey et al. 1984), however, the results were not statistically significant. Similarly, one cross-sectional study of women cooks did not find clear association between frequency of cooking and respiratory symptoms (Ng et al. 1993). However, in the present study, higher prevalence of respiratory symptoms was found in households that used biomass fuel such as wood and agricultural residues. Similar findings have been reported in a study conducted in Nigeria (Desalu et al 2010).

In the present study, some trends of lower pulmonary function indices were observed with higher concentration of NO_2. However, the decrement in pulmonary function indices FEV1 and FEV1/FVC ratio were not significant. Pandey et al. 2011 found similar non-significant association of pulmonary function parameters when compared between biomass and non-biomass users. In a Guatemalan study of women using improved cooking stoves and biomass stoves, pulmonary function indices were non-significant in households where levels of carbon monoxide was measured (Balmes et al. 2015). One longitudinal study found significant decrement of FEV1 among women that were exposed to higher level of NO_2 (Witschi et al 1988). On the other hand, this study also found significantly lower levels of FEV1 in biomass cooking women that spent more time in front of cooking stove ($p < 0.01$). A Brazilian study that evaluated the pulmonary function of 37 professional cooks in the hospital found lower FEV1 with each increasing years of cooking (Braga et al. 2007).

The major strength of this study was that there were three major fuel types as comparator group. In this study, I adjusted the regression model between NO_2 concentration, respiratory symptoms, and pulmonary function indices with several potential confounders. Most of the study conducted in Nepal that looked at biomass use impacts on respiratory symptoms has not been adjusted their statistical models for potential confounders. This multivariate analysis ruled out the potential to run into confounding bias that would otherwise had given false negative results. Any significant association drawn in this study from the multivariate has clearly met the merit to draw conclusion. Additionally, I included only women for this study since women are the main cooks.

This major limitation of this study is that it was a cross sectional study and was conducted in a small city of Bhaktapur in Nepal, and therefore results could not be generalized for the entire country. Other weakness of this study was that I could not measure the NO_2 levels and the pulmonary function measurement in all the houses because of time limitation and resource constraints. The direct measurement of exposure as mean 24-hr idoor NO_2 failed to show any significant association with the pulmonary function parameters but some of the proxy measurements such as biomass and non-biomass fuel types showed a relationship suggesting that exposure to high level HAP as a result of increased period of time spent might be an important risk factors for increased prevalence of respiratory symptoms and reduced pulmonary function.

In the present study, 9.6% of the participants had airflow obstruction and were diagnosed with COPD. The 9.6% prevalence of COPD is alarming, and is in line with other studies which found similar COPD prevalence in Nepal (Kurmi et al. 2014, Joshi et al. 2011, Pandey et al. 1984). One study in Nepal also found greater number of female than male population suffering from COPD (Bhandari et al. 2012). In general, the burden of COPD from biomass smoke exposure was heavy on the households in developing countries that cooked on biomass solid fuels (Kurmi et al. 2010). Additionally, persistence and worsening cough, phlegm production, and dyspnea on exertion are usually symptoms of COPD defined as stage GOLD-0 (GOLD). The GOLD-0 is associated with decline in FEV1 (Mutunayagam et al. 2010). GOLD-0 as a guideline to diagnose risk for COPD has been proven be a poor prognostic value as not all individuals with cough and sputum production develop COPD later in their life. However, early detection of COPD among individuals with persistent respiratory symptoms cannot be understated.

CONCLUSIONS

In summary, the NO_2 levels in the present study were higher than the suggested guideline values stated by the world health organization for indoor air quality. NO_2 levels were higher in the households that use biomass fuel types for cooking. Therefore, it is recommended that flue or chimney should be added to vent out NO_2 to prevent risk of respiratory problems among women that spent significant amount of time cooking. Furthermore, a long-term sustainable solution should focus on replacing the inefficient biomass fuel stoves with cleaner improved cooking alternatives.

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