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Maria Jolly Date

Household Air Pollution ($PM_{2.5}$) and Blood Pressure in Non-Hypertensive Adult Women Living in the Highlands of Peru

By

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Environmental Health - Epidemiology

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By

Maria Jolly

B.S. in Earth Systems, Society, and Environmental Sustainability
University of Illinois at Urbana-Champaign
2013

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An abstract of
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Abstract

Household Air Pollution ($PM_{2.5}$) and Blood Pressure in Non-Hypertensive Adult Women Living in the Highlands of Peru

By Maria Jolly

Purpose: To characterize blood pressure (BP) in non-hypertensive women age 25-65 years who use biomass fuel for cooking in the highlands of Peru. Also, to describe the association between personal exposure to $PM_{2.5}$ from household air pollution and BP in this non-smoking, non-pregnant population in Puno, Peru.

Methods: Conducted a literature review, then analyzed personal $PM_{2.5}$ exposure and BP data. Personal $PM_{2.5}$ exposure was measured using 48-hour direct-reading and gravimetric samples. Corrected $PM_{2.5}$ measurements were used for analysis. Systolic blood pressure (SBP), diastolic blood pressure (DBP), height, weight, date of birth was also measured. The preliminary data used for this thesis included 100 women. SAS 9.4 was used to run two sets of multivariate linear regression models, one with SBP and one with DBP. All independent variables ($PM_{2.5}$, BMI, age, and Time BP was measured) were categorized.

Results: The mean BMI was 26.6 kg/m^2, the mean age was 48 years old, and a large majority of participants had SBP and DBP which were within the normal blood pressure range (since the study excluded hypertensive women). Average personal exposure to $PM_{2.5}$ was 128.83 $\mu g/m^3$. Overall, there was a negative or no correlation between $PM_{2.5}$ and BP. The model indicated an inverse relationship between $PM_{2.5}$ and both SBP and DBP after controlling for age, BMI, and time of day BP was taken (although not statistically significant for DBP). The largest inverse relationship was noted for $PM_{2.5}$ between 57.49 - 92.63 $\mu g/m^3$ when compared to $PM_{2.5}$ less than 34 $\mu g/m^3$ (SBP: -11.91mmHg, p-value: 0.0033, DBP: -5.34 mmHg, p-value: 0.0914).

Conclusions: This study is the first study we identified looking at the association between personal exposure to $PM_{2.5}$ from biomass fuel and BP in the highlands of Peru. The only significant results in our data indicate that personal $PM_{2.5}$ has an inverse association with SBP, after controlling for age, BMI, and time of day BP was taken. Our findings go against a priori knowledge, perhaps due to the cross-sectional study design and restrictions in our study population. As the literature is very sparse on this topic, more research is needed.

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Background:

Exposure to smoke from biomass fuel is a leading contributor to the burden of disease worldwide. It is recognized as a leading risk factor for Chronic Obstructive Pulmonary Disease [1-6], childhood pneumonia [7, 8], low birthweight [9, 10], and all-cause mortality [11-13]. According to a 2014 World Health Organization (WHO) report, every year there are 3.8 million premature deaths attributable to **household air pollution (HAP)** exposure [13]. This is especially detrimental in rural areas of less-developed countries where 90% of people rely on coal and biomass fuels for heating and cooking [14]. In Peru, there are an estimated 6,420 deaths per year from exposure to HAP [15].

Figure 1. Location of Study Site – Puno, Peru

The Cardiopulmonary Outcomes and Household Air Pollution Trial (CHAP, Clinical Trials ID: NCT02994680) site is Puno, a province in southern Peru near Lake Titicaca. Puno is 3,825 meters above sea level and the province had a population of 229,236

inhabitants in 2007 (Figure 1) [16, 17]. CHAP study participants live in rural Puno province, where biomass-burning open-fire stoves are predominantly used for cooking [18]. The women in our study are often from ingenious communities and speak Aymara (a local language) and Spanish. Field staff members collecting data from participants are native Spanish speakers, and at least one member of the field team who speaks Aymara attended each visit [17]. A 2014 cross-sectional study looking at indoor air exposures among rural and urban homes in Puno found that participants in rural homes (cooking primarily with biomass fuels) experienced daily indoor $PM_{2.5}$ and PM_{10} concentrations that were 6-fold higher than participants living in the urban households (where liquefied petroleum gas was used) [18]. Additionally, rural participants cooked with traditional stoves for an average of 32 years in their lifetimes. Because women are the primary food preparers in the household, these data indicate that women in this region experience extremely high lifetime cumulative exposures to biomass smoke [18].

The exposure of interest is **fine particulate matter ($PM_{2.5}$).** These are particles with an aerodynamic diameter less than or equal to 2.5 µm. Fine particles are derived primarily from emissions of combustion processes such as wood or biomass burning [19]. These particles as small enough to be breathed deep into the lungs, remain suspended for longer periods of time, and there is some evidence in current literature of PM-related cardiovascular health effects [19]. The World Health Organization has set an annual average guideline for $PM_{2.5}$ in indoor air at 10 µg/m^3. For 24-hour average exposure, the guideline is 25 µg/m^3 [20].

The outcome of interest in this study is **blood pressure (BP),** which can be an indicator for larger cardiovascular health outcomes because hypertension (abnormally high blood pressure) is a major risk factor for cardiovascular disease [21]. We will use systolic blood pressure (SBP) and diastolic blood pressure (DBP) as our measures of BP, which is consistent with current literature [21-26]. According to the US Centers for Disease Control and Prevention (CDC):

- **Normal BP** levels are SBP less than 120 mmHg *and* DBP less than 80mmHg.
- **Pre-hypertensive BP** levels are SBP 120–139 mmHg *and* DBP 80–89 mmHg
- **High BP** levels are SBP 140 mmHg or higher *or* DBP 90 mmHg or higher [27, 28].

We are interested in assessing of the high elevation environment (3,825 meters above sea) of our population effects BP [17]. There are some literature indicating that indigenous populations living at high elevation have lower BP overall [26, 29, 30], so we will create some summary statistics on what the BP in our study population looks like.

For the analysis of $PM_{2.5}$ on BP, variables of interest include age, body mass index (BMI), and time of day BP measurement was taken. **Age** is known to influence BP. As age increase so do SBP and DBP. This increase in BP with age is primarily associated with structural changes in the arteries - particularly with large artery stiffness [31]. **BMI** is also known to influence BP in the same way. As BMI increases so do SBP and DBP. According to the CDC, a BMI below 18.5 kg/m^2 indicates underweight status, BMI 18.5 – 24.9 kg/m^2 is normal or healthy weight, BMI 25.0 – 29.9 kg/m^2 is overweight, and BMI 30.0 kg/m^2 and above is obese [32]. Stronger relationships between air pollution exposures and adverse health outcomes have been shown for older and obese groups

[22]. **Time of day** impacts BP in relation to activity level. BP is lowest in the morning when you awake from sleep and increases with different activity throughout the day [33].

We have identified a few studies which have looked at the link between PM from household air pollution (HAP) and BP [22-25, 34-37]. Liang et al. (2014) conducted a meta-analysis of 1,028 studies looking at the effect of ambient or personal exposure to $PM_{2.5}$ on blood pressure. Of the 22 studies included, the overall analysis indicated that BP was positively associated with $PM_{2.5}$ [25]. However, they found heterogeneity in the results and used a random effects analysis. When including both ambient and personal air pollution studies, the authors found that for 10mg/m^3 increase in $PM_{2.5}$ there was an elevation of 1.393 mmHg (95% CI: 0.9 to 1.9) of SBP and 0.895 mmHg (95% CI: 0.5 to 1.3) of DBP. Long-term exposure showed a stronger association with BP than short-term [25].

However, of the 22 included studies only 8 were exploring HAP (personal $PM_{2.5}$). The authors mention that when conducting a subgroup analysis on studies looking at personal exposure, there was a positive, but not statistically significant association between $PM_{2.5}$ and BP [25]. From these 8 personal exposure studies, Liang et al. identified 9 estimates for change in SBP and DBP per 10mg/m^3 increase in $PM_{2.5}$. For SBP: 4 estimates were statistically significant and positive, 3 were positive (but did not have statistically significant 95% CI, and the remaining 2 estimates were negative. For DBP: 7 estimates were positive, but did not have statistically significant 95% CI and the remaining 3 were negative [25]. Overall, this meta-analysis indicated a positive

association, however there are mixed results in the literature, with some studies indicating a null or inverse association [23, 38].

We identified very few studies looking at the effects of personal $PM_{2.5}$ exposure from biomass cookstoves on BP. Different impacts of $PM_{2.5}$ on BP have been associated with racial-ethnic and regional variations, and some studies have suggested that exposure to $PM_{2.5}$ from differing sources can have a different impact on BP [25]. There were few studies looking at the association of personal $PM_{2.5}$ exposure from biomass cookstoves and BP in adult women in South America. Burroughs et al. conducted a study looking at biomass use and BP in the highlands of Peru [36], and McCracken et al. (2007) conducted a study on PM and BP in the highlands of Guatemala [23].

The Burroughs et al. study in Puno, Peru included 1,004 adults aged 35 years or older (mean age 55.3 years, 51.7% female). The authors found an association between biomass fuel use and prehypertension with an adjusted relative risk ratio 5.0 (95% CI: 2.6 to 9.9). There was also an association between biomass fuel use and hypertension, with an adjusted relative risk ratio of 3.5 (95% CI: 1.7 to 7.0). When compared to nonusers, biomass fuel users had a higher SBP by 7.01 mmHg (95% CI: 4.4 to 9.6) and a higher DBP by 5.9 mmHg (95% CI 4.2 to 7.6). Overall, the study found that biomass fuel use was associated with an increased risk of hypertension and higher BP in Peru [36].

When looking at longitudinal studies of HAP and BP with exposure-response data for BP, we found a 2011 panel study by Baumgartner et al. [24]. 280 rural Chinese women were enrolled in this study (mean age 52), with multiple personal $PM_{2.5}$ measurements and BP measurements. Ever-smokers and pregnant women were

excluded. The mean of 24-hour personal $PM_{2.5}$ was 55 ug/m^3 in the summer and 117 ug/m^3 in the winter. Using mixed models the authors found an increase in SBP by 2.2 mmHg (95% CI: 0.8 to 3.7) for each unit of log $PM_{2.5}$ among all women, and for women over 50 there was an increase by 4.1 mmHg (95% CI: 1.5 to 6.6) for each unit of log $PM_{2.5}$. There was little effect on SBP in women aged 25-50 years [24].

We did not identify any other comparable published studies of non-pregnant women with personal exposure to $PM_{2.5}$ from HAP and with exposure-response data for BP. However, there are several supporting studies. McCracken et al. (2007) studied 120 rural Guatemalan women of 38 years or older, comparing SBP among those exposed after an intervention with controls [23]. The average personal $PM_{2.5}$ was 264 ug/m^3 in the control group, and 102 ug/m^3 in the intervention group. SBP was 3.7 mmHg lower (95% CI: -0.6 to 8.1) in the intervention arm, and DBP was 3.0 mmHg lower (95% CI: 0.4 to 5.7) in the intervention arm. This study also indicates a lower BP with lower personal exposure to $PM_{2.5}$ [23].

The results from Baumgartner et al. 2011 [24] are consistent with results for women over the age of 40 years in Clark et al 2013 [35], which compared SBP before and after an intervention with an improved cookstove (without a control group) among 74 Nicaraguan non-pregnant women (27 who were over the age of 40 years). 48-hour area $PM_{2.5}$ was reduced from a mean of 1172 ug/m^3 to 208 ug/m^3 in a subset of women (n=25) with pollution data (personal $PM_{2.5}$ not measured). SBP dropped an average of 5.9 mmHg (95% CI: 0.4 to 11.3) in women over 40 years after the intervention, with little effect on women under that age. Finally, similar observations were reported in a 2016

abstract regarding (non-pregnant) women and SBP in relation to HAP by Young et al. [37]. These authors conducted a cross-sectional study of 104 women in rural Honduras, 35 whom were older than 40 years. Among the women 40 years and older, SBP was 4.6 (95% CI: -0.7 to 9.9) mmHg higher per increased unit of log $PM_{2.5}$, a finding very similar to Baumgartner et al. 2011 [24].

With the small number of epidemiological studies on associations between personal $PM_{2.5}$ exposure and BP, results are somewhat mixed, but seem to indicate a positive association. This study is the first study we identified looking at the association between personal $PM_{2.5}$ exposure data from biomass fueled cookstoves and blood pressure in the highlands of Peru.

Methods

Study Objectives

This study will use baseline data from the Cardiopulmonary Outcomes and Household Air Pollution Trial (CHAP), which is an NIH-funded randomized controlled field trial in Puno, Peru [17]. The purpose of CHAP is to determine whether a liquid petroleum gas stove and fuel distribution intervention reduces personal and kitchen exposure to household air pollutants and improves cardiopulmonary health outcomes in non-hypertensive adult women (age 26-65) when compared to traditional cooking methods (open-fire biomass-burning stoves). At baseline, all women included in the used biomass fuel daily for cooking [17]. Collection of baseline data was still underway when this thesis was conducted, but as of March 5, 2018, at most 19 of the 569 (0.03%) women assessed for eligibility were excluded due to hypertension.

Baseline BP and indoor air quality ($PM_{2.5}$) data from CHAP participants' personal monitors were used in this analysis. The analysis looked at what baseline BP is like in the CHAP study population, which is of interest as the population is living at high altitude (3,825 meters above sea) [17]. We then investigated if BP is associated with personal $PM_{2.5}$ exposure. Below are descriptions of our main aims.

Aim 1: *Characterize baseline blood pressure in adult, non-hypertensive women who use biomass cookstoves in Puno, Peru.*

Conduct a literature review on BP levels at high elevation and risk factors that impact BP. Utilizing this information, conduct descriptive statistics on baseline BP data to characterize baseline BP in the CHAP study participants.

Hypothesis for Aim 1: *Based on the literature, we would expect the baseline blood pressure (BP) in our high-elevation population to be lower than the average at sea-level [26, 29, 30].*

Women enrolled in this study are often from ingenious communities. Hannah et al. (1999) found that indigenous groups naturally exposed to total body cooling with suppression of shivering and acclimatization had close to normal, if not lower than western-standard-normal BP [30]. Additionally, the authors found that after years of residence at high-elevation, SBP and DBP gradually decline, in some cases falling to levels below those observed at sea level. SBP seemed more influenced by high elevation than DBP, but the biological mechanism causing this decrease in BP are unknown [30]. Makela el al. (1977) postulated that there were lower BP observed in the indigenous Andean populations at high altitudes due, in part, to lower body weights as a result of the harshness of high altitude environments [29].

Aim 2: *Describe the association between personal $PM_{2.5}$ exposure from household air pollution and blood pressure in adult non-hypertensive, non-smoking, non-pregnant women age 25 to 65 who use biomass cookstoves in Puno, Peru.*

We modeled the cross-sectional data via a multivariate linear regression model. Many studies have modeled the impact of $PM_{2.5}$ on BP using regression analysis [22, 23]. Some additional predictors of interest include: age, Body Mass Index (BMI), and time of

day of BP data were obtained. Per CHAP study restriction, any woman who was pregnant or planning to become pregnant, smoked daily, or has hypertension were excluded from the study. Our models were run for SBP and DBP.

Hypothesis for Aim 2: *High levels of personal exposure to $PM_{2.5}$ (taken over a 48-hour sampling period), is associated with high levels of systolic blood pressure (SBP) and diastolic blood pressure (DBP).*

Project Design and Methodology

Since February 2017, the CHAP trial has been enrolling a target of 180 female participants. To be eligible for the CHAP, women must be 25–64 years old, be the primary cook, be a full-time resident in their current location for at least 6 months, be capable of understanding study procedures, providing informed consent, and responding to questionnaires. Additionally, they must also use biomass fuels daily for cooking and have a cooking area separate from their sleeping area. The latter criterion was added to exclude households that use biomass fuel stoves to heat their living space. Women were excluded if they have hypertension. Hypertension was assessed as whether women are taking antihypertension medications, have systolic blood pressure ≥ 140 mmHg, have diastolic pressure ≥ 90 mmHg, or have a diagnosis of COPD (defined as post-bronchodilator FEV1/FVC below the lower limit of normal of a reference population). Women were also excluded if they smoked cigarettes daily, were pregnant or had plans to become pregnant in the next year, had active pulmonary tuberculosis, or were taking anti-tuberculosis medications. After enrollment, information was collected on socio-demographic characteristics, household characteristics, and cooking practices [17].

Collection of baseline data was still underway when this thesis was conducted, and the enrollment data is still being entered and cleaned, but as of March 5, 2018, our preliminary data indicate 569 women were assessed for eligibility and 181 enrolled. A total of 364 were excluded, at most 19 were excluded due to hypertension, and 131 were excluded because they do not primarily use a biomass stove. 24 women had

dropped out. For more on enrollment, see Figure 2. CONSORT form - CHAP Enrollment March 5, 2018 – Preliminary Data in the Tables & Figures chapter.

Personal indoor air exposure measurements were taken using 48-hour concentrations of fine particulate matter ($PM_{2.5}$). The Enhanced MicroPEM (ECM) real time aerosol monitor (RTI Inc., Research Triangle Park, NC, USA) was used to measure $PM_{2.5}$ via both direct-reading concentration and gravimetric samples. The monitors were placed in each participant's breathing zone via being worn in an apron (developed by a previous Hopkins research team in Peru). The aprons were provided free of charge to the participants and worn as seen in Figure 3. The aprons were selected as the most feasible and acceptable method for personal exposure sampling during formative research. They are common and often used throughout the day by the women in these communities. Women were asked to wear the aprons throughout the duration of the 48-hour sampling period and keep them close and to the height of their heads when they must take the instruments off, for example by hanging them or placing them close to the level of the bed when sleeping [17]. For real-time assessment of $PM_{2.5}$, The ECM has a light-scattering laser. To gravimetrically collect $PM_{2.5}$ in a 15-mm diameter filter, there is a 0.3-L/min pump that runs continuously on for 48 hours. We calibrated the ECM pumps daily with a TSI 4100

Figure 3. Apron developed by a previous Hopkins research team in Peru holding an ECM Monitor

flowmeter (TSI Incorporated, Shoreview, MN, USA). We used 15-mm Teflon filters with a 2-µm membrane (Measurement Technology Laboratories LLC, Minneapolis, MN, USA). All filters were pre- and post-weighed in a humidity- and temperature-controlled room using a XP2U microbalance (Mettler Toledo, Columbus, OH, USA) located in the Department of Environmental Health and Engineering of the Bloomberg School of Public Health at Johns Hopkins University. Direct readings of $PM_{2.5}$ were conducted every 3 out of 10 seconds and these values were time-weighted and averaged into 1-min intervals [17].

Systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured in sets of three readings over five-minute intervals while the woman was in the sitting position. An automatic blood pressure monitor OMRON HEM-780 (Omron, Tokyo, Japan) was used. At enrollment, we determined the arm with the highest SBP and used that arm thereafter for all measurements. The second and third values were then averaged to determine final SBP and DBP [17].

Anthropometric measurements, such as height, weight, date of birth were also measured at baseline. In the Appendix B you will find the approval form from Emory IRB for this study. For this analysis, we will be using the baseline BP and baseline personal exposure to $PM_{2.5}$ data from the CHAP study.

Methods of Analysis

This study is mainly descriptive as it is cross-sectional data. We will be evaluating association, but because there is no temporality in the data, it will be difficult to make a causal inference. We began with continuous cross-sectional data and we categorized the independent variables and modeled the association via a multivariate linear regression. Many studies have modeled the impact of $PM_{2.5}$ on BP using linear regression [22-25]

The SAS 9.4 computer program was used to conduct all data analyses (SAS Institute; Cary, NC, USA). We began by cleaning the dataset to only include data on the exposure, outcome, and other variables of interest. These include: 48-hour mean personal $PM_{2.5}$ exposure, SBP, DBP, age, height, weight, Body Mass Index (BMI), and time of day of BP data were obtained. BMI was calculated using weight (kg) / [height (m)]^2 [32]. Per CHAP study enrollment criteria, any woman who was pregnant or planning to become pregnant, smoked daily, or had hypertension were excluded from the study, so these variables were not considered in the analysis.

After cleaning the data, we conducted exploratory data analysis using PROC UNIVARIATE. We created scatterplots of all bivariate associations between explanatory and response variables to assess linearity. We looked at if the natural log($PM_{2.5}$) indicated a linear relationship with BP. We tested fit using a goodness of fit test and plotting the residuals. The outcome variables (SBP and DBP) were kept continuous. Based on standards in current literature, we examined SBP and DBP independently as indicators for BP [21-26]. We assessed the extent of the correlation between BP and

$PM_{2.5}$ via a Spearman's coefficient using PROC CORR. Our data indicated a linear model would be a good fit, so we test the assumptions of linear regression for these data (homoscedasticity, existence, independence, linearity, normal distribution for residuals). These assumptions were met, and we ran 2 regression models using PROC GLM, one where with BP modeled using SBP and one with DBP. We obtained the initial model below:

$$\mathbf{E\ (BP|\ PM_{2.5}) = \beta_0 + \beta_1\ (PM_{2.5}) + \beta_2\ (BMI) + \beta_3\ (Age) + \beta_4\ (Time\ of\ day\ of\ BP\ taken) + E}$$

To obtain the final model, we identified potential effect modifiers and confounders. In previous air pollution literature, categorization of variables has been useful when a monotonic linear trend in the data cannot be assumed, specifically for dose-response relationships [39]. We categorized our independent variables (BMI, age, and time of day BP measured) using biologically relevant cut-points (BMI, Age), cut-points based on the distribution of the variable ($PM_{2.5}$), and/or cut-points which allow for meaningful data interpretation (Age, Time BP was measured). We utilized backwards elimination to remove any potential confounders which were not statistically significant, except the biologically relevant variables: $PM_{2.5}$ and age. Finally, we checked if there was collinearity between variables in the data. Our final model was:

$$\mathbf{E\ (BP|\ PM_{2.5}) = \beta_0 + \beta_1\ (PM_{2.5}\ category) + \beta_2\ (BMI\ category) + \beta_3\ (Age\ category) + \beta_4\ (Time\ of\ day\ of\ BP\ taken\ category) + E}$$

After obtaining our final model, we ran a multivariate linear regression analysis to assess the relationship between personal exposure to household air pollution and blood pressure. Our results indicate how personal exposure to $PM_{2.5}$ may be associated SBP and DBP levels.

Results

Descriptive Statistics

At the time of this analysis, there were only 100 women (of the 181 enrolled) whom we had collected the appropriate data on BP, $PM_{2.5}$, age, and BMI. 74% participants were over-weight or obese and the mean BMI was 26.6 kg/m^2, indicating an average of overweight status in our sample [32]. The mean age was 48 years old and a large majority of participants had SBP and DBP which were within the normal blood pressure range. 94% had SBP less than or equal to 120 mmHg and 92% had DBP less than 80 mmHg. This was expected since the study excluded hypertensive women. At most 19 of the 569 (0.03%) women assessed for eligibility were excluded due to hypertension. Indoor $PM_{2.5}$ exposure was very high, with an average of 128.83 $\mu g/m^3$. 87% of participants had an exposure above the WHO's 24-hour average limit of 25 $\mu g/m^3$ [20]. Below is a summary of descriptive statistics of the sample of 100 women:

Table 1. Summary of Descriptive Statistics for n=100 Sample

	$PM_{2.5}$ ($\mu g/m^3$)	SBP (mmHg)	DBP (mmHg)	Age (Years)	BMI (kg/m^2)	Time BP taken (hour since 00:00)
Minimum	3.99	71.50	44.50	24.00	17.74	5.90
Median	69.01	100.00	67.00	48.50	25.97	7.63
Maximum	1155.49	134.00	92.00	64.00	36.02	11.02
IQR	91.21	14.00	11.00	16.00	5.48	1.60
Mean	128.83	100.00	66.76	47.85	26.60	7.69
SD	188.71	12.20	8.91	10.43	3.87	1.09

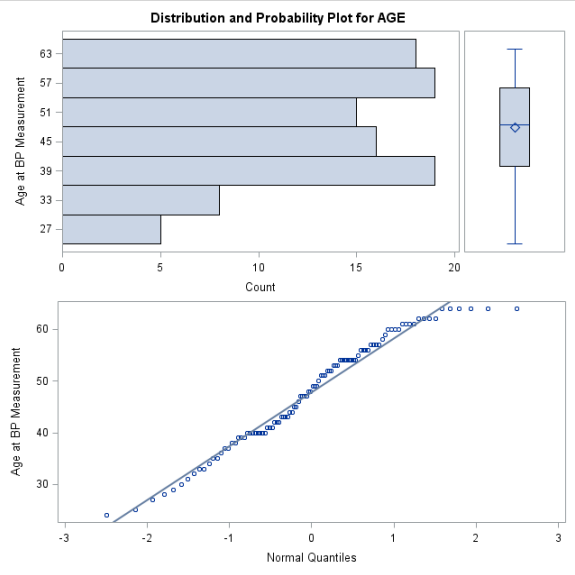

Figure 4. Distribution and Probability Plots for Age

Exploratory data analysis indicated that most variables seemed normally distributed. Age broke from normality among older participants, but this seems to be due to the study design limitation of only enrolling women under 65 years. The normal curve looks as if it were truncated at age 65 (Figure 4). The only gross violation of normality was in our predictor, $PM_{2.5}$, which does not necessarily have to be normal (Figure 5). After log-transforming $PM_{2.5}$ via $\ln(PM_{2.5})$, the data took on a normal distribution (Figure 6). The other assumptions of linear regression (homoscedasticity, existence, independence, linearity, and normal distribution for residuals) were met for the variables in our model.

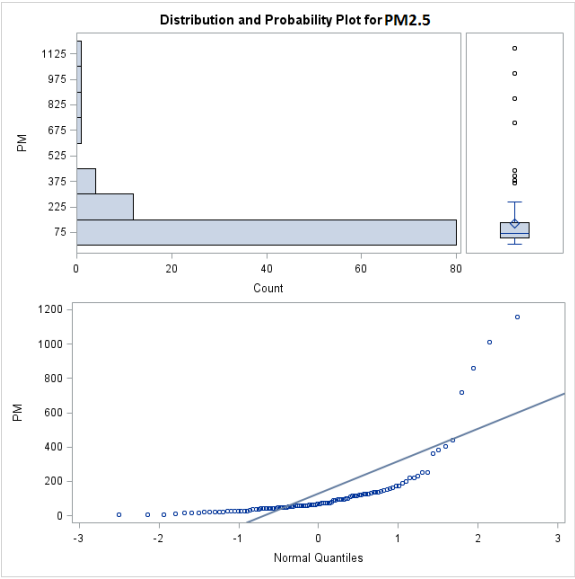

Figure 5. Distribution and Probability Plots for $PM_{2.5}$

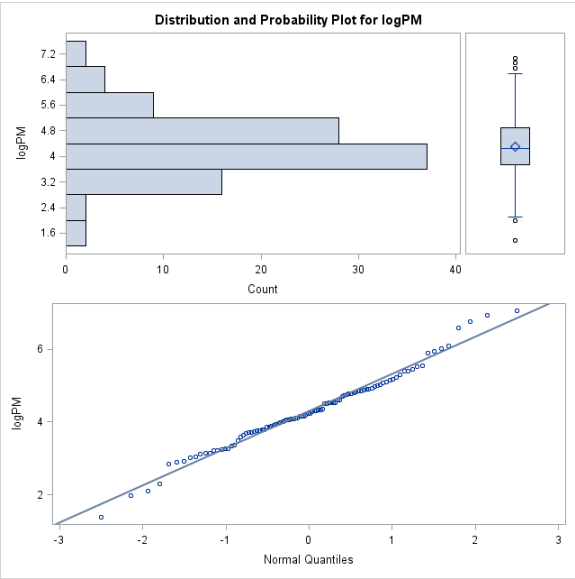

Figure 6. Distribution and Probability Plots for $\ln(PM_{2.5})$

Visual examination of the association between SBP and DBP and $PM_{2.5}$ with and without transformations indicated that there was likely a correlation close to 0. If there was a relationship, it seemed to be non-monotonic. See Figure 7 for scatterplots of SBP and DBP with un-transformed $PM_{2.5}$ and Figure 8 for scatterplots of SBP and DBP with $\ln(PM_{2.5})$. Finally, see Figure 9 Boxplots of SBP and DBP with categorized $PM_{2.5}$.

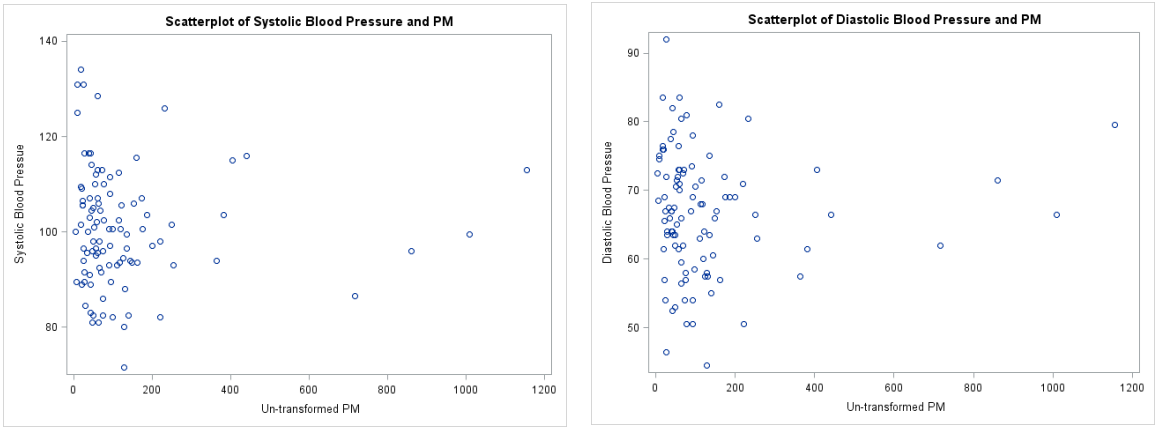

Figure 7. Scatterplots of SBP and DBP with un-transformed $PM_{2.5}$:

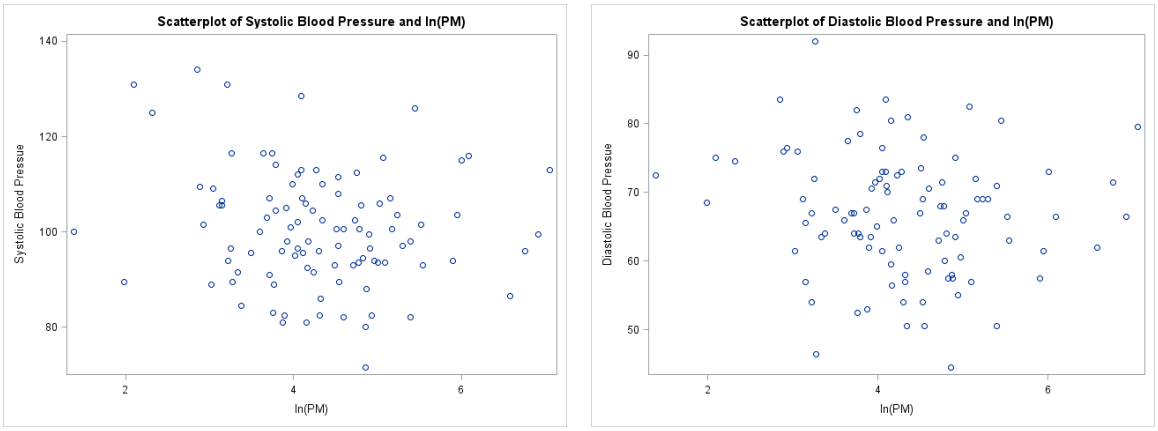

Figure 8. Scatterplots of SBP and DBP with log-transformed $PM_{2.5}$ – $ln(PM_{2.5})$

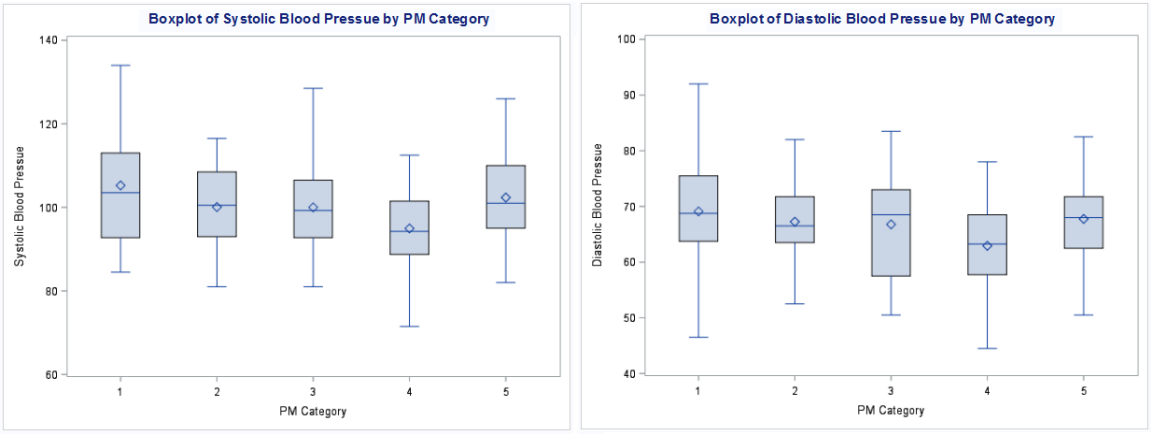

Figure 9. Boxplots of SBP and DBP with categorized $PM_{2.5}$

Analytic statistics:

Overall, there seems to be a negative or no correlation between $PM_{2.5}$ and BP. We conducted a sensitivity analysis via analyzing the association between $PM_{2.5}$ and BP in both personal and kitchen $PM_{2.5}$. The negative or no correlation trend was observed for both personal and kitchen exposure. For this thesis, the focus is on personal exposure data. When stratified by age, there seemed to be some difference in correlation based on age group. For more on the results of age stratification and **Error! Reference source not found.**exposure, Appendix C. We went through various analyses via multivariate linear regression with un-transformed $PM_{2.5}$, $\ln(PM_{2.5})$, and with $PM_{2.5}$ categorized into quintiles. We ran the regression with both SBP and DBP. The zero or negative correlation was present in all these analyses. The full model we began with was:

$$\mathbf{E\ (BP|\ PM_{2.5}) = \beta_0 + \beta_1\ (PM_{2.5}) + \beta_2\ (BMI) + \beta_3\ (Age) + \beta_4\ (Time\ of\ day\ of\ BP\ taken) + E}$$

We began by looking at the Spearman's correlation for SBP and DBP separately related to $PM_{2.5}$, BMI, age, and time of day BP taken. These correlations seemed quite poor and many of the strongest correlations are negative:

Table 2. Spearman's Correlation for BP and $PM_{2.5}$, BMI, Age, and Time

Spearman's correlations for SBP:	**Spearman's correlations for DBP:**
$PM_{2.5}$: -0.13 **BMI:** 0.12 **Age:** 0.22 **Time of day BP was measured:** -0.28	**$PM_{2.5}$:** -0.16 **BMI:** 0.11 **Age:** -0.09 **Time of day BP was measured:** -0.25

In previous literature, categorization of variables has been useful when a monotonic linear trend in the data cannot be assumed, specifically for dose-response relationships [39]. We decided we would categorize our independent variables before continuing to assess the relationship between SBP/DBP and $PM_{2.5}$. **$PM_{2.5}$** was categorized into quintiles with 20^{th}, 40^{th}, 60^{th}, 80^{th} percentiles as cut-points – each category had roughly n=20. The 0-20^{th} percentile $PM_{2.5}$ category (labeled as $PM_{2.5}$ category = 0) was used as the reference group. **Age** was categorized into under 40 years old and 5-year age groups between 40 and 65. All participants under 40 were collapsed into Age category = 0, which was the reference group. **BMI** was categorized into groups based on weight status normal, over-weight, or obese. There were only two underweight participants, and both had BMI above 17.5 kg/m^2. The CDC cut-point for underweight status is 18.5, so we collapsed these two participants into the normal weight category, which was the reference group (labeled as BMI category = 0) [32]. **Time of day** was roughly categorized into hour of day since 7:00am with some collapsing of early and late hours containing very few observations. The earliest time group was used as the reference (Time category = 0). For more details on the categorizations, see Tables 3, 4, 5, and 6 in the Tables & Figures chapter.

The results below are for the multivariate linear regression model we ran, based off the final model:

$$\mathbf{E\,(BP|\ PM_{2.5}) = \beta_0 + \beta_1\,(PM_{2.5}\ category) + \beta_2\,(BMI\ category) + \beta_3\,(Age\ category) + \beta_4\,(Time\ of\ day\ of\ BP\ taken\ category) + E}$$

Our model had an $R^2 = 0.27$ for the outcome of SBP. While not perfectly monotonic, the model indicated that with increasing $PM_{2.5}$ exposure, there was decreasing SBP after controlling for age, BMI, and time of day BP was taken. The largest inverse relationship (-11.91mmHg, p-value: 0.0033) was noted for $PM_{2.5}$ exposure between 57.49 - 92.63 $\mu g/m^3$ when compared to $PM_{2.5}$ exposure less than 34 $\mu g/m^3$. When compared to women younger than 40 years, SBP increases for each 5-year age category above 40. The greatest increase in SBP was noted in those aged 60-65 years (+13.88 mmHg, p-value: 0.0006), followed by those aged 45-50 (+7.15 mmHg, p-value; 0.0945).

For DBP, our model had an $R^2 = 0.14$. While not perfectly monotonic nor statistically significant, the model indicated that with increasing $PM_{2.5}$ exposure, there was a decreasing DBP, after controlling for age, BMI, and time of day BP was taken. The largest inverse relationship (-5.34 mmHg, p-value: 0.0914) was also noted for $PM_{2.5}$ exposure between 57.49 - 92.63 $\mu g/m^3$ when compared to $PM_{2.5}$ exposure less than 34 $\mu g/m^3$. No findings for DBP were statistically significant. The full results for systolic and diastolic blood pressure are in Tables 7 and 8 in the Tables & Figures chapter.

After running this multivariate linear regression with categorical variables, no variable seemed to trend monotonically linear, so we kept all variables as categorical in the final model. Additionally, BMI had multiple categories with p-values above 0.7 and was by far the least statistically significant variable in our model. Via backwards elimination, BMI was removed. The removal of BMI resulted in a minor change in R^2 from 0.27 to 0.26 for SBP and from 0.14 to 0.13 in DBP. It also reduced the number of

statistically significant parameter estimates we had for categories of $PM_{2.5}$, indicating that removing BMI did not help us better predict the association of $PM_{2.5}$ exposure on BP. Additionally, BMI is a biologically relevant predictor of BP, so we decided to keep BMI in the model. There were 4 outliers in the $PM_{2.5}$ data, defined as being above 150% of the inter-quartile range of $PM_{2.5}$ (above 500 $\mu g/m^3$). We explored dropping these four and re-running the model, but there was no appreciable difference in the output. Thus, we decided to keep these in.

Discussion

We identified a few studies which have looked at the link between PM from household air pollution (HAP) and BP [22-25, 34-37]. With the small number of epidemiological studies on associations between personal exposure to $PM_{2.5}$ and BP, results are somewhat mixed, but seem to indicate a positive association. This study is the first study we identified looking at the association between personal $PM_{2.5}$ exposure data from biomass fuel stoves and blood pressure in the highlands of Peru. This study also utilized a novel air monitoring device, The Enhanced MicroPEM real time aerosol monitor (RTI Inc., Research Triangle Park, NC, USA) to measure PM2.5 via both direct-reading concentration and gravimetric samples. However, our results go against the a priori knowledge, likely due to our cross-sectional study design and study participant restrictions.

A meta-analysis by Liang et al. from 2014 found that on average in the 8 identified studies, personal exposure to $PM_{2.5}$ was positively associated with BP, but this finding was not statistically significant [25]. Overall, this meta-analysis indicated a positive association, however there are mixed results in the literature, with some studies indicating a null or inverse association [23, 38]. There were very few studies specifically looked at the effects of personal exposure to PM from biomass cookstoves on BP [7, 23, 36]. The Burroughs et al. study was conducted in the same province of Peru as this study and found that biomass fuel use was associated with an increased risk of hypertension and higher BP in this population [36]. Longitudinal studies of HAP and BP with exposure-response data for BP, include a 2011 panel study by Baumgartner et

al. [24]. This study site was rural China and found an increase in SBP by 2.2 mmHg (95% CI: 0.8 to 3.7) for each unit of log $PM_{2.5}$ among all women, and for women over 50 there was an increase by 4.1 mmHg (95% CI: 1.5 to 6.6) for each unit of log $PM_{2.5}$ [24].

Other supporting intervention studies also indicated a positive association between $PM_{2.5}$ from biomass stoves and BP [23, 24, 35]. Finally, similar observations were reported in a 2016 abstract regarding (non-pregnant) women and SBP in relation to HAP by Young et al. [37]. These authors conducted a cross-sectional of studied 104 women in rural Honduras, 35 whom were older than 40 years. Among the women 40 years and older, SBP was 4.6 (95% CI: -0.7 to 9.9) mmHg higher per increased unit of log $PM_{2.5}$ [37], a finding very similar to Baumgartner et al. 2011 [24].

This study is the first study we identified looking at the association between personal $PM_{2.5}$ exposure data from biomass fuel stoves and blood pressure in the highlands of Peru. The only significant results in our data indicate that exposure to $PM_{2.5}$ has an inverse association with SBP. This was after controlling for age, BMI, and time of day BP was taken. Our findings go against a priori knowledge, perhaps due to the cross-sectional study design and restrictions in our study population.

Most of our estimates were not statistically significant, however it seems that compared to the youngest age group (under 40 years), SBP increase with age, although this relationship is not monatomic. Participants between the ages of 50-60 years had smaller increases in SBP when compared to those aged 45-50 years. The relationship between age and DBP is less clear. For DBP, most age categories above 40 years result in

increased DBP, but the 50-60 years age categories had decreased DBP when compared to the under 40 reference group.

Because we utilized cross-sectional data, we cannot say for certain that temporality between exposure and outcome exists. Most of the published literature on HAP from biomass stoves and BP are longitudinal studies and find a positive association [23, 24, 35]. Our study design limits us from making any causal inferences from our results, since blood pressure and indoor air pollution were measured at the same time. Additionally, this study was looking at non-hypertensive women, so participants were excluded who were taking antihypertension medications, had systolic blood pressure ≥ 140 mmHg, had diastolic pressure ≥ 90 mmHg, or had a diagnosis of COPD (defined as post-bronchodilator FEV1/FVC below the lower limit of normal of a reference population). Women were also excluded if they smoke cigarettes daily, were pregnant, had plans to become pregnant in the next year, or have active pulmonary tuberculosis or are taking anti-tuberculosis medications [17]. If hypertensive and/or women older than 65 years were included in this study, we may have obtained different results.

Another limiting factor may have been proper use of apron. All personal $PM_{2.5}$ measurements were taken from an ECM device worn on the woman's apron. If a woman was not wearing her apron during the day, especially during cooking events, we may be missing significant exposure data. However, this is unlikely as our sensitivity analysis of kitchen concentrations showed similar results to our personal exposure concentrations of $PM_{2.5}$.

Conclusions and Recommendations

A small number of epidemiological studies have looked at the association between personal $PM_{2.5}$ exposure and BP, and results are not fully consistent, but seem to indicate a positive association between personal exposure to $PM_{2.5}$ and BP. Nonetheless, there is a need for further research. A review of epidemiological evidence on the health effects of particulate air pollution conducted in 2011 by Rückerl et al. found that the underlying mechanisms for the effects of PM on blood pressure require a prolonged and cumulative exposure to reach the maximum effect. The review suggested that studies with longer time lags (i.e. 5-day or 7-day averages) demonstrating positive and more pronounced association than those with shorter lag-times, which report more acute effects [38].

To better understand the association between personal $PM_{2.5}$ exposure and blood pressure, the first step would be to re-run this analysis with the full baseline data (n=180), rather than our subset of 100. A next step would be to conduct another analysis in the future which does not exclude hypertensive participants or those above 65 years of age. Additionally, it would be interesting to conduct pilot testing with longer $PM_{2.5}$ averages. Because the result of studies looking at PM and BP are mixed, further research is needed, specifically for the health effects of biomass stoves, which are used by 90% of people in less-developed countries [14].

Nonetheless, our preliminary baseline data indicate that indoor $PM_{2.5}$ exposure is very high for our population using biomass stoves. $PM_{2.5}$ was on average, 128.83

μg/m^3 and 87% of participants had an exposure above the WHO's 24-hour average limit of 25 μg/m^3 [20]. In the interim, measures should be taken to ensure that this population has access to methods of reducing their indoor air pollution burden. Hopefully, currently research on this topic will encourage the Peruvian government to increase the subsidies for clean-burning alternative to biomass.

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Tables & Figures

Figure 1. Location of Study Site – Puno, Peru

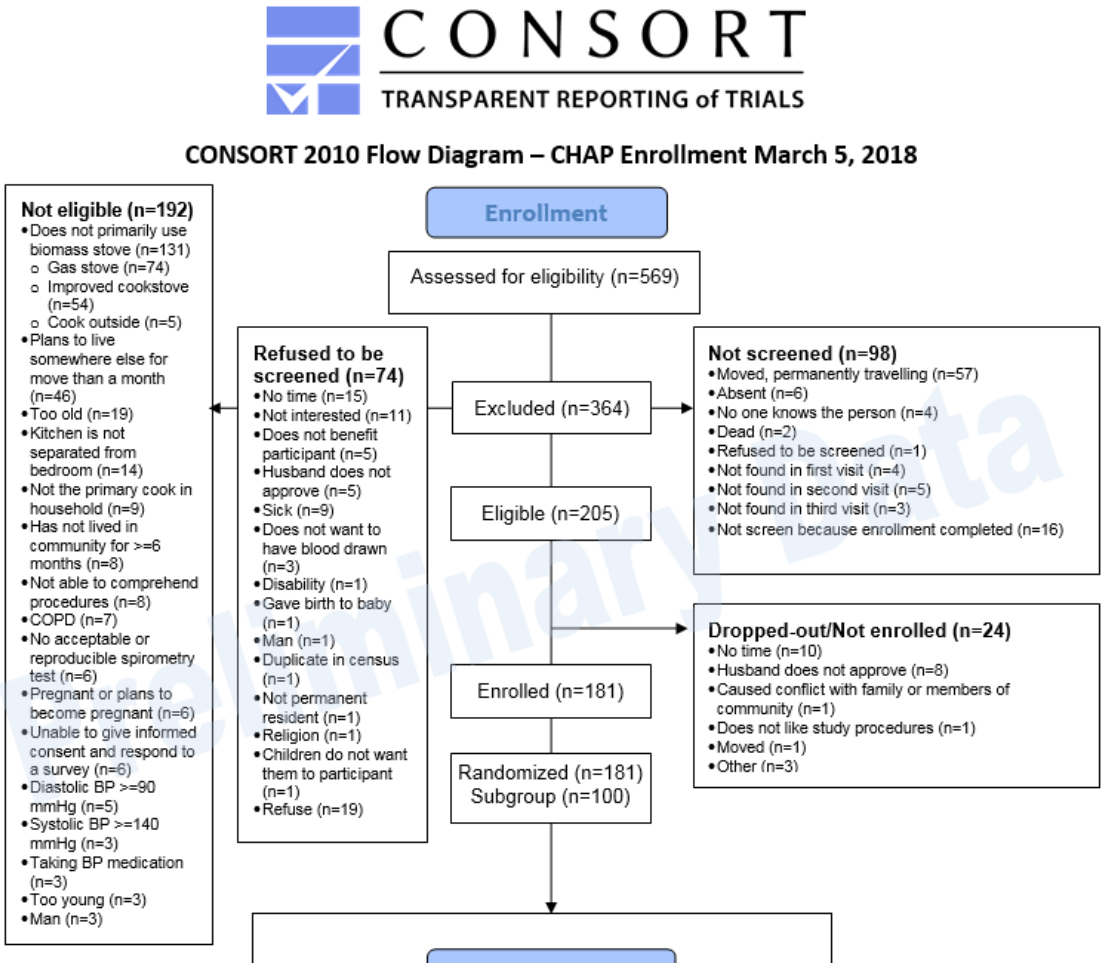


Figure 2. CONSORT form - CHAP Enrollment March 5, 2018 – Preliminary Data

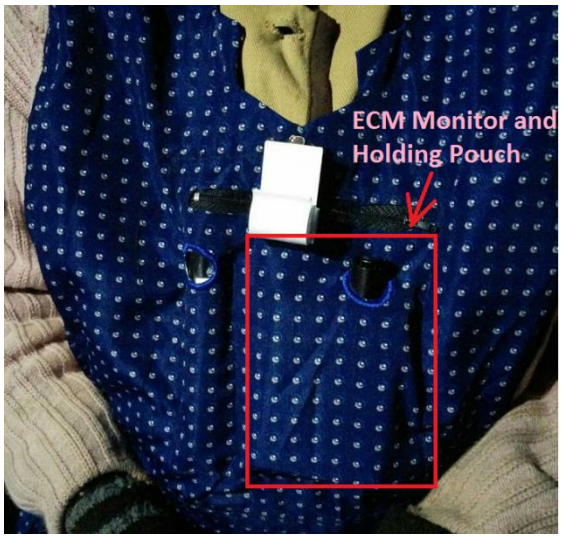


Figure 3. Apron developed by a previous Hopkins research team in Peru holding an ECM Monitor

Table 1. Summary of Descriptive Statistics for n=100 Sample

	$PM_{2.5}$ ($\mu g/m^3$)	SBP (mmHg)	DBP (mmHg)	Age (Years)	BMI (kg/m^2)	Time BP taken (hour since 00:00)
Minimum	3.99	71.50	44.50	24.00	17.74	5.90
Median	69.01	100.00	67.00	48.50	25.97	7.63
Maximum	1155.49	134.00	92.00	64.00	36.02	11.02
IQR	91.21	14.00	11.00	16.00	5.48	1.60
Mean	128.83	100.00	66.76	47.85	26.60	7.69
SD	188.71	12.20	8.91	10.43	3.87	1.09

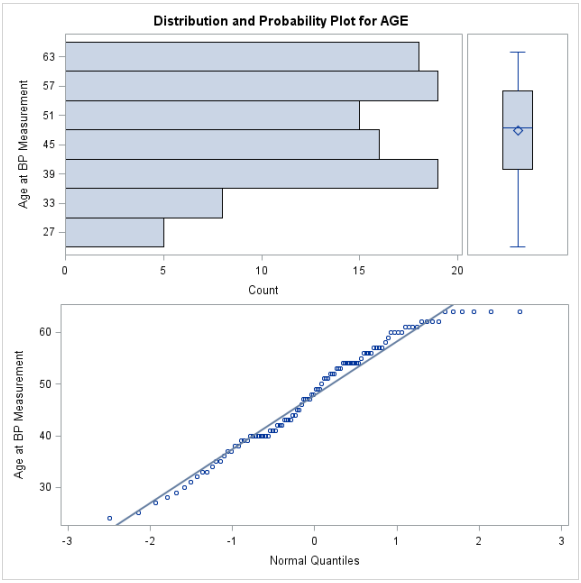


Figure 4. Distribution and Probability Plots for Age

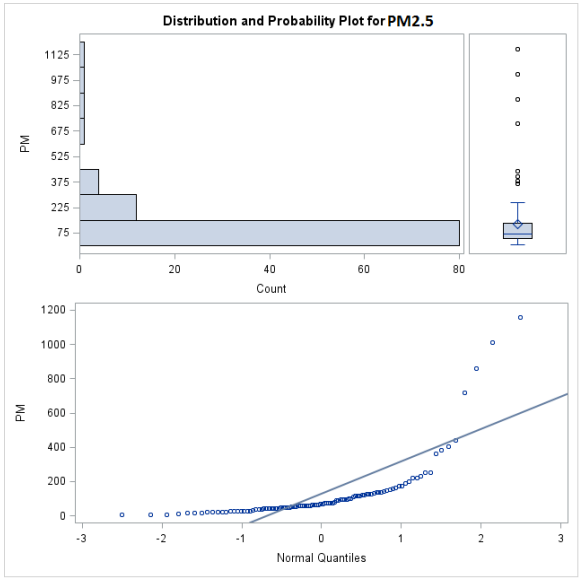


Figure 5. Distribution and Probability Plots for $PM_{2.5}$

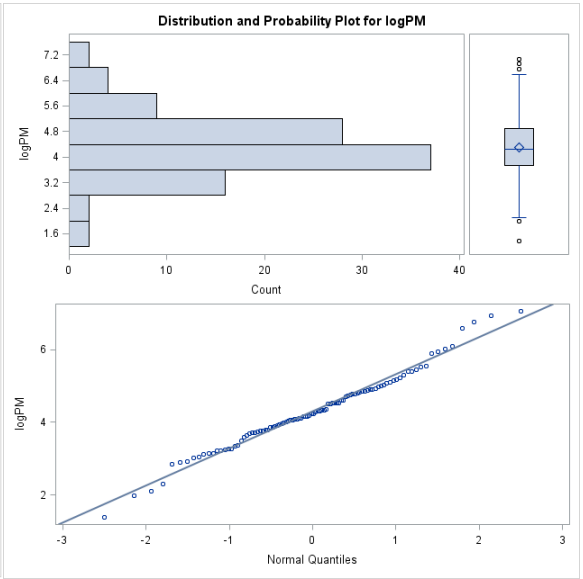


Figure 6. Distribution and Probability Plots for ln($PM_{2.5}$)

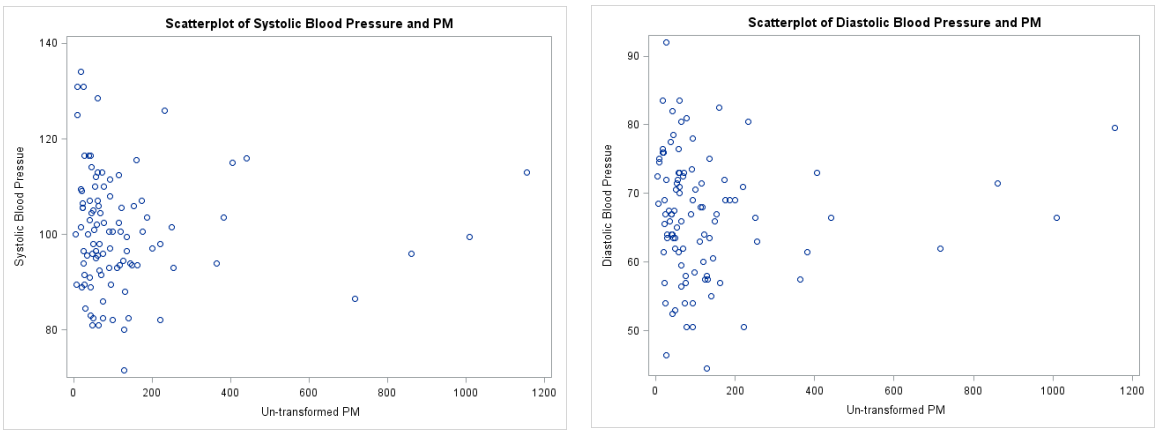


Figure 7. Scatterplots of SBP and DBP with un-transformed $PM_{2.5}$:

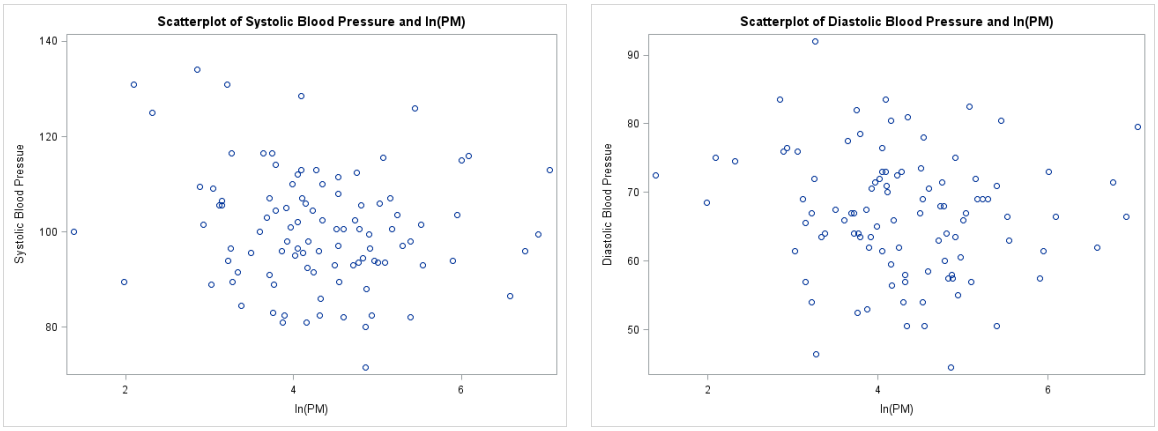


Figure 8. Scatterplots of SBP and DBP with ln-transformed $PM_{2.5}$

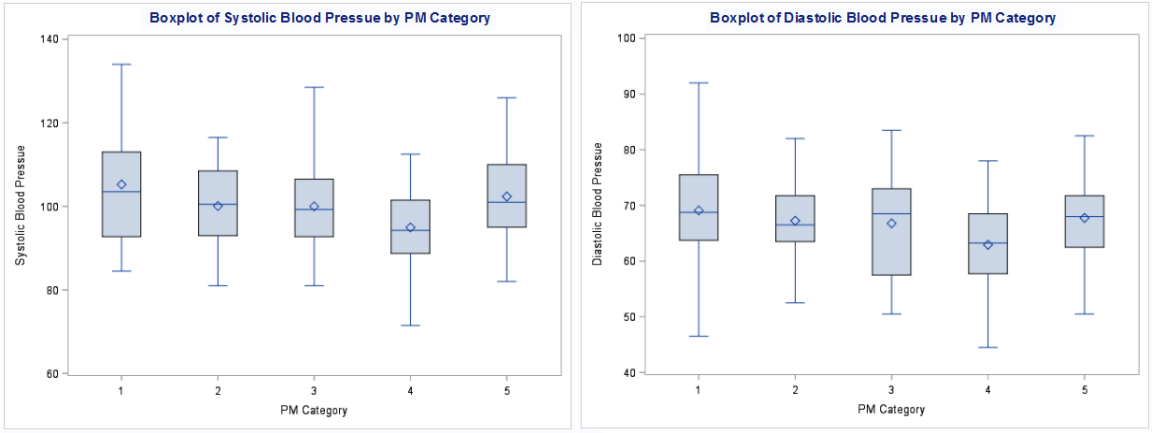


Figure 9. Boxplots of SBP and DBP with categorized $PM_{2.5}$

Table 3. Spearman's Correlation for BP and $PM_{2.5}$, BMI, Age, and Time

Spearman's correlations for SBP:	Spearman's correlations for DBP:
$PM_{2.5}$: -0.13 **BMI:** 0.12 **Age:** 0.22 **Time of day BP was measured:** -0.28	**$PM_{2.5}$:** -0.16 **BMI:** 0.11 **Age:** -0.09 **Time of day BP was measured:** -0.25

Categorizations:

Reminder, the model is: $E(BP| PM_{2.5}) = \beta_0 + \beta_1 (PM_{2.5}) + \beta_2 (BMI) + \beta_3$ (Age at BP measure) + β_4 (Time of day of BP data was obtained) + E

Table 3. $PM_{2.5}$ was categorized into quintiles with 20th, 40th, 60th, 80th percentiles as cut-points – each category had roughly n=20. $PM_{2.5}$ category 0 was the reference group.

$PM_{2.5}$ Category	Includes	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	$PM_{2.5}$<34 μg/m^3	20	20.00	20	20.00
1	34<= $PM_{2.5}$<57.49 μg/m^3	20	20.00	40	40.00
2	57.49<= $PM_{2.5}$<92.63 μg/m^3	20	20.00	60	60.00
3	92.63<= $PM_{2.5}$<150 μg/m^3	20	20.00	80	80.00
4	150<= $PM_{2.5}$ μg/m^3	20	20.00	100	100.00

Table 4. BMI was categorized into groups based on weight status normal, over-weight, or obese. There were only 2 underweight participants, and both had BMI above 17.7 kg/m^2, these 2 were collapsed into the normal weight category, which was the reference group.

BMI Category	Includes	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0 (Normal)	BMI<25 kg/m^2	26	26.00	26	26.00
1 (Over-weight)	25<=BMI<30 kg/m^2	54	54.00	80	80.00
2 (Obese)	30<=BMI	20	20.00	100	100.00

Table 5. Age was categorized into 5-year age groups between 40 and 65. All ages under 40 were collapsed into AGE Category = 0, which was the reference group.

AGE Category	Includes	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	AGE<40 Years	21	21.00	21	21.00
1	40<=AGE<45 Years	20	20.00	41	41.00
2	45<=AGE<50 Years	12	12.00	53	53.00
3	50<=CALC_AGE<55 Years	18	18.00	71	71.00
4	55<=CALC_AGE<60 Years	11	11.00	82	82.00
5	60<=CALC_AGE<65 Years	18	18.00	100	100.00

Table 6. Time of day was categorized into before 7:00 and every hour thereafter. Time category = 0 (7:00 and earlier) was the reference group:

Categories of Time BP Taken	Includes	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	7:00 and earlier	33	33.00	33	33.00
1	7:00-8:00	31	31.00	64	64.00
2	8:00-9:00	24	24.00	88	88.00
3	9:00-13:00	12	12.00	100	100.00

Table 7. The results for systolic blood pressure are below (R^2 = 0.27)

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	102.7509822	4.23885059	24.24	<.0001
pmcat1	-4.8214414	3.74459215	-1.29	0.2014
pmcat2	-7.0499866	3.78748908	-1.86	0.0661
pmcat3	-11.9068355	3.94134008	-3.02	0.0033
pmcat4	-1.6881356	3.83830182	-0.44	0.6612
BMIcat1	-0.1297681	2.83588804	-0.05	0.9636
BMIcat2	3.6166221	3.90624676	0.93	0.3571
AGEcat1	1.9405736	3.69773667	0.52	0.6011
AGEcat2	7.1459386	4.22539235	1.69	0.0945
AGEcat3	4.3066565	3.75258682	1.15	0.2543

AGEcat4	4.2035271	4.50622170	0.93	0.3536
AGEcat5	13.8771254	3.90159230	3.56	0.0006
timehour1	-1.6573672	3.05136465	-0.54	0.5884
timehour2	-6.3570517	3.61562332	-1.76	0.0823
timehour3	-6.0630989	4.03931269	-1.50	0.1371

Table 8. The results for diastolic blood pressure are below (R_2 = 0.14)

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	71.47119372	3.36203383	21.26	<.0001
pmcat1	-0.85256557	2.97001397	-0.29	0.7748
pmcat2	-2.31437845	3.00403757	-0.77	0.4432
pmcat3	-5.33766545	3.12606411	-1.71	0.0914
pmcat4	0.74342431	3.04433957	0.24	0.8077
BMIcat1	-1.94043832	2.24927756	-0.86	0.3907
BMIcat2	0.56711539	3.09822993	0.18	0.8552
AGEcat1	1.35141598	2.93285066	0.46	0.6461
AGEcat2	0.82593974	3.35135946	0.25	0.8059
AGEcat3	-2.75584727	2.97635493	-0.93	0.3571
AGEcat4	-0.52960705	3.57409857	-0.15	0.8826
AGEcat5	2.00239233	3.09453826	0.65	0.5193
timehour1	-2.73330930	2.42018230	-1.13	0.2619
timehour2	-4.17917037	2.86772267	-1.46	0.1487
timehour3	-4.58111333	3.20377084	-1.43	0.1564

Appendices

Appendix A. *Letter of Invitation:*

PRISMA

February 17th, 2017

Dear Committee Members,

On behalf of the Biomedical Research Unit of Asociación Benéfica PRISMA, I am pleased to welcome the Emory University student, Maria Jolly, to conduct field research for our project based in Puno, Peru. Maria will provide valuable data on the environmental exposures of our study participants, including monthly monitoring exhaled carbon monoxide (CO) as well as personal and household PM, CO, and NO_2. She will also be responsible for weekly data quality summaries that will report both how many participants were visited and real-time personal exposure and kitchen concentrations of environmental pollutants. This will potentially help demonstrate that sustained reductions in household particulate matter (PM2.5) and carbon monoxide (CO) emissions after provision of the intervention (LPG stoves and fuel) when compared to traditional open-fire stoves.

We expect that Maria will provide high quality exposure assessment and analysis. The primary contact for Maria throughout their field experience will be Kathryn Lee as she is the project's Sr. Research Program Coordinator in Puno. I am writing from the Asociación Benéficia Prisma, which is leading the field office on-site in Puno, who will also be there to support Maria.

My writing of this letter shows my complete and thorough support to host Maria at our field site in Puno between May and August of 2017. Maria will reside at our staff housing and will have access to office space to conduct her research. She will be responsible for the costs associated with room, board, and in-country transportation. Prisma staff, Johns Hopkins staff, and other Hopkins students will provide additional support to aid Maria in her objectives to ensure the success of their study.

Sincerely,

Marilu Chiang, MD, MSA, MPH
Director of Human Development
A.B. PRISMA

PRISMA ONG
Fundada como Asociación Benéfica Prisma el 23 de abril de 1986, según Partida Registral Nº 01885359 Asiento A00414.
Sede central: Calle Carlos Gonzales 251 Urb. Maranga, Lima 32 – Perú - Teléfono (51)(1) 2090400
Fax: (51)(1) 2090401 Apartado Postal 170070 E-mail: prisma@prisma.org.pe Web: www.prisma.org.pe

Appendix B. *Emory Internal Review Board Approval Letter:*

Institutional Review Board (IRB)/Independent Ethics Committee (IEC) Authorization Agreement

	Name of Institution	Federal-wide Assurance No.	IRB Registration No.
Institution Providing IRB Review (Institution A)	**Johns Hopkins Bloomberg School of Public Health**	**00000287**	**00000112 00000758**
Institution Relying on Institution A's IRB Review (Institution B)	**Emory University**	**00005792**	**00000569**

The Officials signing below agree that Emory University may rely on the designated IRB for review and continuing oversight of its human subjects research described below:

This agreement is limited to the following specific protocol(s):

Name of Research Project: **Effects of a clean fuel intervention on adult cardiopulmonary outcomes** – IRB #7128
Name of PI (Institution A): William Checkley
Name of Investigator (Institution B): Maria Jolly (MSPH Student at Emory University)
Sponsor or Funding Agency: National Cancer Institute (NCI) Award Number, if any: U01TW010107-01

The review and continuing oversight performed by the Institution A's IRB will meet the human subject's protection requirements of Institution B's OHRP-approved FWA. Both institutions agree to the following conditions:

1. Upon request, Institution A will provide Institution B with copies of its findings and actions associated with the project(s) listed above. Institution A also will provide Institution B with copies of minutes associated with the project(s) listed above upon request.
2. Institution A's IRB will notify Institution B if the study is suspended or terminated and will provide a summary of the reasons for the suspension or termination.
3. Institution A's IRB will notify Institution B of any unanticipated problems involving risks to human participants or others, or of any instances of serious or continuing noncompliance related to the research.
4. Institution A's IRB will notify Institution B of audits/investigations by oversight agencies, the sponsor or funding agencies and will provide a summary of the findings.
5. If Institution A fails to notify Institution B as stated above, Institution B shall have the right to terminate this agreement immediately, and request any study related documents associated with Institution B's investigator's role in the study.
6. Institution B agrees to defend, indemnify, and hold Johns Hopkins University harmless from any claims, lawsuits, or demands for payment that arise against either or both of them or against the individual Hopkins IRB members as a result of the Hopkins IRB performing the requirements of Institution B's OHRP –approved FWA, including approval, continuing review and oversight. This obligation shall apply unless the Hopkins IRB is determined by a court of law to be negligent or grossly negligent. Hopkins and its personnel have a duty to notify Institution B in a timely way and cooperate in the handling of such claims.

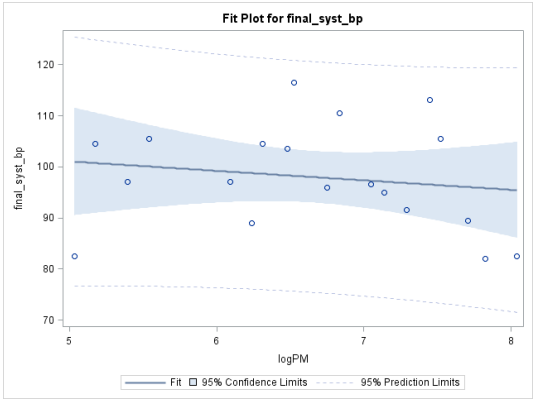
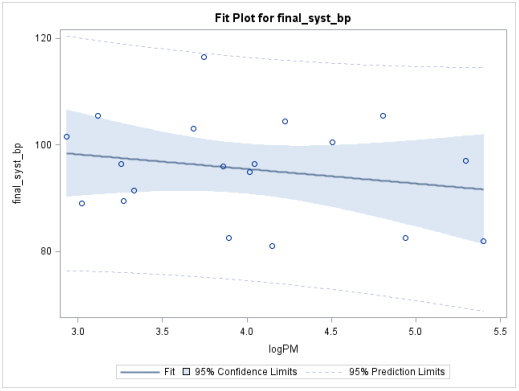
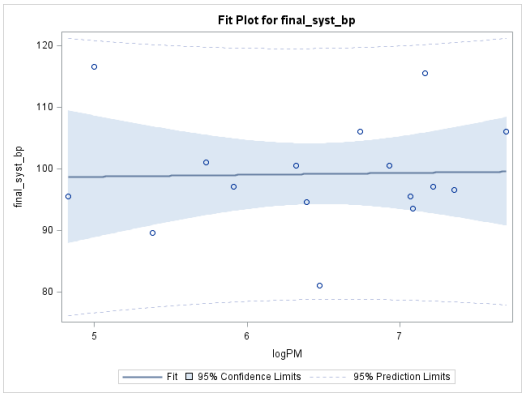
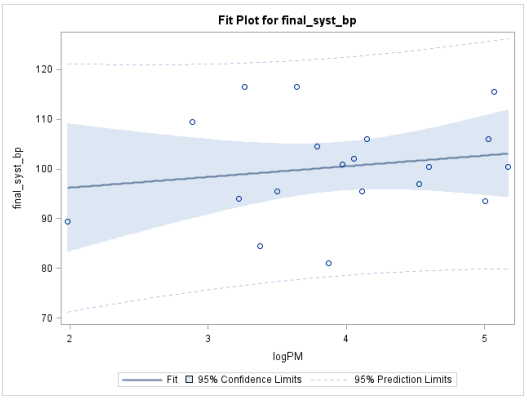
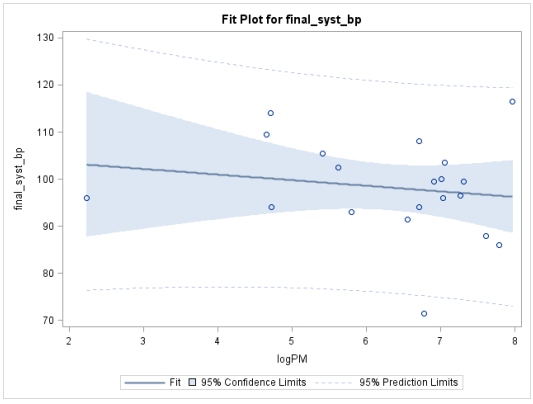
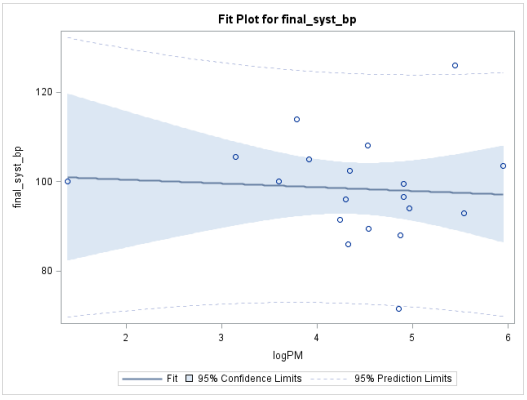
This document must be kept on file by both parties and provided to OHRP upon request.

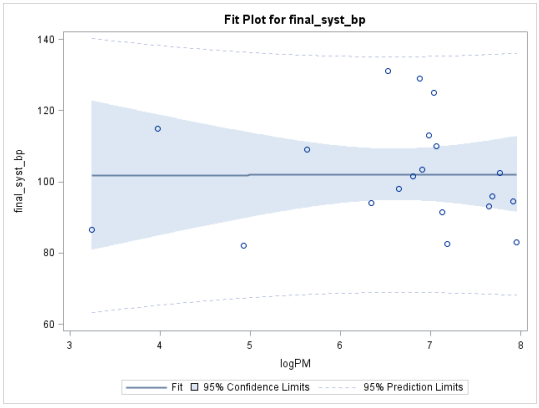
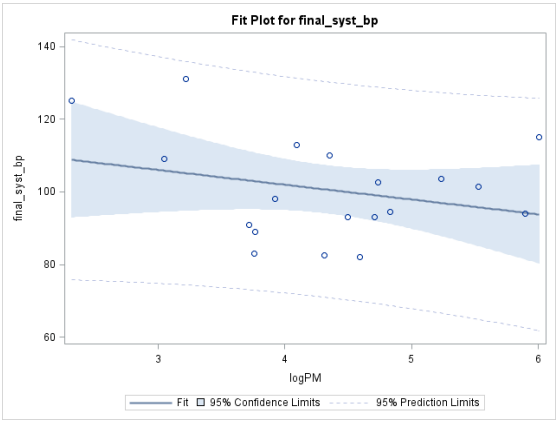
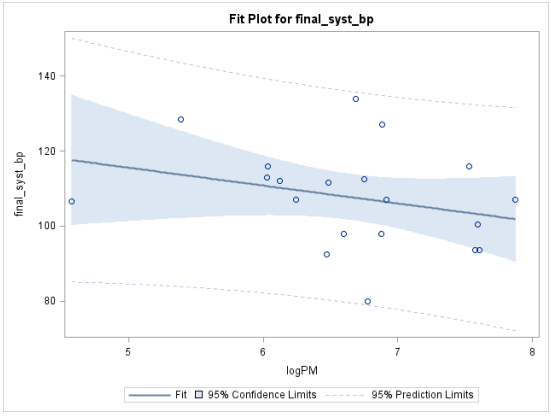
Signature of Institutional Officials

	Institution A Official	Institution B Official
Print Name	Janet A. DiPietro, Ph.D.	David L. Wynes, Ph.D.
Title	Vice Dean for Research and Faculty	Vice-President for Research Administration
Signature	Janet DiPietro	Rebecca Rousell for David Wynes
Date	5-30-2017	5/26/17

IRB Authorization Agreement_V2_Institution B_Template_19Jul2016

Appendix C. *Sensitivity Analysis: Kitchen vs. Personal $PM_{2.5}$ stratified by age quintiles with (20^{th}, 40^{th}, 60, 80^{th} percentiles as cut-point).* Age group 1 = 0-20^{th} percentile, Age group 2 = 20-40^{th} percentile…Age group 5 = 80-100^{th} percentile.

Age Group	Kitchen ln($PM_{2.5}$)	Personal ln($PM_{2.5}$) (no outliers)
1	R^2 = 0.026985 $\beta_{ln(PM2.5)}$ = -1.8541991 	R^2 = 0.045339 $\beta_{ln(PM2.5)}$ = -2.7395777 
2	R^2 = 0.000883 $\beta_{ln(PM2.5)}$ = 0.30470507 	R^2 = 0.032266 $\beta_{ln(PM2.5)}$= 2.15927385 
3	R^2 = 0.026297 $\beta_{ln(PM2.5)}$ = -1.1911444 	R^2 = 0.005254 $\beta_{ln(PM2.5)}$ = -0.8376603 

4	R^2 = 0.000043 $\beta_{ln(PM2.5)}$ = 0.0769861 	R^2 = 0.077926 $\beta_{ln(PM2.5)}$ = -4.0662822 
5	R^2 = 0.083143 $\beta_{ln(PM2.5)}$ = -4.7640416 	R^2 = 0.268331 $\beta_{ln(PM2.5)}$ = -7.7061318