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ADS1 Final Project

Title: Household PM2.5 concentrations in rural and urban households in Peru

Introduction

Peru, along with other low and middle-income countries (LMICs) is experience a transition in the burden of disease from infectious diseases to non-communicable diseases (WHO 2016). Non-communicable disease are the cause of 66% of total deaths in Peru (WHO 2016), and cardiovascular disease and diabetes are the largest source of years lost due to premature mortality (WHO 2014). Air pollution, both ambient and indoor, is a known risk factor for chronic disease of the lungs and heart (Abbey et al. 1994)(Dockery 2001). In Peru, air pollution is known to vary by geography due to differences in both urbanicity and household behaviors (Helen et al. 2015). Characterizing the airborne exposures faced by Peruvians in both urban and rural areas is critical to understanding the contribution of air pollution to rising non-communicable disease and to inform interventions that reduce exposures.

Particulate matter are small, airborne particles that are a major contributor to air pollution (US EPA 2016b). The size of particulate matter particles is inversely associated with the health risk, as small particles are able to lodge deeper into the lungs and cause damage (US EPA 2003). Particulate matter with diameter smaller than 2.5 micrometers are known as PM2.5 or fine particles, and can travel deep into the lungs, causing a range of heart and lung disease (Boldo et al. 2006).

PM2.5 can come from both natural and human-induced sources and is a frequent target of environmental regulations (US EPA 2016b). Natural sources of PM2.5 include dust, sea-spray or ash. The most common source of human-induced PM2.5 is the combustion of fossil fuels for electricity, industrial processes, or transport (Mei Zheng et al. 2002). The Environmental Protection Agency (EPA) has set a PM2.5 regulatory standard of 12 ug/m3 per annual mean with the goal of protecting public health (US EPA 2016a).

Ambient, or outdoor PM2.5 is frequently modeled through remote sensing via satellite images and/or samples taken by air quality monitors at strategic locations that are extrapolated to unmeasured locations (Jerrett et al. 2016). However, less is known about indoor concentrations of PM2.5 due to the strong effect of household activities and kitchen construction that can produce wide variability of concentrations between nearby households (Hartinger et al. 2013). For example, one household may cook with wood while another cooks with gas. The household concentrations and subsequent personal exposures to PM2.5 could vary in orders of magnitude between otherwise identical houses because of the different sources of cooking fuel (Zhang and Smith 2007). The difficulty and lack of measurement of indoor concentrations is important, since many people spend a majority of their time indoors. Understanding household concentrations of PM2.5 is critical to assess total air pollution exposure and to accurately quantify the connections between PM2.5 exposure and chronic disease.

This analysis seeks to compare kitchen PM2.5 concentrations among urban and rural households in Peru.

Methods

Data Collection

To accomplish this aim, a study of household air pollution and clinical outcomes, known as CRONICAS, was conducted in Lima and Puno, Peru from 2010-2015 (Miranda et al. 2012). PM2.5 was measured for 48 hours at one-minute intervals in households in Lima (urban) and in Puno (rural). The devices were placed inside the main kitchen area of all household at approximately 1.5 meters height from the floor.

The study used DataRAM pDR-1000 (PDR) monitors (Thermo Fisher Scientific, Waltham, Massachusetts, USA) to measure PM2.5 levels in real-time. PDR monitors are battery-powered devices about the size of a VHS tape which use light-scattering to estimate concentrations of PM2.5 at one-minute temporal resolution. As air enters the top of the PDR, a laser is directed through the air towards a light-sensing receptacle. As the laser encounters PM2.5, the beam reflects off of the particles and scatters throughout the air chamber. The amount of light measured by the receptacle is inversely related to the concentration of PM2.5 in the chamber, and an estimate is recorded. The data is logged within the device and downloaded upon completion of the 48-hour sample.

Exploratory Analysis

Various plots and graphs were used to perform exploratory data analysis on the raw data. PM levels were transformed to a log base 10 scale to assist in visualization and comparison between geographic groups.

Reproducibility

To provide reproducibility, all analyses were recorded in a R markdown file named "analysis.Rmd". The raw data has been provided in a zipped folder.

Results

PM2.5 samples were taken in 336 urban households and 357 rural households. At one-minute intervals, there were 503,742 PM2.5 estimates logged among urban households and 523,512 among rural households. An average of 25.0 and 24.4 hours of logging was recorded for samples among urban and rural households respectively, a significant departure from the stated goal of 48 hour samples, but nonetheless providing concentration data for all hours of the day.

Due to the large amount of observations at one-minute intervals, all data were summarized into hourly median estimates by household. These hourly household estimates were then summarized across households by mean, median, 95^{th} interval concentrations as well as hourly standard deviation. The mean hourly concentration was 0.664 mg/m3 in rural samples and 0.016 mg/m3 in urban samples. The median hourly concentration was 0.003 mg/m3 among rural samples and 0.005 among urban samples. The 95^{th} percentile hourly estimate in rural samples was 2.066 mg/m3, while among urban samples was 0.048 mg/m3.

The variability among rural samples was also higher, as the hourly standard deviation among rural samples was 5.693 mg/m3 and 0.048 mg/m3 among urban samples.

Concentrations in both urban and rural households were consistently above the EPA standard, and rural concentrations were often two orders of magnitude higher than the standard. Among urban households, the mean hourly median PM2.5 concentration was above the EPA standard (0.012 mg/m3) for 17 hrs of the day, with a range of (0.005, 0.047 mg/m3). In rural households the mean hourly median concentration was among the EPA standard 20 hours of the day, with a range of (0.004, 3.326 mg/m3). The highest concentrations among both groups were between 6:00am and 8:00am with smaller peaks midday and between 6:00pm and 7:00pm in the evening.

Hourly median concentrations among both groups were log-transformed (base 10) to facilitate comparison between the vastly different ranges of concentrations found in urban and rural groups. Box plots were produced to visualize the log hourly median concentrations by hour of the day.

Heat maps were created using the pheatmap package (citation) to visualize changing concentrations throughout the day at the household level.

Discussion

Rural households showed consistently higher concentrations of PM2.5 than urban households. Within this study, rural households had mean PM2.5 concentrations over the EPA standard for 20 hours out of the day. These mean concentrations were two orders of magnitude greater than the EPA standard set to protect public health.

Urban households consistently showed lower and less varying concentrations. In contrast, many rural households showed steep spikes in the morning and evenings, reaching levels orders of magnitude higher than a majority of urban households.

The timing of the concentration spikes in rural households closely aligns with common meal preparation times. It is likely that the increases in PM2.5 concentrations seen in rural households is closely related cooking practices, specifically fuel sources and type of stove. Stoves which use wood, dung, and other solid fuels (collectively known as biomass fuel) are known to cause high spikes in PM2.5 concentrations. It is plausible that the primary cause of variation between urban and rural household PM2.5 concentrations are a result of a greater prevalence of biomass-fueled stoves in rural areas. Additional research is needed to identify the cooking fuel of households in both urban and rural areas to isolate the effect of biomass combustion for cooking from other ambient and household sources of PM2.5.

Regardless of the source, this data suggests that rural households in Peru experience high levels of exposure to PM2.5 within their homes, in relation to both urban households in Peru and the EPA standard.

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