Spatial distribution and estimation of household air pollution from biomass use in Kenya

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Abstract: Over 3 billion people around the globe rely on biomass fuels as a source of energy for cooking and lighting, raising a worldwide concern on the impacts of household air pollution on human health and the environment. 95.6% of the rural population in Kenya use biomass as their primary source of household cooking and/or lighting fuel. Using air pollution data from previous studies, gridded population data, biomass consumption data and counties as spatial units, we try to estimate the spatial distribution of PM$_{2.5}$ in Kenya. Our results indicate that high emissions are concentrated in the central and western part of Kenya.

Keywords: Spatial distribution, household air pollution, biomass, Kenya

1. Introduction

Over 3 billion people (more than 40% of the world’s population) do not have access to clean energy and use traditional methods for cooking (such as firewood and charcoal) (WHO $^1$, 2018). In addition, the lack of access to clean sources of energy, like electricity, is a major impediment to development through health related complications such as increased respiratory infections (KNBS and SID, 2013), which resulted in an estimated 3.8 million deaths worldwide due to household air pollution in 2016 (WHO $^1$, 2018). In recent years, studies have shown that there is a correlation between indoor air pollution and its negative effects on human health (WHO $^3$, 1999). Household air pollution also doubles the risk of pneumonia in children, which is responsible for 45% of all pneumonia deaths in children less than 5 years old. In addition, it contributes to 28% pneumonia deaths in adults (WHO $^3$, 2018).

Indoor pollution due to traditional methods of cooking and lighting (such as firewood, kerosene, charcoal) can be up to 10 times worse than outdoor air pollution and poses a more serious effect as majority of the people spend approximately 80% of their times indoors (Myers and Maynard, 2005). Women are more involved with household chores and cooking, hence, at a higher risk of suffering from respiratory ailments from long-term exposure to harmful pollutants from smoke when using biomass fuel. Figure-1 (a) and (b) show two women from rural Kenya using firewood on traditional “three stone” fire.

![Figure-1 (a, b): Women cooking indoors using firewood on traditional “three stone” fire. (Ross, 2014). (b): (Muoria, 2015).](image-url)

Note that smoke curls up above the fire before dispersing in the kitchen causing collection of soot on the wall and roof (Figure-1 (a)). The smoke causes respiratory ailments as well as eye irritation (Figure-1 (b)).

Wood energy is still an important single source of renewable energy providing about 6% of the global total primary energy supply (FAO, 2017). Based on the 2009 Kenya national population census data, firewood and charcoal represents the most commonly used source of energy for cooking, accounting for 64.6% and 16.9% respectively, with 95.6% of the rural population relying on biomass as their primary source of fuel (KNBS, 2017) (Figure-2). This has led to disastrous environmental degradation such as deforestation with the country losing 310 kha of tree cover from 2001 to 2017: a 9.3% decrease since 2000 and 33.0Mt of CO$_2$ emissions, a rise from 2.23Mt of CO$_2$ in 2010 (Global Forest Watch). According to a joint study by UNEP and the Kenya Forest Service, deforestation cost the country USD 68 million in 2010 and USD 78 million in 2009 in economic losses and as well as increasing the risk of water shortage (UNEP, 2012).
Kenya records 14,300 deaths yearly due to indoor air pollution and pneumonia as the biggest killer associated with air pollution (WHO, 2009). Thus, it is of paramount importance to address the impacts of household air pollution to reduce the losses and ensure better living standards in the societies in order to achieve the sustainable development goals (SDGs). In addition, there is need for the government to intervene in making cleaner fuels more available and at an affordable cost as well as educate the population on the importance of using cleaner sources of energy (Muindi et al, 2016). Improved access to modern energy sources will also enhance the quality of life of the people (Makonese, Ifegbesan and Rampedi, 2017).

2. Methodology
2.1 Study area

Kenya is located at latitudes 5°N and 5°S and longitudes 34° and 42°E and lies on the equator in the East African region covering an area of 582,650km² (Figure-3). Kenya has 47 counties with a population of 49.69 million in 2017, an increase from 38.6 million in the 2009 national census.

The country has a varied climate, for example a warm and humid climate along the coastal region, hot, dry and humid in western region, arid and semi-arid in the northeastern region. It also experiences two main rainy seasons: long rains (from March to May) and short rains (from October to December), with the rest of the months experiencing sunshine.

2.2 Population

We obtained the population data for the last census carried out in Kenya in the year 2009 from the Kenya National Bureau of Statistics (KNBS, 2017). The gridded population count data at a resolution of 2.5 arc-minutes, was retrieved from the Gridded Population of the World database (GPW v4) (CIESIN, 2017) as shown in Figure-4, with high population in major cities such as Nairobi, Mombasa, Kisumu and Nakuru.

2.3 Source of energy data

Sources of energy data for the Kenya Population and Housing Census 2009, was retrieved from the Kenya National Bureau of Statistics (KNBS, 2017). This data contains households’ sources of fuel used for cooking in all the 47 counties and districts. However, we only used data on the county level that we needed to estimate the household air pollution. Figure-5 shows the distribution of firewood usage per county.

2.4 Household air pollution data

We reviewed different literature from previous studies to estimate the spatial distribution of air pollution in Kenya.
Amongst the various types of pollutants, we selected PM$_{2.5}$ to generate the gridded spatial distribution. However, due to inadequate data on household air pollution, we performed field numerical analysis to estimate the mean PM$_{2.5}$ for the counties that lacked data.

2.5 Estimation of gridded spatial distribution of household air pollution in Kenya

We obtained the gridded mean PM$_{2.5}$ through spatial allocation based on the estimated emission rate for each county and gridded population count. The estimated mean PM$_{2.5}$ emission in each grid was calculated using equation 1:

$$E_m = P_m \times f \times 100\% \times 0.126^* \ldots (1)$$

Where:

- $E_m$ is the estimated mean PM$_{2.5}$ of the $m^{th}$ grid
- $P_m$ is the number of population in the $m^{th}$ grid
- $f$ is the fuel type (firewood)
- $0.126^*$ is the reference mean PM$_{2.5}$ obtained from (WHO, 2011)

We used ArcGIS version 10.2.1 to generate the spatial distribution within $1 \times 1$ km$^2$ grid cells for the estimated mean PM$_{2.5}$ in Kenya. Figure-6 shows the $1 \times 1$ km$^2$ estimated mean PM$_{2.5}$ gridded distribution.

3. Results

There exists an apparent disparity in the source of lighting and cooking fuel among different counties across Kenya. This is attributed to socio-economic status of the households, with high-income households (mostly in urban regions) using cleaner sources of energy, like electricity or LPG, while low-income households (mainly in rural regions) using firewood and charcoal as the main source of energy (Figure-2). 95.6% of the rural population rely on biomass for cooking, due to lack of alternative sources, the high cost of electricity installation versus the low cost of free firewood (Makonese, Ifegbesan & Rampedi, 2017).

The urban population is growing at a faster rate with cities like Nairobi having large informal settlements, which are home to nearly 75% of the urban population (UN-Habitat, 2006). A high population density, poverty, poor living and environmental conditions characterize these informal settlements. The congestion may lead to a ‘neighborhood effect’ on indoor air quality, where neighboring households’ may influence other households’ air quality due to indoor emissions (Muindi et al, 2016).

Figure-6 illustrates that the majority of households using firewood are located in counties with more rural and agricultural activities in the northern and western part of Kenya. However, despite some counties being major cities and towns with a high population density (Figure-4), the use of biomass fuel is still prevalent and may be attributed to low socioeconomic status (for example, in urban informal settlements), availability and low cost of firewood and charcoal compared to modern methods, such as LPG or electricity.

PM$_{2.5}$ emission is concentrated in the western part of the country, which may be attributed to high usage of biomass fuels. Although there is a high percentage of biomass use in northern part of Kenya, the PM$_{2.5}$ emission is relatively low and may be due to a low population count compared to the western region (Figure-4).

4. Conclusion

In this study, we highlighted an estimated mean PM$_{2.5}$ gridded distribution for Kenya based on the 2009 Kenya National Population Census and gridded population count data.

There exists an apparent disparity in the source of fuel for households use among different counties across Kenya due to location
and socio-economic status of the households. Firewood is the predominant source of cooking fuel in rural regions. These regions are more likely to experience higher levels of pollutants such as PM$_{2.5}$ due to a great percentage of the population using firewood as the main source of energy for cooking.

We noted that the PM$_{2.5}$ emission is influenced by the population count, for example, there is a low emission in the northern part of Kenya despite the region having a high percentage of biomass use (Figure-5) but a low population count. On the other hand, high emissions are concentrated in the western part of the country, which has a high population count (Figure-4).

There is need to educate the population on the advantages of using cleaner and cheaper sources of energy, such as solar energy, that are not only environmentally friendly, but also poses less or no negative health impacts, regarding their power production.

**References**


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