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A Cross-Sectional Study of Household Biomass Fuel Use among a Periurban Population in Malawi

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Abstract

Rationale—The Global Burden of Disease Study suggests almost 3.5 million people die as a consequence of household air pollution every year. Respiratory diseases including chronic obstructive pulmonary disease and pneumonia in children are strongly associated with exposure to household air pollution. Smoke from burning biomass fuels for cooking, heating, and lighting is the main contributor to high household air pollution levels in low-income countries like Malawi. A greater understanding of biomass fuel use in Malawi should enable us to address household air pollution-associated communicable and noncommunicable diseases more effectively.

Objectives—To conduct a cross-sectional analysis of biomass fuel use and population demographics among adults in Blantyre, Malawi.

Methods—We used global positioning system-enabled personal digital assistants to collect data on location, age, sex, marital status, education, occupation, and fuel use. We describe these data and explore associations between demographics and reported fuel type.

Measurements and Main Results—A total of 16,079 adults participated (nine households refused); median age was 30 years, there was a similar distribution of men and women, 60% were married, and 62% received secondary school education. The most commonly reported occupation for men and women was “salaried employment” (40.7%) and “petty trader and marketing” (23.5%), respectively. Charcoal (81.5% of households), wood (36.5%), and electricity (29.1%) were the main fuels used at home. Only 3.9% of households used electricity exclusively. Lower educational and occupational attainment was associated with greater use of wood.

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Conclusions—This large cross-sectional study has identified extensive use of biomass fuels in a typical sub-Saharan Africa periurban population in which women and people of lower socioeconomic status are disproportionately affected. Biomass fuel use is likely to be a major driver of existing communicable respiratory disease and the emerging noncommunicable disease (especially respiratory and cardiovascular) epidemic in this region. Our data will help inform the rationale for specific intervention studies and the development of appropriately targeted public health strategies to tackle this important and poverty-related global health problem.

Keywords

biomass fuel use; noncommunicable diseases; household air pollution

Household air pollution is an important health risk that is intrinsically linked with poverty. Analysis from the Global Burden of Disease Study attributed almost 3.5 million deaths to household air pollution worldwide in 2010 (1). Recent analyses estimate that 2.8 million people worldwide use solid fuels as their main source of fuel for cooking (2). In this new field, the evidence that household air pollution results in respiratory disease is rapidly growing.

Household use of solid fuels such as coal and biomass are the largest source of household air pollution globally. Biomass fuels refer to fuel that has come from any recently living plant- or animal-based material, including charcoal, wood, dung, and crop residues. Coal is therefore not included. Biomass fuels are used to provide energy for heating and cooking. The inefficient and incomplete combustion of these energy sources produces harmful smoke, including pollutants such as carbon monoxide and particulate matter (3). It is recognized that the cost and efficiency of different types of fuel are inversely related, such that the most efficient fuel type, electricity, is the most expensive, and, conversely, the least efficient fuel types, such as crop residues and animal dung, are the cheapest and most readily available to the world's poorest (Figure 1).

The main burden of household air pollution is found in low- and middle-income countries, where many people are at the bottom of the energy ladder (Figure 2) (4). Local availability determines much of the regional variation in fuel types used. For example, wood is the most commonly used biomass fuel worldwide. However, in China, coal is predominantly used, and in South Asia, cattle dung is often used by rural populations. Access to more efficient fuels also varies greatly between rural and urban populations, with rural populations having less access to cleaner energy sources due to both infrastructure and cost. This difference is most marked in sub-Saharan Africa (5).

The health effects of household air pollution exposure are estimated to be between active and passive smoking (6, 7). In the field of respiratory medicine, there is good evidence that exposure to smoke from solid fuels increases the risk of developing pneumonia in children younger than 5 years old and therefore the risk of particularly premature mortality from pneumonia (8, 9). There is less available research examining the impact of household air pollution on adult pneumonia, particularly biomass fuels. However, a large study in China found that use of coal was associated with pneumonia in adults (10).

It is recognized that a significant proportion of chronic obstructive pulmonary disease (COPD) cannot be attributed to cigarette smoking, and although a causal mechanism has not been described, household air pollution is an established risk factor (11). Metaanalyses have shown an association between solid fuel combustion and COPD (12, 13). There is also evidence of an association between solid fuel use and chronic bronchitis (9, 14). In contrast to COPD, evidence so far indicates that combustion of solid fuels does not increase the risk of developing asthma in children or adults (9). However, biomass fuel was classed as “probably carcinogenic to humans” (group 2a) in the most recent publication from the International Agency for Research on Cancer (15).

The link between household air pollution and COPD is an important part of the emerging epidemic of noncommunicable diseases in the developing world (16). Globally, the region with the greatest use of solid fuels for cooking is sub-Saharan Africa (2). Several studies in sub-Saharan Africa have shown that levels of household particulate matter are high and far exceed the levels recommended by the World Health Organization to avoid detrimental health effects (17, 18). One study in Malawi found levels of particulate matter over a 24-hour period to be more than eight times the recommended level (17). In other developing countries, levels of between 20 to 30 times the recommended limit have been recorded (5). Despite this, there are limited detailed data describing the pattern of biomass fuel use, and so further data on this risk factor are needed to plan preventive strategies for noncommunicable diseases.

Our study was performed in Malawi, a country where it has been shown that more than 95% of the population use biomass fuel as their main source of energy (19). Malawi is a land-locked country in sub-Saharan Africa (Figure 3) that is among the poorest countries in the world (20). Within Malawi, typically open fires are used for crop residues and wood, whereas local stoves (mbaulas) are used for charcoal (Figure 4).

Estimates from the Global Burden of Disease study demonstrate that lower respiratory tract infection is the second largest cause of years of life lost in Malawi, after HIV/AIDs (21). The same study found that the risk factor that accounts for the greatest disease burden in Malawi is household air pollution from solid fuels. A greater understanding of biomass fuel use in Malawi should enable us to address household air pollution–associated communicable and noncommunicable diseases more effectively.

In this paper we describe a cross-sectional study of household biomass fuel use and other demographic characteristics among the adult population of a periurban city setting in Malawi.

Methods

The Blantyre Health Study

Enumeration data gathered for a study of the prevalence and risk factors of noncommunicable diseases (The Blantyre Health Study) were used to describe the pattern of biomass fuel use and population characteristics in the region. The administrative ward of Chilomoni was used as a sampling frame. This ward is a densely populated area with well-

defined boundaries, located immediately northwest of Blantyre city center and in relatively close proximity to the Queen Elizabeth Central Hospital, the biggest referral hospital in Malawi (Figure 5). Chilomoni was reported in the 2008 National Census of Malawi as having a population of 18,990 residents over the age of 18 years, with strong representation across the socioeconomic spectrum (19). This ward was selected as the sampling frame based on the above factors and high admission rates to Queen Elizabeth Central Hospital for both noncommunicable diseases and infectious diseases (clinical observation).

Community Sensitization

Approval and cooperation were gained at both a regional and local level by discussion with the district health officer of Blantyre, health surveillance assistants of each catchment area, and community leaders. Community awareness of the study was raised by the formation of community advisory groups and a community awareness program.

Selection Criteria

All individuals aged 17 years or older living in households within Chilomoni ward were invited to participate in the enumeration exercise. Individuals gave informed consent for participation in the study.

Data Collection and Management

To complete data collection, contact was made with at least one member of each household. A simple questionnaire was developed that could be rapidly administered to an adult household representative and collect information on location of current residence, age, sex, marital status, length of residence in the household, educational level, occupation, and types of fuel used at home. Excluding location and age, for each question participants were given a list of answers to select from. Officially, children attend primary school between the ages of 6 and 13 years, secondary school between 14 and 17 years, and further education includes any education beyond this. If children re-sit school years, they will remain in each education category for longer.

The questionnaires were programmed into personal digital assistants (PDAs) (SoMo Handheld Computer 650-E WM6.1 WW Eng EMEA) with global positioning system (GPS) receivers (GlobalSat BC-337 SiRF Star III Compact Flash GPS Receiver) by a data manager at Liverpool School of Tropical Medicine. For field use, the PDAs and GPS receivers were encased within protective cases (Otterbox 1900 series and Otterbox Tall GPS Unit). Households were identified using GPS coordinates and assigned a unique household identification label, which was later used in the anonymized dataset (Figure 6). A team of eight fieldworkers used these for data collection during household visits (Figure 7). At the end of each day, PDAs were returned for data transfer onto the server, backed up on a second server (password protected). The devices were then charged overnight ready for use the next day.

Analysis

An anonymized dataset containing information from all participants was created. Data were then analyzed using Microsoft Excel 2008. Charts were created using Graphpad Prism version 6.

A descriptive analysis was conducted of individual population characteristics including: age, sex, marital status, length of residence in the household, educational level, and occupation. To assess household fuel use, all unique households were selected from the main dataset. Fuel use data were collected from an individual who stated that the household was where they usually lived. Individuals were able to select as many different fuel types as were used in the household. Households were excluded if no individuals stated that they usually lived in that household and if the dataset did not include fuel use information from any individuals residing in the household. Data from households that used the three most common types of fuel were further analyzed to assess fuel use combinations.

Associations were explored between types of fuel used and the following characteristics: age, sex, length of residence in the household, occupation, education, and marital status.

Ethics Statement

Ethical approval was given by the National Health Sciences Research Committee of Malawi and the Liverpool School of Tropical Medicine Research Ethics Committee.

Results

Data Collection

All households in Chilomoni ward were visited and contact made with a member of the household, of which 6,445 agreed to participate, with 9 refusals. In total, data were collected from 16,079 residents. Complete datasets were obtained from 15,942 participants. Two participants had no recorded data for their education level, occupation, or when they moved to the household. One hundred thirty-five other participants had no recorded fuel use data (Figure 8).

Descriptive Analyses

The age distribution was skewed to the right, reflecting the selection criteria, with a median age of 30 years (range 17–102 years) (Figure 9). There was an even distribution of men (49.7%) and women (50.3%). Analysis of marital status demonstrated that 60% of the population was married. Demographic characteristics are presented in Table 1. A majority of participants (56.8%) had lived in their household for less than 5 years and 33.9% for greater than 5 years. A minority of participants (9.2%) had lived in the same household since birth. The most common occupations among women were “petty trader and marketing” (23.5%), followed by being “unemployed” (22.5%). “Salaried employment” was the most common occupation among men (40.7%) (Figure 10). “Domestic activities” was more commonly reported as an occupation by women (16.2%) than men (0.9%), suggesting that women are likely to have greater exposure to household air pollution. The most common level of

education attended was secondary school (52.3%) (Table 1). No marked difference in education level was observed between men and women.

Household Fuel Use

Analysis of the final dataset of 6,374 unique households revealed that 81.5% of households used charcoal, 36.5% wood, 29.1% electricity, and 1.1% used other fuels including liquid petroleum gas, paraffin, dung, and crop residue. Further analysis of the households that selected the three most common types of fuel (wood, charcoal, and electricity; $n = 6,365$) demonstrated that the most common fuel combination was charcoal alone (37.6%), followed by charcoal and electricity (22.0%) and charcoal and wood (19.2%). It was less common to use wood alone (14.1%), electricity alone (3.9%), and all three fuel types together (2.9%) (Figure 11).

Exploration of Associations between Fuel Use and Population Characteristics

Lower level of education tracked with greater reported use of wood and less use of electricity (Figure 12). Occupations involving more manual labor (e.g., “agricultural worker” and “daily laborer”) were also characterized by greater use of wood and less use of electricity. Up to the age of 75 years, evidence of a trend was observed between increased age and greater use of wood and less use of electricity (Figure 13). For example, use of wood increased from 33.0% to 56.3% between the age categories of 17 to 25 years and 66 to 75 years. Small numbers of participants in the older age categories (Figure 9) result in poor precision of estimates for this group and make interpretation difficult.

Discussion

This large cross-sectional study has given new insight into the demographics and biomass fuel use of this periurban Malawian population. The key findings from the descriptive analysis were that Chilomoni ward has a young and mobile population that demonstrated extensive use of biomass fuel.

A critical message from this study is that reported biomass fuel use is widespread, with 81.5% of households using charcoal and 36.5% using wood in this area of Malawi. Only 29.1% of households used electricity. The extensive use of biomass fuel was also evident in the analysis investigating how the three most commonly used fuels (wood, charcoal, and electricity) were combined. Within this analysis, using charcoal alone was more common than any combination of these fuels, and only 3.9% of households used electricity exclusively. Charcoal was extensively used across all age and education groups. This is likely to reflect the use of multiple fuel types together.

Documenting biomass fuel exposure is important in addressing diseases that have been associated with household air pollution, including both COPD (12, 13) and pneumonia (8, 9). A greater understanding of biomass fuel use is also helpful to enable us to tackle the emerging epidemic of noncommunicable diseases as a whole. This will allow for the planning of appropriate interventions and surveillance to monitor the link between changes in exposure and improved outcomes. The considerable variability worldwide of exposure to

risk factors for noncommunicable diseases such as household air pollution also reinforces the need for epidemiological studies of noncommunicable diseases in sub-Saharan Africa.

Occupational data demonstrated that women were more likely to report “domestic activities” as their occupation, suggesting that women bear a greater burden of biomass exposure and, therefore, higher risk of biomass-related conditions, despite low exposure to traditional noncommunicable disease lifestyle risk factors such as cigarette smoking or obesity.

An important finding of this study is that markers of lower socioeconomic status, such as educational level attainment and occupation, were related to a greater use of more dirty-burning fuels. This pattern was most clearly illustrated by a sixfold increase in use of wood comparing between the highest and lowest levels of education, with an inverse and similar magnitude of difference in use of electricity across the education level spectrum. This finding is reinforced by the pattern observed between manual occupations and greater use of dirty-burning fuels. Chilomoni was an ideal place to conduct this study, given the wide range of socioeconomic statuses in which to evaluate factors related to fuel uses (19). A trend was also seen between increasing age up to age 75 years and use of more dirty-burning fuels. This was not seen over the age of 75 years, but small numbers ($n = 127$, 0.8% of sample) make the results from the oldest categories less precise.

This young population represents a different demographic to many developed countries, within which the majority of noncommunicable disease research has historically taken place (20, 22, 23). This study describes a mobile population with only 9.2% of individuals having lived in the same household since birth, highlighting the importance of the Blantyre Health Study following quickly after the enumeration exercise. A mobile population comes with both positive and negative implications, namely that it may be difficult to apply the findings of the Blantyre Health Study back to the same reference population several years later. Conversely, this also implies that a wide range of people will be captured within the study, and therefore the relevance of the Blantyre Health Study findings should be applicable beyond the boundaries of Chilomoni ward. Population mobility also has implications for health both in the transmission of infectious diseases and in exposure to risk factors for noncommunicable diseases.

These results overall are consistent with the literature, adding to available information regarding demographics and biomass fuel use in Malawi. In keeping with our findings it has been previously documented that Malawi has a young population (19, 24). High levels of population mobility have previously been described in northern Malawi (25) and in South Africa (26) but not in the Blantyre region of southern Malawi.

The 2008 population and housing census of Malawi provides the largest recorded information source regarding household fuel use, in which the main source of energy for cooking in both rural and urban Malawi are described. Compared with our finding that 36% of households use wood as one of their energy sources, the census found that throughout Malawi, 96% of the rural population and 42% of the urban population used wood as their main energy source. Although our results are not directly comparable, this suggests a decrease in the use of wood compared with the 2008 census. It is already described within

the literature that women bear a greater burden of household air pollution (4), which is reinforced by our findings. In support of our observed association between increased age and use of more dirty-burning fuels, a study by Fullerton and colleagues also found that their participants who used wood were significantly older than those using charcoal (27).

The link between markers of lower socioeconomic status with more dirty-burning fuels is in keeping with two studies in Malawi by Fullerton and colleagues (17, 27). Their findings included a nonsignificant association between lower socioeconomic status and use of wood compared with charcoal (27). The second study demonstrated that lower socioeconomic status and burning of wood were both significantly associated with living in a rural area (17). A larger study in Ghana found that neighborhoods with a lower socioeconomic status used a greater amount of biomass fuels and had higher particulate matter levels in cooking areas (28). These findings are supported by a study by Gakidou and colleagues, who used a population-level comparative risk assessment model to assess the mortality effects of interventions on child nutrition and environmental risk factors, stratified by economic status (29). They found that implementing environmental changes including cleaner fuels aimed initially at the poorest people would give a greater reduction in child mortality. It is well recognized that the greatest burden of disease from household air pollution is found in less-developed areas of the world (4). There is also evidence that noncommunicable diseases have a disproportionally large effect on those of lower socioeconomic status (30–32).

The main strength of our study was its scale, including 16,079 individuals from 6,445 different households, which accounts for more than 80% of the Chilomoni ward adult population according to the 2008 census (19). To our knowledge, it is the largest available study in the developing world that has examined household fuel use and related factors in detail. These enumeration data now enable stratified random sampling to take place for the Blantyre Health Study and other future studies. The completeness of the dataset reflects that the methodology was appropriate and effective in the field. GPS-enabled and battery-operated PDAs programmed with relevant questionnaires proved a useful tool to conduct surveys in a resource-poor environment. Using the PDAs, a complete dataset was gathered for more than 99% of participants. This is of particular relevance to future studies that wish to conduct questionnaire-based research in developing countries. As the data were gathered primarily to enable stratified randomization for the Blantyre Health Study, this study was limited by a lack of detail in some areas. For example, the fuel use data did not specify which fuel was most frequently used, and there were no measurements of environmental exposure. A more detailed assessment of socioeconomic status would have enabled more robust analysis of associations between fuel use and socioeconomic status.

Prevention of Chronic Lung Disease in the Exposed Population

The young, mobile, biomass fuel smoke–exposed population of periurban Blantyre described here is representative of the estimated 646 million people living in sub-Saharan Africa who are exposed to solid fuel use (2) and at high risk of COPD. Preventive strategies including tobacco control, provision of electric lighting, and smoke-free cooking energy must be implemented to avoid the forecast epidemic of noncommunicable diseases in low- and middle-income countries. Respiratory physicians readily support vaccination against

pneumonia but equally have a duty of care to promote appropriate legislation, town planning, and governmental energy strategies to prevent epidemic COPD.

Conclusions

This large cross-sectional study demonstrates extensive use of biomass fuels in a typical sub-Saharan Africa periurban population in which women and people of lower socioeconomic status are disproportionately affected. Biomass fuel use is likely to be a major driver of the emerging noncommunicable disease (especially respiratory and cardiovascular) epidemic in this region. There is a clear need for high-quality data describing the current burden of disease attributable to biomass smoke exposure in the context of other noncommunicable diseases and their risk factors in sub-Saharan Africa. These data will help inform the rationale for specific intervention studies and the development of appropriately targeted public health strategies.

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Figure 1. World Health Organization energy ladder describing the relationship between different types of household fuels and prosperity. Adapted by permission from Reference 33.

Cooking with solid fuel
Percentage of households
using solid fuel for cooking
2003 or latest available data

Figure 2.

World map showing the percentage of the population using solid fuels. Reproduced by permission from Myriad Editions (www.myriadeditions.com).

Figure 3.
Map of Africa with Malawi highlighted in *red*.

Figure 4.
An African woman using biomass fuel in an open fire in Malawi. Reproduced by permission from the photograph subject and photographer (K.M.).

Figure 5.
Map of Blantyre city wards with Chilomoni ward in *red* and Queen Elizabeth Central Hospital as a *yellow cross*.

Figure 6.
Image showing the global positioning system mapping of households, created using Google Earth Pro (licensed version).

Figure 7. Photograph showing collection of enumeration data using global positioning system-enabled personal digital assistant (SoMo Handheld Computer 650-E WM6.1 WW Eng EMEA). Reproduced by permission from all photograph subjects and the photographer (K.M.).

Figure 8.
Consort diagram.

Figure 9. Age distribution of the study population. This frequency histogram describes the age distribution of the full study population ($n = 16,079$). Note the youngest participants were 17 years of age. Median age was 30 years (range, 17–102 yr).

Figure 10.

Female and male occupations. This chart demonstrates occupations of the study population by sex for $n = 16,076$ ($n = 3$ missing data). “Other” includes any occupations that did not fit into the categories set out in the questionnaire.

Figure 11.

Household fuel use of wood, charcoal, and electricity. This demonstrates the combinations of fuel use in 6,365 households that used wood, charcoal, or electricity (the three most common fuel types). Participants were allowed to select multiple fuel types. For clarity of presentation “electricity and wood” is not presented on the graph, as this group represented 0.3% of households (n = 22).

Figure 12.

Fuel use according to education level. Exploration of distribution of types of fuel used by level of education achieved. Results suggest a relationship between lower level of education and greater use of wood and less use of electricity. The three most common fuel types are presented; “other” fuel types (lpg gas, paraffin, dung, and crop residue) were reported by less than 5% of each educational level group.

Figure 13.

Fuel use according to age. Up to the age of 75 years, a trend was seen between increasing age and increased use of wood and decreased use of electricity. Data represent types of fuel used by 15,944 participants (135 individuals had no recorded fuel use). For clarity of presentation, the three most common fuel types are presented for individuals aged 17 to 95 years (excluding n = 1 respondent).

Table 1

Demographic information

	Demographic	Number of Individuals (% of Total)
Sex	Male	7,994 (49.7)
	Female	8,085 (50.3)
Marital status	Married	9,481 (60.2)
	Single	4,858 (30.2)
	Widowed, divorced, separated	1,540 (9.6)
Education	No school	404 (2.5)
	Primary school	4,355 (27.1)
	Secondary school	8,406 (52.3)
	Higher education	2,912 (18.1)