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# Pulmonary function and respiratory health of rural farmers and artisanal and small scale gold miners in Ghana

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## Abstract

The recent increase in artisanal and small scale gold mining (ASGM) worldwide has elicited a number of public health concerns for miners and mining communities, including respiratory health. The two primary inhalational exposures of concern are crystalline silica expected to be present in gold ore and smoke from biomass fuels used in cooking. Here, measurements of pulmonary function and of respiratory symptoms were performed in an ASGM community, Kejetia, and a comparison agricultural community, Gorogo, in the Upper East Region of Ghana in May-July 2011. Of 172 participants, 159 performed spirometry, yielding 119 and 95 valid measurements for $FEV_1$ and FVC, respectively. Percent predicted $FEV_1$, FVC and $FEV_1$/FVC, which were lower than predicted for a healthy population, were not significantly different between Kejetia and Gorogo or by mining status in Kejetia. Abnormal lung function was elevated for predicted $FEV_1$ (15.0%) and $FEV_1$/FVC (22.0%) beyond an expected five percent in healthy populations. This first examination of pulmonary function in an ASGM community in Ghana (and possibly worldwide) did not show an obvious relationship between mining involvement and lung function abnormality, but did show associations between the use of biomass fuels, adverse respiratory symptoms, and reduced pulmonary function in both populations. A number of factors including age differences between the populations and the required lag time after silica exposure for the onset of respiratory disease may have affected results. Additional research is needed with

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**Ethical Approval**

Institutional Review Board (IRB) approval was obtained through the University of Michigan (HUM00028444). Permission to work with the communities was given by each community's traditional chief.

larger sample sizes and with more detailed questionnaires to further assess the impact of multiple stressors on respiratory health in ASGM communities.

**Keywords**

mining; cooking; biomass; respiratory health; public health

## Introduction

Artisanal and small-scale gold mining (ASGM) is rapidly growing worldwide with upwards of 15 million miners estimated to be directly involved in the sector and potentially 100 million people living in ASGM communities (World Health Organization, 2016; United Nations, 2012). There are a number of public health concerns in ASGM communities (Basu et al., 2015a). For example, mineworkers and the surrounding community may be exposed to chemical agents present in the gold ore or added intentionally for processing, such as mercury used to form amalgams (Basu et al., 2011; Paruchuri et al., 2010; Rajaee et al., 2015a). Miners often work without personal respiratory protection, protective gloves, or boots (Parachuri et al. 2010; Calys Tagoe et al., 2015). Key infrastructure, such as sanitation and health clinics, are often lacking as many ASGM sites exist in impoverished areas (Barry, 1996).

One possible issue of notable concern within ASGM communities is related to respiratory health, though little empirical information exists on related exposures and outcomes. The crushing, grinding, and sifting of gold-containing ore generates dust. Crystalline silica ($SiO_2$) content of dust associated with some gold ore can exceed 30% (Greenberg, Waksman, & Curtis, 2007), and airborne levels of crystalline silica in ASGM sites can exceed exposure limits (Gottesfeld et al., 2015). Long-term inhalation and/or high-level exposure to crystalline silica can lead to the development of silicosis, an irreversible pulmonary fibrosis disease that can develop from five to 45 years after exposure to silica dust (Greenberg et al., 2007). Silicosis is classically identified by the presence of bronchial opacities on chest radiographs. Exposure to silica can accelerate decrements to lung function, which can occur even in the absence of such opacities on a chest x-ray. Silicosis has been shown to accelerate substantial pulmonary function loss among miners, with the degree of the decrease proportional to the severity of silicosis (Ehrlich et al., 2011; Cowie, 1998).

ASGM sites are often situated in resource-limited, rural settings, and thus workers and community members may be exposed to biomass fuel (BMF) smoke. Cooking is often performed either outdoors or inside mud-brick dwellings without windows or roof ventilation, typically using BMF in coal pots or open fires. Cooking smoke from BMFs can affect respiratory health, especially when coupled with lack of ventilation (Fullerton, Bruce, & Gordon, 2008). For example, studies among women who cook with BMFs have shown a correlation between duration of BMF smoke exposure and a decline in pulmonary function (Regalado et al., 2006), an increased likelihood of developing chronic bronchitis (Dossing, Khan, & al-Rabiah, 1994; Ekici et al., 2005), as well as morbidity and mortality associated

with the development of Chronic Obstructive Pulmonary Disorder (COPD) similar to that seen in tobacco smokers (Ramirez-Venegas et al., 2005). It should be noted that acute respiratory infections in children under five years of age comprise the largest single category of deaths from indoor air pollution from BMFs (Smith & Mehta, 2003). It is also important to consider the contribution of tobacco smoke exposure in the development of COPD and other respiratory illnesses (Behera & Jindal, 1991).

Ghana is one of the most important gold-producing countries in the world. Within the country ASGM accounts for 10.5% of Ghana's national gold production and employs between 500,000 and 1 million people mostly in rural areas (Basu, 2015b). Since 2009, our research team has conducted field studies to examine associations between a range of exposures and health outcomes in ASGM communities in the Talensi-Nabdam District of Ghana's Upper East Region (Paruchuri et al., 2010; Basu et al., 2011; Renne et al., 2011, Long et al. 2015, Long et al. 2013, Rajaee et al. 2015b, Rajaee et al. 2015c). To increase understanding of potential respiratory health effects in ASGM communities, here we conducted a comparative study in the Talensi-Nabdam District of Ghana to compare exposure-outcome relationships between an ASGM community and a non-mining, subsistence farming community, and also focus on two main *a priori* areas of concern for potential adverse respiratory effects to workers and the surrounding community: 1) inhalational exposure to dust and potentially crystalline silica that may be present in gold ore, which is directly associated with the mining process; and 2) the use of biomass fuels for cooking, associated with the general living conditions of such communities.

## Materials and Methods

### Study Populations

Data were collected May-July 2011 from participants in an ASGM community, Kejetia, and one non-mining comparison community in the Talensi-Nabdam District in Ghana's Upper East Region. The non-mining community, Gorogo, was selected over other communities because of its lack of gold mining, comparable population size, ease of access, and its hydrologically upstream location relative to local gold mining sites. Institutional Review Board (IRB) approval was obtained through the University of Michigan (HUM00028444). Permission to work with the communities was given by each community's traditional chief.

### Participant Sampling Strategy

Neither site had community maps, distinct village boundaries, or official population estimates, creating challenges for random sampling. Households in Kejetia and Gorogo were defined by individuals who eat food that is prepared at the same place, in accordance with local cultural norms (Ghana Statistical Service and Ghana Health Service, 2009). In Kejetia, a set of coordinates was recorded for every household in the community using a handheld global positioning system (GPS; Oregon 450; Garmin International, Inc., Olathe, KS). Households were then assigned to twenty clusters of approximately 20 households each based on geographic proximity. Each household was then assigned a number within its cluster. Each day, households were selected by randomly pulling numbers from a bag. Up to three households were interviewed per day, each from a different cluster. Each cluster had

two to three participating households in total. If a household was not eligible or declined participation, another number from within the cluster was pulled from the bag until an appropriate household was found (Hoshaw-Woodward, 2001). In Gorogo, the greater geographic dispersion of the community made definition of clusters not feasible. Instead, convenience sampling was done by spinning a plastic bottle at a landmark at the geographic middle of the community and selecting the house that the bottle pointed to most closely. The bottle was then spun from each participating household to find the next household to be surveyed, and from different geographic locations throughout the community. If a household was not eligible or declined participation, a replacement house was chosen by re-spinning the bottle in the same location as the previous spin. The convenience sampling method did appear to cover a substantial fraction of the geographic spread of the community.

## Surveys

Surveys written in English were administered by a team of university students and verbally translated by local Ghanaian translators in the language of choice of the participants (Talen, Nabt, Gurune, Twi, Dagbani, or Hausa). Translators were trained prior to conducting interviews on the appropriate vocabulary and medical terms for health outcomes in the local languages. At each identified household, a request was made to identify the head of household (HOH). Preference for the interviews was given to the HOH, followed by their spouse or any adult (age 18 or older) who appeared knowledgeable about the individuals in the household. The HOH or identified alternative completed a survey on demographics and relationships of people in the household, as well as household characteristics and amenities, including cooking methods to assess BMF exposure. Participants were asked to list all cooking fuels ever used in the household as well as their main source of cooking fuel and cooking locations (to assess indoor and outdoor cooking, where indoor cooking locations included in the house and in a separate building).

A maximum of four adults per household, including the HOH, were administered a separate adult member survey, which included occupational history, smoking history, and respiratory symptoms. Adults were also offered spirometry. When there were more than four adults, decisions on who to interview were made with guidance from the HOH. All the information in the current paper came from the household and adult member survey. Survey questions were adapted from the Ghana Demographic and Health Survey (Ghana Statistical Service and Ghana Health Service, 2009), the British Medical Research Council Questionnaire (MRCQ) on Respiratory Symptoms, and the American Thoracic Society's Epidemiology Standardization Project (Ferris, 1978). Participants were asked to give the total number of years in each mining activity (excavation, crushing/grinding, sifting, washing, amalgamation, and burning). A composite variable was created to capture the minimum number of years a participant performed the identified mining activities ("minimum years mining"). Minimum years mining were split into two sets of mining activities to distinguish activities likely to have higher dust exposure (excavation, crushing, and sifting) from activities with lower dust exposure (washing, amalgamation, and burning). Current miners were defined as having engaged in a mining activity within the previous three months. Ex-miners have engaged in mining activities, but not within the previous three months.

## Smoking

Smoking history was obtained for each participant, and included the year of starting smoking, current number of cigarettes smoked per day, number of years smoking, current smoking status, and pipe tobacco use. Participants were classified as current, ex, and never smokers. Those who had smoked less than 100 cigarettes in their lifetime were classified as never-smokers. In these populations, recall was difficult for many individuals regarding smoking history.

## Respiratory Symptoms

Participants were interviewed on a standard set of respiratory symptoms as well as history and treatment of asthma, tuberculosis (TB), and other respiratory illnesses. Symptom outcomes were defined as follows:

1. Usual cough: Answered yes to “do you usually cough first thing in the morning?” or “Do you usually cough during the rest of the day or at night?”
2. Cough longer than three months: Answered yes to “do you cough like this on most days/nights for as much as three or more months in each of the last two years?”
3. Usual phlegm production: Answered yes to “do you usually bring up any phlegm from your chest during the day or at night?”
4. Phlegm production longer than three months: Answered yes to “do you bring up phlegm like this on most days/nights for as much as three or more months in each of the last two years?”
5. Chronic bronchitis: Answered yes to symptom 2 (cough longer than three months) and to symptom 4 (phlegm production longer than 3 months).
6. Breathlessness when walking: Answered yes to “do you get short of breath walking with other people of your own age on level ground?”
7. Severe breathlessness when walking: Answered yes to “do you have to stop for breath when walking at your own pace on level ground?”
8. Wheezing: Answered yes to “have you had this wheezing or whistling when you did not have a cold or flu?”
9. Chest tightness: Answered yes to “have you been woken up with a feeling or tightness in your chest at any time in the last 12 months?”
10. Shortness of breath: Answered yes to either “have you had an attack of shortness of breath that came on during the daytime when you were at rest at any time in the last 12 months?” Or “have you been woken by an attack of shortness of breath at any time in the last 12 months”?

## Pulmonary Function Assessments

Pulmonary function assessments were performed using EasyOne Diagnostic spirometers (NDD Medical Technologies, Andover, MA) following American Thoracic (ATS) guidelines

(Miller et al., 2005; American Thoracic Society, 1995). The lung function indices of primary interest are Forced Vital Capacity (FVC) and forced expiratory volume in the first second ($FEV_1$) of the maneuver. Study personnel demonstrated spirometry maneuvers for each participant. A minimum of three maneuvers to a maximum of six maneuvers were performed per session by each participant. The spirometers stored data on the best three exhalation maneuvers. Weight was measured using a bathroom scale and height was measured without shoes using a measuring stick fixed to a level platform. Age, weight, and height were recorded for each participant before performing maneuvers. All devices were verified to be properly calibrated at the beginning of the study. Study staff analyzed all recorded maneuvers for validity through observing measures and spirograms (Miller et al., 2005). Validity for $FEV_1$ measures was determined based on an initial "blast" of air and no disruption (e.g., a cough) in the first second. Valid FVC measures required a smooth exhalation for at least three seconds and no additional breaths during the maneuver. Each participant's session of maneuvers was rated based on reproducibility (i.e., <0.15 L difference between maneuvers for $FEV_1$ and FVC measures; Miller et al., 2005). Participants were not excluded from analysis for a failure to meet reproducibility requirements. Participant's largest $FEV_1$ and FVC measures were used for analyses, even if they were from separate maneuvers (Miller et al., 2005).

Prediction equations for $FEV_1$, FVC, and the $FEV_1$/FVC ratio are based on the U.S. National Health and Nutrition Examination Survey (NHANES) III equations for African Americans adults (Hankinson, Odencrantz, & Fedan, 1999). As there are currently no pulmonary function prediction equations for Ghanaians, the U.S. African American population was selected given the West African ancestry of many African Americans and because of the potential better fit than with prediction equations for other African populations (Bio et al., 2005). U.S. African American prediction equations were created using NHANES III data collected from 1988 to 1994 in a random sample, with 2,508 African American eligible participants (Hankinson et al., 1999). The lower limit of normal (LLN) for $FEV_1$, FVC, and the $FEV_1$/FVC ratio are based on the lower fifth percentile of normal performance based on this NHANES III population. The LLN was used to assess abnormality instead of an arbitrary cut off of 70% of predicted to reduce any overestimation of dysfunction that may occur in older individuals (Pellegrino et al., 2005).

## Statistical Analyses

Data were entered and analyzed in Microsoft Excel (v. 2010) and SPSS v. 21 (IBM). The outcome variables of interest were respiratory symptoms and percent predicted pulmonary function measurements $FEV_1$, FVC, and $FEV_1$/FVC. The exposure variables of interest included mining, smoking status and pack-years, and type of primary cooking fuel. Four linear regression models were conducted for each PFT measure: one for all participants, one for each of the two communities, and one restricted to those reporting ever-mining involvement. Results are expressed as mean (SD) unless otherwise indicated. Statistical significance was assessed as $\alpha = 0.05$.

# Results

## Demographics and Mining

Fifty-four households from Kejetia and 26 households from Gorogo participated in the study. There were 172 participants total: 97 from Kejetia and 75 from Gorogo. The number of persons participating per household varied from one to four. Fifty-two percent of participants in Kejetia and 45% in Gorogo were male. Very few individuals refused participation, and most individuals cited lack of time as the main reason. No individuals refused for reasons obviously related to health status.

Participant demographics are detailed in Table 1. Gorogo had a higher mean age than Kejetia. Mean BMI was similar between the two populations, but Gorogo had a higher prevalence (16.2%) of underweight (BMI < 18.5) participants than Kejetia (5.2%). Seventy-one percent of residents from Kejetia reported current involvement in mining activity. Because there was only one Gorogo participant who was classified as a current miner, she was excluded from analyses for consistency. Gorogo ex-miners (n=10) remained in analyses. Nearly all participants in Gorogo reported farming as their current occupation (94.7%), compared to only 7.2% in Kejetia. Cooking as an occupation was more common in Kejetia (15.5%) than in Gorogo (4.0%).

In Kejetia, the mean minimum number of years in any mining activity was 8.00 (7.03) for males and 2.93 (4.92) for females (Table 1). Of Kejetia current miners, the mean minimum number of years in any mining activity was 7.3 (6.7) years, with only 31.4% mining for greater than a minimum of ten years and 47.1% greater than a minimum of five years (Supplementary Table 1). The mean minimum number of years was 6.6 (6.1) in excavation, crushing or sifting, and 5.5 (6.7) in washing, amalgamation and burning for Kejetia current miners. Kejetia and Gorogo ex-miners (n=4 and n=10, respectively) had lower mean minimum numbers of years in any mining activity (5.6 ± 7.1 years and 4.6 ± 3.5 years, respectively) than Kejetia current miners.

## Smoking

In Kejetia, 30% of males and no females were current smokers, and in Gorogo, 38.2% of males and 2.4% of females were current smokers (Table 1). Mean pack-years for ever-smokers was significantly higher in Kejetia than in Gorogo (16.8 and 3.9, respectively), and higher in Kejetia among current smokers than among ex-smokers (18.0 and 9.0, respectively). In Kejetia, all current smokers reported having done some mining activity. Percent predicted pulmonary function test (PFT) measurements ($FEV_1$, FVC, and $FEV_1$/FVC) were not significantly different for current, ex, and never smokers in Kejetia or Gorogo. Pipe tobacco use was uncommon; only two males in Kejetia and one male in Gorogo reported ever having used pipe tobacco regularly.

## Spirometry Maneuvers and Pulmonary Function Tests

Among the 172 participants, 159 attempted to perform spirometry maneuvers. Ten of those who did not perform spirometry refused, and three attempted but were unable to perform the measure. Four refused because of health reasons (such as feeling ill or pregnancy). No

participants refused based on a report of breathing problems. Other reasons for refusing included religious fasting and difficulty with correctly performing the forced exhalation maneuver during preliminary practice.

There were a greater number of valid $FEV_1$ measurements (119 of the 159 sessions) than FVC measurements (95 sessions), because a number of participants performed the maneuver correctly during the first couple of seconds, but failed to continue blowing long enough for a reliable FVC or took multiple breaths. $FEV_1$ measurements were invalid if a participant failed to "blast" air in the first second. Valid maneuvers for $FEV_1$ and FVC were slightly higher in Kejetia than Gorogo ($FEV_1$: 78.0% and 70.6%, and FVC: 62.6% and 55.9% in Kejetia and Gorogo, respectively). Males had higher frequencies of valid $FEV_1$ and FVC maneuvers than females in both communities, except FVC in Kejetia is approximately equal between sexes. Kejetia current and ex-miners were combined as ever-miners for analyses of PFTs, as there was only one valid $FEV_1$ and FVC measurement for a female ex-miner and one valid $FEV_1$ measurement for a male ex-miner.

Based on the NHANES prediction equations for healthy U.S. African Americans, the mean percent predicted $FEV_1$, FVC, and $FEV_1$/FVC were not significantly different for Kejetia and Gorogo by sex, nor when comparing never and ever-miners in Kejetia (Table 2). The mean PFT measurements were lower than predicted for a healthy population, although they were similar for males and females in Kejetia and Gorogo, except percent predicted $FEV_1$ was lower for Gorogo males than females (p=0.276). Although the sample size is limited, Kejetia male ever-miners have a significantly smaller percent predicted $FEV_1$/FVC ratio than male never miners (p=0.002). Mean percent predicted $FEV_1$, FVC, and $FEV_1$/FVC in Kejetia were not significantly associated with mining involvement overall or by specific mining activity (Supplementary Table 2), although those who had ever done excavation (n=23) had lower mean percent predicted $FEV_1$/FVC ratios nearing statistical significance as compared to those who had not (p=0.06).

Using the NHANES prediction equation for the lower limit of normal (LLN) (based on a cutoff of 5% of a healthy population, equal to approximately two standard deviations below the mean), the prevalence of PFTs below the LLN was elevated among Gorogo participants and Kejetia females for $FEV_1$ and $FEV_1$/FVC (Table 2). $FEV_1$ and $FEV_1$/FVC ratio abnormality were higher in Gorogo than in Kejetia. In Kejetia, females had a higher prevalence of abnormal $FEV_1$ and $FEV_1$/FVC ratios than males. The percent predicted $FEV_1$ in Gorogo and percent predicted $FEV_1$/FVC ratio abnormality in Kejetia and Gorogo were significantly increased from 5%. No participants had abnormal FVC measures, except for Gorogo females. Abnormal lung function varied with age with no obvious trend (Supplementary Table 3).

### Reported History of Respiratory Diseases

Only two participants reported ever having had tuberculosis, and only three participants reported ever having had asthma. Usual cough, usual phlegm production, chest tightness, and shortness of breath were the most common respiratory symptoms (Table 3). Usual phlegm, cough and phlegm production for more than three months, chronic bronchitis, wheezing, chest tightness, and shortness of breath were significantly more common in

Kejetia than Gorogo. In bivariate analyses, no symptoms of interest were significantly associated with any of the measures of pulmonary function (percent predicted $FEV_1$, FVC, $FEV_1$/FVC). When stratified by mining activity involvement in Kejetia, only phlegm production for longer than three months, chronic bronchitis, breathlessness when walking, severe breathlessness when walking, and shortness of breath were significantly correlated with a mining activity (Supplementary Table 4).

### Cooking Smoke

The most commonly used cooking fuels overall and as the primary fuel source were charcoal, wood, and crop residues (Table 4). Only participants living in Gorogo used crop residues for cooking. Electricity, kerosene, biogas, straw, and animal dung were not used by any participants. LPG and natural gas were used by only a few households and were not primary fuel sources. Seven male participants in Kejetia lived in households that only purchased food from vendors rather than cooking. All male and female participants in Gorogo cooked indoors (including in the house or in a separate building), whereas in Kejetia, only 36.2% of female participants and 25.6% of male participants cooked indoors (three participants cooked both indoors and outdoors). In Kejetia, charcoal was primarily used outdoors (82.1%), while only half (52.5%) of wood users cooked outdoors.

In bivariate analyses among Kejetia participants, there were no significant differences in PFTs by cooking fuel use or stove type (Supplementary Table 5). In analyses restricted to Kejetia males, percent predicted $FEV_1$ was significantly higher for cooking indoors (97.7 ± 12.9%) compared to not cooking indoors (86.7 ± 10.1%, p=0.038), excluding non-cooking males (data not shown). In Gorogo, percent predicted $FEV_1$ and FVC were significantly lower for any use of an open fire compared to coal pot use. The mean percent predicted $FEV_1$/FVC ratio was significantly lower for wood as a main fuel source compared to participants using charcoal or crop residue. Percent predicted $FEV_1$/FVC was significantly lower for main use of an open fire for cooking and using wood or crop residue as the main fuel source compared to main use of a coal pot and charcoal fuel. Gorogo males had significantly lower mean percent predicted $FEV_1$/FVC ratios for main wood fuel use (85.2 ± 14.0%) compared to main charcoal or crop residue use (98.8 ± 5.1%, p=0.024) (data not shown).

### Regression Analyses

Models of all Kejetia participants and ever-miners showed no significant associations with percent predicted PFTs with any covariates (Table 5). In Gorogo, there was a significant association only between wood cooking fuel for the percent predicted $FEV_1$/FVC ratio (p=0.007). For each respiratory symptom, three logistic models (not including those restricted to reporting ever mining involvement) were examined for those with ten or more participants reporting the respiratory symptom in question. Logistic regression for respiratory symptoms included the same covariates and, in addition, age (Table 6). Logistic regressions were only conducted for usual cough, usual phlegm production, phlegm production longer than three months, breathlessness when walking, severe breathlessness when walking, wheezing, chest tightness, and shortness of breath.

Logistic regression models (Table 6) of respiratory symptoms showed no statistically significant results for Kejetia and Gorogo participants for cooking fuel or minimum years mining in excavation, crushing, or sifting. Gorogo participants had significantly lower odds of usual phlegm production, phlegm production longer than 3 months, wheezing, chest tightness, and shortness of breath. Current smoking status as compared to never smoking had a significantly elevated odds of usual phlegm production (OR=4.12; CI: 1.09, 15.6) (not shown on table), but no other significant associations.

## Discussion

The aim of this study was to determine the impact of ASGM involvement and biomass fuel smoke on pulmonary function and respiratory health. We believe this is the first study of its kind despite estimates of ~100 million people worldwide living in ASGM communities (World Health Organization, 2016; United Nations, 2012). We observed the prevalence of abnormal percent predicted $FEV_1$ and $FEV_1$/FVC measures higher than the lower fifth percentile of normal performance based on healthy U.S. African American adults (Hankinson et al., 1999; Pelegrino et al., 2005). In Kejetia, this trend is driven by lower percent predicted values among the female participants. Restrictive lung diseases are characterized by reduced $FEV_1$ and FVC, while the $FEV_1$/FVC ratio may be normal or slightly increased (Pellegrino et al., 2005). Obstructive diseases like COPD are marked by a reduction in $FEV_1$ in relation to the FVC, causing a reduced $FEV_1$/FVC ratio, namely below the LLN (Pellegrino et al., 2005). Silicosis can cause both restrictive and obstructive disease patterns as it develops (Greenberg et al., 2007). The prevalence of abnormality suggests higher than expected obstructive disease in both communities.

The prevalence of usual cough and breathlessness when walking are lower in Kejetia than other studies of rural and urban adults have observed (Gamsky, Schenker, McCurdy, & Samuels, 1992, Gallotti et al., 2006; Nriagu et al., 1999). Chronic bronchitis and shortness of breath prevalence in Kejetia is similar to some other studies among rural Canadian swine farmers (Dosman et al., 1988) and urban South African adults (Nriagu et al., 1999). Usual phlegm production, usual phlegm production for longer than three months, and wheezing are higher in Kejetia than found in other groups of rural and urban adults (Dosman et al., 1988; Gallotti et al., 2006; Nriagu et al., 1999). In Gorogo, cough for longer than three months, usual phlegm production, usual phlegm production for longer than three months, chronic bronchitis, breathlessness when walking, wheezing, and shortness of breath are all generally lower than other potentially exposed and non-exposed groups (Gamsky et al., 1992; Gallotti et al., 2006; Nriagu et al., 1999; Dosman et al., 1988). Exposure to elemental mercury may also cause coughing, chest tightness, and shortness of breath (Clarkson & Magos, 2006; Poulin & Gibb, 2008).

Analyses did not show an obvious relationship between mining involvement and pulmonary function abnormality. Although participants that had engaged in mining activities generally had minimally higher $FEV_1$, FVC, and $FEV_1$/FVC measures than those with no mining involvement, bivariate analyses of PFT measures did not show a clear pattern. Similarly, linear regressions were in the counter-intuitive direction for $FEV_1$ and $FEV_1$/FVC for Kejetia and Gorogo, but not significantly associated with changes in lung function.

One should be circumspect in over-interpreting these seemingly negative results. We suspect that the ore dust to which miners are exposed may contain silica (Gottesfeld et al., 2015), but the latency period for silicosis development is longer than many people in Kejetia have mined, so some potential effects of this exposure may not yet be apparent. Kejetia is a younger, more transient population with only 31.4% of miners having mined for greater than a minimum of ten years and 47.1% having done a minimum of five years of mining. Since chronic silicosis, the most common form, typically appears 20 to 40 years after initial exposure to respirable silica dust, it is possible that these miners are too early in their mining careers to show pulmonary function changes associated with silicosis. The transient nature of the ASGM community makes it difficult to track the development of long latency period diseases such as silicosis. While accelerated silicosis can develop within five to 15 years of initial exposure to respirable silica dust, the exposure to respirable silica, which is unknown in this study, may not be great enough to cause this heightened effect (Mason & Thompson, 2010). Elemental mercury, a common exposure in Kejetia and Ghanaian ASGM communities, has been found to influence pulmonary function and vital capacity, although specific impacts on $FEV_1$, FVC, and the $FEV_1$/FVC ratio are unknown (Lilis et al., 1985; McFarland and Reigel, 1978; Lim et al., 1998). It is possible that the observed elevated $FEV_1$/FVC ratio abnormality is an early sign of pulmonary obstruction, which is characterized by a reduced $FEV_1$/FVC ratio (Pellegrino et al., 2005). The Healthy Worker Effect may also place a selection bias on participants in Kejetia, as adults with pulmonary dysfunction may not be able to continue mining and may choose to leave the community and return to a familial village.

While smoking prevalence was slightly higher for Gorogo than Kejetia participants, smoking pack-years were lower in Kejetia and Gorogo than in U.S. American populations (Center for Disease Control and Prevention, 2005). This may explain the relatively low associations of smoking with respiratory outcomes. Chronic respiratory symptoms of cough, phlegm production, and breathlessness have been reported more often among smokers in a small Italian community (Gallotti et al., 2006).

Our analyses showed some associations between use of biomass fuels like charcoal and wood and reduced pulmonary function in the Gorogo population. Main wood fuel use was associated with a significant decrease in the percent predicted $FEV_1$/FVC ratio in Gorogo. In Kejetia, cooking fuel use was not significantly associated with decrements in PFTs. There is strong evidence of the influence of BMF smoke on negative respiratory health and pulmonary function (Regalado et al., 2006; Ramirez-Venegas et al., 2006; Ekici et al., 2005; Zelikoff et al., 2002), and the type of biomass fuel may also play a significant role. BMF smoke has been associated with increased chronic bronchitis (Ekici et al., 2005), and chronic wood smoke exposure has specifically been associated with chronic bronchitis and pulmonary fibrosis (Zelikoff et al., 2002). A study with Malawian adults found that adults using wood as their primary cooking fuel had significantly worse lung function than adults using charcoal, and that wood use was a significant predictor of $FEV_1$ (Fullerton et al., 2011). Wood BMF was associated with pulmonary dysfunction measured in Nigerian adults (Oluwole et al., 2013). A Nepalese study of adults found that participants using biomass fuel were twice as likely to have an $FEV_1$/FVC ratio below the LLN (8.1%) than those using LPG (3.6%) (Kurmi et al., 2013). Studies examining air pollution and BMFs have found that

particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs), which both have adverse health effects, were higher for wood and charcoal fuel than crop residues, kerosene/charcoal mixes, and LPG (Titcombe & Simcik, 2011; Lisouza et al., 2011), and another found PAH and PM emissions from wood to be close to double that of charcoal (Oanh et al., 1999; Partnership for Clean Indoor Air, 2012). A study in Malawi and Nepal comparing total inhalable endotoxins, which have been associated with respiratory illnesses, found that endotoxin levels were higher in homes using wood fuel than homes using charcoal fuel (Semple et al., 2010).

Gender is anecdotally important in predicting exposure to BMF smoke, as women do the majority of cooking in both communities. Based on our observations, cooking-related gender roles are strongly associated with biological sex. In Kejetia, abnormal $FEV_1$ and $FEV_1/FVC$ is higher among females than males, and in Gorogo, FVC and $FEV_1/FVC$ are higher among females than males. This difference may be due to the differential gender roles in cooking. Early life exposures to BMF smoke may be common for all participants, which may explain decreased pulmonary health but the overall lack of significant associations when all participants are exposed. Additionally, decrements to pulmonary function from BMF smoke are difficult to tease apart from mining. Because participants in Gorogo cook almost exclusively indoors using an open fire, where there is little or no ventilation, the effect of BMF smoke on pulmonary function may be greater than observed in Kejetia, where cooking is done primarily outdoors. This should result in a reduced negative effect from BMF smoke exposure for Kejetia residents, however, elevated decrements in pulmonary function were still observed. It is possible that cumulative and combined exposures to dust, respirable silica, and/or elemental mercury play a role in Kejetia residents' pulmonary function.

## Limitations

A number of limitations may have affected the results of our study. A set of criteria was established to ensure the comparison community was as comparable to Kejetia as possible, but choices among communities were limited, and there were substantial differences in the population structure between Kejetia and Gorogo. We were especially limited by a relatively small sample size, particularly of ASGM miners for greater than ten years. This limited statistically significant results and resulted in larger confidence intervals in regression analyses. A larger study focusing on long-term ASGM miners would aid in revealing relationships with ASGM. For many older participants in Gorogo, difficulty performing the spirometry maneuver may have skewed the results. Inaccuracies in translation may have compromised the information relayed between participants and researchers during performance of the maneuvers and during surveys, but the entire research team was trained prior to collecting spirometry data to reduce this problem.

As we did not have information on the total number of years that miners did excavation, crushing, and/or sifting; we used a variable of the minimum number of years doing any one of those activities. This may not have accurately captured the actual length of time that participants were involved in these activities. We also do not have accurate measures of dust or silica exposure (e.g., biomarkers or environmental measurements) and rely upon surveys.

Furthermore, there is a latency period between exposures and adverse respiratory outcomes that we are not able to well account for with our study design.

It is possible that the pulmonary function prediction equations may not be appropriate for the study participants, as it is based on U.S. African Americans. We are limited, as there are no prediction equations for West Africans or Ghanaians. A study of male Ghanaian gold miners found that the European Community for Steel and Coal (ECSC) equations were a better fit than other African prediction equations, but still needed a conversion factor of 0.87 (Bio et al., 2005). Since many African Americans have West African ancestry, the U.S. African American NHANES equations may align better than other African prediction equations. The prevalence of abnormal pulmonary function may be influenced more significantly by an ill-fitting prediction equation, which we were unable to quantify.

Since participants were not clinically evaluated by medical professionals, there may have been false reporting and an information bias in reported respiratory symptoms. Smoking pack-years were calculated based on the assumption that an individual smoked the same number of cigarettes on average throughout the entirety of his/her smoking period. Increased prevalence of abnormal percent predicted $FEV_1$ and $FEV_1$/FVC measures in Gorogo emphasize that other, non-mining, exposures or factors may be decreasing respiratory health and pulmonary function. In a resource-limited setting lacking basic sanitation, infrastructure, and access to healthcare, a variety of other unforeseen health problems may have also confounded results.

## Conclusions

This study is the first to investigate pulmonary function and respiratory symptoms with small-scale miners, to the authors' knowledge. In a setting where there are multiple stressors from occupational and household activities, it is difficult to isolate causes of respiratory dysfunction. However, our study demonstrates that pulmonary obstruction is elevated in both the rural ASGM and subsistence farming communities. This may be due to mining or biomass fuel smoke exposures, but also may result from inadequate pulmonary function prediction equations for Ghanaian populations. Further research is needed with larger sample sizes and with more detailed questionnaires to further assess the impact of multiple stressors on respiratory health in small-scale mining communities. This study will help to guide future research on pulmonary function with rural and ASGM communities. This is particularly necessary since about 100 million people worldwide are estimated to live in ASGM communities.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## HIGHLIGHTS

- ASGM communities have many respiratory hazards but little public health evidence
- Cross-sectional study performed using surveys and spirometry
- No obvious mining-related changes but biomass fuel use is of potential concern
- This is the first study examining pulmonary function in an ASGM community

## Table 1

Demographic, occupational, and smoking information for Kejetia and Gorogo participants by sex.

| | | Kejetia | | Gorogo | |
|---|---|---|---|---|---|
| | | Male | Female | Male | Female |
| *n* participants | | 50 | 47 | 34 | 41 |
| Age (years) | Range | 18 – 52 | 18 – 75 | 23 – 87 | 19 – 80 |
| | Mean (SD) | 32.0 (8.9) | 30.8 (12.6) | 54.2 (18.7) | 49.3 (18.9) |
| BMI[a] | Mean (SD) | 22.1 (2.5) | 23.4 (3.7) | 20.9 (2.7) | 22.4 (3.4)[b] |
| Height (cm) | Mean (SD) | 171 (7) | 162 (6) | 169 (6) | 161 (7) |
| Occupation[c] | | | | | |
| | Current Miner[d] | 86.0% | 59.6% | 0.0% | 0.0% |
| | Ex-Miner[d] | 2.0% | 6.4% | 14.7% | 12.2% |
| | Farmer | 8.0% | 6.4% | 97.1% | 92.7% |
| | Cook[e] | 0.0% | 31.9% | 0.0% | 7.3% |
| | Vendor | 8.0% | 29.8% | 2.9% | 14.6% |
| | Other | 8.0% | 17.0% | 11.8% | 7.3% |
| Minimum Years Mining[f] | Mean (SD) | 8.00 (7.03) | 2.93 (4.92)[g] | 0.62 (1.65) | 0.61 (2.25) |
| Smoking Status | | | | | |
| | Current Smokers | 30.0% | 0.0% | 38.2% | 2.4% |
| | Ex-Smokers | 14.0% | 0.0% | 26.5% | 0.0% |
| | Never Smoked | 56.0% | 100.0% | 35.3% | 97.6% |
| Pack years[h] | Mean (SD) | 16.8 (27.2) | - | 4.2 (2.0) | 0.5 |

[a]BMI is body mass index, calculated by: weight(kg)/height(m)$^2$

[b]n = 40 for Gorogo: Female

[c]Participants were able to select more than one occupation

[d]Current miners engaged in a mining activity within the last 3 months

[e]This includes individuals that cook food or pito, an alcoholic beverage made from millet

[f]Minimum years in any mining activity (excavation, crushing, sifting, washing, amalgamation, burning, or owning); see Methods section for more details.

[g] n=46 for Kejetia: Female

[h] Pack years of ever (current and ex) smokers

## Table 2

Mean percent predicted $FEV_1$, FVC, and $FEV_1$/FVC values and percent abnormalities by community, sex and mining status among Kejetia participants.

| | | Percent Predicted $FEV_1$ | | | Percent Predicted FVC | | | Percent predicted $FEV_1$/FVC | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Population** | | ***n*** | **Mean (SD)** | **Abnormal[a]** | ***n*** | **Mean (SD)** | **Abnormal[a]** | ***n*** | **Mean (SD)** | **Abnormal[a]** |
| Kejetia | Male | 40 | 89.4 (12.3) | 7.5% | 30 | 92.7 (11.9) | 0.0% | 29 | 94.5 (9.0) | 3.4% |
| | Female | 31 | 87.8 (12.7) | 12.9% | 27 | 92.9 (10.9) | 0.0% | 24 | 93.7 (9.4) | 20.0% |
| Gorogo | Male | 24 | 83.5 (16.0) | 25.0% | 22 | 94.6 (12.8) | 0.0% | 21 | 89.7 (13.3) | 23.8% |
| | Female | 24 | 89.8 (22.8) | 20.8% | 16 | 94.8 (21.7) | 6.3% | 16 | 89.1 (12.7) | 25.0% |
| Kejetia Miners: | | | | | | | | | | |
| Never Miners | Male | 5 | 93.8 (20.2) | 0.0% | 5 | 92.7 (20.7) | 0.0% | 5 | 102.1 (3.8)[b] | 0.0% |
| | Female | 9 | 88.8 (9.4) | 11.1% | 10 | 94.3 (10.8) | 0.0% | 8 | 91.0 (4.5) | 11.1% |
| Ever-Miners | Male | 35 | 88.7 (11.1) | 8.6% | 25 | 92.7 (10.0) | 0.0% | 24 | 92.9 (9.0) | 4.2% |
| | Female | 22 | 87.4 (14.0) | 13.6% | 17 | 92.0 (11.2) | 0.0% | 16 | 95.1 (10.9) | 25.0% |

[a] Abnormality defined as a PFT measure below the lower limit of normal (LLN) defined by NHANES (Pellegrino et al., 2005)

[b] Independent T-test comparing never miners to ever-miners in Kejetia for PFTs (stratified by sex); p-value < 0.05

**Table 3**

Percent of respiratory symptoms in Kejetia and Gorogo.

| | Kejetia | | Gorogo | |
|---|---|---|---|---|
| **Symptom** | ***n*** | **%** | ***n*** | **%** |
| Usual cough | 27 | 27.8 | 23 | 30.7 |
| Cough longer than three months | 9 | 9.3[a] | 0 | 0.0 |
| Usual phlegm production | 38 | 39.6[a] | 6 | 8.0 |
| Phlegm production longer than three months | 22 | 22.7[a] | 3 | 4.0 |
| Chronic bronchitis | 6 | 6.2[a] | 0 | 0.0 |
| Breathlessness when walking | 6 | 6.2 | 8 | 10.7 |
| Severe breathlessness when walking | 8 | 8.2 | 8 | 10.7 |
| Wheezing | 15 | 15.5[a] | 3 | 5.3 |
| Chest tightness | 51 | 52.6[a] | 25 | 33.3 |
| Shortness of Breath | 28 | 28.9[a] | 12 | 16.0 |

[a]Significantly different symptom prevalence between Kejetia and Gorogo participants, Chi-square $p < 0.05$

## Table 4

Household characteristics, cooking fuel sources, stove types, and cooking location by Kejetia (n=54) and Gorogo (n=26).

| | Kejetia | | Gorogo | |
|---|---|---|---|---|
| | *n* | Percent | *n* | Percent |
| **Main Fuel Source**[a] | | | | |
| Charcoal | 36 | 67.9 | 5 | 19.2 |
| Wood | 11 | 20.8 | 15 | 57.7 |
| Crop Residue | 0 | 0.0 | 6 | 23.1 |
| No Cooking | 6 | 11.3 | 0 | 0.0 |
| **Main Stove Type**[a] | | | | |
| Open fire | 11 | 22.9 | 22 | 84.6 |
| Coal pot | 36 | 75.0 | 4 | 15.4 |
| Open stove | 1 | 2.1 | 0 | 0.0 |
| **Location**[a] | | | | |
| Indoors[b] | 14 | 25.9 | 26 | 100.0 |
| Outdoors | 35 | 64.8 | 0 | 0.0 |
| **Household characteristics** | Mean (SD) | | Mean (SD) | |
| Total rooms | 2.4 (1.4) | | 9.8 (7.9) | |
| Rooms for sleeping | 2.1 (1.2) | | 6.9 (6.3) | |
| Total persons | 5.4 (3.0) | | 12.6 (7.1) | |

[a] n = 53 for Kejetia (K): Main fuel source; n = 48 for K: Main stove type; n = 49 for K: Location

[b] Indoors includes in the house or in a separate building

## Table 5

Linear regression results for percent predicted $FEV_1$, FVC, and $FEV_1$/FVC. Each row represents a separate model.[a]

| | Model[a] | n | Adjusted $R^2$ | Intercept | Min. years mining[b] | | Wood cooking fuel[c] | | Crop residue cooking fuel[c] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | β | β | 95% CI | β | 95% CI | β | 95% CI |
| Percent Predicted FEV[1] | All | 111 | −0.05 | 85.72 | 0.27 | (−0.45, 0.99) | −3.31 | (−11.78, 5.16) | −2.59 | (−15.10, 9.91) |
| | Gorogo | 48 | −0.06 | 95.13 | 0.30 | (−2.70, 3.30) | −15.05 | (−35.95, 5.85) | −13.22 | (−34.95, 8.51) |
| | Kejetia | 63 | −0.61 | 87.31 | 0.08 | (−0.55, 0.72) | 2.50 | (−5.38, 10.37) | - | - |
| | Kejetia ever-miners | 51 | −0.09 | 88.14 | 0.08 | (−0.66, 0.82) | 0.60 | (−9.68, 10.87) | - | - |
| Percent Predicted FVC | All | 89 | −0.06 | 91.00 | −0.16 | (−0.88, 0.55) | 2.38 | (−5.89, 10.66) | −1.38 | (−13.99, 11.23) |
| | Gorogo | 38 | −0.17 | 96.46 | −0.04 | (−2.78, 2.69) | −0.74 | (−20.16, 18.68) | −4.97 | (−25.96, 16.02) |
| | Kejetia | 51 | 0.01 | 90.94 | −0.36 | (−1.00, 0.29) | 5.10 | (−2.94, 13.15) | - | - |
| | Kejetia ever-miners | 38 | −0.004 | 93.53 | −0.55 | (−1.28, 0.19) | 6.86 | (−3.38, 17.10) | - | - |
| Percent Predicted $FEV_1$/FVC | All | 84 | 0.04 | 95.96 | 0.09 | (−0.46, 0.63) | −5.14 | (−11.47, 1.19) | 2.78 | (−7.04, 12.61) |
| | Gorogo | 37 | 0.13 | 100.81 | 0.72 | (−1.09, 2.52) | −18.33 | (−31.13, −5.53) | −6.56 | (−20.59, 7.48) |
| | Kejetia | 47 | −0.13 | 95.86 | 0.06 | (−0.48, 0.60) | 0.33 | (−6.48, 7.14) | - | - |
| | Kejetia ever-miners | 36 | −0.13 | 95.27 | 0.04 | (−0.65, 0.74) | 0.60 | (−8.97, 10.17) | - | - |

[a]Covariates included in the models but not shown here are sex and current and ex-smoking status (never-smoking as reference) for all models. Models of “all” participants include a covariate to account for Gorogo community participants.

[b]Minimum years of mining in excavation, crushing or sifting. See Methods section for more details.

[c]Main fuel source (charcoal fuel as reference). Crop residue only included in models of all and Gorogo participants. Kejetia models excluding 7 male miners that do no cooking in their household.

## Table 6

Logistic regression of respiratory symptoms. Each row represents a separate model.[a]

| Model[a] | Respiratory Symptom | N | Respiratory Symptom | Nagelkerke $R^2$ | Min. years mining[c] OR | Min. years mining[c] 95% CI | Wood cooking fuel[d] OR | Wood cooking fuel[d] 95% CI | Crop Residue cooking fuel[d] OR | Crop Residue cooking fuel[d] 95% CI | Gorogo community OR | Gorogo community 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Usual Cough | 162 | 47 | 0.13 | 0.99 | (0.90, 1.07) | 0.67 | (0.28, 1.60) | 0.07 | (0.01, 0.59) | 1.79 | (0.62, 5.12) |
| | Usual phlegm production | 161 | 41 | 0.26 | 0.96 | (0.88, 1.04) | 1.67 | (0.63, 4.44) | 2.76 | (0.36, 21.06) | 0.06 | (0.01, 0.28) |
| | Phlegm production longer than 3 months | | 24 | 0.20 | 1.00 | (0.92, 1.10) | 1.97 | (0.67, 5.82) | 3.06 | (0.21, 45.03) | 0.08 | (0.01, 0.56) |
| All | Breathlessness when walking | | 13 | 0.14 | 1.06 | (0.93, 1.20) | 3.56 | (0.67, 19.07) | 7.96 | (0.79, 80.02) | 0.71 | (0.10, 5.16) |
| | Severe breathlessness when walking | 162 | 14 | 0.14 | 1.06 | (0.94, 1.20) | 0.84 | (0.19, 3.74) | 1.97 | (0.27, 14.50) | 1.42 | (0.23, 8.70) |
| | Wheezing | | 17 | 0.14 | 0.98 | (0.88, 1.09) | 1.87 | (0.52, 6.75) | 7.04 | (0.61, 81.10) | 0.04 | (0.004, 0.41) |
| | Chest tightness | | 73 | 0.15 | 0.95 | (0.88, 1.02) | 2.13 | (0.88, 5.20) | 4.41 | (1.17, 16.63) | 0.19 | (0.06, 0.56) |
| | Shortness of breath | | 38 | 0.11 | 0.94 | (0.86, 1.02) | 1.73 | (0.66, 4.50) | 1.95 | (0.36, 10.62) | 0.17 | (0.05, 0.62) |

[a]Covariates included in the models but not shown here are sex, age, current smoking and ex-smoking status (never-smoking as reference) for all models

[b]Number of participants with the corresponding respiratory symptom.

[c]Minimum years mining in excavation, crushing or sifting. See Methods section for more details.

[d]Main fuel source; charcoal is the reference; only Gorogo participants use crop residue fuels; excluding 7 male miners from Kejetia that do no cooking in their household.