Assessing health vulnerabilities through diet, stress, and noise exposure in a small scale-gold mining community of northeastern Ghana

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Abstract

Patterns in dietary diversity, biochemical (salivary cortisol) and physiological stress (heart rate), and noise exposures were assessed in a small-scale gold mining village in northeastern Ghana. A 2011 cross-sectional study of 106 participants showed dietary diversity score (DDS) ranging from 1- 17 (out of 22 food categories) with a mean (±SD) of 8.1 ± 3.0. DDS groupings based on the Ghana Demographics and Health Survey ranged from 1-12 (out of 12) with a mean (±SD) of 5.8 ± 2.1. Women showed a significantly higher level of total concerns related to money, food, environmental conditions, and illness than did than men. A 2013 cross-sectional study of salivary cortisol level changes between morning and evening among 22 subjects showed patterns consistent with chronic stress, i.e., a relatively low decline in cortisol through the day (-1.44 ± 4.27 nmol/L, n = 18). A multiple linear regression model pairing noise exposures measured through personal dosimetry with changes in cortisol from evening to morning revealed an increase of 0.45 nmol/L significantly associated with an increase in 1 dBA L_{eq} (Adj. R^2 = 0.188, n = 17). Similarly, multiple regression models showed variation in heart rate (HR), as measured by the standard deviation of the running average, significantly associated with variation in noise exposure over time, as measured by the standard deviation of L_{eq}. Regardless of gender or involvement with small-scale mining, 95% of participants in 2013 were exposed to 24-hour noise levels over the World Health Organization's guideline of 70 dBA. These findings suggest that small-scale mining community residents may face cumulative health risks from mining activities that are not yet well documented, including hearing loss and cardiovascular effects of stress and noise. By documenting baseline levels for dietary diversity, stress, and noise in this community, this study adds to the growing body of research linking noise with physiological stress responses and suggests that further research into determinants of health unique to these communities is warranted.

Contents

1. Introduction

Small-scale gold mining is increasing worldwide in response to both demand (gold prices have risen substantially in recent years) and new regulations that have created economic opportunities for rural communities. As a key producer in the global gold market, Ghana relies on gold for almost 40% of its total exports, with production having risen 700% since 1980 (Hilson, 2002). Much of that increase has come from small-scale gold mines, which now provide an estimated 20-30% of total gold output worldwide (UNEP Chemicals 2002). Mining communities face a number of public health concerns, including direct and indirect exposure to chemicals present in gold ore and those used in amalgamation (e.g., mercury); degraded environmental quality through water pollution and deforestation; and dust exposures resulting from the mining process (Aryee, Ntibery, & Atorkui, 2003; Grandjean & Landrigan, 2006; Basu et al., 2010). Given that these communities are often rural and impoverished with limited healthcare and sanitation (Barry 1996), these added stressors from mining compound the health risks already faced by residents.

Between 2009-2013, a research team from the University of Michigan School of Public Health (UMSPH) conducted interdisciplinary research in the Talensi District in the Upper East region of Ghana (see Figure 1) focusing specifically on the relationship between mining activities and the health of mine workers (see Paruchuri et al., 2010; Renne et al., 2011). This region relies heavily on the gold industry for economic opportunities, with over 10,000 men, women, and children employed in small-scale gold mines (Hilson 2010). A 2004 study in the Talensi-Nabdam District revealed patterns in the social and economic hierarchy of mining communities that underlie potential social and health disparities. The hierarchy among mine workers tends to favor migrants with mining experience as higher level workers with locals filling lower level and unskilled labor and women doing the work of “shanking” (sifting ore to separate powder from larger pieces) at the lowest economic level. The finding that 72% of residents surveyed in mining communities belonged to households outside of the community (as opposed to just 13% in farming communities) highlights the migratory nature of these mining communities (Awumbila and Tsikata 2004).

Awumbila and Tsikata (2004) suggest that these social dynamics, in addition to differential health hazards faced by the segmented work force and environmental degradation due to mining, create a need for more holistic migration policies that are sensitive to these community dynamics. The small-scale gold-mining town of Kejetia in the Talensi District, where work by the UMSPH team has taken place (Figure 1), was founded in 1995 and grew to around 15,000 by 2000. Ten years later, Kejetia was home to an estimated 2,500 people, illustrating the unstable nature of gold-mining seen in other mining towns where many residents are transient (Renne et al. 2011). Compounding the social stressors in the community brought by migration and economic hierarchies is the fact that mining activities are interspersed with residential and commercial areas. This raises particular concern since health hazards are not confined to just those working in the mining sector.

Both social and physical vulnerabilities arising from the gold mining itself and the nature of the community are beginning to be documented, but most studies to date have focused on mercury associated with amalgamation activities. Although migrant households may be more likely to be food insecure (Crush 2013), and both stress and noise exposure have been linked to a multitude of adverse health effects (Cohen et al. 2007; Gouin 2011; Passchier-Vermeer and Passchier 2000), trends in diet, food insecurity, stress, and noise have not been well documented in this community or other small-scale mining settings. Based on these findings and the literature reviewed below, a greater understanding of

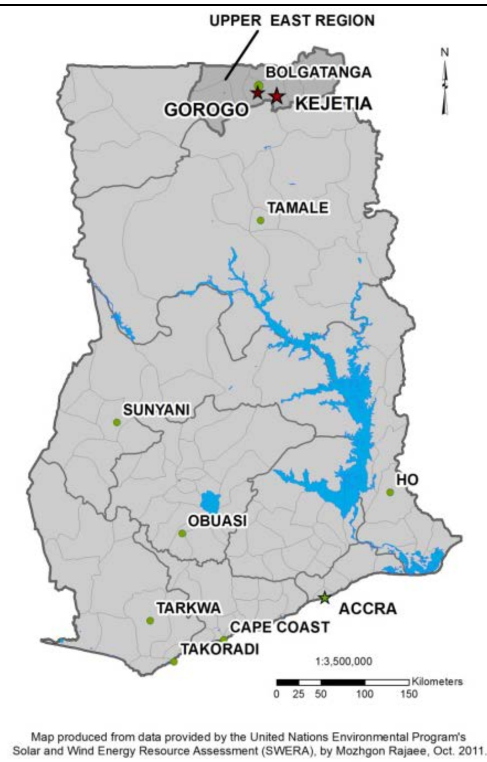

Figure 1. Map of Ghana showing the study site, the small-scale mining village of Kejetia, in the Upper East region.

dimensions of cumulative stressors related to small-scale gold mining in Kejetia is needed to better inform policies and practices that support the overall health and well-being of residents there and elsewhere.

The aims of this research, then, are twofold:

AIM 1: *Determine the relationship between dietary diversity, food insecurity, personal concerns, and qualitative (self-reported) stress among adults in Kejetia.* This aim will use cross-sectional data collected in both 2011 and 2013 to test the hypothesis that:

a. Residents with higher social status (e.g., household heads, higher educational attainment) will report greater dietary diversity, a lower degree of food security, and a lower degree of personal concerns overall.
b. Level of concern expressed in 2011 will be positively correlated with self-reported stress measured in 2013.

AIM 2: *Determine the relationship between noise exposure and qualitative (self-reported) as well as biochemical, and physiological indicators of stress among adults in Kejetia.* This aim will use cross-sectional data in 2011 and 2013 to test the hypothesis that:

a. Qualitative, biochemical, and physiological indicators of stress will be positively correlated with noise exposure.
b. A higher level of personal concerns will be associated with biochemical stress responses indicative of chronic stress.

2. Background

2.1 Diet and Food Insecurity

Nutrition is crucial to child growth and development, and dietary diversity scores can be useful indicators of micronutrient adequacy and have been associated with child anthropometric measurements

(Steyn et al. 2007). Diet diversity in the Savelugu-Nanton district of northern Ghana was associated with child stature but only for children of household heads, potentially due to preferential serving of high-status children during common meals or by supplementation that these children receive outside of common household meals (Leroy et al. 2008). While dietary diversity should not be taken as a direct reflection of the quality of a diet, it has, nonetheless, been consistently correlated with nutrient adequacy (Ruel 2003).

In addition to its usefulness in assessing nutritional adequacy, dietary diversity has also been studied in association with socioeconomic status. Having inconsistent access to affordable, healthy food as a result of any number of barriers, especially poverty, can influence health outcomes (see Casey et al. 2005; Cook et al. 2004; Stuff et al. 2004). For this reason, a growing body of research is exploring food insecurity alongside dietary diversity in order to more fully understand the connection between these two measures of well-being and to better characterize nutritional status.

In a study on community concerns in the Talensi-Nabdam district, participants ranging from local leaders to community members in urban, rural, farming, and small-scale mining communities ranked food insecurity as the top problem related to environmental degradation (Agyemang 2011). Food insecurity, as characterized by an inadequate and instable food supply, may not always be a good indicator of nutrition in all populations (Bhattacharya et al. 2004); however, it has been associated with negative health effects such as poor physical health in young children and poor physical and mental health in adults (Cook et al. 2004; Stuff et al. 2004). Well-nourished children perform better academically, due in part to learning productivity during the school year (Glewwe et al. 2001), while hunger has been associated with anxiety, chronic illness, and behavioral problems in children (Weinreb et al. 2002). Hoddinott and Yohannes (2002) found that an association between dietary diversity and food access was consistent across studies from 10 different countries, in both rural and urban areas, and through all seasons, regardless of dietary diversity being defined by the number of individual foods or food groups. They also associated dietary diversity with an increase in household per capita consumption and caloric availability. As an indicator of food security and socioeconomic status, dietary diversity scores based on the number of food groups consumed within a given time period have been useful in revealing positive associations between various measures in developing nations (Ruel 2003). Even with these associations, dietary diversity may not be an adequate proxy for food insecurity in all cases, since food insecurity is a measure of not only consumption, but of food availability and access as well.

Looking at Ghana specifically, a 2006 study in a neighboring district of northern Ghana found that the level of food insecurity was positively correlated with the number of people in a household but saw no significant correlation with education levels (Hesselberg and Yaro 2006). While measuring income in rural Ghanaian communities is complicated, research using the Ghana Living Standards Surveys from 1987-88 and 1991-92 revealed that simply being female had a significant negative effect on earnings, but a positive association was found between earnings and being a female head of a household (Canagarajah et al. 2001). If these patterns hold true in Kejetia, female headed households, regardless of education, may be more financially secure than other females in the community and therefore potentially more food secure. On the other hand, the concerns elicited by Agyemang (2011) over hunger, nutrition, and other social stressors, especially by women in the Talensi-Nabdam district, may also be shared regardless of income and status.

2.2 Stress

As noted, vulnerabilities that affect overall health and well-being may arise indirectly (e.g., social dimensions) or directly from mining activities. Studies focusing specifically on stress resulting from mining activities, however, are sparse. Evidence for physical health risks is becoming increasingly common in the literature; yet, studies highlighting the potential for stress in mining communities have not paired qualitative measures of stress with physiological data (see Agyemang, 2011; Hinton, Veiga, & Beinhoff, 2003; Hoadley & Limpitlaw, 2004). In addition to ranking food security as a top concerns, the above-mentioned study by Agyemang focusing on the social vulnerabilities of residents in the Talensi-Nabdam district also elicited concerns over cultural tensions, increased prevalence of diseases related to environmental degradation, youth abandoning education and farming to join the small-scale mining and sand winning workforce, and stress (particularly on women) (Agyemang 2011).While the aim of that particular study was to associate environmental degradation with social concerns, it paints a complex picture of potential stressors in the area that could be further elucidated through combining qualitative and quantitative stress measurements. On the other hand, studies looking at physiological markers of health in mining communities have not measured stress either. For example, a review focusing specifically on underground mine work and mercury amalgamation identified health problems such as infectious diseases, respiratory ailments, hearing loss, and mercury exposure but did not raise the issue of stress as either a psychological or physiological health risk (Eisler 2003).

Links between psychosocial stress and health outcomes have been extensively reviewed in the literature. Chronic psychosocial stress, from sources such as work, home life, and socioeconomic status, have been associated with cardiovascular disease, acute myocardial infarction, inflammation, hypertension, and immune dysregulation (*cardiovascular disease* - Bairey Merz et al., 2002; von Känel, 2012; *myocardial infarction* - Rosengren et al., 2004; *inflammation* - McEwen & Gianaros, 2010; *hypertension* - Spruill, 2010; *immune dysregulation* - Gouin, 2011). The endocrine response in the hypothalamic-pituitary-adrenocorticol axis (HPA) is one of the physiological mediators of disease linked with psychological stress, with cortisol being increasingly used as a hormonal biomarker for stress in research.

Cortisol levels in saliva are a commonly used indicator of the total amount of this hormone circulating in the body, and because saliva samples can be easily taken in the field, one-day repeated measures of salivary cortisol is becoming an increasingly reliable and popular measure of stress, particularly in noise exposure studies (for review see Bigert, Bluhm, & Theorell, 2005). Repeated measures are necessary to capture diurnal secretion patterns, with cortisol typically increasing 50-100% within 30-45 minutes of awakening in the morning and declining steadily through the day. These daily cortisol patterns can be difficult to interpret across studies with different methodologies, since confounders to the pattern include age, gender, menstrual cycle, hormonal status, alcohol consumption, smoking, and certain medications (for review see Smyth, Hucklebridge, Thorn, Evans, & Clow, 2013). General life conditions have also been suggested as being important confounders in interpreting cortisol levels. Chronic stressors are associated with generally high average cortisol levels and a relatively flat *cortisol slope* (change in cortisol levels from morning to evening) (Bigert et al. 2005). For example, blue collar workers showing signs of high burnout had higher average salivary cortisol levels than those with low burnout. The difference in cortisol, however, was only significant for subjects who also showed signs of chronic burnout, as defined by symptoms lasting for 6 months or longer (Melamed et al. 1999). Other long-term stressors at home and work that have been associated with high cortisol levels include time pressure and effort reward imbalance in women, as well as high degrees of effort, effort reward imbalance, and over-commitment in men (Eller et al. 2006). Consistent with evidence relating chronic stress to a flat cortisol slope, call center workers with low job strain showed a greater salivary cortisol response after waking than workers with high job strain (Maina et al. 2009).

Cortisol responses to acute stressors have also been documented, with many studies using cognitive stress tasks to test cortisol changes in response to the task. For example, a 5-minute stress procedure that combines cognitive, emotional, acoustic, and motivational stressors elicited a post-stress spike in salivary cortisol during a 45-minute recovery period in 60% of participants compared to pre-stress levels. This study also saw increased heart rate during the stress event (Reinhardt et al. 2012). A 2004 review of acute stressors in laboratory settings concluded that cortisol tends to increase in tests that involve uncontrollable tasks or a social-evaluative threat that involves judgment of the participants' abilities. In terms of predictors for cortisol changes, adding two methodological factors —time of day and time between stressor and sampling—significantly improved fit of the regression model in a meta-analysis of 208 laboratory stress studies. Out of the 208 studies reviewed, six used noise as an uncontrollable stressor in laboratory tests. On average, no significant change in cortisol was noted for these studies, and the authors concluded that with noise, the inability to control the situation may not evoke a cortisol response because the stressor does not pose a threat to the overall goal of the task. No conclusions were drawn about the effect of noise itself on stress and cortisol, but research using salivary cortisol as a biomarker is becoming increasingly important in understanding the relationship between stress, health, and noise exposure (Dickerson and Kemeny 2004). Other methodological considerations, such as timing of samples and adherence to protocol (see Smyth et al., 2013), as well as individual determinants of cortisol response (e.g., early life experiences) have been reviewed elsewhere (Kudielka et al. 2009).

2.3 Noise

One particular environmental exposure that has not been well studied in small-scale gold mines in Ghana or elsewhere in the world is noise. The mining process, as observed by the UMSPH research team in Kejetia, involves multiple steps with the potential for elevated noise exposures. Dynamite can be used during the excavation process along with shovels and picks. Ore is then processed either using a generator-powered grinding machine (see Figure 2) or by hand using mortar and pestle. In Kejetia, these processes can last throughout the day, concentrating noise in certain areas and adding to the overall occupational hazards faced by miners.

Figure 2. Example small-scale mining activity involving high noise – crushing and grinding of ore.

Sufficient evidence exists for a causal relationship between long-term noise exposure and hearing impairment, hypertension, ischemic heart disease, annoyance, school performance, and sleep disturbances, including subjective sleep quality and heart rate, in various indoor, outdoor, and occupational settings (Passchier-Vermeer and Passchier 2000). Cardiovascular effects associated with noise exposure include changes in heart rate, blood pressure, and stress hormones; vascular and heart muscle changes in animal studies; and a higher risk for high blood pressure and myocardial infarction in high noise occupational studies (see Babisch, 2011). In reviewing these associations, Babisch (2011) notes that while some studies see differences in effects based on level of noise annoyance and on gender, the results of these studies are not consistent enough to draw major generalizations. A UK-based study estimated an additional 542 cases of acute myocardial infarction, 788 cases of stroke, and 1169 cases of dementia per year due to hypertension associated with environmental noise above the 16-hour daytime recommended L_{eq} of 55 dBA. An L_{eq} measurement provides a standardized measure of the average sound pressure level for both continuous and time-varying noise. Overall, these cases were valued at £1.09 billion, with 31% of that value coming from L_{eq} over 65dBA (Harding et al. 2013). Nighttime noise levels have also been associated with cardiovascular risks, in addition to sleep disturbance. Hume et al. (2012) suggest that while evidence for nighttime noise and sleep disturbance causing cardiovascular disease is still needed, the effects of nighttime noise may be even more pertinent than daytime noise in understanding cardiovascular effects.

The effects of environmental noise have also been studied in children, with many studies specifically looking at noise from traffic or aircrafts. A study of 340 8-11 year old London residents noted significantly higher noise annoyance and lower reading comprehension in kids attending schools with 16-hour outdoor L_{eq} above 66 dBA compared to those with less than 57 dBA, despite confounders like socioeconomic status (Haines et al. 2001). Learning difficulties have been associated with noise in other studies as well, although evidence for lowered reading comprehension varies (Kaltenbach et al. 2008;

Ljung et al. 2009; Stansfeld et al. 2010). In reviewing noise considerations with vulnerable populations, van Kamp and Davies find evidence that physiological effects may be more evident in children than noise annoyance and sleep disturbance. Fatigue, headache, and lack of concentration have also been noted in multiple studies (van Kamp and Davies 2013). Evidence for physiological effects carrying over into adulthood has not yet been gathered (Babisch 2011), but long-term consequences of learning disruptions, especially in terms of reading, raises serious concerns for the long-term success and well-being of children in these settings.

Besides environmental noise, workplace exposure is of particular concern, since an estimated 16% of the disabling hearing loss in adults worldwide is a result of occupational noise-induced hearing loss. In the African subregion that includes Ghana, 25% of hearing loss in males and 11% in females is attributed to occupational noise-induced hearing loss, corresponding to an estimated 157,000 DALYs (Nelson et al. 2005). Although only sampling patients admitted for hearing problems, a study of 6,428 patients in a Ghanaian hospital found significant hearing loss in 89.9% of participants, with 8.1% of all hearing loss being noise-induced (Amedofu et al. 2006). In this same area of Ghana, 23% of workers at a surface gold mine showed signs of noise-induced hearing loss. While not all of this hearing loss may be attributable to work in the mine, noise levels above 85 dBA were recorded at four out of five areas of the mine that were surveyed (Amedofu 2002). This elicits concern for noise exposures being over the NIOSH Recommended Exposure Limit of 85 dBA (average) over an 8 hour period (NIOSH 1998). In a study of Nicaraguan gold miners, audiometric tests showed hearing impairment in 35% of subjects (21 of 59 participants). These results, however, did not correlate with estimated noise exposure, though it should be noted that noise exposure was crudely determined by self-reported time spent doing various activities (Saunders et al. 2013).

Because of the localized nature of small-scale mines, it is not just miners who face potential adverse health effects from exposures but other community residents as well. While the 8-hour 85 dBA recommendation is pertinent to small-scale miners working in high-noise areas, noise exposure in Kejetia and other mining communities may extend beyond the typical work day. Based on observation, mining activity in Kejetia can occur throughout the day, 7 days a week. Hence, miners may be exposed to excess noise even while not working if they live near mining activities, and non-miners living near such activities may also face exposures above recommendations. The World Health Organization has set a recommended 24-hour noise exposure guideline of 70 dBA in industrial areas to protect against noise-induced hearing loss (Berglund et al. 1999), and this recommendation may be more relevant for assessing overall exposures for miners and non-miners in the community. If noise exposures in Kejetia mirror those observed in other settings, they have the potential to cause the psychological and physiological effects described above. Because noise has yet to be adequately assessed in the community, this study will begin to shed light on specific vulnerabilities associated with noise exposure.

2.4 Stress and Noise

The body of research linking noise exposure and stress outside of the mining sector is growing, with studies using both self-reported measures of psychological stress and physiological indicators such as cortisol and heart rate. Specific associations between noise and salivary cortisol, however, vary with study settings. Exploring the effects of environmental noise, a 2011 study on 115 Austrian 4th grade students from higher noise neighborhoods (greater than 50 dBA day-night average) reported higher perceived stress levels, had higher overnight urinary cortisol levels, and a greater average increase in heart rate during a challenging reading test (Evans et al. 2001). Depression, anxiety, and elevated cortisol in UK children was not, however, associated with aircraft noise in another study (Haines et al. 2001). Women exposed to aircraft noise over a 60 dBA 24-hour average in a cross-sectional European study had a higher morning cortisol level, but no significant difference was observed in men (Selander et al. 2009). Increased salivary cortisol was also seen in people performing arithmetic with 90 dBA of white noise, and participants also reported feeling more irritable under noisy conditions (Miki et al. 1998). Interestingly, self-reported stress was found to be an important risk factor, along with age and noise exposure, for severe tinnitus ("ringing" in the ears) in a study of over 12,000 Swedish adults (Baigi et al. 2011).

Occupational settings also show mixed evidence for a relationship between noise and stress. L_{eq} over 80 dBA were associated with increased salivary cortisol in a study of 80 male manufacturing industry workers (Fouladi et al. 2012), but occupational noise levels had no significant effect on salivary cortisol levels outside of work in a study of industrial, finance, and service workers (Stokholm et al. 2014). A study of 101 preschool employees also found no significant correlations between noise levels and cortisol measurements, but higher self-reported stress levels at work were associated with high noise annoyance. Morning cortisol levels were also associated with noise annoyance (Sjödin et al. 2012).

Finally, a European study found that children in neighborhoods with greater ambient noise (above 60 dBA day-night average sound level), mostly from rail and road traffic, reported a higher level of stress than children in quieter neighborhoods (less than 50 dBA). Additionally, for girls in this study, there was a significant negative correlation between noise and performance on a task meant to assess deficits in motivation that could reflect learned helplessness (Evans et al. 2001).

2.5 Stress and Diet

Dietary insufficiencies, stress, and noise have all been separately associated with adverse health and educational outcomes. In the U.S., children under 36 months in food-insecure households had an adjusted odds ratio of having "fair or poor" health almost twice as high as those in food secure households (Cook et al. 2004). Food-insecure adults in the U.S. are also more likely to report fair or poor health and score lower on a mental and physical health assessment tool (Stuff et al. 2004). In Ghana, lactating women reporting high levels of stress (scored high on the Perceived Stress Scale) had significantly lower energy intakes (as measured by three 24-hour dietary recalls and portion weighing) in one study, and high stress levels were also seen more often in women from food insecure households (Addo et al. 2011).

Taken together, this evidence, along with the evidence of short and long-term health effects described above, suggests that diet, stress, and noise are all individual predictors of child and adult well-being. This study will begin to document how these factors may influence quality of life both individually and cumulatively in a small-scale gold-mining community.

3. Methods

3.1 Ethical Considerations

All research was done with the approval of the University of Michigan Institutional Review Board (IRB-HSBS# HUM00028444 and HUM00079313). Each participant gave oral and written consent to take part in the study and received financial compensation according to their level of participation. Permission to work with the communities was given by the community's traditional chief.

3.2 Data Collection

3.2.1 Sampling and Interviews

Researchers worked with translators to conduct interviews and explain all processes in the participant's own language. Table 1 summarizes interview questions and measurements in each study. Interviews took place either in the morning or afternoon at the participants' home or workplace. Diet and personal concerns (e.g., food insecurity, environmental exposures, and health) data were collected during June-August of 2011 from 106 individuals from 54 households. All houses in Kejetia were assigned a number and grouped into clusters. From each of the 20 clusters, 2-3 house numbers were randomly drawn for interviews (as described in Long et al., 2013). Stress and noise data collection took place in April 2013 over a six day period in Kejetia. The data reported here were extracted from a larger data set collected during personal interviews, where participants answered a qualitative questionnaire, gave biological samples, and received noise and heart rate monitoring equipment to measure 24-hour noise exposure and heart rate variation. Using a convenience sample, the research team interviewed a subset of 22 people from 16 households who were part of the 2011 survey.

3.2.2 Diet and Personal Concerns (2011)

A maximum of four adults from each participating household in 2011 completed a dietary survey consisting of two parts: a 24-hour dietary food group recall and questions asking level of concern for various measures. The head of each household (if available) and other adults in the household who were responsible for feeding a child participated in the survey. For the dietary recall, participants were asked "During the last day and night (24 hours), did you or your children eat or drink any of the following things" (see Table 2 for food groups). Dietary recall questions were adapted from the 2008 Ghana Demographic and Health Survey (DHS) (Ghana Statistical Service (GSS) et al. 2009). Personal concerns were measured by asking participants to think back over the last 12 months and tell whether s/he worried about: (a) not having enough money to raise their children, (b) not having clean air to breathe, (c) not having a clean environment, (d) not having safe water to drink, (e) having their food run out before you have money to buy more, (f) becoming ill themselves, (g) their children becoming ill. Frequency response options for each item were "never, sometimes, often, or all of the time." These specific questions were developed by the research team (see Appendix A for full questions).

Table 1. Interview items and measurements collected in 2011 and 2013 cross-sectional studies.

2011 – Diet and Concerns	**2013 – Stress and Noise**
Interview Demographics 24-hour dietary recall – Dietary diversity score (DDS) Personal Concerns – Enough money – Enough food – Clean air – Clean water – Clean environment – Self-illness – Child-illness	*Interview* Demographics Noise annoyance Perceived Stress Scale items (PSS) – Upset – Unable to control important things – Nervous and "stressed" – Confident – Angered 24-hour Activity Log *Measurements* 24-hour noise exposure (L_{eq}) – Personal noise dosimeter (dBA) 24-hour heart rate (HR) – Heart rate monitor (beats per minute, bpm) Salivary cortisol – Afternoon, evening, and morning samples (nmol/L)

3.2.3 Stress and Noise (2013)

In a return trip to Kejetia in April 2013, we measured perceived and physiological stress and personal noise exposure during one 18-24 hour period after the interview. Perception of stress was measured using five items from the Perceived Stress Scale (PSS) (see Cohen, Kamarck, & Mermelstein, 1983). Participants were asked to report how often in the last month (never, almost never, sometimes, fairly often, or very often) they had felt upset, unable to control important things in their life, nervous or stressed, confident, and angered (see Appendix A for full questions). These particular PSS questions were chosen, instead of the typical PSS4 questions, in consultation with translators because they were thought to be more translatable than others. While the PSS has not been validated in this context, it was developed for general use and has been used previously in Eastern Ghana (Addo et al. 2011).

In addition to perceived stress, salivary cortisol and heart rate were measured as biomarkers of physiological stress. Participants gave saliva samples with Salimetrics Oral Swabs (Salimetrics Europe, Ltd: Product #5001.02) held under the tongue for 60 seconds at the time of the interview (afternoon sample), before going to bed (evening sample), and upon waking the next day (morning sample). Verbal and pictorial instructions reminded participants to avoid eating any food or drinking dairy products within an hour of each sample, to abstain from alcohol consumption, and to rinse their mouth out with water 10 minutes before each sample. The following day, equipment and saliva samples were collected and participants were asked to recall the type, approximate start time, and duration of all activities they participated in during the sample period. Salivary cortisol samples were kept unrefrigerated and processed within three weeks at the University of Michigan Core Assay Facility using a DPC Coat-A-Count Cortisol modified protocol for saliva. Heart rate (HR, in beats per minute) was logged in 5 second intervals with a Garmin FR70 Fitness Watch with Heart Rate Monitor worn by participants, and resting average heart rate for comparison was measured three times during the interview with a manual sphygmomanometer (Omron HEM-432C; Omron Healthcare, Inc., Lake Forest, IL). Personal noise exposure was measured using an Etymotic Research Inc. ER-200D Personal Noise Dosimeter attached to the collar of each participant, logging equivalent continuous average (L_{eq}) noise levels every 3.75 minutes. The dosimeter approximated the performance of a Type 2 dosimeter (American National Standards Institute 1991), and had a measurement range of 70-130 dBA.

3.3 Data Coding

3.3.1 Diet

Using the 24-hour diet recall, each participant was assigned a Dietary Diversity Score from 1-22 (DDS (22)), based on the total number of individual food categories (excluding any water) reported, and a DDS from 1-12 (DDS (12)), based on groupings used in the 2008 Ghana DHS (Ghana Statistical Service (GSS) et al. 2009). See Table 2 for specific food categories and groupings.

3.3.2 Personal Concerns

Responses to the personal concerns questions were scored according to frequency, from never, almost never, sometimes, often, or all of the time (never = 0, all of the time = 3). Since concern for running out of food before having money to buy more is a key component of food security measurements, scores for this question were used as a basic indicator of household food security. Frequency response options were assigned a value from 0-3 for being worried “never” through “all the time” and were summed to create a Total Personal Concerns score for each person that answered all seven questions. Cronbach’s alpha was used to assess the coherence of these items. The relationship between Personal Concerns scores and dietary diversity was assessed with Pearson’s correlations.

3.3.3 Perceived Stress

Responses to the PSS questions were scored according to frequency, from never, almost never, sometimes, fairly often, or very often (never = 0, fairly often =4), with the positive question referring to confidence levels reverse scored (never=4, always = 0), according to the standard PSS procedure (Cohen et al. 1983). Cronbach’s alpha was used to assess the coherence of the PSS items.

Table 2. Specific foods included in 24-hour dietary recall and Dietary Diversity Scores. Categories for DDS(22) and groupings for DDS(12) adapted from the 2008 Ghana DHS (Ghana Statistical Service (GSS),Ghana Health Service (GHS), & ICF Macro, 2009)

Total Dietary Diversity Score DDS(22)	**Grouped Dietary Diversity Score DDS(12)**
1. Milk: tinned, powdered, fresh animal milk	1. Milk DDS(22) – 1
2. Tea or coffee	2. Tea or coffee DDS(22) – 2
3. Other liquids such as juice, cocoa, minerals	3. Other liquids DDS(22) – 3
4. Bread, rice, noodles/spaghetti, or other foods made from grain	4. Grains DDS(22) – 4, 5
5. Maize: Kenkey, banku, koko, tuo zaafi (t.z.), akple, weanmix	
6. White potatoes, yam, manioc, cassava, cocoyam, fufu, gari, or any other foods made from roots, tubers or plaintain	5. Roots or tubers DDS(22) – 6
7. Foods made w/beans, peas, lentils, or nuts	6. Legumes DDS(22) – 7
8. Liver, kidney, heart, or other organ meats	7. Meat, fish, and eggs DDS(22) – 7, 8, 9, 10, 11, 12
9. Any meat such as beef, pork, lamb, goat, guinea fowl, chicken or duck	
10. Fresh fish	
11. Dried fish	
12. Eggs	
13. Yogurt, cheese, or other milk products	8. Dairy products DDS(22) – 13
14. Ripe mangoes, paw paw	9.Vitamin A-rich fruits and vegetables DDS(22) – 14, 15, 16
15. Pumpkin, red/yellow yam, carrots, yellow or orange sweet potatoes	
16. Any dark green leafy vegetables such as bitto, berese, kotomire, aleefu, ayoyo, kale, cassava leaf	
17. Oranges, watermelon, bananas, pineapples, grapes	10. Other fruits or vegetables DDS(22) – 17, 18, 19
18. Shea fruits	
19. Any other fruits or vegetables	
20. Oils, fats, or butter	11. Oil DDS(22) – 20
21. Sweets, biscuits, cakes	12. Sweets DDS(22) – 21
22. Alcohol: Pito	DDS(22) (Not included)

3.3.4 Cortisol

Self-reported adherence to protocol, intraassay coefficient of variation (c.v.), and distance from other data points for each salivary cortisol sample was examined as criteria for exclusion. The change in salivary cortisol level between each sample period was calculated by subtracting the afternoon sample from the evening and the morning sample from the evening so that a negative change between samples corresponds to a decrease in cortisol over time. Average cortisol levels were also calculated using all three samples. Both the morning to evening change and average cortisol measures differ from standard practice in the literature since the evening sample preceded the morning sample, but this sampling procedure was necessitated by constraints on interactions with subjects. We assumed consistency in variables, such as sleep duration and awakening time, that have been identified as potential confounders affecting salivary cortisol levels (as reviewed by Smyth, Hucklebridge, Thorn, Evans, & Clow, 2013). To account for these possible confounders, total sleep duration and the time from awakening to afternoon and evening samples was calculated using self-reported times on the Activity Log (see Appendix A). The start time of the dosimeter (which was started during the personal interview at roughly the same time as the afternoon saliva sample was collected) was used as the afternoon sample point, the time reported going to bed served as the evening sample point, and the time reported waking up as the morning sample point, assuming that the saliva samples were taken near the time the dosimeter was started, directly before going to bed, and directly after waking. Again, we assumed that the reported awakening time is consistent with the awakening time from the previous day when afternoon and evening samples were collected.

3.3.5 Noise

Since the dosimeters recorded measurement intervals rather than actual time of day, the time for each data point was ascertained using written records in order to match noise levels with self-reported activities. Dosimeter start-times were either recorded by the research team or estimated by back-calculating from the recorded end-of-interview time. After assigning a time of day to each dosimeter time point, these time points were then assigned a corresponding activity based on the Activity Logs filled out by each participant (see Appendix A). Many participants gave estimated times and durations for activities, introducing error into noise levels estimated for each activity; however, these errors were assumed to be randomly distributed. While the accuracy could have been improved for some activities by making judgments based on changes in L_{eq} and heart rate (e.g., during sleep), no data were changed using these or other techniques in order to avoid introducing additional, non-random error.

All datapoints with L_{eq}= 0 (i.e., entire measurement interval below the unit's 70 dBA measurement threshold) were recoded as $70/\sqrt{2}$ to better reflect the distribution of noise levels below the dosimeters' limit of detection (Hornung 1991). Datapoints beyond 24 hours were excluded from analysis. Overall L_{eq} was calculated for each participant over 24 hours or the duration of time the dosimeter was worn, whichever was greater. Within that timeframe, a separate L_{eq} for occupational activities, leisure, and sleeping was also calculated by combining the 3.75 min L_{eq} levels from the dosimeter with activities reported via activity card; occupational activities were further broken down into non-mining and mining, with a specific L_{eq} for each major activity. To match noise exposures with salivary cortisol responses, L_{eq} for the time between samples was also calculated for each participant, using the start of the dosimeter as the afternoon sample point, the time reported going to bed as the evening sample point, and the time reported waking up as the morning sample point.

3.3.6 Paired Noise and Heart Rate

Heart rate (HR) data was paired timewise with sound level measurements, and the 5 second HR datapoints were averaged to match the 3.75 min intervals of the dosimeters to create a Running Avg HR. In most cases, 45 consecutive 5 second heart rate intervals were averaged for each 3.75 minute interval; however, in cases where data was missing during the 3.75 minute interval, the Running Avg HR represents an average of however many 5 second intervals were present. For each self-reported activity, a Running Avg HR and L_{eq} were calculated using each datapoints over the total duration of the activity. These activity-specific L_{eq} values may differ from those calculated solely on dosimeter data because HR data was not consistently recorded throughout the entire sampling period due to monitor connectivity issues. While some participants have consecutive HR data for the entire duration of an activity, most HR monitors recorded inconsistently.

3.4 Statistical Analysis

3.4.1 Diet and Personal Concerns

All statistics were performed using IBM SPSS Statistics 21.0, and Shapiro-Wilk tests were performed to determine distributions and appropriateness of tests. Independent Samples t-tests, χ^2 tests, and correlation coefficients were used to examine differences and relationships among DD(23), DDS(8) between men and women, miners and non-miners, education levels, religion, and food insecurity. Differences in Total Personal Concerns were examined with One-Way ANOVA and χ^2 tests. Linear regression models were built with DDS(22) as an outcome, first with each variable of interest drawn from the literature and from hypotheses in simple linear regressions and then combined in a final multiple linear regression model.

3.4.2 Stress and Noise

Mann-Whitney U and Kruskall-Wallace tests were used to compare changes in cortisol and differences in L_{eq} between men and women, miners and non-miners, education levels, and noise annoyance responses. Correlations between variables of interest were calculated using Spearman's rho. The overall morning to evening change (e.g., morning to evening cortisol levels) as well as the change between afternoon and evening samples were used as outcomes in backward stepwise regression. Models were developed using backwards stepwise regression with $p = 0.05$ as a threshold for entry into the model and $p = 0.1$ for removal. In addition to predictors identified as significant in stepwise regression, other predictors were included in the final adjusted models, regardless of coefficient significance, based on literature review and significant relationships to the outcome. This method was also used to create models for paired HR and noise exposure, with Overall HR, Work HR, Leisure HR, and Sleep HR all used as outcomes. Variables were transformed as necessary when assumptions of linear regression were violated.

Table 3. Demographics summary in 2011 and 2013 cross-sectional studies.

	2011						2013 Subset					
	Total		Female		Male		Total		Female		Male	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Average Age (years)	**33.2**	**11.8**	31.6	12.7	32.1	9.3	**34.1**	**10.3**	32.5	9.8	36.0	11.1
Years Lived in Kejetia	-	-	-	-	-	-	**10.5**	**6.7**	10.1	6.9	11.0	6.7
Household Size	**5.6**	**2.9**	-	-	-	-	-	-	-	-	-	-
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Total Participants	**106**	-	48	45%	58	55%	**22**	-	12	55%	10	45%
Household Heads	**43**	**41%**	14	13%	29	27%	**12**	**55%**	5	23%	7	32%
Households	**54**	-	-	-	-	-	**16**	-	-	-	-	-
Religion												
None	-	-	-	-	-	-	**3**	14%	2	9%	1	5%
Catholic Christian	-	-	-	-	-	-	**7**	32%	4	18%	3	14%
Protestant Christian	-	-	-	-	-	-	**2**	9%	2	9%	0	0%
Muslim	-	-	-	-	-	-	**4**	18%	1	5%	3	14%
Traditional	-	-	-	-	-	-	**6**	27%	3	14%	3	14%
Marital Status												
Single	**21**	20%	4	4%	17	16%	**4**	18%	1	5%	3	14%
Married	**82**	77%	41	39%	41	39%	**16**	73%	9	41%	7	32%
Widowed	**3**	3%	3	3%	0	0%	**2**	9%	2	9%	0	0%
Highest Level of Education Completed												
No School	**32**	30%	22	21%	10	9%	**6**	27%	3	14%	3	14%
Nursery/Preschool	**9**	8%	6	6%	3	3%	-	-	-	-	-	-
Primary	**33**	31%	12	11%	21	20%	**7**	32%	5	23%	2	9%
Middle	**18**	17%	5	5%	13	12%	**5**	23%	3	14%	2	9%
Secondary	**11**	10%	2	2%	9	8%	**3**	14%	0	0%	3	14%
Post-Secondary	**1**	1%	0	0%	1	1%	**0**	0%	0	0%	0	0%
Missing	**2**	2%	1	0%	1	1%	**1**	5%	1	5%	0	0%
Self-Reported General Health												
Excellent	**9**	8%	3	3%	6	7%	**3**	14%	1	5%	2	9%
Very Good	**11**	10%	4	4%	7	8%	**4**	18%	4	18%	0	0%
Good	**32**	30%	16	17%	16	17%	**4**	18%	1	5%	3	14%
Fair	**24**	23%	11	12%	13	14%	**8**	36%	5	23%	3	14%
Poor	**16**	15%	10	11%	6	7%	**3**	14%	1	5%	2	9%
Missing	**14**	13%	4	4%	10	11%	**0**	0%	0	0%	0	0%
Occupation												
Current miner	**67**	63%	26	25%	41	39%	**13**	59%	4	18%	9	41%
Non-miner	**25**	24%	18	17%	7	7%	**9**	41%	7	32%	2	9%
Missing	**14**	13%	4	4%	10	9%	0	0%	0	0%	0	0

3. Results

3.1 Demographics

Demographics are summarized in Table 3. In 2011, 106 participants (48 female, 58 male) with an average age of 33.2 years participated in the diet and personal concerns survey. The 2013 subset included 12 women and 10 men for a total of 22 subjects with an average age of 34.1 years. No significant differences were found between 2011 and 2013 sample populations in average age (accounting for the two years between studies), marital status, education levels, general health, or occupation (miner vs. non-miner). The 2013 population included a higher percentage of household heads.

3.2 Diet and Personal Concerns

3.2.1 Dietary Diversity

Responses to the 24-hour dietary recall and Dietary Diversity Scores (DDS) are summarized in Table 4. DDS (23) ranged from 1- 17 with a mean (±SD) of 8.1 ± 3.0. DDS(12) ranged from 1-12 with a mean (±SD) of 5.8 ± 2.1. DDS(22) was not significantly correlated with the total number of people in the household (Pearson's r = 0.024, p = 0.808). Independent Samples T-Tests showed no significant difference in mean DDS(22) or DDS(12) between men and women, heads of households, or miners and non-miners. One-way ANOVA tests revealed a significant difference in mean DDS(22) and DDS(12) according to highest educational level completed as DDS(22) and DDS(12) increased with education (p = 0.014 and p = .037, respectively, n = 104).

A One-way ANOVA also showed a significant difference in the mean number of animal products (any meat, dairy, or eggs – DDS(12) categories 1, 7 , 8. See Table 2) consumed by highest educational level completed (p = 0.001). There was no significant difference, however, in the proportions of educational groups who reported eating at least one animal product (p = 0.586, Fisher's exact). A significantly greater proportion of participants who completed nursery school or middle school (both 33.3%, n = 9 and n = 18, respectively) reported consuming sweets, biscuits, or cakes (p = 0.038, Fisher's exact). 19.4% who completed primary school, 18.2% who completed secondary school, and 6.3% with no school consumed sweets, biscuits, or cakes. A significantly greater proportion of people with a secondary education ate eggs (63.6%, p = 0.003, n = 11, Fisher's exact), but no other differences were found in patterns of food group consumption according to educational attainment.

Table 4. Summary of 2011 cross-sectional Dietary Diversity Scores and Personal Concerns.

		Dietary Diversity[a]				Food Groups		
		DDS(22)		**DDS(12)**		**Animal Products**	**Any Fruit**	**Any Vegetable**
	n	Mean	SD	Mean	SD	%	%	%
Overall	**106**	**8.1**	**3.0**	**5.8**	**2.1**	**94%**	**60%**	**58%**
Female	48	7.7	2.5	5.6	1.7	96%	67%	56%
Male	58	8.5	3.3	6.0	2.4	91%	55%	60%
Household Head	55	8.4	2.8	6.0	2.1	98%	67%	64%
Not Household Head	51	7.8	3.1	5.6	2.1	88%	53%	53%
Current Miner	67	8.3	2.8	5.8	2.0	96%	64%	57%
Non-miner	25	8.1	2.9	6.0	2.1	96%	56%	64%
Highest Level of Education Completed								
No School	32	7.0*	2.5	5.3*	1.9	91%**	53%	63%
Nursery/ Presch.	9	7.8*	3.6	5.8*	2.5	89%**	67%	56%
Primary	33	8.1*	2.6	5.5*	1.9	94%**	64%	61%
Middle	18	9.6*	2.5	6.7*	1.6	100%**	67%	50%
Secondary	11	9.6*	3.7	7.1*	2.7	100%**	55%	45%
Post-Secondary	1	12.0*	-	8.0*	-	100%**	100%	100%

[a]See Table 2 for food groups included in each dietary diversity score
*Significant difference between at least one educational group at $p < 0.05$, One-Way ANOVA
**Significant difference between at least one educational group at $p < 0.001$, One-Way ANOVA

Ninety-eight percent of household heads reported eating at least one animal product compared to 90% of participants who are not heads of a household, but this difference was not significant ($p = 0.237$, Fisher's exact). The proportion of non-miners reporting consuming oils, fats, or butter was significantly higher than the proportion of miners ($p = 0.033$, Fisher's exact). On the other hand, a greater proportion of miners consumed grains than non-miners ($p = 0.009$, Fisher's exact). Out of 106 participants, 93.7% reported eating at least one animal product (any meat, dairy, or eggs), with 23% eating fresh fish and 70% eating dried fish. Eighty-four percent reported eating at least one fruit or vegetable in the previous 24 hours. The results of simple and multiple linear regression models for DDS(22) of household heads are summarized in Table 5.

In both models, being married was the only significant predictor of DDS(22). In the adjusted model, using predictors based on hypotheses and the literature, being married was significantly associated with a 2.5 point decrease in DDS(22), while increasing education was associated with increasing dietary diversity(Adj. $R^2 = 0.088$, $n = 43$). Sex, age, and total number of people in each household did not show any strong patterns.

In 2013, 45% (n=10) of participants reported eating food they prepared themselves either fairly often or very often. The other 50% (n=11) reported preparing their food sometimes, while one single male participant (5%, n=1) reported never preparing his own food.

Table 5. Multiple regression models for Dietary Diversity Score (22) of household heads.

Unadjusted[a]			Adjusted[b]		
R^2	Predictor	β (95% CI)	Adj. R^2	Predictor	β (95% CI)
0.018	Sex	-0.1 (-2.1, 1.9)	0.088	Sex	0.2 (-1.8, 2.3)
0.079	Age	-0.1 (-0.1, 0.01)		Age	-0.04 (-0.2, 0.1)
0.00	Total Household Size	-0.0 (-0.3, 0.3)		Total Household Size	0.01 (-0.3, 0.3)
0.357	Marital status	-2.7 (-5.0, -0.5)*		Marital status	-2.5 (-5.0, -0.1)*
0.003	Nursery School	-0.7 (-4.3, 3.0)		Nursery School	-0.2 (-4.7, 3.8)
0.023	Primary School	1.0 (-1.0, 2.9)		Primary School	1.6 (-0.7, 4.0)
0.006	Middle School	0.6 (-1.8, 3.0))		Middle School	1.7 (-1.1, 4.4)
0.034	Secondary School	1.7 (-1.2, 4.6)		Secondary School	2.6 (-0.6, 5.7)

[a] Coefficients are the result of simple linear regression using each variable as the single predictor in the model. (n = 43)
[b] Full adjusted model using all variables of interest. Reference levels: female, unmarried, and no school. Constant =10.45 (5.3, 15.6)**
*Significant at $p < 0.05$
**Significant at $p < 0.01$

3.2.3 Personal Concerns

Responses to the individual items were varied, but the majority response was either “sometimes” or “all the time” for each one (Figure 3). Differences between men and women were seen with level of concern for self-illness and clean air, with more women than men worried “all the time” about themselves getting sick (48% vs. 18%, p = 0.043, Fisher’s exact) and about having clean air (38% vs. 14%, p = 0.054, Fisher’s exact). Comparing miners to non-miners showed that a greater percentage of non-miners (50%) were worried “all the time” about having a clean environment compared to miners (27.5%) (p = 0.051, Fisher’s exact). This pattern was also seen in concern for clean air, though the difference was not significant (p = 0.666). A greater percentage of miners were worried “all the time” about not having enough money, but more non-miners were worried “all the time” about themselves or their children getting sick. Household heads were less worried about all items except for a clean environment and enough food, but none of these differences were significant. When stratified based on highest education level completed, the frequency of worrying about having enough money was marginally different (p = 0.062, n = 42), with the frequency of worrying “all the time” decreasing with higher education.

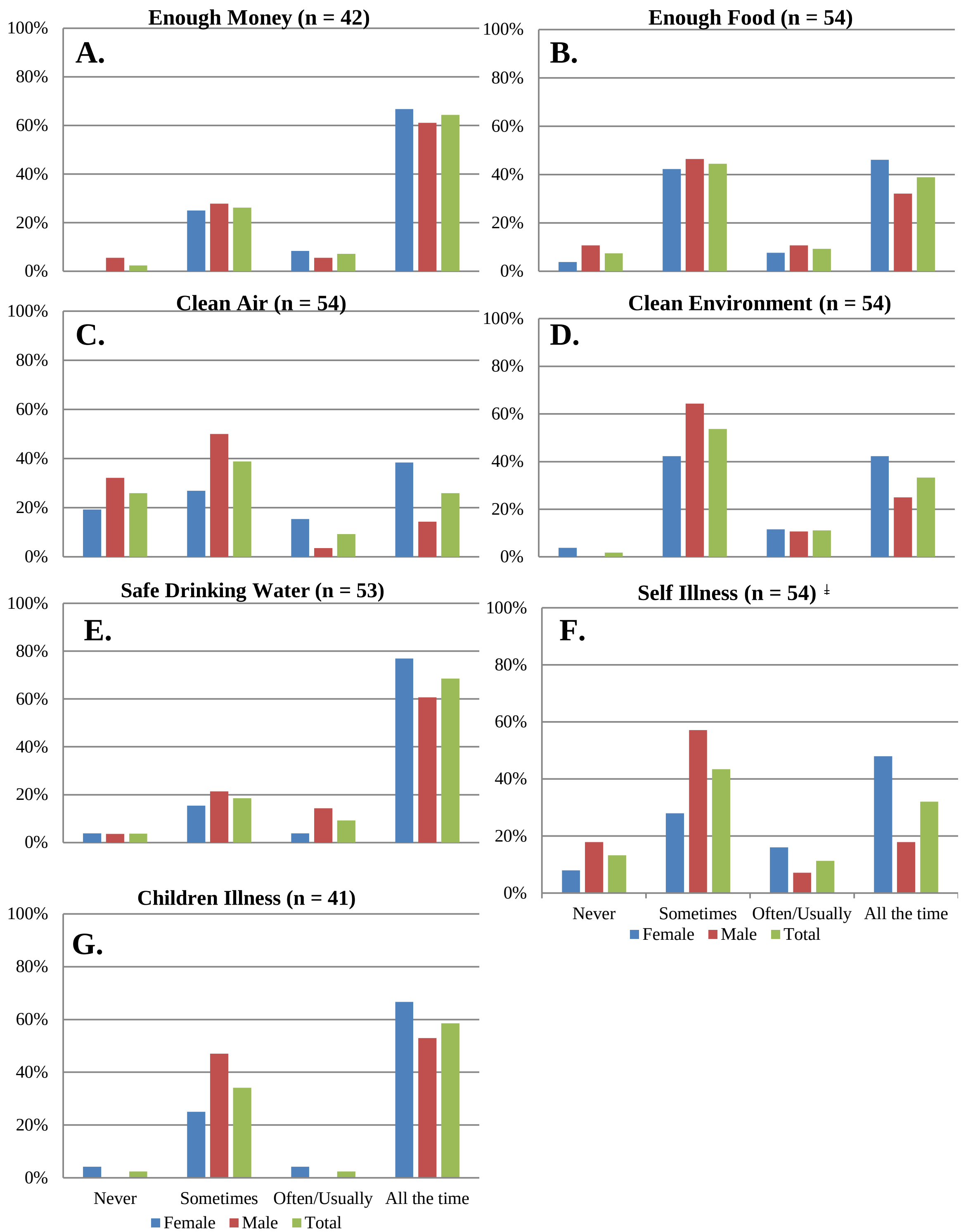

Figure 3. Summary of individual Personal Concerns expressed in 2011. "Female" and "Male" represents the percent of men and women responding in each category. Frequency response options were assigned a value (0 = Never, 3 = All the Time) and summed to create a total Personal Concerns score with higher scores indicating greater concerns.

Table 6. Aggregate Personal Concerns Scores

	n	Mean	SD
Overall	**41**	**11.8**	**3.7**
Female	23	13.0*	3.5
Male	18	10.2*	3.5
Household Head	39	11.7	3.8
Not Household Head	2	12.5	0.7
Current Miner	30	11.9	3.2
Non-miner	11	11.5	5.0
Highest Level of Education Completed			
No School	14	12.9	3.1
Nursery/Preschool	4	13.8	1.3
Primary	13	11.1	3.4
Middle	7	12.1	4.6
Secondary	3	5.7	2.1
Post-Secondary	-	-	-

Total Personal Concerns represents the sum of all Personal Concerns responses (see Figure 3)
*Significant difference between men and women at $p < 0.05$, Independent T-test

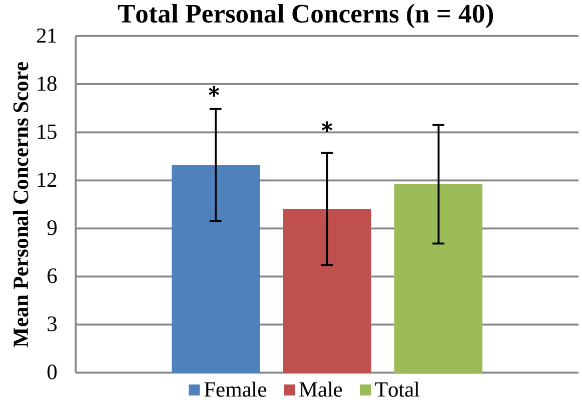

Figure 4. Mean Personal Concerns scores for women, men, and the total study population.
*Significant difference between women and men ($p < 0.05$, Independent t-test)

Aggregated Personal Concerns scores are summarized in Table 6. Mean Personal Concerns for women (13.0 ± 3.5, n = 23) was significantly higher than men (10.2 ± 3.5, n = 18, p = 0.018, Independent T-test) (Figure **4**), but there was no significant difference between mean scores for heads of households even though household heads were less concerned overall than those who were not heads of households (13.7 vs. 15.9, p = 0.125).. Total Personal Concerns scores for miners and non-miners were almost equal. Mean Personal Concerns for subjects with a secondary education were significantly lower than those with no school and nursery school, following a One-Way ANOVA with Tukey's post hoc test (p = 0.017). There was also no significant correlation between Personal Concerns and DDS(22) or DDS(12).

Looking specifically at food insecurity, there were also no significant differences in level of concern for having enough food between men and women, miners and non-miners, household heads and household members, people in male vs. female headed households, and highest education level completed (Fisher's exact test). Based on a One-way ANOVA, no significant differences in DDS(22) or DDS(12) were found between people who reported different levels of concern for having enough food. A One-way ANOVA showed a significant difference in mean Personal Concern score by level of concern for having enough food (p = 0.001, n = 38). The mean Personal Concern score for people who were "often/usually" worried about having enough food was significantly greater than the mean for those worried "never" and "sometimes" (Tukey's post-hoc test).

3.3 Stress

3.3.1 Perceived Stress

See Figure 5 for a summary of responses to individual PSS items and Appendix A for full questions. The majority of respondents were "sometimes" upset, unable to control important things in life, and nervous or stressed, and more women responded "never" to those items. Responses to being confident and angered were more varied. Since Cronbach's α = -0.978 for the five PSS items, they were not combined to create a total PSS score. Two individual items, being upset and feeling nervous or stressed, were significantly negatively correlated with each other (Spearman's rho = -0.500, $p < 0.05$). Kruskall-Wallace tests revealed no significant difference in any of the individual PSS items based on level of concern for having enough food.

3.3.2 Salivary Cortisol

Intraassay coefficient of variation (c.v.) for salivary cortisol samples ranged from 0-16.55%. No values were discarded based on high c.v., but one evening sample that was over three standard deviations higher than all other values was excluded as an outlier. Evening and morning samples

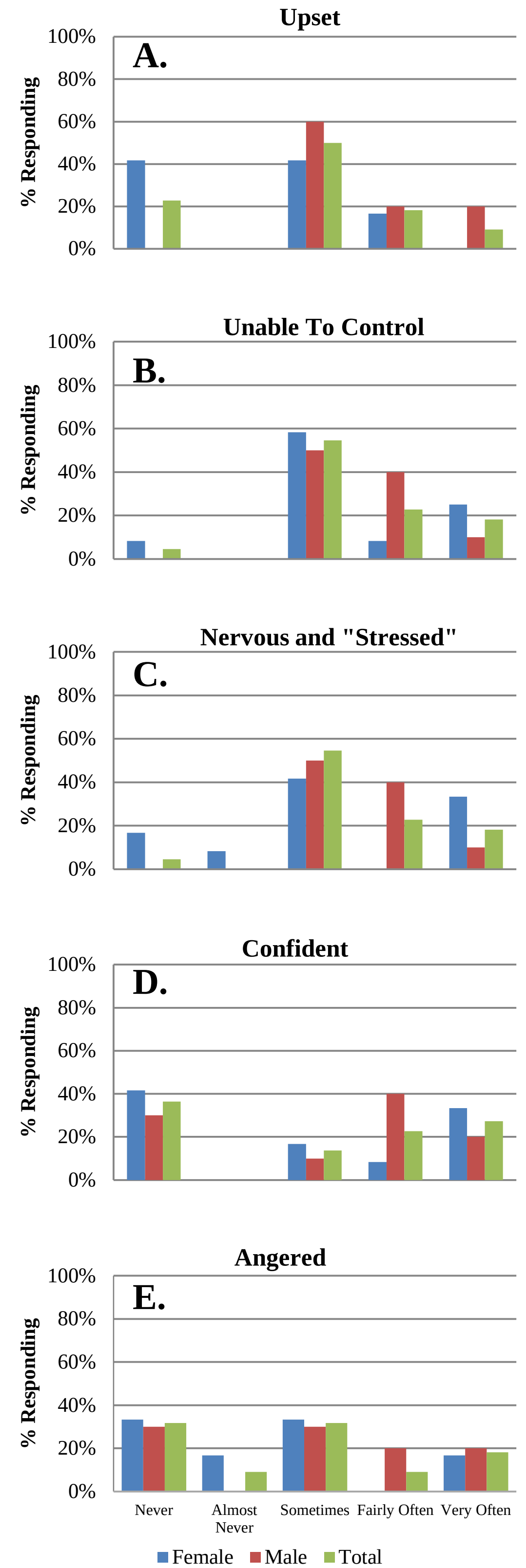

Figure 5. Summary of Perceived Stress Score responses in 2013.

were discarded for one participant who reported taking both samples consecutively in the morning. Mean (±SD) cortisol average, across participants with three valid samples, was 3.55 ± 1.19 nmol/L (n = 17) and mean (±SD) morning to evening change was -1.44 ± 4.27 nmol/L (n = 18). The mean (±SD) afternoon to evening change was -0.89 ± 2.01 nmol/L. Neither the average cortisol nor the morning to evening change was significantly correlated with any of the PSS items. Morning to evening change was not significantly correlated with age; however, the afternoon to evening change did show a negative significant correlation with age (Spearman's rho = -0.601, p = 0.011, n = 16). Mann-Whitney tests revealed no significant differences in average cortisol, morning to evening change, or afternoon to evening change between males and females. No significant differences were found in average cortisol between PSS frequency response groups in Kruskall-Wallace tests. A significant difference in morning to evening change (p = 0.038, n = 17) and afternoon to evening change (p = 0.009, n = 0.038) was found between groups responding to one PSS item – being unable to control important things in life.

Morning to evening change was not significantly correlated with Personal Concerns, DDS(22), or DDS(8). The afternoon to evening change, though not significant, suggests a positive association with Personal Concerns (Spearman's rho = 0.454, p = 0.067), meaning a higher level of concern is associated with an increase in cortisol through the day. Kruskall-Wallace tests revealed no significant difference in average cortisol or morning to evening change between Personal Concerns percentile groups or between the levels of concern for having enough food.

Patterns in morning to evening change for women and men are shown in Figure 6. Compared to men, women showed a greater mean decline in cortisol from morning to evening (-2.30 ± 4.86 and -0.59 ± 3.93 nmol/L, respectively); men showed a relatively flat decline through the day, suggesting chronic stress. This difference between sexes, however, was not significant. Subjects who were not household heads also had a greater decline in cortisol than household heads as a group, but this difference again was not significant (-2.52 ± 5.58 and -0.58 ± 3.07 nmol/L, respectively). Morning to evening change was similar for miners and non-miners, and no real patterns were seen with level of education completed.

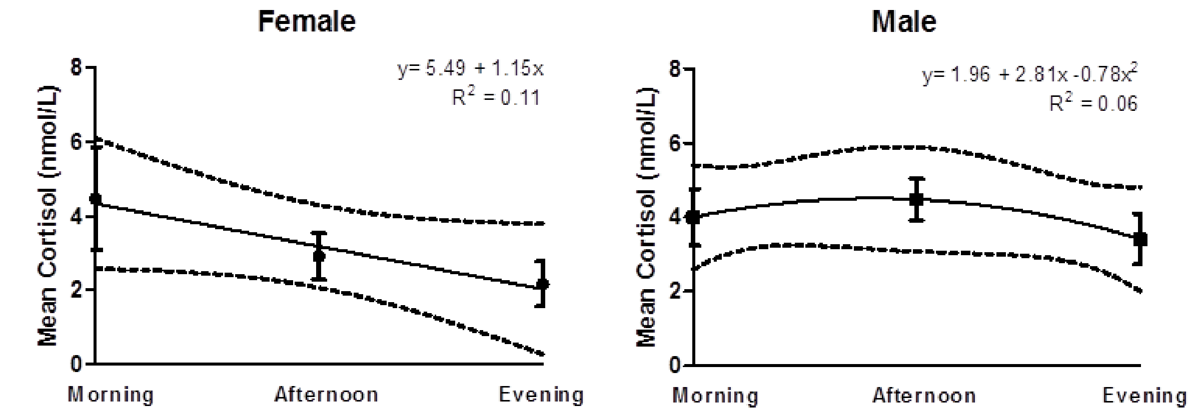

Figure 6. Change in salivary cortisol measurements over sampling period (morning to evening) for females (n = 9) and males (n = 8). Total duration between afternoon and morning samples ranged from 13.4 – 19.4 hours. While the mean decrease for women was steeper than for men, this difference was not significant ($p = 0.690$)

Using tertiles to group participants into categories that showed a high morning to evening change (Tertile 1 range: -9.66 nmol/L, - 3.59 nmol/L), a relatively flat change (Tertile 2: -2.48, -1.10), and an increase from morning to evening (Tertile 3: 0.28, 6.35), showed no major patterns in terms of Personal Concerns or PSS items. The mean Personal Concerns score for Tertile 1, the group with a morning to evening change most like a normal cortisol pattern, was actually slightly higher than other groups, but this difference was not significant according to a Kruskall-Wallace test ($p = 0.464$, $n = 8$).

3.3.3 Heart Rate

HR measurements were sporadic due to equipment failure, so 16 participants logged data from less than one to over 14 hours during the period in which they also wore the dosimeter. As seen in Table 10, across all 16 participants, a total of 5,925 minutes of HR data was collected with a subject mean duration of 370.3 ± 332.4 min. There was no significant difference between the mean (±SD) overall Resting Avg HR of 82.1 ± 13.5 beats per minute (bpm), as measured during the interview, and the overall Running Avg HR of 84.6± 11.2 bpm, as measured over the course of entire sampling period (Wilcoxon Signed Rank test). The Running Avg HR for men and women was significantly different while relaxing but not for any other activities ($p < 0.001$, Whitney- Mann U test) (see Table 10).

3.4 Noise

When asked to choose the biggest source of noise in their community, 50% of participants said small-scale mining was the biggest source while 37% chose the nearby industrial Chinese-operated mine. Thirty percent reported being not bothered by high noise at work, and 60% said they were bothered "a little." Only 10% were bothered "a great deal." A majority (70%) of people thought noise exposures at work were loud enough to harm their hearing, but only 45% believed the same about exposures outside of work.

The actual start-time was recorded for seven dosimeters, and the average time between starting the dosimeter and ending the interview for this group was 24.4 minutes. This time was used to mark the end of interviews and beginning of reported activities for the remaining 15 dosimeters. Activity data was not collected for one female participant (reported as "Uncoded Activity" when used in analysis). Dosimeter timepoints beyond 24 hours were excluded from analysis, as was a single interval L_{eq} measurement that was determined to be an outlier (114.8 dBA).

Noise levels recorded by the dosimeters ranged from 56.9 to 92.0 dBA, with a mean (±SD) Overall L_{eq} of 82.2 ± 7.3 dBA, for participants over 17-24 consecutive hours (Mean 22.1± 1.9 hours) . Twenty one out of 22 participants (95.4%) had an overall L_{eq} over the WHO guideline of 70 dBA over 24 hours. Mann-Whitney U tests showed no significant differences in Overall L_{eq}, Leisure L_{eq}, Work L_{eq},.or Sleeping L_{eq} between men and women or miners and non-miners (Table 7). There was also no significant difference in Work L_{eq} between people who thought noise exposure at work was loud enough to harm their hearing and those who thought otherwise. Work L_{eq} was, however, significantly lower ($p = 0.037$) for people who reported being bothered either "a little" or "a great deal" by noise at work (84.3, n = 12) compared to those who reported not being bothered at all (90.0, n = 5). According to Wilcoxon Signed Rank tests, overall mean (± SD) Work L_{eq} (86.1 dBA) is significantly higher ($p = 0.01$, n = 15) than mean Leisure L_{eq} (81.9 dBA) (Table 7).

Table 7. Summary of personal noise exposure over sampling period.

			Total		Female		Male		Miner		Non-miner	
			Leq (dBA)		Leq (dBA)		Leq (dBA)		Leq (dBA)		Leq (dBA)	
		N	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Overall		**22**	**82.2**	**7.3**	**82.2**	**4.4**	**82.3**	**10.0**	**82.8**	**8.8**	**81.5**	**4.6**
Activity												
	Leisure	17	81.9*	8.2	83.0	3.8	80.9	11.0	81.7	9.6	82.2	4.2
	Work	19	86.1*	5.2	85.2	5.5	87.3	5.6	87.6	5.2	83.9	5.5
	Sleeping	21	65.0	11.1	61.1	8.3	69.3	12.5	68.7	11.6	58.9	7.2
	Non-mine work	13	80.1	16.3	85.2	5.8	63.4	30.1	74.1	25.9	83.9	5.5
	Mine work	7	89.4	3.6	87.8	4.2	90.1	3.6	89.4	3.6	-	-
	Grinding or crushing	3	92.4	2.0	-	-	92.4	2.0	92.4	2.0	-	-
	Sifting or shanking	2	89.0	2.5	89.0	2.5	-	-	89.0	2.5	-	-
	Excavation	3	84.2	3.0	-	-	84.2	3.0	84.2	3.0	-	-

*Significant difference ($p < 0.05$) between mean Leisure and Work Leq based on Wilcoxon Signed Rank test

3.5 Stress and Noise

3.5.1 Salivary Cortisol and Noise

Both the morning to evening change and the change from afternoon to evening were positively correlated with corresponding L_{eq} measurements, with Spearman's rho of 0.619 (p=0.008, n=17) and -\0.691 (p=0.003, n=16), respectively. This supports the hypothesis that higher noise levels would be associated with an increase in cortisol over time. With average cortisol as the outcome in backward stepwise regression, no significant predictors were entered into the model. L_{eq} between cortisol samples was a significant predictor for both morning to evening change and cortisol change from afternoon to evening. Time between cortisol samples, age, sex, and smoking status were included in the adjusted models in accordance with the literature (Kudielka et al. 2009; Smyth et al. 2013) but Personal Concerns was not identified as a significant predictor in any models and was therefore not forced into the adjusted models. The unadjusted and adjusted models for morning to evening change and afternoon to evening change are summarized in Table 8. In both adjusted models, L_{eq} between cortisol samples was significantly associated with an increase in cortisol, with a 1 dBA increase in L_{eq} associated with 0.45 nmol/L increase in cortisol between morning and evening and a 0.25 nmol/L increase from afternoon to evening. An adjusted model for average cortisol, forcing L_{eq} into the model as a predictor, yielded an Adj. R^2 of -0.131 with no significant coefficients.

Table 8. Multivariate regression models for salivary cortisol and noise.

		Unadjusted[a]			Adjusted[b]		
Outcome	n	Adj. R^2	Predictor	β (95% CI)	Adj. R^2	Predictor	β (95% CI)
Cortisol change -morning to evening	17	0.352	Constant	-42.22 (-14.13, -70.31)**	0.188	Constant	-47.83 (-4.58, -91.09)*
			Morning to Evening Leq	0.49 (0.82, 0.15)**		Morning to evening Leq	0.45 (0.88, 0.02)*
						Hours between morning and evening	0.56 (1.92, -0.81)
						Age	-0.01 (0.23,- 0.25)
						Sex	-0.16 (4.67,- 5.00)
						Smoking status	0.48 (8.36, -7.40)
Cortisol change - afternoon to evening	16	0.411	Constant	-22.49 (-8.82, -36.16)**	0.502	Constant	-16.79 (-1.02, -32.57)*
			Afternoon to evening Leq	0.25 (0.41, 0.09)**		Afternoon to evening Leq	0.25 (0.42, 0.08)**
						Hours between afternoon and evening	-0.34 (0.09, -0.76)
						Age	-0.06 (0.02, -0.15)
						Sex	-0.51 (1.35, -2.37)
						Smoking status	0.71 (3.63, -2.21)

[a] Backwards stepwise regression
[b] Predictors added based on significant relationships to the outcome and literature review
Reference levels: female, current smoker
*Significant at $p < 0.05$
**Significant at $p < 0.01$

3.5.2 Heart Rate and Noise

While mean Overall Running Avg HR was not significantly correlated with the corresponding mean Overall L_{eq} over the sampling period (Spearman's rho = 0.032, p = 0.905, n = 16), the variability in HR over time did follow closely with variability in L_{eq} for some individual participants (see Figure 7). Similarly, the standard deviation of the mean Overall Running Avg HR showed a moderate positive correlation with the standard deviation of Overall L_{eq} (Spearman's rho = 0.532, p = 0.034). Backwards stepwise regressions were run with Running Avg HR as the outcome and corresponding L_{eq} as a predictor. The variation in HR, as measured by the standard deviation (SD) of Running Avg. HR, was also used as an outcome. See Table 9 for complete results. After controlling for sex and age, L_{eq} was not significant in models for Overall, Work, Leisure, or Sleeping HR in either unadjusted or adjusted models. An increase in L_{eq} SD was, however, was associated with an increase in HR SD in all models except for Work HR SD. Being bothered "a little" or "a great deal" by high noise at work was associated with a slight increase in HR and HR SD in the Work models, but this increase was not significant. Overall HR was not significantly correlated with morning to evening change in cortisol (Spearman's rho = 0.036, p = 0.915). Overall HR SD showed no significant correlation either (Spearman's rho = 0.014, p = 0.968).

Table 9. Multiple linear regression models for heart rate and noise exposure.

		Unadjusted[a]			Adjusted[b]		
Outcome	n	Adj. R^2	Predictor	β (95% CI)	Adj. R^2	Predictor	β (95% CI)
Overall HR	16	N/A	None	N/A	-0.19	Constant	44.0 (-28.8, 116.8)
						Overall L_{eq}	0.5 (-0.4, 1.3)
						Sex	4.2 (-16.8, 8.4)
						Age	0.3 (-0.3, 0.9)
Overall HR SD	16	0.341	Constant	1.6 (-3.3, 6.5)	-0.229	Constant	3.1 (-5.4, 11.8)
			Overall L_{eq} SD	0.5 (0.1, 0.9)*		Overall L_{eq} SD	0.5 (0.04, 0.9)*
						Sex	1.1 (-2.5, 4.7)
						Age	0.5 (-0.2, 0.1)
Work HR	11	N/A	None	N/A	-0.394	Constant	25.3 (-140.1, 190.8)
						Work L_{eq}	0.6 (-1.2, 2.3)
						Sex	2.9 (-21.3, 27.2)
						Age	0.5 (-0.8, 1.8)
						Noise annoyance	1.0 (-25.2, 27.2)
Work HR SD	11	0.421	Constant	5.5 (3.6, 7.4)**	0.475	Constant	1.6 (-4.8, 8.0)
			Sex	3.6 (0.8, 6.5)*		Work L_{eq} SD	0.1 (-0.5, 0.7)
						Sex	3.9 (0.0, 7.8)*
						Age	0.0 (-0.1, 0.2)
						Noise annoyance	2.4 (-1.2, 5.9)
Leisure HR	6	0.609	Constant	90.7 (79.0, 102.4)**	0.889	Constant	45.7 (-11.4, 102.8)
			Sex	-15.3 (-29.6, -1.0)*		Leisure L_{eq}	0.5 (-0.1, 1.1)
						Sex	-17.4 (-32.3, -2.5)*
						Age	0.3 (-0.4, 1.0)
Leisure HR SD	6	0.969	Constant	3.7 (-2.8, 10.2)	0.979	Constant	3.3 (-4.0, 10.7)
			Leisure L_{eq} SD	0.6 (0.2, 1.0)*		Leisure L_{eq} SD	0.7 (0.2, 1.3)*
			Sex	-4.6 (-8.3, -0.9)*		Sex	-2.9 (-9.3, 3.6)
						Age	-0.1 (-0.2, 0.1)
Sleep HR	5	N/A	None	N/A	0.449	Constant	41.1 (-424.3, 506.4)
						Sleeping L_{eq}	0.6 (-5.6, 6.6)
						Sex	-4.4 (-55.1, 46.4)
						Age	0.1 (-5.9, 6.1)
Sleep HR SD	5	N/A	None	N/A	-0.789	Constant	18.8 (-647.7, 685.2)
						Sleeping L_{eq} SD	0.03 (-15.6, 15.5)*
						Sex	-2.8 (-155.9, 150.3)
						Age	-0.4 ('22.7, 21.9)

[a] Backwards stepwise regression
[b] Predictors added based on significant relationships to the outcome and literature review
Reference levels: female, not bothered by noise at work
*Significant at $p < 0.05$
**Significant at $p < 0.01$

Table 10. Paired heart rate and noise measurements representing per person averages for self-reported activities.

	Total								Female						Male					
		Total Duration	Per Person Duration (min)		L_{eq} (dBA)		Running Average HR (bpm)			*Total Duration*	L_{eq} (dBA)		Running Average HR (bpm)			*Total Duration*	L_{eq} (dBA)		Running Average HR (bpm)	
Activity	*n*	*(min)*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*n*	*(min)*	*Mean*	*SD*	*Mean*	*SD*	*n*	*(min)*	*Mean*	*SD*	*Mean*	*SD*
Total (per person)	**16**	**5925.00**	370	332	74.9	7.9	**84.6**	**11.2**	**9**	**2568.75**	71.4	11.7	**87.0**	**12.7**	**7**	**3356.25**	73.4	9.7	**81.5**	**8.8**
Crushing	1	596.25	37	149	87.2	-	86.8	-	0	0	-	-	-	-	1	596.25	87.2	-	86.8	-
Drain mine water	1	236.25	15	59	84.5	-	92.7	-	0	0	-	-	-	-	1	236.25	84.5	-	92.7	-
Excavation	2	397.5	25	90	67.2	7.6	92.2	5.3	0	0	-	-	-	-	2	397.5	67.2	7.6	92.2	5.3
Grinding	1	603.75	38	151	91.3	-	76.6	-	0	0	-	-	-	-	1	603.75	91.3	-	76.6	-
Leisure	6	963.75	60	121	74.1	11.2	80.5	8.7	2	528.75	73.9	3.3	90.7	0.3	4	435	72.7	14.1	75.5	6.9
Other[a]	4	202.5	13	25	67.8	12.7	81.2	9.7	3	142.5	73.8	4.5	83.5	8.1	1	60	49.5	-	72.0	-
Relaxing	6	618.75	39	83	77.2	11.4	83.1	10.5	2	333.75	83.3	5.4	92.4*	4.2	4	285	74.2	13.1	76.2*	6.7
Retail vendor at home	2	1316.25	82	227	70.8	4.7	87.8	3.8	1	566.25	74.1	-	89.6	-	1	750	67.5	-	84.2	-
Seamstress work	1	165	10	41	82.4	-	98.8	-	1	165	82.4	-	98.8	-	0	-	-	-	-	-
Sell drinks	1	420	26	105	80.9	-	110.1	-	1	420	80.9	-	110.1	-	0	-	-	-	-	-
Selling food	2	266.25	17	59	80.7	13.2	79.6	20.1	2	266.25	80.7	13.2	79.6	0.2	0	-	-	-	-	-
Shopping or market	1	120	8	30	74.9	-	100.5	-	1	120	74.9	-	100.5	-	0	-	-	-	-	-
Sifting or shanking	1	153.75	10	38	87.6	-	91.3	-	1	153.75	87.6	-	91.3	-	0	-	-	-	-	-
Sleeping	5	532.5	33	72	55.3	4.9	73.3	3.1	2	195	54.8	0.4	74.9	6.7	3	337.5	55.7	6.9	71.7	3.4
Uncoded Activity[b]	1	206.25	13	52	68.3	-	84.1	-	1	206.25	62.9	-	84.1	-	0	-	-	-	-	-
Walk kids to school	1	90	6	23	65.7	-	70.8	-	0	0	-	-	-	-	1	90	65.7	-	70.8	-
Work	13	4222.50	264	275	78.8	8.4	88.0	11.2	8	1639	78.5	8.2	88.8	13.2	5	2583.75	77.9	10.6	86.7	7.2

[a]Includes all activities with a duration of less than 75 minutes per person. Activities in this category: bathing, cooking at home, plastering, selling water, and washing

[b]No activity data available

*Difference between females and males significant at $p < 0.001$ (Mann-Whitney U test)

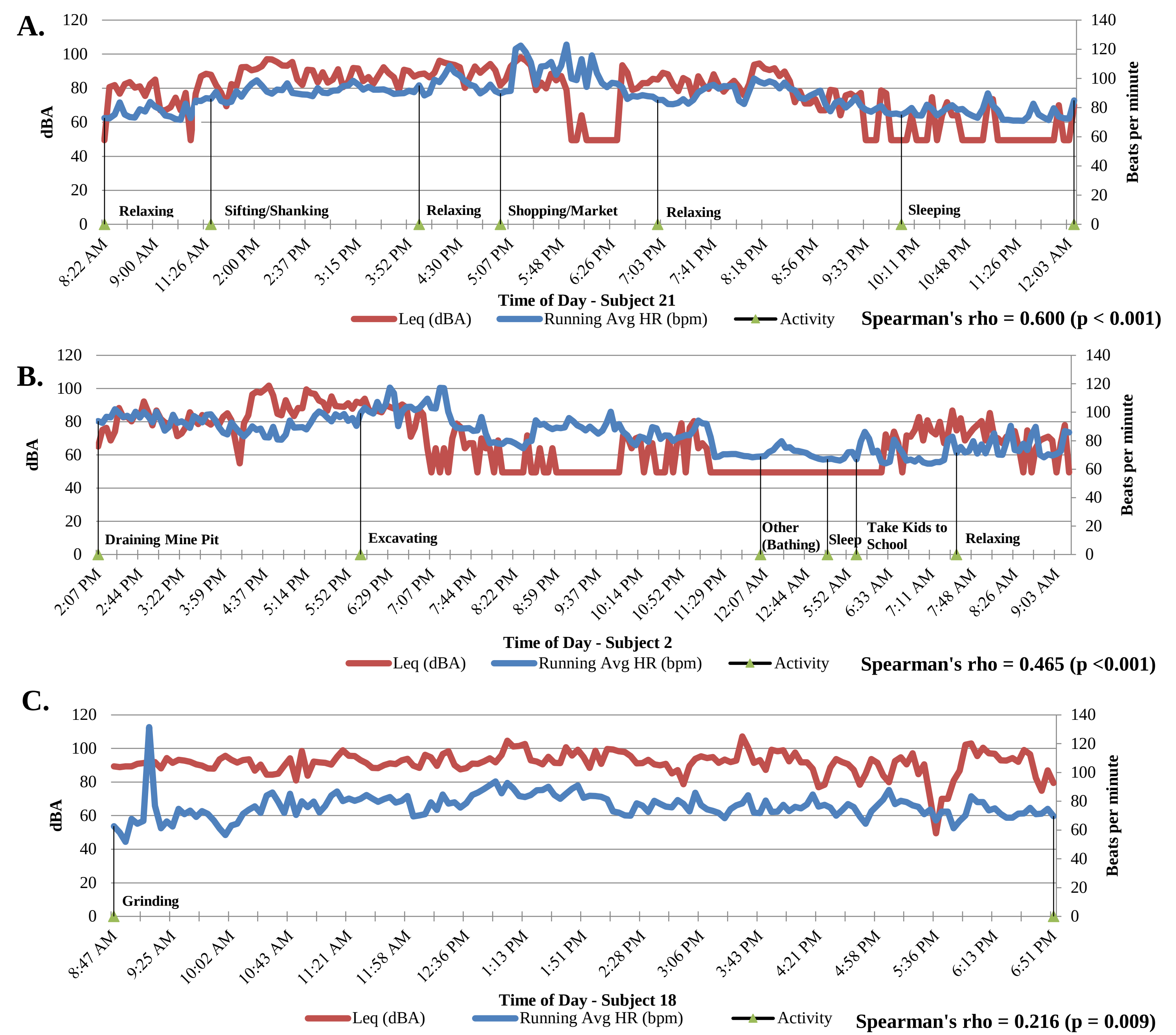

Figure 7. Example individual heart rate variation with noise over time.

4. Discussion

With vulnerabilities in small-scale gold-mining communities arising both indirectly, through social structures and migration, and directly through mining activities that introduce noise and other environmental hazards, documenting the range of stressors in these communities can lead to a better understanding of how they cumulatively influence well-being. By exploring the relationship between diet, stress, and noise, this study begins to elucidate the interaction between a few of these indirect and direct vulnerabilities. Specifically, evidence from this pilot study supports dietary patterns reported elsewhere but found limited evidence linking dietary diversity with other measures of concern or stress. In terms of noise exposure, 95% of subjects in the 2013 cross-sectional study were over the WHO recommended guideline of 70 dBA over 24 hours, suggesting these individuals are at risk for hearing loss. High noise levels were seen across the board, with means around 80 dBA for both genders and for both miners and non-miners. This study also documented noise levels and changes in heart rate associated with common small-scale mining and other occupational activities. The relationship between stress and noise was mixed, with salivary cortisol showing a positive relationship with daily noise exposure and heart rate data limited by small sample size. In using the standard deviation of heart rate and noise levels over time, however, this study adds to the growing evidence suggesting variations in heart rate as a mechanism for cardiovascular effects in response to daily noise exposures.

4.1 Diet

The relationship between educational attainment and higher dietary diversity seen here is consistent with the literature (Ajani 2010; Bernal and Lorenzana 2003; Clausen et al. 2005). Patterns in food group consumption in this study are also comparable with results from the 2008 Ghana Demographics and Health Survey (DHS) for the Upper East region (see Figure 8), except for a notably lower percentage of people in this study eating vitamin A-rich fruits and vegetables (60% compared to 95.5% in the Upper East region) (Ghana Statistical Service (GSS) et al. 2009) .

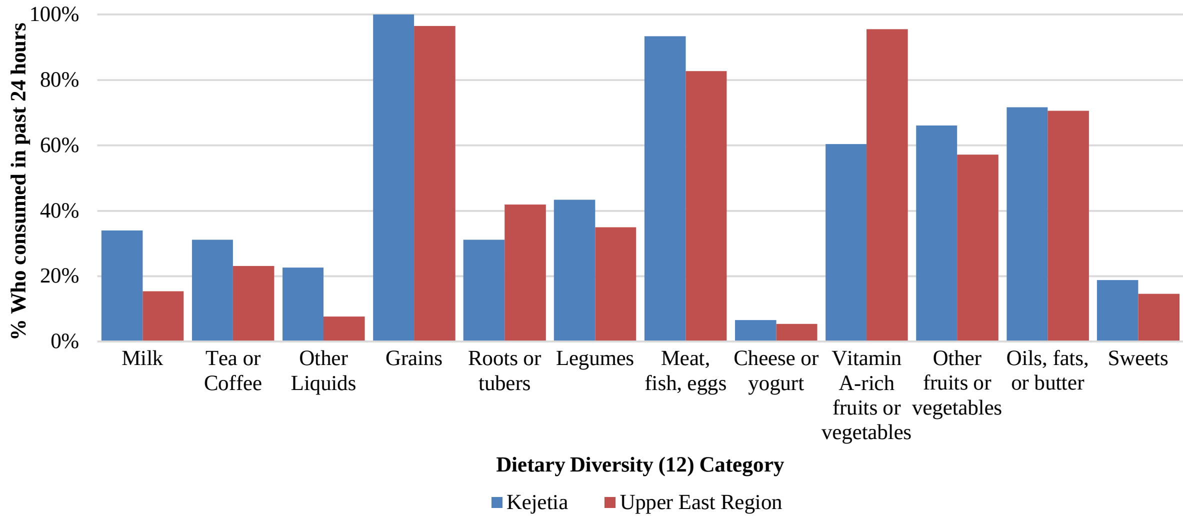

Figure 8. Dietary Diversity (12) in Kejetia compared to the Upper East Region. Upper East Region data source: Ghana Statistical Service (GSS) et al. 2009.

Using a crude measure of food insecurity (level of concern for having enough food to feed their family), no evidence was found in this study to support a relationship between dietary diversity and food insecurity. This could be a reflection of seasonality, as households in the Upper East perceive April – July to be the hardest months to find sufficient food (World Food Programme and VAM Food Security Analysis 2012). Interviews in this study were conducted in June – August, but the timing of interviews was not considered in analysis. While Hoddinott and Yohanes (2002) found a consistent positive association between dietary diversity and caloric intake across all seasons, another study suggests that measuring dietary diversity at the beginning of the food shortage season may more accurately identify vulnerable households (Savy et al. 2006). In Kejetia, educational attainment did not seem to influence level of concern for having enough food. In a study of northern Ghanaian farming communities, Hesselberg and Yaro (2006) found education to be a predictor of household vulnerability, as measured through a livelihood vulnerability framework, in only one out of three communities, and the authors suggest that skills, more than formal education, can be more influential in earning a steady income and contributing to food security and other stabilizing factors. Neither of the Kejetia studies reported here included a measure of income, but the finding that people with no education were significantly more worried about having enough money may reflect a socioeconomic hierarchy based on educational attainment. Further research in the community could reveal patterns in socioeconomic status as they relate to both dietary diversity and food insecurity.

Aside from nutritional intake and food insecurity, the safety of food itself is a concern in Kejetia. Environmental hazards can also be introduced through diet, as evidenced by mercury levels in hair that suggest exposure through fish consumption in Kejetia (Paruchuri et al. 2010). This study found that while miners working directly with amalgamation had the highest levels of mercury in hair and urine, other community members, including women, had elevated levels of mercury as well. While this study does not make any direct links to health effects of mercury exposure, the association between methylmercury ingestion, most often as a result of contaminated food, and neurodevelopmental effects has been widely documented (for review see Honda, Hylander, & Sakamoto, 2006).

Only 23% of residents in this study reported eating fresh fish and 70% eating dried fish, and it is unclear how much of that fish or other food is sourced and grown locally. If residents with low dietary diversity are depending on foods with a high level of contaminants for the majority of their diet, however, this raises concerns for disproportionate health impacts among sectors of the community, potentially compounding the effects of other vulnerabilities such as poverty and stress. The finding in this study that people with higher education ate a greater number of animal products suggests this group of people may actually be more vulnerable to mercury exposure through bioaccumulation in the food chain. Altogether, this highlights another avenue of research that can more fully characterize health determinants in mining communities, looking at complex mercury exposure pathways through multiple media (food, air, water, soil) and the relationship between food safety, dietary diversity, and other social factors in this community.

4.2 Personal Concerns and Perceived Stress

While Hilson found that residents of small-scale mining communities may not be aware of the health risks of mercury (2007), the self-reported measured of concern we assessed here show that residents in Kejetia are at least concerned about environmental and health risks in general. Similar findings were elucidated by interviews in the Talensi-Nabdam District, and these concerns for health were directly related to involvement in mining (Agyemang 2010). More research is needed in Kejetia to understand whether or not these concerns are directly related to mining. Women expressed more concern for dimensions of economic, environmental, and physical well-being overall, supporting the literature on the unique challenges women face in mining communities because of responsibilities at home and social expectations (see Hinton et al. 2003; Renne et al. 2011; Yakovleva 2007).

The hypothesis that these concerns would be correlated with Perceived Stress Scale (PSS) responses was not tested because the PSS items lacked internal consistency. The highly negative α points to potential issues with translation in this context. Additionally, the PSS was developed for populations with at least a junior high school education level, so the combination of low education levels and complexities arising during translation could have rendered these questions unreliable as a total measure of perceived stress. The personal concerns questions utilized in this study (e.g., level of concern for enough money, enough food, a clean environment, and illness) have not been validated as indicators of perceived stress, but with more "all the time" than "none of the time" responses, it appears that Kejetia residents show relatively high levels of concern for economic, environmental and physical well-being.

4.3 Stress and Noise

As an indicator of physiological stress in this study, changes in salivary cortisol through the day were consistent with patterns associated with chronic stress (see Bigert et al. 2005; Maina et al. 2009; Melamed et al. 1999) , as mean cortisol levels were only slightly lower in the evening than in the morning. When paired with noise exposure, these results supported the hypothesis that increased noise would be associated with an increase in biochemical stress response throughout the day..

The relationship between salivary cortisol and noise exposure varies across studies. Long-term and daily noise exposure research is becoming increasingly popular, but the myriad physical and psychosocial factors that can influence cortisol levels makes study design and analysis especially important in interpreting results (Kudielka et al. 2009). Sjödin et al. (2012) did not see an association between cortisol responses and preschool employee's noise exposure during work. Compared to these subjects, who had on average of around 70 dBA L_{eq} during work, Kejetia residents were exposed to significanlty higher noise levels (average occupational L_{eq} = 86.06 dBA). Sjödin et al. only focused on noise exposures at work relating to overall daily cortisol patterns, whereas the Kejetia study directly compared noise levels experienced between cortisol samples. In a comparable study assessing noise exposure and cortisol in industrial occupational settings, Fouladi et al. (2012) saw less of a decline in cortisol with high noise, but this pattern was not seen for 7am-4pm L_{eq} < 80 dBA. A study on cumulative environmental risk and stress responses in New York City included 2-hour indoor L_{eq} as one factor, along with physical and social stressors such as housing and income, in calculating an overal environmental risk for participants. With average L_{eq} for low and middle income being 64 dBA and 61 dBA, respectively, researchers saw an increase in urinary cortisol in kids with increased cummulative risk, suggesting chronic stress (Evans and Marcynyszyn 2004).

While regression models in this study controlled for common confounders such as age and smoking status, cortisol can show acute reponses or diurnal patterns according to physical activity, sleep quality, and psychological state as well (Nicolson 2008). Specific diurnal patterns have also been associated with material hardship (Ranjit et al. 2005), but regression models for Kejetia did not account for socioeconomic status. Subjects were briefed on saliva sampling protocol, but strict adherence to protocol and exact timing of samples was not checked when saliva samples were collected. These methodological considerations, plus the small sample size and lack of repeated measures, should be factored into the weight of evidence, alongside clinical significance, for the positive relationship between noise exposure and change in salivary cortisol through the day. Even with these limitations, because this study used personal noise measurements corresponding directly to the time period between cortisol samples, rather than average ambient noise levels, it improves upon earlier study designs and adds to the body of research exploring the complexities of the cortisol response.

Similarly, despite limitations in sample size and instrument failure in measuring heart rate, adjusted regression models show a positive association between variation in heart rate and variation in L_{eq}. Other studies have found associations between noise and changes in heart rate in lab settings. For example, Greifahn et al. (1993)found consistent heart rate acceleration in response to 19 second intervals of 62–80 dBA noise impulses. Examining environmental noise, but again in a laboratory setting, Tassi et al. (2010) saw a dose-dependent increased heart rate response with the equivalent of 40 dBA and 50 dBA 8-hour L_{eq} train noises. While using the SD of both HR and noise is not directly comparable to the methods of analysis of these other studies (i.e., pre- and post- noise averages or polysomnography analysis), the results of paired HR and noise data in Kejetia suggest that continued research into the cardiovascular response to environmental noise is warranted outside of laboratory settings.

With average personal noise exposures well over the recommended 24-hour average exposure of 70 dBA during 17-24 hour sampling periods, Kejetia residents, whether directly involved in high noise mining activities or not, are at risk for noise-induced hearing loss and other health effects related to excess noise exposure. Noise has been raised in the small-scale mining literature as an occupational hazard, alongside mercury exposure and injuries (Hinton et al. 2003), but measurements from Kejetia did not show any differences in noise exposure between those working in the mining sector and those not currently involved in mining.

In reviewing lab-based and epidemiological evidence for cardiovascular effects associated with environmental noise exposure, Münzel et al. (2014) conclude that current research provides evidence that both daytime and nighttime noise exposures are important conrtibutors to a higher prevalence of cardiovascular disease. With evidence for increased salivary cortisol levels in response to noise exposure and the overall trend of relatively flat cortisol levels through the day, it is possible that dysregulation of the hypothalamic-pituitary-adrenocortical (HPA) axis is responsible for the cortisol response (Marin et al. 2011). Cortisol plays a central role not only in the stress response but in regulating a number of physiological pathways, such as immune function and metabolism, and is involved in mediating disease responses. Cohen, Janicki-Deverts, and Miller's (2007) review of psychological stress and disease specifically supports an association between stress and cardiovascular disease. The relationship between health outcomes, dietary diversity, and food insecurity among children and adults are complex but also key in understanding determinants of well-being (Bhattacharya et al. 2004; Ruel 2003). By documenting all of these vulnerabilities—diet, stress, and noise exposure—this study adds to the understanding of each of these variables individually and begins to addresses the lack of literature on cumulative health hazards in small-scale gold-mining communities.

5. Conclusion

By addressing understudied vulnerabilities—diet, stress, and noise—this study provides baseline data to begin exploring cumulative environmental risks in artisanal and small-scale gold mining (ASGM) communities. While patterns in dietary diversity in Kejetia were comparable to patterns from across the Upper East region, 24-hour noise exposures were consistently above the WHO guideline of 70 dBA, and increases in noise were associated with increases in both biochemical and physiological stress responses measured through salivary cortisol and heart rate. Qualitative stress measures were not reliably assessed, but the level of concern for money, food, environmental quality, and illness is grounds for further research into the relationship between social and environmental stressors and actual stress responses.

Special attention to health hazards has been given to ASGM communities because of the unique exposures associated with mining activities (see Aryee, Ntibery, & Atorkui, 2003; Grandjean & Landrigan, 2006; Basu et al., 2010). The social dynamics of small-scale mining have also been documented (see Awumbila and Tsikata 2004; Hinton et al. 2003; Maconachie and Hilson 2011; Tschakert 2009). No previous studies, however, have provided a framework for considering both the physical and social vulnerabilities potentially faced by ASGM community residents, as has been accomplished here. Given the small sample size and limited scope of this study, further research should focus on documenting diet, stress, and noise across similar communities to assess how widespread these patterns are. Further research is also needed to document actual health impacts associated with these exposures. For example, exploring cardiovascular health could give insights as to whether the specific noise exposures and patterns in cortisol seen in Kejetia are actually associated with a greater prevalence of cardiovascular disease. Including more robust measures of nutritional adequacy would also add to the overall picture of health in these communities, and combining these measures, along with already-documented hazards such as mercury exposure and poverty, can contribute to a better understanding of the determinants of overall well-being. Although some patterns were seen in diet and stress by gender and education, further research could explore any differential effects on subpopulations, such as non-miners, and add physiological data to the social inequalities documented in ASGM communities. Specifically documenting cumulative exposures in ASGM communities can inform policies and practices that address the unique challenges faced by residents directly and indirectly involved in mining.

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Appendix A – Survey Instruments

Table A1. Personal Concerns questionnaire used in 2011 cross-sectional study.

2. How often do you worry about…	
2a. Not having enough money to raise your children	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time ☐789 Not applicable - have no children
2b. Not having clean air to breathe	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time
2c. Not having a clean environment	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time
2d. Not having safe water to drink	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time
2e. Having your food run out before you have money to buy more	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time
2f. Yourself becoming ill	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time
2g. Your children becoming ill	☐1 Never ☐2 Sometimes ☐3 Often/Usually ☐4 All of the time ☐789 Not applicable - have no children

Table A2. Perceived Stress Scale (PSS) items used in 2013 cross-sectional study (adapted from Cohen et al. 1983)

In the last month, how often have you been upset because of something that happened unexpectedly? [ ]$_0$ Never [ ]$_1$ Almost never [ ]$_2$ Sometimes [ ]$_3$ Fairly often [ ]$_4$ Very often
In the last month, how often have you felt that you were unable to control the important things in your life? [ ]$_0$ Never [ ]$_1$ Almost never [ ]$_2$ Sometimes [ ]$_3$ Fairly often [ ]$_4$ Very often
In the last month, how often have you felt nervous and "stressed"? [ ]$_0$ Never [ ]$_1$ Almost never [ ]$_2$ Sometimes [ ]$_3$ Fairly often [ ]$_4$ Very often
In the last month, how often have you felt confident about your ability to handle your personal problems? [ ]$_4$ Never [ ]$_3$ Almost never [ ]$_2$ Sometimes [ ]$_1$ Fairly often [ ]$_0$ Very often
In the last month, how often have you been angered because of things that happened that were outside of your control? [ ]$_0$ Never [ ]$_1$ Almost never [ ]$_2$ Sometimes [ ]$_3$ Fairly often [ ]$_4$ Very often

Table A3. Activity Log survey instrument used in conjunction with noise and heart rate monitoring.

Name: ________________________________ **Date:** ____/____/_____ **SS ID** **(researcher completes):**_______

MORNING **Activities** *TIME OF DAY →*	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**		**11**		**12**	
	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30
EXAMPLE: ***If the subject worked from 7 to 10:30 am and 11 to 11:30 am, you would mark:*** Working																								
Working outside the home ***Please check the primary work activity for the day*** [ ]1 Non-mine work ___________________________ [ ]2 Crushing or grinding [ ]3 Sifting/shanking [ ]4 Washing/sluicing [ ]5 Amalgamation [ ]6 Burning [ ]7 Excavating [ ]8 Other mine work ____________________________																								
Working at home																								
Relaxing at home																								
Sleeping																								
Shopping / market																								
Exercising or sport																								
Socializing																								
Write in any other activities the subject reports that are not listed: 1:																								
2:																								
3:																								
4:																								
Other information	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**		**11**		**12**	
	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30
Using earmuffs or earplugs to block noise																								
Listening to music: Without headphones																								
Listening to music: With headphones																								

AFTERNOON *TIME OF DAY →* **Activities**	**13**		**14**		**15**		**16**		**17**		**18**		**19**		**20**		**21**		**22**		**21**		**24**	
	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30
EXAMPLE: ***If the subject worked from 7 to 10:30 am and 11 to 11:30 am, you would mark:*** Working													←						→		↔			
Working outside the home ***Please check the primary work activity for the day*** [ ]1 Non-mine work ____________________________ [ ]2 Crushing or grinding [ ]3 Sifting/shanking [ ]4 Washing/sluicing [ ]5 Amalgamation [ ]6 Burning [ ]7 Excavating [ ]8 Other mine work _____________________________																								
Working at home																								
Sleeping																								
Shopping / market																								
Relaxing at home																								
Exercising or sport																								
Socializing																								
Write in any other activities the subject reports that are not listed: 1:																								
2:																								
3:																								
4:																								
Other information	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**		**11**		**12**	
	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30	:00	:30
Using earmuffs or earplugs to block noise																								
Listening to music: Without headphones																								
Listening to music: With headphones																								