Environmental Health and Safety Hazards of Indigenous Small-Scale Gold Mining Using Cyanidation in the Philippines

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ABSTRACT

OBJECTIVES: This cross-sectional study aimed at the environmental health hazards at work and cyanide exposure of small-scale gold miners engaged in gold extraction from ores in a mining area in the Philippines.

METHODS: Methods consisted of structured questionnaire-guided interviews, work process observation tools, physical health assessment by medical doctors, and laboratory examination and blood cyanide determination in the blood samples of 34 indigenous small-scale gold miners from Benguet, Philippines.

RESULTS: The small-scale gold miners worked for a mean of 10.3 years, had a mean age of 36 years, with mean lifetime mining work hours of 18,564. All were involved in tunneling work (100%) while a considerable number were involved in mixing cyanide with the ore (44%). A considerable number were injured (35%) during the mining activity, and an alarming number (35%) had elevated blood cyanide level. The most prevalent hazard was exposure to chemicals, particularly to cyanide and nitric acid, which were usually handled with bare hands.

CONCLUSION: The small-scale gold miners were exposed to occupational and environmental hazards at work.

KEYWORDS: small-scale mining, cyanide exposure, environmental health and safety, gold extraction, Philippine mining, artisanal mining

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Introduction

Small-scale gold mining (SSGM) refers to mining by individuals, groups, families, or cooperatives with minimal or no mechanization, often in the informal (illegal) sector of the economy. In the Philippines, the gross production value of small-scale gold mining is 1.0 billion pesos (USD 21.7M) as of 2014.[1]

Sitio Dalisay in Gumatdang, a small community in the municipality of Itogon, is the site of the study. It is located in Benguet Province in the Cordillera Administrative Region, Philippines. The province of Benguet hosts several large- and small-scale mining industries in the country. A majority of the people belong to the ethnolinguistic groups called Ibaloi and Kankanaey. Among these indigenous groups, the rudiments of small-scale mining are learned as early as the age of seven years and passed on through generations. In the 1970s and 1980s, the indigenous small-scale gold miners started using chemicals, and almost every miners' group had its own ball mill and cyanide leaching pad.[1]

Small-scale gold miners (SSGMs) have been labeled worldwide as notorious users of mercury and cyanide. Cyanide in high doses is highly lethal as it rapidly diffuses into tissue and binds to target sites within seconds.[2] Hydrogen cyanide can be easily absorbed from all routes of entry of exposure.[3] Milder cases of cyanide poisoning include symptoms such as headache, nausea, vertigo, anxiety, altered mental status, tachypnea, hypertension, and the smell of bitter almonds in the patient's expiration. More severe cases of cyanide poisoning include dyspnea, bradycardia, hypotension, and arrhythmia. Most severe cases include unconsciousness, convulsions, cardiovascular collapse followed by shock, pulmonary edema, and death.[3] Mild toxicity is shown at cyanide concentrations of 0.5–1.0 μg/mL and severe toxicity is at concentrations 2.5 μg/mL and higher, which are associated with coma, seizures, and even death.[4] Cyanide concentrations measured in the blood are usually inaccurately low. This is because cyanide has a very short half-life, and blood samples are rarely obtained within a short period of time.

The most widely employed mining technique in the area is called *dog hole mining*, which is a tedious and hazardous process. This type of SSGM involves several subprocesses: (1) tunneling, (2) ball milling and gravity concentration, (3) cyanide leaching, and (4) smelting. First, tunneling involves digging a pathway or tunnel into the rock or earth under which the gold ore is believed to be located. The gold ore usually runs through the earth in vein-like formations. The tunnels are blasted out of rock using dynamite. Second, in the ball milling and gravity concentration subprocess, large ore fragments are crushed into small fragments measuring 2–3 cm in diameter. The milling process produces gold particles. In the third subprocess, cyanide is dissolved in sacks of tailings (about 40 kg of cyanide for mixing in 200 sacks of tailings). The cyanide solution is then siphoned into the cyanide pond and left to react for five to six days. More cyanide is added as it evaporates. Finally, in the smelting subprocess, chemicals such as sodium borate and nitric acid are mixed separately until a gold nugget is finally obtained.

Environmental health and safety programs among miners are lacking in most developing countries.[5] In a study in Northern Nigeria, it was found that 100% of the miners were not using personal protective equipment and that the quarry sites had no safety measures for their workforce at all.[5] In another study in India, it was found that sandstone quarry workers were not using face masks to prevent silica inhalation.[5]

Therefore, it is imperative to investigate the environmental health and safety status of the Itogon small-scale gold miners in order to implement the necessary policies and safeguards. The main objective of this study was to look into cyanide concentration in human blood as well as to investigate the environmental and occupational hazards of indigenous SSGM in the target community in the Philippines.

Methods and Materials

The target population in this study was the small-scale gold miners in Sitio Dalisay located in Barangay Gumatdang in the province of Itogon, Philippines. This study confined the target population to the males since they are the ones who handle cyanide for the extraction of gold. Females and children are also involved in artisanal mining, but to a significantly lesser extent.

Subjects included in this study fulfilled the following criteria: male and working as a small-scale gold miner in Sitio Dalisay for at least 24 hours/week in the past year immediately preceding the study. Residents who were employed in corporate mines at the time of the study were excluded. There is a subpopulation of small-scale gold miners who are not permanent residents of the community, but are hired seasonally to work with cyanide in ore refinement. They were not included in this study.

Since the projected study population was small, all residents who fulfilled the inclusion criteria were included in this research. Sampling and randomization were not done. A census of all households to identify those who were qualified as subjects was accomplished prior to the actual survey of small-scale gold miners. The total subject respondents included 34 small-scale gold miners.

There were four major tools used in this study: (1) structured interviewer-guided survey questionnaire, (2) work process observation tool, (3) physical health assessment, including mental health status, conducted by medical doctors, and (4) laboratory assessment of blood samples, including cyanide determination.

The structured interviewer-guided survey questionnaire consisted of the following items: sociodemographic profile, occupational history such as the number of years in mining work, and occupational safety and health hazard exposures such as exposure to cyanide. This was based on the questionnaire developed by the National Poison Control and Management Center of the Philippine General Hospital.

Work process observation was also done. The tasks of the miners were to look into the workflow, work process, and possible factors contributing to accidents and actual causes of such accidents.

Complete physical health assessment and cognitive status examination were also done. The cognitive status examination is a measure that covers areas of cognitive function, such as orientation, calculation, memory, recall, language, among others, which takes about 5–10 minutes to administer and, hence, is practical. The maximum score is 30, and a score of 23 or less is indicative of cognitive impairment. This assessment was conducted by trained medical doctors and based on the questionnaire developed by the National Poison Control and Management Center of the Philippine General Hospital.

For the blood samples, the following were analyzed: blood sugar, hemoglobin, hematocrit, white blood cell, platelet count, reticulocyte count, blood urea nitrogen, creatinine, aspartate aminotransferase (AST), alanine aminotransferase (ALT), and blood cyanide. Blood samples were extracted from all 34 subject respondents during the physical examination procedure and transported to the laboratory within 12 hours of extraction. The blood samples were sealed and stored in an ice-filled cooler and maintained at 2 °C–8 °C. These conditions were maintained during land transport. Samples were processed for cyanide determination using spectrophotometry/Natelson colorimetric method. Blood samples were kept at room temperature to test other parameters. An informed consent form duly approved by the ethics review board of the University of the Philippines – National Institutes of Health accompanied each interview schedule. The study procedures were approved by the ethics review board of the University of the Philippines – National Institutes of Health, and the research was conducted in accordance with the principles of the Declaration of Helsinki.

All data were later converted for analysis using the STATA statistical software version 6. Descriptive analysis of quantitative data was done by computing frequencies and percentages as well as mean, median, and standard deviation when relevant.

Pearson chi-square test was used to identify any correlations between symptoms and blood cyanide level. Spearman's correlation was used to compute for possible correlations between the results of the laboratory tests and total life exposure to cyanide.

Results

Sociodemographic data. The community of Sitio Dalisay is made up of 50 households where the adult males are engaged in SSGM on a full-time basis.

The 34 small-scale gold miners had a mean age of 36 years (±10.51 SD), the oldest was 61 years old, and 76% were married. A total of 39% had up to high school level education. The miners had been working for an average of 10.3 years (±7.79 SD), with the maximum of 30 years. Total lifetime mining work hours averaged at 18,564 (Table 1).

Majority (62%) of the small-scale gold miners were smokers, with at least 15 (±12.97 SD) pack-year smoking history. A total of 29% were betel nut chewers as well. Betel nut chewing is common in the local area, and all of them used to drink alcoholic beverages.

The miners had some exposure to chemicals outside of their immediate work, mostly from the use of pesticides in farming. Possible environmental exposure to chemicals came from fish and vegetables brought to the community from neighboring areas. The province of Benguet is referred to as the "vegetable bowl of the Philippines" since it is the top vegetable producing area in the northern part of Luzon.

The typical miner in the sample population works for an average of six hours (±1.75 SD), five to six days a week. All (100%) were involved in tunneling work, while less than 50% were involved in mixing cyanide with the ore (Table 2). The average daily income was Philippine Peso (PhP) 312.47 (USD 6.5), but this varied widely from PhP 100 to 2,400 (±395.00 SD; USD 2.08–50). There is no certainty about how much a small-scale gold miner will earn as this depends on how much gold is extracted from the ore at any one cycle of the processing.

Table 1. Sociodemographic data of small-scale gold miners in Benguet, Philippines (*n* = 34).

SOCIODEMOGRAPHIC DATA	MEAN	STANDARD DEVIATION
Age	35.8	10.51
Total years work in mining	10.3	7.8
Number of working hours per day	6.3	1.74
Number of workdays per week	5.8	0.43
Total lifetime work hours in mining	18,564	14,416
Average daily income	312.47	395.00
Proportion of SSGM directly handling cyanide	37.5	–

Table 2. Involvement of small-scale gold miners in various mining tasks in Benguet, Philippines (*n* = 34).

TASKS IN MINING	FREQUENCY	PERCENTAGE
Tunneling	34	100
Ball mill operation	24	71
Cyanide mixing	15	44
Refining the gold	21	62
Buying/selling gold	22	65

Note: multi-response- the respondents checked more than one of the categories which means that they are involved in several tasks.

Work sites. The tunnels are found in Surong and Tuap. Ball mills are located at many sites in the entire village. Cyanide leaching ponds are also located at many different sites, mostly along the Ambalanga River that runs across Sitio Dalisay. There can be as short as 5 m between houses and cyanide leaching ponds. Smelting is done within residential areas. The mixing of nitric acid is done along the river bed in order to keep some distance from the houses, to avoid the fumes produced during mixing. However, the fumes were still observed to rise up above the river and move into vegetable and flower gardens. The water used in washing the gold amalgam during smelting is poured directly into drainage canals running beside the houses. This water eventually ends up in the Ambalanga River that cuts across Sitio Dalisay in Gumatdang. The bottle in which nitric acid is kept is washed directly in the river. After extracting the gold, the mine waste is dumped directly into the river. All the wastes from Gumatdang SSGM go into the Ambalanga River.

Safety issues. As for safety issues observed during the work process observation, the five most frequently cited causes of accidents in small-scale mines were rock falls, subsidence, lack of ventilation, misuse of explosives, and obsolete and poorly maintained equipment. The most frequently cited accidents were: (1) trips or falls (at the same level, or from one level to another); (2) being hit by machinery or a moving object (eg, rocks, stone chips, tools); and (3) effects of cave-ins or rock falls (eg, fractures, sprains, contusions).

The most prevalent hazard observed was the exposure to cyanide, which was usually handled with bare hands. At most, a handkerchief or a piece of cloth was used as a face mask during the dissolution of cyanide and while smelting. Dust was another hazard present during most of the mining process. However, no workers were observed wearing a respirator. Ergonomic hazards due to the uncomfortable positions and heavy loads required in mining were also prominent. A total of 35% of miners experienced accidents. Miners' head protection consisted only of bonnets and caps; no one wore a hard hat. The preferred clothing was a short-sleeved or sleeveless shirt and shorts.

Occupational health of miners. The most frequently self-reported health symptoms of the respondents were dizziness (35%), followed by fever (23%) and easy fatigability (21%).

A total of 9% of the respondents had rough skin texture, and 21% had constricting and pulsating facial disorder. A total of 21% suffered from blurring of vision, and 18% suffered from eye pain and eye redness. Notably, respondents experienced ear aches (12%), chest pains (23%), exertional dyspnea (23%), low back pain (23%), and bone joint pains and redness/swelling of joint (32%). A total of 41% were in prehypertension stage, whereas 29% were in stage 1 hypertension (Table 3). The results of the cognitive status examination are shown in Table 4. Data show that most deficits were in repeat phrase (97.1%) and recent or short-term memory (67.6%). Furthermore, 15% had experienced dyspnea and 3% were hypotensive, which are manifestations of a more severe case of cyanide poisoning. The cognitive status examination showed that most deficits were in repeat phrase (97.1%) and recent or short-term memory (67.6%).

Table 3. Frequency distribution of general symptoms among small-scale gold miners in Benguet, Philippines ($n = 34$).

HEALTH SYMPTOMS	FREQUENCY	PERCENTAGE
Easy fatigability	7	21
Dizziness	12	35
Vertigo	4	12
Loss of consciousness	3	9
Anorexia	4	12
Night sweats	5	15
Weight loss	4	12
Fever	8	23
Chills	4	12
Head/facial disorders		
Pounding	4	12
Constricting	7	21
Pulsating	7	21
Eye disorders		
Eye pain	6	18
Blurring of vision	7	21
Eye redness	6	18
Eye tearing	5	15
Eye itchiness	3	9
Respiratory disorders		
Frequent cough	4	12
Occasional cough	20	59
Dyspnea	5	15
Clear phlegm production	6	18
Purulent phlegm production	13	38
Expectoration, difficult	5	15
Cardiovascular disorders		
Chest pain	8	23
Palpitations	11	32
Exertional dyspnea	8	23
Musculoskeletal disorders		
Limb weakness	8	23
Bone joint pains	11	32
Redness/swelling of joint	11	32
Edema	23	68
Leg cramps	4	12

Note: multi-response.

Table 4. Frequency distribution of small-scale gold miners with 23 or less than scores in various components of the cognitive status examination ($n = 34$).

COGNITIVE STATUS EXAM	FREQUENCY	PERCENTAGE
Total score	28	82.4
Orientation	8	23.5
Calculation	8	23.5
Recent memory	23	67.6
Repeat phrase	33	97.1
Anomia	2	5.9
Reading comprehension	3	8.8
3-Step command	4	11.8
Sentence construction	2	5.9
Object construction	3	8.8

Findings in this study showed that 17.7% of the miners had elevated serum creatinine level. AST and ALT were also found to be elevated among miners, 24.7% and 20.6%, respectively.

Laboratory examination results are shown in Tables 5 and 6. Hemoglobin was elevated in 26.5% (9) miners, by 1%–16% above the upper limit or an average of 7.67 g/L. Hematocrit was elevated in only one miner, by 5% above the upper limit or 0.26 L/L. Reticulocyte count was elevated in 26.5% (9) of the small-scale gold miners, by 6%–87% or 5.67×10^{-3}/L above the upper limit. Serum creatinine was elevated in 17.7% (4) of the respondents, by 7%–23% or an average of 0.175 mg/dL above the upper limit. AST increased in 24.7% (9) small-scale gold miners, by 2%–100% or an average of 13.97 U/L above the upper limit of 38 U/L. ALT was also

Table 5. Frequency distribution of small-scale gold miners with abnormal laboratory parameters ($n = 34$).

LABORATORY PARAMETER	NORMAL RANGE	ELEVATED	
		FREQUENCY	PERCENTAGE
Hemoglobin	120–170 g/L	9	26.47
Hematocrit	04–0.54 L/L	1	2.94
Reticulocyte count	$5–15 \times 10^{-3}$/L	9	26.47
Creatinine	0.6–1.3 mg/dL	6	17.65
AST	0–38 U/L	9	26.47
ALT	0–41 U/L	7	20.59
Blood cyanide	0–0.5 ug/mL	5	14.71

Table 6. Laboratory parameters of small-scale gold miners (*n* = 34).

PARAMETER	MEAN	SD	MEDIAN	MINIMUM	MAXIMUM
Random blood sugar	96.4	22.3	96.5	40	139
Hemoglobin	164.4	11.5	162	146	197
Hematocrit	0.5	0.0	0.5	0.417	0.566
White blood cell count	7.5	1.7	7.2	5.1	10.7
Platelet count	adequate				
Reticulocyte count	13.2	5.6	12	5	28
Blood urea nitrogen	4.0	0.8	3.9	2.5	5.4
Creatinine	1.2	0.2	1.2	0.9	1.6
AST	34.3	13.6	32.2	13.2	81.7
ALT	30.3	18.3	23.4	4.6	81.7
Free T4	1.3	0.2	1.26	0.99	1.69

increased in 20.6% (7), by 18%–99% or an average of 20.36 U/L above the upper limit of 41 U/L. Random blood sugar level was within the normal limits in all the respondents.

The presence of cyanide was detected in the blood of all 34 miners. About 15% had blood cyanide levels above 0.5 µg/mL, which is the level for acute toxicity among smokers. The mean blood cyanide level was 0.4 (±0.1 SD). The minimum blood cyanide level was 0.32 µg/mL and the maximum was 0.59 µg/mL.

Discussion

Small-scale gold miners are considered subsistence miners who work using their own resources in mining or in panning for gold. They are generally working with handheld tools.[6] SSGM uses rudimentary or primitive extraction techniques and employs unskilled manpower.[7] Cyanide is considered as one of the most cost-effective methods to extract bits of gold, but quantities of hydrogen cyanide as small as a grain of rice (50–200 mg) can be fatal. To be able to obtain an ounce of gold, 100 tons or more of earth have to be extracted. The widespread use of cyanide among the small-scale gold miners in this study with minimal personal protection is very alarming. This has occurred in Guyana in 1995, Kyrgyzstan in 1998, and Romania in 2000.[8]

The small-scale gold miners in this study are a young population of workers. Majority are married and expected to support their families for many decades more. Although the average age is 36 years, they worked for a mean of 10 years, which means that most started working at an early age.

The task of extracting gold from underground is a long and tedious process. The workplace condition of small-scale mining is often very hazardous and difficult.[9] SSGM methods such as the use of gravity concentration in panning pose health risks among workers.[9] Furthermore, the nature of work of small-scale gold miners is physically demanding and dangerous due to heavy workloads, unstable underground structures, non-ergonomically designed tools and equipment, exposure to dusts and toxic chemicals, extremes of temperature, and poor lighting.[10] Despite these hazardous work conditions, the salary of small-scale miners is almost negligible.[11]

The work conditions among small-scale gold miners in this study are similar to those described for miners worldwide: lack of or limited use of mechanization; a lot of physically demanding work; low level of occupational safety and health care; poor qualification of personnel at all levels of the operation; inefficiency in exploitation and processing of mineral production (low recovery value); exploitation of marginal and/or very small deposits, which are not economically exploitable by mechanized mining; low level of productivity; low level of salaries and income; insufficient consideration of environmental issues; and chronic lack of working and investment capital.[12] Likewise, the living conditions of the transient miners in this study in the Philippines were characterized by poor sanitation and lack of clean water, and this is consistent with the dismal working conditions of small-scale gold miners around the world.[13]

There are documented researches on working conditions of miners worldwide. The major hazards identified in the small-scale mining areas, such as chemicals, dust, and ergonomic hazards, are also similar to those identified by the International Labour Organization. These are exposure to dust (silicosis); exposure to mercury and other chemicals; effects of noise and vibration; effects of poor ventilation (heat, humidity, lack of oxygen); and effects of overexertion, inadequate work space, and inappropriate equipment.[14] In Congo, miners who were involved in crushing were exposed to trauma and injury risks, whereas those who were involved in loading were exposed to handling heavy loads.[14] In South Africa, mining took place in very restricted places with low ceiling heights and high thermal heat loads and required large physical work.[15] Miners experienced musculoskeletal disorders and risk factors such as awkward body posture, manual material handling, repetitive motions, and exposure to whole body vibration, noise, and dust.[15]

While it is widely believed that cyanide easily breaks down in the presence of sunlight, its behavior in rain-rich countries such as the Philippines is not well established. The breakdown products of cyanide such as cyanates, thiocyanates, ammonia, and nitrates are also toxic to aquatic organisms. In fact, thiocyanates have been documented to bioaccumulate.[16] This was reiterated by Donato et al, who underscored that cyanide is a fast-acting poison and its toxicity is related to cyanide complexes it creates along its pathway in the air, water, and cyanide leaches. For instance, wildlife deaths are more likely to occur at mines possessing copper–gold ores.[17] Therefore, this makes the management of cyanide-bearing mine waste solutions a challenge. In the study by Johnson on the fate of cyanide leach wastes at gold mines, he stated that cyanide leaching produces numerous other cyanide-containing and cyanide-related products, which pose threat to humans and living organisms. The dispersal of free cyanide in gold leach operations predicts its catastrophic effect.[18] A case was presented in Ecuador where SSGM using mercury amalgamation and cyanidation yielded 9–10 tons of gold/annum, resulting in annual releases of around 0.65 tons of inorganic mercury and 6,000 tons of sodium cyanide in the local river system, thus reducing biodiversity downstream the processing plants and enriching metals in bottom sediments and biota.[19]

According to the Agency for Toxic Substances and Disease Registry, cyanide anion binds to enzymes and other proteins that contain ferric ion.[20] This results in inactivation and loss of function among those who are exposed to cyanide by any route. The affinity of cyanide anion and ferric iron cytochrome oxidase (an enzyme in the use of oxygen in mitochondria) would result in cessation of cellular respiration and, eventually, to rapid cell death. Cyanide also binds with the iron of hemoglobin, resulting in reduction of the oxygen-carrying capacity of the blood. Accordingly, exposure to even lower cyanide concentrations over a long period of time leads to various symptoms from fatigue, dizziness, and headaches to ringing in the ears, paresthesias of extremities, and syncopes, or even hemiparesis and hemianopia. In addition, behavioral changes were reported following prolonged cyanide exposure in humans and animals, and a loss of memory, a decrease in visual acuity, psychomotor ability, and visual learning were reported in workers.[20,21] Similar symptoms were reported by the Philippine miners in this study. The manifestations of cyanide toxicity occur at less than one minute after inhalation and within a few minutes after ingestion.

There are other adverse effects of chemicals used in mining such as cancers. In the study by Fernández-Navarro et al, in Spain, there was an association between proximity to Spanish mining industries and the risk of mortality resulting from various kinds of cancers, such as respiratory, digestive, hematologic, and thyroid cancers.[22] The distance to pollution source of cyanide is an important factor in illness etiology.

In comparison with other studies on adverse effects of cyanide exposure, similarities can be drawn from the findings in the Philippines. Self-reported health symptoms among the miners included chronic cough, chest pain, progressive breathlessness, mucoid/bloody sputum, joint pains, and constant headaches in the study in northern Nigeria.[23] These were also experienced by the Philippine small-scale gold miners in this study. In northern Nigeria, health symptoms such as cuts, as well as skin irritation and chest pain, were reported among the artisanal miners.[24]

In this study, the respondents experienced pulmonary edema and loss of consciousness. As noted in another study, pulmonary edema and loss of consciousness are manifestations of later features or most severe cases of cyanide poisoning.[25] The cognitive status examination among the small-scale gold miners showed most deficits in recent or short-term memory. Memory loss has been cited in literature as being associated with chronic cyanide exposure.[25] Cyanide has also been shown to cause hemorrhagic necrosis in those brain structures with a high oxygen requirement such as the basal ganglia, cerebellum, and sensorimotor cortex. Six weeks after acute cyanide intoxication, magnetic resonance imaging showed hemorrhagic necrosis in the striatum and globus pallidus.[26]

Findings in this study showed that the small-scale gold miners had elevated serum creatinine level. Studies on the relation between creatinine levels and cyanide indicate that an increased serum creatinine level is expected among those chronically exposed to cyanide.[27] AST and ALT were also found elevated. A study among workers in cassava-processing industries showed a 10% increase above normal limit of AST, and this increase was attributed to occupational cyanide exposure.[27] In a study among rabbits injected with potassium cyanide for several days showed that the stimulation of the erythropoietic function of the bone marrow was caused by cyanide.[27] Blood glucose level among cassava-processing industry workers has been found to be elevated when compared with cassava consumers.[27] T4 levels showed a trend toward correlation with total lifetime hours working with cyanide. Likewise, depressed T4 levels have been documented among workers handling cyanide compounds in an electroplating process of a cable industry.[28]

Cyanide was detected in the blood of all 34 small-scale gold miners who were tested. A total of 14% (5) had levels above 0.5 μg/mL, which is the level for acute toxicity among smokers. A similar increase in hemoglobin, red blood cell, and reticulocyte counts has been documented among rabbits injected with potassium cyanide for several days. Serum creatinine was elevated in the subject respondents. A study of rabbits fed a cyanide-containing diet by Okolie and Osagie for 10 months showed such a result.[29] AST and ALT were also elevated among the subject respondents. This increase was attributed to occupational cyanide exposure.[30] In a study in Ghana, cyanide exposure, which was measured via oral and dermal contacts, was found to be high among residents in the gold mining community and posed a health risk for acute toxicity.[31]

The symptoms reported by miners were nonspecific and could be caused by other environmental factors. However, cyanide exposure consists of a constellation of symptoms and health problems. In such a situation, a precautionary principle is applied which states that when workers are exposed to cyanide in mining, and there are no appropriate control and preventive measures implemented such that when such symptoms arise, this may be well linked to cyanide exposure. Cyanide was detected even in the blood of miners who claimed to never have handled this chemical. Upon relaying this finding to the miners, they pointed out that while some miners may not handle cyanide directly, many of them live near or regularly pass by the cyanide leaching ponds. Therefore, using total lifetime work exposure as an indicator of cyanide exposure tends to underestimate actual cyanide exposure in a setting where the workers' work areas overlap with their living areas.

Some limitations of this study were recall bias in the quantification of exposure (eg, number of hours per day when cyanide is used) and the physical distance from Itogon to the laboratory, which may have led to an underestimation of the true cyanide levels found in the samples due to the aforementioned half-life. Another limitation is the *healthy worker effect*. Healthy workers are preferred for employment. This results in a selection or employment of healthy workers relative to the general working population. There is no screening or preemployment for small-scale gold miners in the local area since mining is tedious and requires work experience. Those who remain as miners are more likely to be the healthier workers since the sick and disabled will not continue.

Conclusion

The small-scale gold miners in this study are a population of workers in the prime of their productive years. However, the task of extracting gold from underground is a long and tedious process that exposes the miners to many hazards, particularly to cyanide, with very little personal protection. The study showed adverse health symptoms experienced by the small-scale gold miners. Furthermore, blood cyanide level was elevated in all 34 subject respondents.

Cyanide use in the extraction of gold is both an occupational and environmental health issue for these miners. Measures to minimize damage to the health of the miners, their families, and the environment must be instituted. These include strict regulation of cyanide use, possible relocation of the cyanide leaching ponds away from the residential area, and health education and promotion among the miners and their families.

Author Contributions

Conceived and designed the experiments: AMRL, JLDPL. Analyzed the data: AMRL, JLDPL. Wrote the first draft of the manuscript: AMRL, JLDPL. Contributed to the writing of the manuscript: AMRL, JLDPL. Agree with manuscript results and conclusions: AMRL, JLDPL. Jointly developed the structure and arguments for the paper: AMRL, JLDPL. Made critical revisions and approved final version: AMRL, JLDPL. Both authors reviewed and approved of the final manuscript.

REFERENCES

1. Mines and Geosciences Bureau (MGB). *Mining Industry Statistics*. Available at: http://www.mgb.gov.ph/Files/Statistics/MineralIndustryStatistics.pdf. Accessed January 10, 2016.
2. Hamel J. A review of acute cyanide poisoning with a treatment update. *Crit Care Nurse*. 2011;31:72–82.
3. Lawson-Smith P, Jansen EC, Hyldegaar CC. Cyanide intoxication as part of smoke inhalation – a review on diagnosis and treatment from the emergency perspective. *Scand J Trauma Resusc Emerg Med*. 1996;19:14.
4. *Agency for Toxic Substances and Disease Registry*. 2006. Available at: http://www.atsdr.cdc.gov/toxguides/toxguide. Accessed December 15, 2015.
5. Babatunde OA, LM Ayodele, Elegbede OE, et al. Practice of occupational safety among artisanal miners in a rural community in Southwest Nigeria. *Int J Sci Environ Technol*. 2010;2(4):622–33.
6. Mallo SJ. Mitigating the activities of artisanal and small-scale miners in Africa: challenges for engineering and technological institutions. *Int J Mod Eng Res*. 2012;2(6):4714–25.
7. Elgstrand K, Vingard E. Occupational Safety and Health in Mining Anthology on the Situation in 16 Mining Countries. Gothenburg: University of Gothenburg, Kompendiet; 2013:47.
8. Boulanger A, Gorman A. *Hard Rock Mining: Risks to Community Health*. 2004. Available at: www.womenandenvironment.org. Accessed March 5, 2016.
9. Ako TA, Onoduku US, Oke SA, et al. Environmental impact of artisanal gold mining in Luku, Minna, Niger State, North Central Nigeria. *J Geosci Geomatics*. 2003;2(1):28–37.
10. Dinye RD, Erdiaw-Kwasie MO. Gender and labour force inequality in small-scale gold mining in Ghana. *Int J Res Econ Bus Manage*. 2012;1(1):6–15.
11. Bodenheimer M. *Certifying Improvement, Improving Certification: An Analysis Based on the Artisanal and Small-Scale Mining Sector*. 2013. Available at: http://www.isi.fraunhofer.de/isi-media/docs/n/de/publikationen/Bodenheimer-Masterarbeit-17-07-13.pdf. Accessed January 25, 2016).
12. Hentschel T, Hruschka F, Priester M. Artisanal and Small-Scale Mining Challenges and Opportunities. Mines, Minerals and Sustainable Development. London: Projekt-Consult GmbH; 2003.
13. International Labour Organization. Social and Labour Issues in Small-Scale Mines (Report for Discussion at the Tripartite Meeting on Social and Labour Issues in Small-Scale Mines). Geneva: 1999. Available at: http://www.ilo.org. Accessed February 4, 2016.
14. Elenge MM, De Brouwer C. Identification of hazards in the workplaces of artisanal mining in Katanga. *Int J Occup Med Environ Health*. 2011;24(1):57–66. doi: 10.2478/s13382–011–0012–4.
15. Steven J. Ergonomic hazards associated with small-scale mining in Southern Africa. *Int J Pure Appl Sci Technol*. 2013;15(2):8–17.
16. Moran R. Cyanide Uncertainties (Observations on the Chemistry, Toxicity, and Analysis of Cyanide in Mining-Related Waters). Mineral Policy Center Issue Paper No. 1. 1998.
17. Donato DB, Nichols O, Possingham H, Moore M, Ricci PF, Noller BN. A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife. *Environ Int*. 2007;33(7):974–84.
18. Johnson CA. The fate of cyanide in leach wastes at gold mines: an environmental perspective. *Appl Geochem*. 2015;57:194–205.
19. Guimaraes JRD, Betancourt O, Miranda MR, Barriga R, Cueva E, Betancourt S. Long-range effect of cyanide on mercury methylation in a gold mining area in Southern Ecuador. *Sci Total Environ*. 2011;409(23):5026–33.
20. *Agency for Toxic Substances and Disease Registry*. 2006. Toxicological Profile for Cyanide. U.S. Department of Health and Human Services. Available at: http://www.atsdr.cdc.gov/toxprofiles. Accessed December 10, 2015.
21. International Labour Organization. *Social and Labour Issues*.
22. Fernández-Navarro P, García-Pérez J, Ramis R, Boldo E, López-Abente G. Proximity to mining industry and cancer mortality. *Sci Total Environ*. 2012; 435–6:66–73.
23. Babatunde OA, et al. *Practice of Occupational Safety*. 622–33.
24. Rachinger J, Fellner FA, Stieglbauer K, Trenkler J. MR Changes after acute cyanide intoxication. *Am J Neuroradiol*. 2002;23:1398–401.
25. Meredith TJ, Jacobsen D, Haines JA, Berger JC, van Heijst ANP. Management of cyanide poisoning. *Emerg Med Australas*. 1993;24:225–38.
26. Rachinger J, Fellner FA, Stieglbauer K, Trenkler J. Changes after acute cyanide intoxication. *Am J Neuroradiol*. 2002;23:1398–401.
27. Okafor PN, Okorowkwo CO, Maduagwu EN. Occupational and dietary exposures of humans to cyanide poisoning from large-scale cassava processing and ingestion of cassava foods. *Food Chem Toxicol*. 2002;40(7):1001–5.
28. Banerjee KK, Bishavee A, Marimuthu P. Evaluation of cyanide exposure and its effect on thyroid function of workers in a cable industry. *J Occup Environ Med*. 1997;39(3):258–60.
29. Okolie NP, Osagie AU. Liver and kidney lesions and associated enzyme changes induced in rabbits by chronic cyanide exposure. *Food Chem Toxicol*. 1999;37(7):745–50.
30. Okafor PN, Okorowkwo CO, Maduagwu EN. *Dietary Exposures of Humans to Cyanide*. 1001–5.
31. Obiri S, Dodoo DK, Okai-Sam F, Essumang DK. Non-cancer health risk assessment from exposure to cyanide by resident adults from the mining operations of Bogoso gold limited in Ghana. *Environ Monit Assess*. 2006;118(1–3):51–63.