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Dermal Exposure to Heavy Metals in the Soil and Occupational Risks for Placer Small-Scale Gold Miners in Myanmar: A Case Study in Banmauk Township

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“အသေးစားရွှေသတ္တုတူးဖော်ထုတ်လုပ်ရေးလုပ်ငန်းများတွင် မြေထုတွင်းပါရှိသည့် Heavy Metal များနှင့် လုပ်သားများ၏ အရေးပြား ထိတွေ့မိခြင်းကြောင့် ဖြစ်ပေါ်လာနိုင်သည့် လုပ်ငန်းခွင် ကျန်းမာရေးအခြေအနေများကို မြန်မာနိုင်ငံ၊ ဗန်းမောက်မြို့နယ်၌ လေ့လာခြင်း”

အောင်ဇော်ထွန်း၊ ဦးစီးအရာရှိ

ပတ်ဝန်းကျင်ထိန်းသိမ်းရေးဦးစီးဌာန

စာတမ်းအကျဉ်း

သတ္တုတူးဖော်ခြင်းလုပ်ငန်းများတွင် သတ္တုတူးဖော်ရေးလုပ်သားများသည် လုပ်ငန်းဆောင်ရွက်စဉ် အတွင်း Heavy Metals များနှင့်ထိတွေ့မှုများသည် ကျန်းမာရေး ပြဿနာတစ်ခုဖြစ်ပါသည်။ဤစာတမ်းနှင့်ပတ်သက်သည့် လေ့လာမှုကို မြန်မာနိုင်ငံ၊ ဗန်းမောက်မြို့နယ်၊ မော်ဘုံကာကွယ်တောနှင့် နန့်ကျင်ကြိုးဝိုင်းအတွင်းရှိ ရွှေတူးဖော်ရေးလုပ်ကွက် (၃)ကွက် ဆောင်ရွက်ခဲ့ပါသည်။ ဤလေ့လာမှု၏ ရည်ရွယ်ချက်မှာ Placer ရွှေသတ္တု တူးဖော်ရေး လုပ်ငန်းစဉ်များဖြစ်သည့် ရွှေပါဝင်သောမြေကို ရေစုပ်စက်ဖြင့်ရေဖျော်ခြင်း၊ မျှောစဉ်ပေါ်သို့ ရွှေပါဝင်သော မြေကို တင်ပို့ခြင်း၊ ရွှေဝိုင်းခြင်းနှင့် ပြဒါးဖမ်းခြင်း အဆင့်တို့တွင် လုပ်ငန်း ဆောင်ရွက်စဉ်အတွင်း မြေကြီးအတွင်းရှိ Arsenic (As)၊ Cadmium (Cd)၊ Mercury (Hg)၊ နှင့် Lead (Pb) တို့အား ခန္ဓာကိုယ်အရေပြားနှင့် ထိတွေ့မိသည့် အသေးစားရွှေသတ္တုတူးဖော်ရေး လုပ်သားများ၏ ကျန်းမာရေးအခြေအနေကို လေ့လာဆန်းစစ်ရန် ဖြစ်ပါသည်။ မြေနမူနာများအား ဓါတ်ခွဲစမ်းသပ်ခြင်းကို Atomic Absorption Spectroscopy (AAS) ဖြင့် ဆောင်ရွက်ခဲ့ပါသည်။ မြေနမူနာ များအတွင်း Heavy Metals ပါဝင်မှု ပမာဏများမှာ Arsenic အနေဖြင့် 1.04 mg/kg မှ 22.17 mg/kg ၊ Cadmium အနေဖြင့် 0.13 mg/kg မှ 3.07 mg/kg ၊ Mercury အနေဖြင့် 0.15 mg/kg မှ 77.44 mg/kg နှင့် Lead အနေဖြင့် 7.67 mg/kg မှ 210.00 mg/kg အတွင်းတွင်ရှိကြောင်း တွေ့ရှိရပါသည်။ လေ့လာမှုဆောင်ရွက်ခဲ့သည့် ရွှေလုပ်ကွက်တိုင်း တွင် Heavy Metals ပါဝင်မှု အများဆုံးကို ပြဒါးဖမ်းခြင်းအဆင့်တွင် ကောက်ယူခဲ့သည့် မြေနမူနာများတွင် တွေ့ရှိရပါသည်။ ဤလေ့လာမှုတွင်ပါဝင်သော ရွှေလုပ်သားများအနက် ၇၉% ရာခိုင်နှုန်းမှာ ရွှေသတ္တုတူးဖော်ခြင်း လုပ်ငန်းဆောင်ရွက်စဉ်အတွင်း မည်သည့် Personal Protective Equipment (PPE)ကိုမျှ အသုံးပြုခြင်းမရှိကြောင်း တွေ့ရှိရပါသည်။ ရွှေလုပ်သား များအား ကင်ဆာမဟုတ်သည့် အခြားသော ရောဂါများဖြစ်နိုင်မှု အခြေအနေနှင့်ပတ်သက်၍ လေ့လာဆန်းစစ်ချက်အရ မည်သူတစ်ဦးတစ်ယောက်မျှ ဖြစ်နိုင်ခြေ မရှိကြောင်းတွေ့ရှိရ ပါသည်။ ကင်ဆာဖြစ်နိုင်မှုအခြေအနေအား လေ့လာဆန်းစစ်ရာတွင် လက်ရှိရွှေလုပ်သားများ၏ ပျမ်းမျှလုပ်သက်အရ 8.02×10^{-8} မှ 1.75×10^{-6} အတွင်းဖြစ်ပြီး လုပ်သက်၉ နှစ်ရှိပါက 4.78×10^{-7} မှ 1.04×10^{-5} အတွင်းရှိမည်ဖြစ်ပါသည်။ အဆိုပါကင်ဆာဖြစ်နိုင်မှု ပမာဏများသည် United State Environmental Protection Agency (U.S. EPA) မှ သတ်မှတ်ထားသော လက်ခံနိုင်သည့်

ကင်ဆာဖြစ်နိုင်ခြေ ပမာဏ 1 x 10^{-6} (လူ ၁ သန်းတွင်တစ်ယောက်) ထက် သာလွန်နေကြောင်း တွေ့ရှိရပါသည်။ ကင်ဆာမဟုတ်သော အခြားရောဂါများနှင့် ကင်ဆာ ဖြစ်နိုင်ခြေ ပမာဏ အမြင့်ဆုံးကို ရွှေလုပ်ကွက်(၃)ကွက်လုံးတွင် ပြဒါးဖမ်းခြင်းအဆင့်တွင် တွေ့ရှိရပါသည်။ အကြံပြုချက်အနေဖြင့် ရွှေလုပ်သားများအား Heavy Metals နှင့်ပတ်သက် သည့် ကျန်းမာ ရေးဆိုးကျိုးများကို အသိပညာပေးရန်နှင့် ရွှေသတ္တုတူးဖော်ခြင်းလုပ်ငန်း ဆောင်ရွက်စဉ်အတွင်း PPE အသုံးပြုရန် တိုက်တွန်းသင့်ပါသည်။

Dermal Exposure to Heavy Metals in the Soil and Occupational Risks for Placer Small-Scale Gold Miners in Myanmar: A Case Study in Banmauk Township

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Abstract

Exposure to heavy metals in mining activities are one of the health issues as miners are exposed to heavy metals during conducting mining processes. This study was carried out in three placer gold mining sites located in Hmawbon public protected forest and Nant Kyin reserved forest in Banmauk Township, Myanmar. This study aims to assess health risks of small-scale gold miners who are exposed to arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) in the soil through dermal route during working in the placer gold mining steps of ore processing, sluicing, panning and amalgamation. The soil samples analysis was conducted through atomic absorption spectroscopy (AAS). The concentrations of the heavy metals ranged from 1.04 mg/kg to 22.17 mg/kg (As), 0.13 mg/kg to 3.07 mg/kg (Cd), 0.15 mg/kg to 77.44 mg/kg (Hg) and 7.67 mg/kg to 210.00 mg/kg (Pb). The highest concentrations of the heavy metals were found in the amalgamation step in all the gold mining sites. In this study, 79% of the participants do not use any form of personal protective equipment (PPE) during working in the placer gold mining processes. Regarding non-cancer risks assessment, all the participant in this study may not be at risks. In case of cancer risk assessments, current cancer risks ranged from to 8.02 x 10^{-8} to 1.75 x 10^{-6}, and estimated cancer risks for 9 years ranged from 4.78 x 10^{-7} to 1.04 x 10^{-5}. Therefore, the cancer risks of the miners were greater than United State Environmental Protection Agency (U.S. EPA) acceptable cancer risk level, 1 x 10^{-6}, and they may be suffering from developing carcinogenic diseases. The highest non-cancer and cancer risks were found in the amalgamation steps in all the gold mining sites. The simple suggestion is to educate the miners about the health risks of the heavy metals and to encourage using personal protective equipment (PPE) in order to prevent heavy metals exposure during working in the placer gold mining processes.

Keywords: Banmauk, Gold Mining, Heavy Metals, Myanmar, Risk Assessment, Soil

Dermal Exposure to Heavy Metals in the Soil and Occupational Risks for Placer Small-Scale Gold Miners in Myanmar: A Case Study in Banmauk Township

1. Introduction

Artisanal and small-scale mining (ASM) activities play an important role in the socio-economy of many developing countries in Asia, Africa, Oceania, and Central and South America (Hentschel et al., 2003). In some countries, it provides the income of about three to five times greater than that of other rural-based work sectors, for example, small-scale agriculture, fisheries, and forestry; therefore, around 20 to 30 million people throughout the world are conducting ASM activities and these activities are a great livelihood for many poor communities to escape from poverty. Among ASM activities, activities of gold production are the most common in many countries (Buxton, 2013).

Although artisanal and small-scale gold mining (ASGM) activities are normally conducted in unsafe conditions, twenty to thirty percent of the total world gold manufacturing is provided by ASGM (UNEP, 2008). These mining activities generally use simple tools and methods to extract gold from ore deposits (Buxton, 2013). In these gold mining processes, mercury is extensively used to capture gold; as a result, mercury can enter into the environment such as soil, water and atmosphere (Wilson et al., 2015). Therefore, ASGM has identified as a world's largest anthropogenic mercury releasing source into the environment (UNEP, 2013). Furthermore, these mining activities can lead to increase the concentrations of heavy metals, which is naturally occurred in the earth's crust as arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb), in the environment. As a result, it can cause sediment, soil and water contamination, and exposure to these heavy metals can also results in serious non-carcinogenic and carcinogenic diseases to human such as muscular pain, rashes, skin tumors, etc., (Goyer & Clarkson, 1996; He et al., 2005; Herawati et al., 2000; Matthew et al., 2002; Shallari et al., 1998; Srikanth et al., 1993).

The most common naturally found heavy metals in the gold mining area have been reported as As, Cd, Hg, Pb, copper (Cu), and zinc (Zn) (Da Silva et al., 2004; Tech, 2013). Among them, As, Cd, Hg, and Pb are classified as the most toxic heavy metals to human and animals because of their elemental impurities, carcinogenicity and likelihood of occurrence (Jignesh et al., 2012; WHO, 2007). Furthermore, many studies had been reported high concentrations of these heavy metals in the soil and tailing of the gold mining areas in Ghana (Ahmad & Carboo, 2000; Bempah et al., 2013), Tanzania (Bitala et al., 2009), Iran (Rafiei et al., 2010), Kenya (Abdul-Wahab & Marikar, 2012; Matshusa et al., 2012) and Oman (Ogola et al., 2002). Also, the main exposure pathway to these heavy metals from tailings and the soil to human was reported as dermal route. And then, exposure to these heavy metals can have many serious health problems such as kidney and liver cancers, dermal keratosis (Lansdown, 2013; Mazumder, 2000), damaging the central nervous system, heart disease (Faroon et al., 2012), joint pains, shyness, irritability (Risher & Dewoskin, 1999), vomiting, poor attention span, and headache (Belle et al., 2010; Castro-Gonzalez & Mendez-Armenta, 2008) . Therefore, previous researches had been conducted non-cancer and cancer risks assessment of dermal exposure to these heavy metals in gold mining areas in Nigeria (Olujimi et al., 2015), Ghana (Obiri et al., 2016), South Africa (Kamunda et al., 2016; Ngole-

Jeme & Fantke, 2017), China (Li et al., 2014; Liang et al., 2017), and unacceptable non-cancer and cancer risks have been reported.

Gold mining activities have been conducted all over the country in Myanmar, especially in Kachin, Sagaing, Mandalay, and Bago Region of Myanmar (Osawa & Hatsukawa, 2015). Therefore, Myanmar's gold production was recorded as 1,692 kg in 2015 and 1,700 kg in 2016, and placer gold mining method has been commonly used for ASGM that is the main sector of Myanmar's gold production (CEIC, 2018). Although gold mining activities are being wide conducted everywhere the country, limited amount of papers exist regarding human health risks of gold mining activities. As a consequence, Myanmar has little information on the gold mining impacts on miners in terms of occupational health risks. Therefore, this study tries to identify the local placer gold mining processes that might have the adverse health effects on miners. And then, this study aims to assess occupational health risks of both male and female small-scale gold miners who were dermally exposed to As, Cd, Hg and Pb during working. This study was conducted at three placer small-scale gold mining sites located in the Hmawbon public protected forest and Nant Kyin reserved forest, Banmauk Township, which is one of the main small-scale gold mining areas in the Sagaing Region of Myanmar.

2. Placer Small-Scale Gold Mining in Myanmar

In Myanmar, the placer small-scale gold mining method mainly involves the steps of extraction of material, ore processing, concentration: sluicing and panning, amalgamation, and burning of the amalgam as shown in Figure 1 (Osawa & Hatsukawa, 2015; UNEP, 2015).

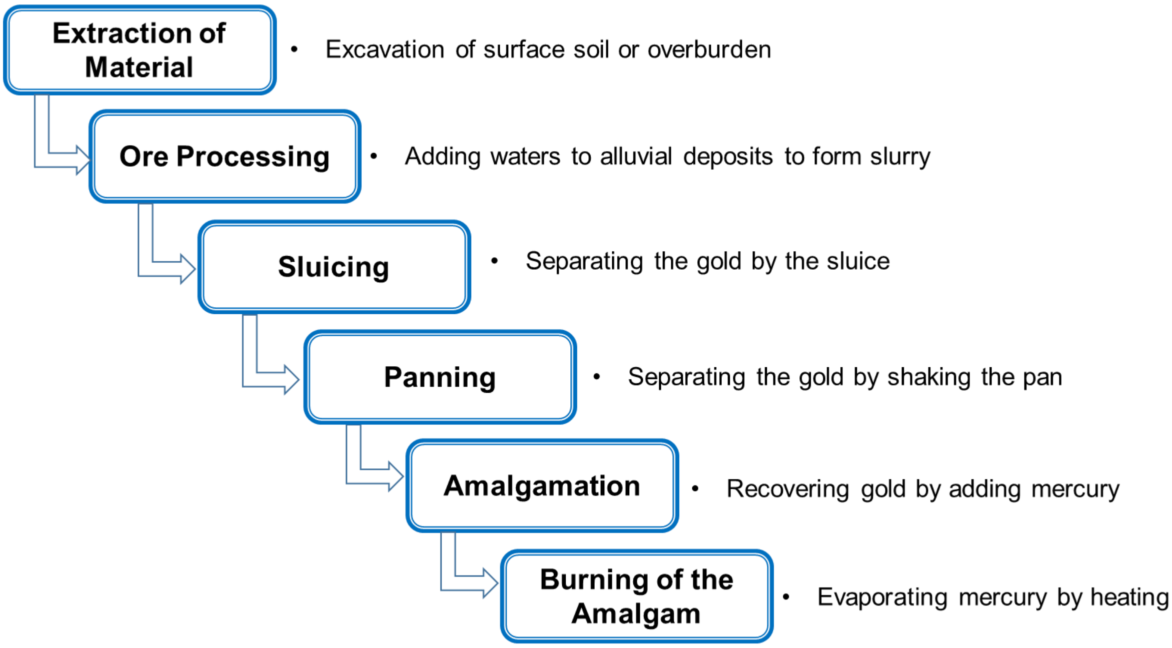

Figure 1. Placer Small-Scale Gold Mining Processes

In the extraction of material step, the top soil over the placer deposits (ore) is removed and ore is mined by using machines, like backhoes and dump trucks (Fig. 2a). After that, in the ore processing step, the extracted ore is processed to form slurry by adding water into the placer deposits in order to liberate gold from other minerals (Fig. 2b). Once the gold is liberated, it is then concentrated into a smaller mass through gravity methods: sluicing and panning. In the sluicing step, gold-containing soil is caught by waterproof carpets from the liberated ore slurry through sluicing (Fig. 2c). Then, the gold-containing soil obtained from sluicing step is then concentrated again by hand-shaking the pan in the panning step (Fig. 2d). Afterward, Hg is added into the smaller mass of gold-containing soil attained from panning step to capture the liberated gold particles (Fig. 2e). As a result, mercury adhere onto the surface of gold particles because of the higher surface tension of gold than Hg by separating from the soil. After that, the mixture of Hg and gold particle is put into a cloth bag and squeezed by hand in order to attain amalgam, and then the soil is removed. In some mining sites, this mercury rich soil residues is then reused about 3-5 times for further recovery of gold through cyanide leaching techniques in some mining sites. After obtaining the amalgam, it is heated in order to evaporate Hg and to recover gold (Fig. 2f) (UNEP, 2015; WHO, 2016).

Among these gold mining steps, the extraction of material step mainly requires machines, like backhoes and dump trucks, to extract and carry the ore instead of manual labors. In the other gold mining steps, manual labors are mainly used. However, the burning of the amalgam step is normally conducted in a specific place or room in order to prevent gold losing, and the labors in this step are mainly exposed to the Hg vapor through inhalation. As a result, among the gold mining step, ore processing, sluicing, panning and amalgamation steps mainly use manual labors and these placer gold mining steps have the potential to be exposed to the heavy metals in the soil on the body parts of the labors through dermal route. Therefore, these aforementioned four placer small-scale gold mining steps were focused for occupational health risk assessment of the miners in this study.

Figure 2. Placer small-scale gold mining in Banmauk Township: (a) Removing surface soil by using backhoe and truck. (b) Ore processing by adding water. (c) Sluicing through wooden sluice. (d) Panning by using wooden pan. (e) Recovering gold particles by adding. January 25, 2019.

3. Materials and Methods

3.1 The Study Area

The study was conducted in three placer small-scale gold mining sites: Site A, Site B and Site C in Banmauk Township, Sagaing Region, Myanmar as shown in Figure 3. Site A is located in the Hmawbon public protected forest, and Site B and Site C are located in the Nant Kyin reserved forest. The areas that are permitted by the Government of Myanmar for Site A, Site B and Site C are 0.081 km^2, 0.081 km^2 and 0.055 km^2 respectively. In the permitted areas, the actual working areas for Site A is 0.032 km^2, Site B is 0.028 km^2, and Site C is 0.016 km^2. Normally, these mining sites are permitted by the Government to conduct gold mining activities in their respective mining sites for one year. Therefore, after every one year of gold mining, the site owners have to request to the government for the extension of their mining activities in the same sites for another one year. By this way, the gold mining activities have been conducting in the same sites year by year. Therefore, in the same gold mining sites, Site A has been working for about five years; Site B has been working for about three years; and Site C has been working for about three years. These mining sites are situated about 46.7 kilometers away from the north-east of the Banmauk Town. Banmauk Township is one of the main gold mining areas in the Sagaing Region of Myanmar. In Banmauk Township, both legal and illegal gold mining activities can be widely found because of the wide occurrence of the placer deposits in this area, but research paper regarding the impacts of mining activities in this area is very limited. Placer deposits, which are very common for artisanal and small-scale miners due to its easy to assess and extract placer gold, can also be widely found in the vicinity of the study area.

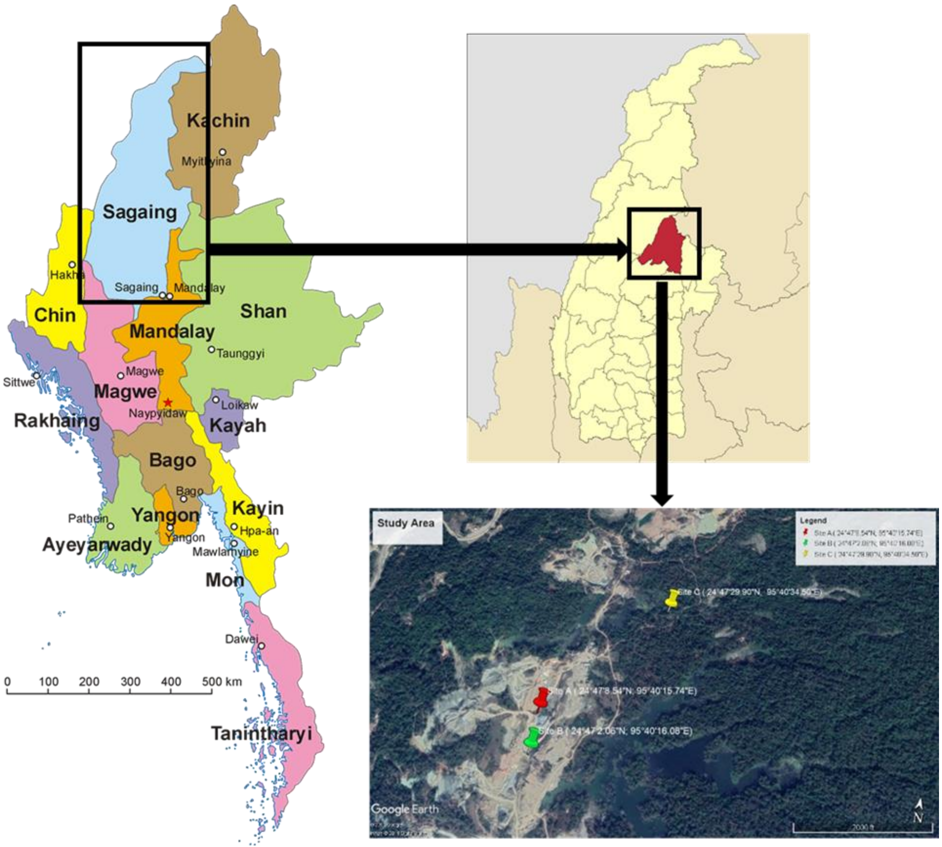

Figure 3. The study mining sites are located in Banmauk Township, Sagaing Region, Myanmar

3.2 Data Collection

This study was a cross-sectional study. Questionnaire and soil samples were collected in this study in order to investigate the occupational health risks of both male and female miners. This study have already approved by The Ethic Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University with certificate of approval - COA No. 002/2019 (Date of approval: 3 January 2019). Both questionnaire and soil samples were collected in January, 2019.

3.3 Questionnaire Survey and Analysis

The targeted population in this study was both male and female placer small-scale gold miners within the age range of 18-60 years. Furthermore, miners whom were considered as targeted population only if they were working in the aforementioned gold mining steps of having high potential of exposure to the heavy metals in soil at least 12 months. After recruiting the participants, a total of 53 participants (19 participants from site A, 17 participants from site B, and 17 participants from site C) were explained the purpose of the study clearly before asking the questions. Continuously, information sheets that were written in English and Myanmar separately including informed consent forms were provided to the participants, and then they were asked to sign the informed consent forms with full understanding and willingness. After that, face-to-face questions regarding the personal information of the miners such as height, weight, job responsibilities and personal protective equipment (PPE) use behaviors were asked to the participants in order to prevent misunderstanding of the questionnaire, thereby obtaining information on working behaviors of the miners in the gold mining steps.

3.4 Soil Samples Collection

3 soil samples from each of the gold mining steps of ore processing, sluicing, panning, and amalgamation in each gold mining site in the study area were collected. Therefore, a total of 36 soil samples from 3 mining sites were collected with a steel trowel at a depth of 0-10 cm. At each sampling point, 5 replicated soil samples were collected within a 2 m × 2 m grid, and then these samples were thoroughly mixed in order to obtain a homogenous sample. After getting a homogenous sample, 50 g of soil samples were collected according to the Batley & Simpson, (2016). The collected samples were then put into the polyethylene plastic bags that were thoroughly pre-washed in 10% nitric acid and distilled water before using (ASTM, 1991; U.S. EPA 2001). After collecting all samples and placed in the bags, these samples were stored in the icebox and sent to the Pesticide Analytical Laboratory, which is under the Department of Agriculture, Ministry of Agriculture, Livestock and Irrigation, Myanmar to analyze the concentrations of the aforementioned heavy metals and soil pH as soon as possible.

3.5 Soil Sample Analysis

The collected soil samples were sent to the Department of Agriculture, Ministry of Agriculture, Livestock and Irrigation, Myanmar to analyze the concentration of the heavy metals and soil pH. In the laboratory, the soil samples were air-dried by spreading out on the brown papers for 2 – 3 days. After that, the samples were sieved by using a 2 mm nylon mesh in order to attain a homogenous sample. 5 g dry weight of each fine powder soil sample was then put in 250 ml beaker and 21 ml concentrated hydrochloric acid was added and swirled. 7 ml concentrated nitric acid was also added to the mixture and swirled well again. Hence, the soil samples were digested on a hot plate at 115℃ for about 1 – 2 hours for the dissolution of the heavy metals from the soil samples by covering in a fume cupboard. The digested soil samples were then allowed to cool down for about 20 minutes and filtered through Whatman No. 40 filter paper. Then after, the filtrates were washed by hot distilled water, and they were collected and made up the volume in 100 ml volumetric flask with distilled water. This volume was then used for determination of the heavy metals through AAS. Agilent 240FS AA was used for the determination of the concentration of lead (Pb) and cadmium (Cd). However, Arsenic (As) and mercury (Hg) were analyzed through Agilent 240FS AA with graphite tube atomizer (GTA) 120 and Agilent 240FS AA with Agilent vapor generation accessory (VGA) 77 respectively.

Soil pH was measured by the Thermo Scientific™ Orion™ Star A211 pH Benchtop Meter with soil: water ratio of 1: 2.5 in the laboratory. Calibration of the pH meter was conducted after measuring every 10 soil samples by using pH buffers at 4, 7 and 10.

3.6 Results of Quality Control

Soil samples were analyzed by the Pesticide Analytical Laboratory, which is authorized the Department of Agriculture, Ministry of Agriculture, Livestock and Irrigation, Myanmar. Association of Analytical Community (AOAC) Peer-Verified Methods Program was chosen by the laboratory for quality control. Reagents used in the digestion process were analaR grade that meets the requirements of the American Chemical Society Committee on Analytical Reagent. The calibration for quantification was automatically conducted by AAS and $R^2 \geq 0.999$. The digested samples were introduced into the AAS by auto sampler, and the wavelength was 193.3 nm. Limit of detection (LOD) of As, Cd, Hg, and Pb were 0.0007 mg/kg, 0.0099 mg/kg, 0.0003 mg/kg, and 0.069 mg/kg respectively, and all the result of heavy metals analysis in this study were above the respective LOD. Each of the samples was analyzed in duplicates, and blank solutions were analyzed to account for any contamination through the acids used in the digestion before analyzing each of the heavy metals. Relative standard deviations (RSD) of the heavy metals were < 5%.

4. Health Risk Assessment

Risk assessment consists of four fundamental steps: 1. Hazard identification, 2. Dose-response assessment, 3. Exposure assessment and 4. Risk characterization (Asante-Duah, 2002; Fairbrother, Wenstel, Sappington, & Wood, 2007; USEPA, 2016).

4.1 Hazard Identification

Hazard identification is the first step in the risk assessment process, and this step seeks to qualitatively identify and review any potential incidence or degree of adverse health effects that might be produced by a chemical, and the exposure conditions under which public health damage, injury or disease will be produced (Asante-Duah, 2002; Fairbrother et al., 2007; USEPA, 2016). In this study, arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) were identified as potential hazards for the miners.

4.2 Dose-Response Assessment

Dose-response assessment is the process that quantitatively estimates a relationship between the amount of exposure to a substance and the possibility of adverse health effects or disease (Asante-Duah, 2002; Fairbrother et al., 2007; Robson & Toscano, 2007). Dose-response is generally carried out by use of in vitro tests, in silico studies and studies in animals, particularly in rodents and also in other species in order to use in humans (Adamson, 2016). From the quantitative dose-response relationship, appropriate toxicity values were derived, and this is subsequently used to estimate the incidence of adverse effects occurring in populations at risk for different exposure levels (Asante-Duah, 2002). In this study, cancer slope factor (CSF) and reference dose (RfD) of the heavy metals for dermal exposure route that are provided by U.S. EPA were used in the evaluation of risks, and cancer slope factor for As is 1.5 $(mg/kg/day)^{-1}$, and RfD for As, Cd, Hg, and Pb are 0.0003, 0.0005, 0.0003, and 0.0036 (mg/kg-day) respectively (USEPA, 1989).

4.3 Exposure Assessment

Exposure assessment is defined as "the identification and evaluation of the human population exposed to a toxic agent, describing its composition and size, as well as the type, magnitude, frequency, route, and duration of exposure (USEPA, 2018; WHO, 2004)." The exposure assessment in this study was an occupational setting involving small-scale gold miners. The small-scale gold miners in the study area had the potential to expose to the aforementioned heavy metals in soil during working in the steps of ore processing, sluicing, panning, and amalgamation. Therefore, this study conducted cancer and non-cancer risks assessment of dermal exposure to As, Cd, Hg and Pb in soil. Average daily intakes for dermal route (ADI_{dermal}) were calculated by using the following equation (1) provided by USEPA (USEPA, 1989).

$$\mathbf{ADI}_{\boldsymbol{dermal}} = \frac{(\boldsymbol{C_s} * \boldsymbol{CF} * \boldsymbol{SA} * \boldsymbol{AF} * \boldsymbol{ABS} * \boldsymbol{EF} * \boldsymbol{ED})}{(\boldsymbol{BW} * \boldsymbol{AT})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where: ADI_{dermal} = Average daily intake (mg/kg/day); C_S = Chemical concentration in soil (mg/kg); CF = Conversation factor (kg/mg); SA = Skin surface area available for contact (cm^2/day); AF = Soil adherence factor (mg/cm^2); ABS = Absorption Factor (unitless); EF = Exposure frequency (days/year); ED = Exposure duration (years); BW = Body weight (Kg); and AT = Averaging time (days). Table 1 shows the exposure parameters used in the calculation of average daily intake for dermal exposure (ADI_{dermal}) in this study.

Table 1. Exposure Parameters

Parameter	**Symbol**	**Unit**	**Adult**		**References**
			U.S.EPA Default Value	Questionnaire	
Skin Surface Area	SA	cm^2/day	-	*	
Soil Adherence factor	AF	mg/cm^2	0.07	-	(USEPA, 2017)
Conversion factor	CF	kg/mg	10^{-6}	-	(USEPA, 1989)
Absorption factor	ABS	unitless	0.13	-	(USEPA, 2017)
Exposure frequency	EF	days/yr	-	*	
Exposure duration	ED	yrs	9	*	(USEPA, 2017)
Averaging time	AT	days			
For carcinogens		days	365 x life expectancy		(USEPA, 2017)
For non-carcinogens		days	365 x ED		(USEPA, 2017)
Life expectancy in Myanmar: Male = 65; Female = 69; Average = 67					(WHO, 2018)

*Data were obtained from questionnaire.

For skin surface area, USEPA provided total body surface area of men and women as 1.94 ± 0.00374 m^2 and 1.69 ± 0.00374 m^2 respectively through the studying Caucasian adults (USEPA, 1997), but total body surface area of Myanmar people may not be the same with that of Caucasian people. Therefore, total body surface area of Myanmar people were calculated by using weight and height of 42 male miners and 11 female miners through the following equation (2) (Moya et al., 2011).

$$\textbf{In TSA} = \textbf{In } a_0 + a_1 \textbf{In H} + a_2 \textbf{In W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: TSA = Total surface area in square meters; H = height in centimeters; W = weight in kilogram; a_0 = 0.024264; a_1 = 0.3964; a_2 = 0.5378.

4.4 Risk Characterization

Risk characterization is the final step of risk assessment, and this process summarizes and integrates the findings of the previous three steps of the risk assessment in order to be able to qualitatively and/or quantitatively define risk levels (Asante-Duah, 2002; Fairbrother et al., 2007; USEPA, 2016). In this study, risk characterization predicted the potential cancerous and non-cancerous health risk of the small-scale gold miners who dermally exposed to the heavy metals in soil during working.

4.5 Non-Carcinogenic Risk Characterization

Non-carcinogenic health risks of small-scale gold miners who exposed to As, Cd, Hg and Pb in soil via dermal route were expressed as the hazard quotient (HQ). The hazard quotients for an individual heavy metal were calculated by using the following equation (3):

$$\textbf{Hazard Quotients (HQ)} = \frac{\textbf{ADI}}{\textbf{RfD}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3) \quad \text{(USEPA, 1991)}$$

Where; HQ = Hazard Quotient; ADI = Average daily dose (mg/kg/day); and RfD = Reference dose. After HQ was calculated, Hazard Index (HI) was calculated by using the following equation (4).

$$\textbf{Hazard Index (HI)} = \sum \textbf{HQi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4) \text{ (USEPA, 1991)}$$

Where; HI = the sum of hazard quotients; and HQi = summation of HQ of non-carcinogens;

The RfD is an estimation of daily dermal exposure to the human population that is possible to be without a significant risk of harmful effects during a lifetime, and the hazard quotient (HQ) is an indicator of risks associated with health effects. The sum of the HQs is called hazard index (HI) which assumes that the effects of the different compounds and effects are additive. If HI is greater than 1, there may have the potential for adverse systemic health concerns in the exposed individuals. If HI is less than or equal to 1, there may have no significant adverse health effects (Fowle & Dearfield, 2000; USEPA, 1991).

4.6 Carcinogenic Risk Characterization

In this study, only arsenic (As) was considered for the cancer risks of dermal exposure to soil because cancer slope factors for dermal route of the other heavy metals mentioned in this study were not available. Cancer risks were calculated by using the following equation (5).

Carcinogenic risk characterization

$$\textbf{Cancer Risk} = \textbf{ADI x CSF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$ (USEPA, 1991)

Where: CSF = Cancer Slope Factor $(mg/kg/day)^{-1}$; and ADD = Average daily dose (mg/kg/day).

According to the U.S. EPA, the acceptable range for lifetime cancer risk is expressed as 1×10^{-4} to 1×10^{-6}, that is, one in ten thousand to one in one million excess cancer cases. However, 1×10^{-6} was used as an acceptable cancer risks and the cancer risks greater than that value were assumed as having potential carcinogenic diseases because cancer risks of the miners for occupational exposure to the heavy metals in the polluted soil were considered in this study. Unlike the reference dose for non-carcinogenic health risk assumes, the cancer slope factor (CSF) that exposures to any amount of a carcinogen will produce the cancer risk, i.e. there is no threshold dosage. A cancer slope factor is an upper bound, approximating a 95% confidence limit, on the increased cancer risk from a lifetime exposure to toxicant by dermal exposure route (Fowle & Dearfield, 2000; USEPA, 1991).

5. Results and Discussion

5.1 Skin Surface Area of the Miners

In this study, total body surface areas of the miners were derived by using the weights and heights of the 53 participants (42 male and 11 female) obtained from questionnaire survey. The results showed that height of all the participants ranged from 146.3 to 179.8 cm with the median 149.4 cm and mean height (±SD) of 163.2 (±8.8) cm. For male respondents, height ranged from 155.5 to 179.8 cm and the mean height (±SD) was 166.8 (±5.9) cm, whereas height of the female participants ranged from 146.3 to 152.4 cm with the mean (±SD) of 149.4 (±1.8) cm. With regard to the body weight of all the participants, it ranged from 46 to 75 kg, the median was 59 kg, and mean (±SD) was 58.72 (±6.8) kg. Ranging from 52 to 75 kg with the mean (±SD) of weight 60.76 (±5.8) kg and ranging from 46 to 60 kg with the mean (±SD) of weight 50.9 (±9.6) kg were for male and female participants respectively. The body mass index of the participants were measured based on their heights and weights obtained from questionnaire by using the formula of Body weight (kg) / $Height^2$ (m), and most of the participants (92.5%) were in the normal range (18.5-24.9), and only 7.5% of the participants were overweight (25-29.9). By using the average weight and height of the male and female participants, average total body surface area of the miners in the study area were calculated through the equations (2) that are mentioned in section 4.3, and Table 2 shows the average total body surface area in meter of male and female participants.

Table 2. Average total body surface area of the miners (m^2)

	Weight (kg) Mean ± SD	Height (cm) Mean ± SD	Total body surface area (m^2) Mean ± SD
Male (n = 42)	60.76 ± 5.81	166.77 ± 5.89	1.68 ± 0.10
Female (n = 11)	50.91 ± 3.87	149.35 ± 1.84	1.46 ± 0.06

5.2 Job Responsibilities of the Participants in the Gold Mining Processes

Regarding the main responsibilities of the participants, most of them (47%) in this study mainly worked in the ore processing step called hydraulic mining and dredging. The others 27% of the participants worked in the sluicing step; 15% of them worked in the panning step;

and 11% of them were working in the amalgamation step. However, the miners sometimes had to involve in the other gold mining steps that were not their main responsibilities because of the requirements of the job. Furthermore, the numbers of miners might be expanded or diminished depending on the accessibility of gold, and the highest numbers of miners are generally utilized in the ore processing step followed by sluicing. Table 3 shows the main job responsibilities of the participants regarding the numbers of miners in each gold mining step of the mining sites. In addition, the mean (± SD) exposure frequency for all the miners was 331 (± 51) days per year and ranged from 209 to 365 days, and the mean (± SD) exposure duration was 1.51 (± 0.77) years and ranged from 1 to 4 years as shown in Table 4.

Table 3. Job responsibilities of the participants in the four gold mining steps

Gold mining sites	**Numbers of miners (%) in the gold mining steps**			
	Ore processing	**Sluicing**	**Panning**	**Amalgamation**
Site A (n=19)	8 (42%)	5 (26%)	3 (16%)	3 (16%)
Site B (n=17)	8 (47%)	5 (29%)	2 (12%)	2 (12%)
Site C (n=17)	9 (53%)	4 (24%)	3 (18%)	1 (6%)
Total (n=53)	**25 (47%)**	**14 (27%)**	**8 (15%)**	**6 (11%)**

Table 4. Average exposure frequency and exposure duration of the miners

Exposure parameters	**Mean ± SD**
Exposure Frequency (EF) (day/year)	331 ± 51
Exposure Duration (ED) (year)	1.51 ± 0.77

5.3 PPE Use Behaviors of the Miners

Although the miners can be exposed to the soil on their body parts during working, 42 participants (79%) did not use any form of personal protective equipment (PPE) among 53 participants. However, 11 participants (21%) used more than one type of PPE. Among them, 5 participants (9%) used hand-length fabric gloves as shown in Figure 4, 4 participants (8%) used hand-length rubber gloves as shown in Figure 5, and 3 participants (6%) used mid-length rubber boots as shown in Figure 6, in which one participant wore both hand-length rubber gloves and mid-length rubber boots. Correspondingly, another study in the Upper East Region in Ghana showed 70% out of 120 miners did not use any form of PPE (Paruchuri et al., 2010). Nonetheless, some of the participants, including those who did not use any PPE or who used PPE, wore more than one type of normal clothes during working. 51% of the participants used full trousers, 17% of them knee-length pants, 87% of them used long-sleeve shirts, 8% of them used elbow-length shirts, and 8% of them used shorter-than-elbow-length shirts. Actually, these kinds of normal clothes and fabric gloves might not protect from the heavy metals exposure on miners' body parts during working. Moreover, using only hand-length rubber gloves and mid-length rubber boots cannot provide full protection of the whole body from the heavy metals exposure.

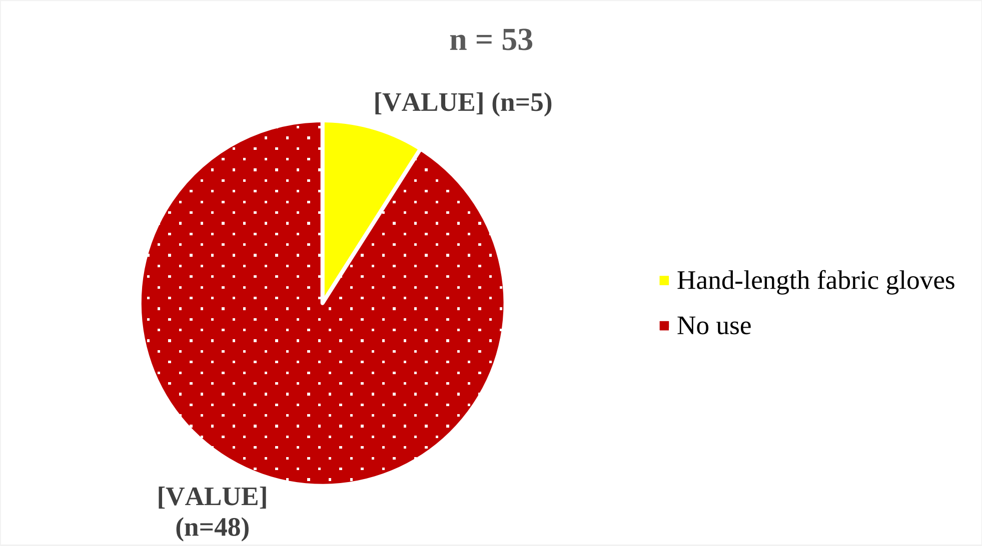

Figure 4. Hand-length fabric gloves use behavior of the participants

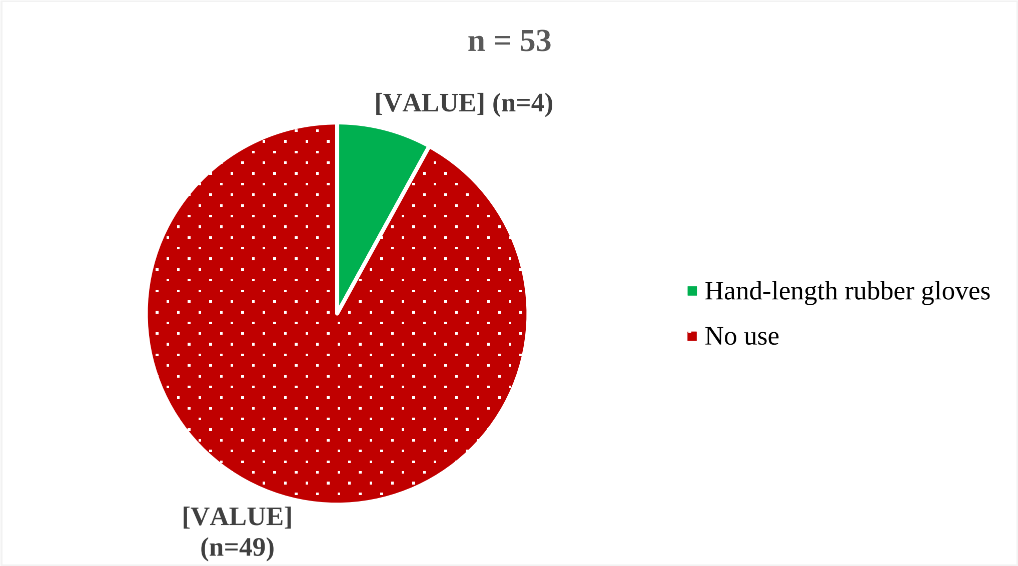

Figure 5. Hand-length rubber gloves use behavior of the participants

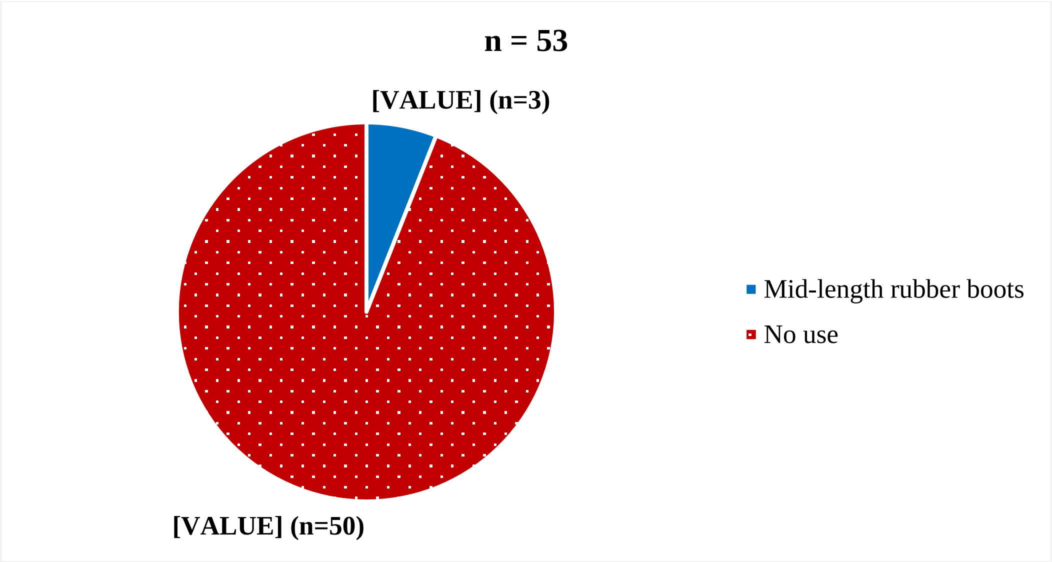

Figure 6. Mid-length rubber boots use behavior of the participants

5.4 Concentration of Heavy Metals in the Soil Samples from the Gold Mining Sites

Table 5 shows the concentrations of the heavy metals and soil pH in each placer small-scale gold mining step. The significant differences of the heavy metals concentrations among the gold mining steps in each gold mining site was identified through independent t-test.

Table 5. Concentrations of the heavy metals and soil pH

Gold mining steps	As mean ± SD (mg/kg)	Cd mean ± SD (mg/kg)	Hg mean ± SD (mg/kg)	Pb mean ± SD (mg/kg)	pH mean ± SD
Ore processing					
Site A	5.69±0.14	0.27±0.01	0.47±0.23	9.73±0.64	7.43 ± 0.42
Site B	6.55±1.25	0.27±0.02	0.68±0.43	11.80±1.73	5.91 ± 0.35
Site C	1.80±0.48	0.33±0.04	0.53±0.13	12.80±2.99	8.57 ± 0.11
Average ± SD	**4.68 ±2.53**	**0.29 ±0.03**	**0.56 ±0.11**	**11.44 ±1.57**	**7.30 ±1.33**
Sluicing					
Site A	1.04±0.19	0.36±0.02	0.15±0.03	8.60±1.56	8.54 ± 0.22
Site B	9.02±5.60	0.40±0.12	0.35±0.11	10.27±3.50	6.91 ± 0.58
Site C	1.31±0.22	0.13±0.06	0.51±0.04	7.67±0.90	8.45 ± 0.10
Average ± SD	**3.79 ±4.53**	**0.30 ±0.15**	**0.34 ±0.18**	**8.85 ±1.32**	**7.97 ±0.92**
Panning					
Site A	1.24±0.42	1.32±0.16	4.86±5.87	34.40±13.22	7.73 ± 0.15
Site B	16.25±2.29	1.67±0.89	1.53±0.49	74.67±65.62	7.70 ± 0.18
Site C	14.89±6.97	0.61±0.36	0.58±0.31	27.33±4.16	7.95 ± 0.50
Average ± SD	**10.79±8.30**	**1.20 ±0.54**	**2.32 ±2.25**	**45.47±25.54**	**7.79 ±0.14**
Amalgamation					
Site A	15.58±11.98	3.03±0.47	40.95±5.81	75.67±25.01	4.87 ± 2.12
Site B	20.72±7.38	3.07±0.35	77.44±16.73	210.00±17.32	7.78 ± 0.10
Site C	22.17±12.58	1.13±0.75	35.73±1.88	39.33±7.51	7.39 ± 0.06
Average ± SD	**19.49±3.46**	**2.41 ±1.11**	**51.37±22.72**	**108.33±89.90**	**6.68 ±1.58**

In site A, the concentrations of the heavy metals in the soil seemed to decrease in the gold mining step orders of amalgamation, ore processing, panning and sluicing for As; amalgamation, panning, sluicing and ore processing for Cd; and amalgamation, panning, ore processing and sluicing for Hg and Pb. However, according to the results of t-test, the heavy metal concentrations between some gold mining steps were no significant differences. For the As concentration, significantly different concentrations were found between ore processing step and sluicing step (P-value = 4.589 x 10-6 < 0.05) and ore processing step and panning step (P-value = 6.385 x 10-5 < 0.05). For the Cd concentration, significantly different concentrations were found between all of the gold mining steps; and the results of the P-values were 0.002 between ore processing and sluicing step, 0.0003 between ore processing and panning step, 0.005 between ore processing and amalgamation step, 0.0004 between sluicing and panning step, 0.0006 between sluicing and amalgamation step, and 0.004 between panning and amalgamation step. For the Hg concentration, the significantly different concentrations were only found between amalgamation step and the other steps. The P-values of 0.0003 was between amalgamation and ore processing step, of 0.0002 was between amalgamation and sluicing step, and of 0.001 was between amalgamation and panning step. In case of Pb concentration, significant differences were observed between ore processing and panning step (P-value = 0.03), between ore processing and amalgamation step (P-value = 0.01), between sluicing and panning step (P-value = 0.03) and between sluicing and amalgamation step (P-value = 0.01).

In site B, the concentrations of As and Cd in the soil looked to decline in the gold mining step order of amalgamation, panning, sluicing, and ore processing. And, the concentrations of Hg and Pb in the soil appeared to lessen in the gold mining step order of amalgamation, panning, ore processing, and sluicing. However, the heavy metal concentrations between some mining steps were also not significantly different. Regarding As concentrations, significant differences were occurred between ore processing and panning step (P-value 0.003) and ore processing and amalgamation step (P-value = 0.03). Significantly different Cd concentrations were found between ore processing and amalgamation step (P-value = 0.0001) and between sluicing and amalgamation step (P-value = 0.0002). In case of Hg concentrations, significant differences were found between amalgamations step and the other steps in addition to between sluicing and panning step. The results of the P-values were 0.001 between amalgamation and ore processing step, 0.001 between amalgamation and sluicing step, 0.001 between amalgamation and panning step, and 0.01 between sluicing and panning step. For the Pb concentrations, significant differences were found between amalgamation and ore processing step (P-value = 3.90 x 10-5), between amalgamation and sluicing step (P-value = 4.01 x 10-5) and between amalgamation and panning step (P-value = 0.03).

In site C, the concentrations of all the heavy metals in the soil seemed to decrease in the same gold mining step order of amalgamation, panning, ore processing and sluicing. Also, the heavy metal concentrations in some gold mining steps were not significantly different. For As concentrations, significant differences were found between ore processing and panning (P-value = 0.03), between sluicing and panning step (P-value = 0.03), between amalgamation and ore processing step (P-value = 0.04) and between amalgamation and sluicing step (P-value = 0.04). For Cd concentrations, significant difference was only found between ore processing and sluicing step (P-value = 0.01). In case of Hg concentrations, significant differences were found between amalgamation and ore processing step (P-value = 5.47 x 10-6), between amalgamation and sluicing step (P-value = 5.41 x 10-6) and between amalgamation and panning step (P-value = 5.75 x 10-6). Regarding Pb concentrations, significant differences were found between ore processing and sluicing step (P-value = 0.04), between ore processing and panning step (P-value = 0.007), between ore processing and amalgamation step (P-value = 0.005), between sluicing and panning step (P-value = 0.001) and between sluicing and amalgamation step (P-value = 0.002).

Generally, the highest concentrations of all the heavy metals were found in the amalgamation step in all the mining sites. This could be explained by considering about the gold recovery through placer small-scale gold mining technique. In the placer gold mining technique, gold is recovered through gravity method, like sluicing and panning as the density of gold (19.39 cm^{-3}) is higher than other minerals in the ore. Consequently, the largest mass of gold is attained in the amalgamation step among the other placer gold mining steps: ore processing, sluicing and panning. Similarly, the density of the heavy metals: As (5.7 $g.cm^{-3}$), Cd (8.7 $g.cm^{-3}$), Hg (13.6 $g.cm^{-3}$) and Pb (11.34 $g.cm^{-3}$) is also higher than the other minerals in the ore (LENNTECH, 2019). Therefore, the highest concentrations of all the heavy metals together with the largest mass of gold could be found in the amalgamation step.

The highest concentration of As in this study was found in site C at 22.17 mg/kg that was drastically lower than the concentrations of As in the previous studies in Witwatersrand gold mining basin, South Africa (79.40 mg/kg) (Kamunda et al., 2016); in Castromil gold mining area, Portugal (820 mg/kg) (Da Silva et al., 2004); in the gold mine tailings dams at Obuasi, Ghana (1752 mg/kg) (Bempah et al., 2013), and in Obuasi, Ghana (8305 mg/kg) (Ahmad & Carboo, 2000). The highest concentration of Cd was found in site B at 3.07 mg/kg that was greater than the concentration of Cd in the previous study in Witwatersrand gold mining basin, South Africa (0.05 mg/kg) (Kamunda et al., 2016) and lower than the concentration of Cd in the study in the vicinity of North Mara gold mine in Tarime District, Tanzania (6.4 to 11.7 mg/kg) (Bitala et al., 2009). In case of Hg, the highest concentration was found in site B at 77.44 mg/kg that was higher than the concentration of Hg in the study in Witwatersrand gold mining basin, South Africa (0.09 mg/kg) (Kamunda et al., 2016) and radically lower than the concentration of Hg in the studies in gold mining tailings of Iran (100 mg/kg) (Rafiei et al., 2010) and in the gold mine tailings of Kenya (1920 mg/kg) (Matshusa et al., 2012). For Pb, the highest concentration was found in site B at 210.00±17.32 that was 42 times and approximately 3 times higher than the concentrations of Pb in the studies in gold mining basin of South Africa (4.79 mg/kg) (Kamunda et al., 2016) and in the gold mine tailings of Oman (80 mg/kg) (Abdul-Wahab & Marikar, 2012) respectively. However, the highest concentration of Pb in this study was approximately 2 times lower than the concentration of Pb in the study in the gold mining tailings of Kenya (510 mg/kg) (Ogola et al., 2002).

In case of the soil pH, the results revealed that very strongly acidic, moderately acidic, neutral, slightly alkaline, moderately alkaline and strongly alkaline were found in this study. However, very strongly acidic, moderately acidic and neutral were found only in the amalgamation step in site A (4.87), ore processing step in site B (5.91) and sluicing step in site B (6.91) respectively. In the other steps of the gold mining sites, all the pH values from the soil samples were alkaline; however, pH of these gold mining steps varied from slightly alkaline (7.39) to strongly alkaline (8.57). To be more specific, pH in the gold mining steps of site A ranged from 4.87 – 8.54, of site B ranged from 5.91 – 7.78, and of site C ranged from 7.39 to 8.57. Similarly, the high soil pH level (alkalinity) was also reported as the range from 7.46 to 8.8 in the soil of artisanal gold mining area in North of Atbara, Sudan (Ali et al., 2017). However, the soil pH level in the amalgamation step of Site A was found as strongly acidity at 4.87. Site A could therefore be considered that cyanide leaching technique is being used to further recover the gold from mercury rich soil attained from the amalgamation step. In the cyanide leaching technique, the mercury rich soil is processed in a tank by adding sodium cyanide (NaCN), which solubilizes gold (Esdaile & Chalker, 2018). After the completion of solubilization, gold is recover by utilizing active carbon, which absorbs gold onto its surface from the gold-cyanide complexes solution (Austrocarbon, 2017). Afterwards, sulphuric acid (H_2SO_4) is utilized to strip the gold from the carbon, and the acid residues from this process can lead to decrease soil acidity (OCEANAGOLD, 2019).

5.5 Non-Carcinogenic Risks of the Heavy Metals for Dermal Exposure

In order to calculate non-cancer risks for the miners, ADI for dermal exposure route was calculated through equation (1) by using the exposure parameters presented in Table 1, 2, 3 and 4. After that, hazard quotients were calculated based on the RfD values presented in section 4.2 through equation (3), and then hazard index were calculated through the equation (4) and (6).

The detail results of HI for both male and female miners from Site A, Site B and Site C exposed to As, Cd, Hg, and Pb through dermal exposure to the soil are presented in Table 6, 7 and 8 respectively. In Site A, the results of HI for the miners in all gold mining steps ranged from $1.60 x10^{-2}$ to $5.07 x10^{-1}$. In Site B, it ranged from $6.33 x10^{-2}$ to $9.19 x10^{-2}$. In Site C, it ranged from $1.92 x10^{-2}$ to $4.85 x10^{-2}$. Therefore, all the HI results for the miners from three mining sites are less than 1, and then it indicates that all the participants in this study might not be suffering from any non-cancerous diseases. The results of HIs in this study were in line with the previous studies in Igun, Osun State, Nigeria (Olujimi et al., 2015); Krugersdorp, South Africa (Ngole-Jeme & Fantke, 2017); and Withwatersrand gold mining basis, South Africa (Kamunda et al., 2016). Although the concentrations of the heavy metals in these previous studies were higher than that of this study, non-cancer risks were not reported.

Table 6. Non-carcinogenic risks for the miners in site A

Heavy Metals	**Hazard Quotient (HQ)**							
	Ore processing		**Sluicing**		**Panning**		**Amalgamation**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
As	$4.30x10^{-2}$	$4.46x10^{-2}$	$7.85x10^{-3}$	$8.14x10^{-3}$	$9.36x10^{-3}$	$9.71x10^{-3}$	$1.18x10^{-1}$	$1.22x10^{-1}$
Cd	$1.22x10^{-3}$	$1.27x10^{-3}$	$1.63x10^{-3}$	$1.69x10^{-3}$	$5.98x10^{-3}$	$6.20x10^{-3}$	$1.37x10^{-2}$	$1.42x10^{-2}$
Hg	$3.55x10^{-3}$	$3.68x10^{-3}$	$1.13x10^{-3}$	$1.17x10^{-3}$	$3.67x10^{-2}$	$3.81x10^{-2}$	$3.09x10^{-1}$	$3.21x10^{-1}$
Pb	$6.12x10^{-3}$	$6.35x10^{-3}$	$5.41x10^{-3}$	$5.61x10^{-3}$	$2.16x10^{-2}$	$2.25x10^{-2}$	$4.76x10^{-2}$	$4.94x10^{-2}$

HI	**5.39 x10^{-2}**	**5.59 x10^{-2}**	**1.60 x10^{-2}**	**1.66 x10^{-2}**	**7.36 x10^{-2}**	**7.65 x10^{-2}**	**4.88 x10^{-1}**	**5.07 x10^{-1}**

Table 7. Non-carcinogenic risks for the miners in site B

Heavy Metals	**Hazard Quotient (HQ)**							
	Ore processing		**Sluicing**		**Panning**		**Amalgamation**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
As	4.95x10^{-2}	5.13x10^{-2}	6.81x10^{-2}	7.06x10^{-2}	1.23x10^{-1}	1.27x10^{-1}	1.56x10^{-1}	1.62x10^{-1}
Cd	1.22x10^{-3}	1.27x10^{-3}	1.81x10^{-3}	1.88x10^{-3}	7.57x10^{-3}	7.85x10^{-3}	1.39x10^{-2}	1.44x10^{-2}
Hg	5.13x10^{-3}	5.33x10^{-3}	2.64x10^{-3}	2.74x10^{-3}	1.16x10^{-2}	1.20x10^{-2}	5.85x10^{-1}	6.06x10^{-1}
Pb	7.42x10^{-3}	7.70x10^{-3}	6.46x10^{-3}	6.70x10^{-3}	4.70x10^{-2}	4.87x10^{-2}	1.32x10^{-1}	1.37x10^{-1}
HI	**6.33 x10^{-2}**	**6.56 x10^{-2}**	**7.90 x10^{-2}**	**8.19 x10^{-2}**	**1.89 x10^{-1}**	**1.96 x10^{-1}**	**8.87 x10^{-1}**	**9.19 x10^{-1}**

Table 8. Non-carcinogenic risks for the miners in site C

Heavy Metals	**Hazard Quotient (HQ)**							
	Ore processing		**Sluicing**		**Panning**		**Amalgamation**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
As	1.36x10^{-2}	1.41x10^{-2}	9.89x10^{-3}	1.03x10^{-2}	1.12x10^{-1}	1.17x10^{-1}	1.67x10^{-1}	1.74x10^{-1}
Cd	1.50x10^{-3}	1.55x10^{-3}	5.89x10^{-4}	6.11x10^{-4}	2.76x10^{-3}	2.87x10^{-3}	5.12x10^{-3}	5.31x10^{-3}
Hg	4.00x10^{-3}	4.15x10^{-3}	3.85x10^{-3}	3.99x10^{-3}	4.38x10^{-3}	4.54x10^{-3}	2.70x10^{-1}	2.80x10^{-1}
Pb	8.05x10^{-3}	8.35x10^{-3}	4.83x10^{-3}	5.01x10^{-3}	1.72x10^{-2}	1.78x10^{-2}	2.47x10^{-2}	2.57x10^{-2}
HI	**2.72 x10^{-2}**	**2.82 x10^{-2}**	**1.92 x10^{-2}**	**1.99 x10^{-2}**	**1.36 x10^{-1}**	**1.42 x10^{-1}**	**4.67 x10^{-1}**	**4.85 x10^{-1}**

5.6 Carcinogenic Risks Results

According to U.S. EPA and the International Agency Research on Cancer (IARC), only As is likely to be carcinogenic through dermal contact with the soil among the heavy metals listed in this study. Therefore, the carcinogenic risk of As for the miners from three mining sites was calculated through equation (1) for ADI and equation (5) for cancer risks assessment by using the exposure parameters from Table 1, 2, 3, 4and cancer slope factor from section 4.2.

In this study, two kinds of cancer risks calculations were conducted by using two different values of exposure duration. In the first calculation, current cancer risk of the miners from the three mining sites were estimated by assuming their average current years of working in their respective mining sites obtained from questionnaire survey as exposure duration. The second calculation was carried out by using the central tendency exposure duration from Table 1 that is recommended from U.S. EPA in order to estimate the cancer risks of the miners for 9 years. The results of the cancers risks of the miners from Site A, Site B and Site C are shown in Table 9, 10 and 11 respectively.

Regarding current cancer risk assessment of the miners, the results that are greater than acceptable U.S. EPA cancer risks level, 1 x 10^{-6} (i.e., 1 case of cancer per every 1,000,000) were found in the amalgamation step in Site A and in the panning step and amalgamation step in site B and site C. It indicates that the miners who are working in the panning and amalgamation steps may have cancerous diseases with their current working experience.

In case of estimated cancer risk for 9 years, ore processing and amalgamation steps in Site A and panning and amalgamation step in Site C were above the acceptable cancer risk level. However, the cancer risk results of Site C were above the acceptable cancer risk level in all the gold mining steps. It indicates that the miners in this study may have As related cancerous diseases if they continue working up to 9 years in the same mining site or other mining sites that have the similar concentration level of As without using any personal protective equipment (PPE). Likewise, the other previous studies in gold mining areas from different countries were also reported cancer risks for dermal exposure to As in the soil. The cancer risks of 7.7×10^{-6} was reported in China (Li, Ma, van der Kuijp, Yuan, & Huang, 2014), 1.73×10^{-5} was reported in Witwatersrand gold mining basin, South Africa (Kamunda, Mathuthu, & Madhuku, 2016), and 2.2×10^{-3} was reported in Krugersdorp, South Africa (Ngole-Jeme & Fantke, 2017).

Table 9. Carcinogenic risks of the miners for exposure to As in soil for site A

Cancer Risks	**Ore processing**		**Sluicing**		**Panning**		**Amalgamation**	
	Male	Female	Male	Female	Male	Female	Male	Female
Current Cancer Risks	4.49 x10^{-7}	4.39 x10^{-7}	8.21 x10^{-8}	8.02 x10^{-8}	9.79 x10^{-8}	9.56 x10^{-8}	1.23 x10^{-6}	1.20 x10^{-6}
Estimated Cancer Risk for 9 years	2.68 x10^{-6}	2.62 x10^{-6}	4.89 x10^{-7}	4.78 x10^{-7}	5.83 x10^{-7}	5.70 x10^{-7}	7.33 x10^{-6}	7.16 x10^{-6}

Table 10. Carcinogenic risks of the miners for exposure to As in soil for site B

Cancer Risks	**Ore processing**		**Sluicing**		**Panning**		**Amalgamation**	
	Male	Female	Male	Female	Male	Female	Male	Female
Current Cancer Risks	5.17 x10^{-7}	5.05 x10^{-7}	7.12 x10^{-7}	6.96 x10^{-7}	1.28 x10^{-6}	1.25 x10^{-6}	1.64 x10^{-6}	1.60 x10^{-6}
Estimated Cancer Risks for 9 years	3.08 x10^{-6}	3.01 x10^{-6}	4.24 x10^{-6}	4.15 x10^{-6}	7.65 x10^{-6}	7.47 x10^{-6}	9.75 x10^{-6}	9.52 x10^{-6}

Table 11. Carcinogenic risks of the miners for exposure to As in soil for site C

Cancer Risks	Ore processing		Sluicing		Panning		Amalgamation	
	Male	Female	Male	Female	Male	Female	Male	Female
Current Cancer Risks	1.42×10^{-7}	1.39×10^{-7}	1.03×10^{-7}	1.01×10^{-7}	1.18×10^{-6}	1.15×10^{-6}	1.75×10^{-6}	1.71×10^{-6}
Estimated Cancer Risks for 9 years	8.47×10^{-7}	8.27×10^{-7}	6.16×10^{-7}	6.02×10^{-7}	7.01×10^{-6}	6.84×10^{-6}	1.04×10^{-5}	1.02×10^{-5}

The non-cancer and cancer risks assumption in this study could lead to overestimation if the concentration levels of the listed heavy metals in the soil decline. Conversely, the risks assumptions could also lead to underestimation if the mining activities are increased. Furthermore, exposure to the listed heavy metals in the other media such as air, water and food were not taken into consideration in this study. Therefore, it could also lead to underestimation of the risks. However, this type of study provides baseline information for future studies on such kind of public health concern pollutants and policy interventions.

6. Conclusion

As this study just focused on the dermal exposure pathway to the heavy metals in the soil, no miners who were at non-cancer risks were investigated. However, the results of cancer risk estimations revealed that the placer small-scale gold miners in the study area are at the risk of developing cancerous diseases because of the dermal exposure to As. In fact, As, Cd, Hg, and Pb might also be found in air, water and food media. Therefore, the miners may also have non-cancer and cancer risks due to the exposure to the heavy metals in these media through inhalation and ingestion pathways.

In this study, the highest non-cancer and cancer risks were found in the amalgamation steps in all the gold mining sites. Moreover, in all the gold mining sites, the significantly higher concentrations of Hg were found in the amalgamation steps among the other gold mining steps. This is because Hg is mainly used to form a stable amalgam in order to extract gold from gold ore in the amalgamation step. From this step, Hg can also directly go into the nearby soil, water and sediment, and it can even release into the atmosphere due to the burning of the amalgam in order to recover gold by evaporating Hg. As a consequence, it can cause contamination of the atmosphere, soil, underground water, rivers, and lakes, and eventually bioconcentration of methylmercury is contributed by the process of methylation through bacteria and food chains, thereby leading to critical environmental issues and health problems.

Therefore, further studies of health risk investigations that are taking into consideration of all possible exposure media and exposure pathways to the heavy metals for miners and local people are necessary to develop in Banmauk Township and Myanmar as well. Moreover, it is very important to educate the miners and local people about the health risks of heavy metals and about the ways to protect from exposure to heavy metals.

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