Environmental Risk and Health Hazardous Substances in Artisanal Small-Scaled Gold Mining in Sekotong, West Nusa Tenggara, Indonesia

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Abstract. Gold (Au), copper (Cu) and nickel (Ni) are mined within Indonesia’s Archipelago as predominantly a mineral-rich country. Au is the worthiest metals compare to all these minerals over the years. Because of that reason, gold mining is one of major economic activity in Indonesia participated through by large-scale, artisanal and small-scale entities Artisanal Small-Scale Gold Mining (ASGM) has been a source of chances for employment and subsistence to thousands of people. On the contrary, artisanal small-scale gold mining contributes to serious environmental and health issues for miners, nearby populations, and larger society when the use of mercury (Hg) occurs. This study aims to review environmental risk and health-hazardous substances in Artisanal Small-Scaled Gold Mining in Sekotong, West Nusa Tenggara, Indonesia which also emphasized geological data from the former study. The results showed that Sekotong’s ASGM area is centered by three hydrothermal alteration halos developing from proximal argillic, distal propylitic and superimposed advance argillic alteration also capped by ore mineralization. A high-dense mineralized stockwork of quartz vein as the main characterization founded. Under those circumstances, pledge local miners around the area to execute the prospects without knowing self-assessment and investigation. In conclusion, Sekotong’s ASGM area became one of the shortlisted areas that investigating the effects of mercury on the environment and people's health signifies urgently necessary for developing a better solution to eliminate further mercury contamination to the environment in Sekotong’s ASGM area due to the extraction of the prospects before another catastrophe befalls.

Keywords. ASGM, epithermal, mercury, mitigation, sekotong

1. Introduction
As a metal-rich country, Indonesia is recognized as one of the main gold producers in the world. In order to involve in modern large-scale gold mining, artisanal gold mining has a significant contribution to gold production. Artisanal mining refers to an informal and unregulated system of small-scale mining (ASGM, abbreviation from Artisanal Small-scaled Gold Mining). Artisanal mining also plays an important role both in economic development and employment opportunities. Past records imply that artisanal gold mining has been exercised throughout Indonesia for hundreds of years. However, the scale of operation has steadily increased since 2000 [1]. Few methodologies of various scientific assessment
to evaluate the health and hazardous risk have been done in the former study but not well linked with geological features as well. However, given the complexity of natural systems resulting in a geological model almost contains uncertainties on controlling the health and risk affected people around the ASGM. Hence, we deliver an emphasized work that has been done by reviewing former studies which integrating geological features and health significances, especially related to uncontrollable rules on consuming mercury (Hg) amalgamation as a gold recovery technique in ASGM, 7 local miners found dead in ASGM’s area at June, 18th 2018 [2].

In this study, we generate a comprehensive work by concerning geological features of the affected area and its relationship of people’s behavior vicinity Sekotong’s ASGM area. On the other hand, most of the former research activities for this area generally focus on analyzing characteristics of the health risk by only health assessments without considering geological aspects or analyzing for its geological feature only without considering the health and risk affected. In order to emphasize the understanding of the roots of Sekotong’s ASGM area case, we integrate some approaches that haven’t been done by former research activities as mentioned before.

This study comprises an example of a combination within multidisciplinary studies in order to maintain sustainability for people around the affected area as seen in Figure 1. Moreover, the first geological mapping conducted within this area of Sekotong ASGM system is a volcaniclastic terrain occupied by Pengulong Formation (Tomp) intruded by a series of intermediate to acidic plutonic rocks (Tomi), which is dominated by andesitic, dacitic and dioritic (an, da, di) intrusions, and also lied Ekas Formation (Tome) which dominated by limestone [3,4]. Hydrothermal alteration zone within this area comprises of hydrothermal alteration halos developing from proximal argillic, distal propylitic and superimposed advance argillic alteration also capped by ore mineralization [3]. The fault system in this area tends to be in the NW-SE trend on its normal fault, and the strike-slip fault which has NNE-SSW trending direction [5]. This fault has been controlled ore mineralization in the area. Thus, the area became more valuable and tend to be exploited with locals around there. Unfortunately, locals execute the prospects without undergoing self-assessment and inspection. This situation has raised concerns about risks that may affect some aspects such as environmental sustainability and health-hazardous disease because they use mercury to extract the prospects. Mercury amalgamation is used as a gold recovery technique by 10-12 million ASGM miners around the world [6] and an estimated 1000 tons of mercury are released into the environment annually as a result of poor mining practice [6].

Besides, our research aims to reconstruct the relationship between geological features and health-hazardous that affect Sekotong’s ASGM. ASGM itself is practiced in West Nusa, at the Sekotong region of Lombok Island, and in 2010 spread out to Sumbawa Island [3]. Hipleach is the advanced extraction process in moderate to large scale gold mining but on this small-scale gold mining, the concept that miners use are filling sacs with rock excavated from simplistic mine shafts, the rock is pounded manually by using hand and then pulverized using simple rod mills. Liquid mercury is added during the final stages of grinding for amalgamation [6]. Next, the amalgamated of mercury-gold is insulated from the waste rock (tailings) before the waste is settled of to land or water, or further methods to cyanidation mills [6]. Last, a final cyanide leach of the amalgamation tailings will obtain more gold, before the cyanidation tailings are distributed of, again to land or water (riverbanks and sea) [1]. From this study given the results which allow the characterization of geological feature related to health-hazardous risk at Sekotong’s ASGM. A more detailed explanation will comprehensively be discussed in the next section and following soon after that also the results of reviewed data and field experiments discussed harmoniously.
Figure 1. Modified map of research site at Sekotong Regency West Nusa Tenggara Province Indonesia map shows the geographical layout of the study area [1]. Grey pin shows the location of ASGM's area which caused 7 local miners found dead at June 18th, 2018 [2]

2. Geological Setting
Regionally, Sekotong, West Nusa Tenggara, Indonesia is a volcanoclastic terrain consisted of the oldest (Late Oligocene - Early Miocene) unit considered as Pengulung Formation (Tomp), which consisted of volcanic breccia, tuff, and andesite lava widespread on western and southern of Island; locally hydrothermal altered which also included sulfides and quartz vein. In Middle Miocene, series of intermediate to acidic plutonic rocks (Tomi) intruded former rocks unit, which are dominated by andesitic, dacitic, and dioritic (an, da, di) intrusions. Ended up with unconformity deposition of Ekas Formation (Tome) dominated by limestone (calcarenite) during Early Miocene until Late Miocene. It can be seen from Figure 2, SW-NE, N-S, SE-NW strike slip faults contribute the hydrothermal process and mineralization in this area.

The intensity of alteration in the study area are ranged from weakly-strongly altered. Hydrothermal alteration zones manifested on the surface can be divided into chlorite-calcite-albite-tepidote-quartz (propylitic), kaolinite-smectite-quartz (argillic), and quartz-alunite-pyrophyllite with silicification (advanced argillie). The study of the paragenesis study shows that propylitic alteration was developed earlier, supplanted by argillic and advanced argillic alterations [5]. Locally, mineralization is found within an advanced argillic alteration zone with mineral assemblages consisting of tennantite-tetrahedrite and enargite associated with massive silica. Paragenesis of sulfide minerals showed that chalcopryite is found disseminated within propylitic alteration in the early stage, overprinted by tetrahedrite-tennantite assemblage, which is crosscut by enargite vein in the following stage, associated with advanced argillic alteration [5]. Quartz-alunite-pyrophyllite mineral assemblage with vuggy quartz and silicification, associated with enargite-tennantite-tetrahedrite, indicates high sulfidation epithermal mineralization type [5].
Secondary geological structures found in the research area are consisting of a normal fault, trending NW-SE, and sinistral strike-slip fault trending NNE-SSW, consistent with the main structural pattern of Lombok Island. The distribution of hydrothermal alteration zones and mineralization correspond to the trends of the normal fault and strike-slip faults. The spatial association of structural patterns with alteration zones implies that faults and fractures have acted as hydrothermal fluid pathways that controlled hydrothermal alteration zones and mineralization in the study area. Based on the mineral paragenetic study, alteration zones and their sulfide mineral association as well as secondary geological structure patterns, a conceptual model that links between alteration mineral assemblages and the depth of hydrothermal fluid-rock interaction (i.e. shallow-intermediate depth) and their fault-fracture controls are constructed in this study [7].

![Figure 2](image)

**Figure 2.** Modified Geological map of Lombok Island shows the distribution of rock units, recent volcanism and inferred older volcanism as drawn on the dashed line as circular feature. Yellow squared on map shown study area [3]

3. Materials and Methods

In general, the author refers to systematically methods consisting of assembling the data and analysing the data by reaching a certain conclusion either. The study consisted of field and laboratory studies. To obtain evidence and information to deliver the research’s objective, two methods of data collection were applied: a review of documentation and interviews with stakeholders involved in ASGM on the earlier researches which have been done by other researchers. Interviews and documentation generate primary and secondary data, respectively. The combination of both methods is expected to not only provide further in-depth data but also to authenticate data/information through cross-verification between the methods [8].

The laboratory study was done for heavy metal analysis and mycorrhiza identification, conducted at the Department of Soil Science and Department of Basic Science at the University of Brawijaya,
Malang, Indonesia, the field study was conducted in the dry season of 2013 (August 2013) to identify and collect the sample of the plant species grown in the area [9]. Other data gathered from the former study conducted field observation and laboratory studies. Three disciplinary studies correlating geological features by field observation conducted by [3], health-hazardous risk by [1] and environmental risk by [6].

4. Result and Discussion

4.1. Result

4.1.1. Geological Aspects. The alteration halos in the area spread out from the peripheral to the distal area; phyllic zone, argillic zone, silicified zone, and capping out into propilitic zone [5]. There is a prosperous area in Sekotong which includes mineralization in a high sulphidation epithermal environment. It can be seen from Figure 3, the model of hydrothermal alteration and ore mineralization system which causing local miners to elucidate the ores without considering the health and safety issues.

Figure 3. Modified schematic reconstruction of high-sulphidation deposit in general. Red box is the representative of mineralization on study area. The mineralization process mostly occurred in advance argillic zones whereas near surface area hence that local miners can easily exploited [10]

Enclosed the detailed alteration zone in the Sekotong’s ASGM as well can be seen on Figure 4, thus will be comprehensively described in the next chapter.
Figure 4. Representative Outcrop of Study Area. (a). The outcrop of weakly altered tuff vicinity Sekotong’s ASGM (b). Outcrop of Propilitic Alteration Zone shown whitish mineral, illite consider that the area is weakly altered. (c) Photomicrograph of outcrop in Sekotong, indicates Andesite, moderately altered, shown plagioclase (plg)^a phenocryst ond cross nicols and (d). Photomicrograph of mineralization of Sekotong’s ASGM, ore minerals consisted of pyrite (py)^b and hematite (hm)^c on cross nicols [3] (^a plg: plagioclase, ^b py: pyrite, ^c hm: hematite).

4.1.2. Propilitic Alteration Zone. This zone altered tuff units and pyroclastic breccia units. The color of the outcrop mostly light green colored which caused by assembly of epidote as can be seen in Figure 5. Chalcopyrite and pyrite found within this zone. Chlorite-calcite-albite-epidote as mineral assemblages in this zone which can be correlated as Propilitic Zone [10].
Figure 5. Representative Outcrop of Propilitic Alteration Zone in the Study Area. (a). The outcrop of moderately altered breccia tuff vicinity Sekotong’s ASGM (b). Outcrop of oxidized breccia tuff on Propilitic Alteration Zone shown redish mineral, hematite consider that the area is currently being oxidized. (c) Photomicrograph of outcrop in Propilitic Alteration Zone, indicates breccia tuff, moderately altered, shown epidote (epi) phenocryst as secondary process on parallel nicols and (d). Photomicrograph cross nicols with the same location also show epidot minerals [5] (epi: epidote).

4.1.3. Argillic Alteration Zone. This zone altered tuff units, pyroclastic breccia units, and dacitic lava units. The color of the outcrop dominantly yellow colored and rich of clay minerals such as kaolinite and smectite as can be seen in Figure 6. Pyrite is also abundant in this zone. Kaolinite-smectite-quartz as mineral assemblages in this zone which can be correlated as Argillic Zone [10].
Figure 6. Representative Outcrop of Argillic Alteration Zone in the Study Area. (a). The outcrop of moderately altered tuff vicinity Sekotong’s ASGM (b). Outcrop of oxidized tuff on Argillic Alteration Zone shown reddish mineral, hematite consider that the area is currently being oxidized. (c) Photomicrograph of outcrop in Argillic Alteration Zone, indicates tuff, moderately altered, secondary quartz as secondary process on parallel nicols and (d). Photomicrograph cross nicols with the same location also shown kaolinite minerals [5].

4.1.4. Advance Argillic Alteration Zone. This zone altered tuff units and dacitic lava units. The outcrop mostly yellow-whitish colored or red-whitish is colored as the oxidation began. Quartz-Alunite-Pyrophiilitedeidaspore are the mineral assemblages in this zone which can be correlated as Advance Argillic Zone [10] as seen on Figure 7.
Figure 7. Representative Outcrop of Advance Argillic Alteration Zone in the Study Area. (a). The outcrop of strongly altered tuff vicinity Sekotong’s ASGM (b). Outcrop of oxidized tuff on Advance Argillic Alteration Zone shown reddish mineral, hematite consider that the area is currently being oxidized.

Figure 8. (a). Photomicrograph of outcrop in Advance Argillic Alteration Zone, indicates tuff, strongly altered, secondary quartz as secondary process on parallel nicols shows interlocking texture which comes dominant within this zone and (b). Photomicrograph cross nicols with the same location also shown interlocking quartz minerals [5].

4.1.5. Environmental Aspects. From the research taken by [9], the environmental aspects taken from the research of the sample were taken from cyanidation contaminated soil at a depth of 20 cm. The sample was then dried and processed for laboratory analysis. pH, Hg, Cd, Pb, Cu, Fe, Mn, and Zn analysis has been done by the former researcher1:2.5 ratio soil solutions pH (with de-ionized water) was contained in soil detected a pH meter (Jenway 3305). Mercury (Hg) in the sample was reduced with SnCl₂ [11].

The results displayed in Table 1 show that the heavy metals in the uncontaminated soil could not be recognized. However, the cyanidation tailing of artisanal mining at Sekotong, Lombok, Indonesia has a high concentration of manganese (Mn), iron (Fe), Zinc (Zn), mercury (Hg), copper (Cu), lead (Pb) and
The highest concentration was Mn, reached 3,810 mg/kg, and then ensued by Fe (3,810 mg/kg) and Cu (3,760 mg/kg) [9].

Table 1. Some characteristics and heavy metal content of uncontaminated and tailing contaminated soil from artisanal gold mining at Sekotong, Lombok, Indonesia.

| Soil Characteristic | Uncontaminated Soil | Tailing Contaminated Soil |
|---------------------|---------------------|---------------------------|
| Soil Texture        | Silty loam          | Sandy loam                |
| C (%)               | 0.95                | 0.19                      |
| N (%)               | 0.1                 | 0.001                     |
| CEC (cmol/kg)       | 14.25               | 11.57                     |
| K (cmol/kg)         | 3.25                | 0.001                     |
| Ca (cmol/kg)        | 3.04                | 1.99                      |
| Mg (cmol/kg)        | 1.26                | 0.84                      |
| Na (cmol/kg)        | 0.29                | 0.64                      |
| Cu (mg/kg)          | Unidentified        | 792                       |
| Cd (mg/kg)          | Unidentified        | 4                         |
| Hg (mg/kg)          | Unidentified        | 1,090                     |
| Pb (mg/kg)          | Unidentified        | 530                       |
| Fe (mg/kg)          | Unidentified        | 3,810                     |
| Mn (mg/kg)          | Unidentified        | 4,840                     |
| Zn (mg/kg)          | Unidentified        | 3,760                     |

*Data derived from [9]

4.1.6. Health Aspects. The extraction of gold as seen on Figure 9 needed a bunch of mercury for gold amalgamation on the tailing. Mercury concentration in the tailing is also very high, i.e. 1.090 mg/kg which far higher compared to the WHO standard (0.001 ppm) or Indonesian standard (0.002 ppm). The most eminent mercury level in the air was 54,931.84 ng/m³ at a gold shop in Sekotong, Lombok, and the lowest one was 121.77 ng daL in front of a community's house where a ball-mills unit was in operation was about 20,891.93 ng daL, next to an assumed patient's house [12]. Mercury is a toxic metal with impacts on human health ranging from acute to chronic in a very short time of illness. Thus, artisanal and small-scale gold mining (ASGM) is the foremost source of direct human endangerment to mercury.

Figure 9. Situation on Sekotong’s ASGM (a). Local miners collected the rock sample of ore deposit vicinity areas. (b). Local miner undergo amalgamation on extracting gold with mercury manually
without using any protectors or safety tools, this caused increasing of affected people by extracting gold with mercury [6].

As seen on the Figure 10, the affected children caused by mercury contamination. Human exposure to mercury (Hg) can occur through both direct inhaling of mercury vapor and the consumption of food taken from contaminated areas. To defend the health of ASGM workers and surrounding communities, a health assessment of mercury exposure and its impacts is essentially needed. The former study by [12] has analyzed the 100 subjects were miners that have been exposed to mercury for at least 5 years and their spouses and children (non-miners) from who lived around the gold processing field. Tailings control must be executed to warrant the sustainability of ASGM and that mining practices do not impact on the future sustainability of other aspects such as tourism and agriculture on the adjacent area. In order to ensure the future sustainability of ASGM, it was suggested that ASGM in Sekotong should be regulated. The environmental sustainability of mining can be better regulated within legalized areas, and tailings management plans implemented. Program of environmental monitoring should be implemented throughout the current ASGM area to monitor the concentrations of mercury in soil and water that expected will determine unacceptable hazard and allow for advanced implementation of therapeutic measures before an insurgent disaster occur [12].

Table 2. Correlation Between Exposure Group and Urine Protein Level, Hemoglobin and Hematocrit, Urine and Hair Mercury Levels on Sekotong’s ASGM

| Exposure Group | Urine Protein Level (g/L) | Hemoglobin (g/dL) | Hematocrit (%) | Urine Mercury Level (µg/L) | Hair Mercury Level (µg/L) |
|----------------|---------------------------|-------------------|---------------|---------------------------|--------------------------|
| Miners         | 1.68±1.023                | 12.74±2.39        | 38.21±7.18    | 69.39±62.41               | 2.77±1.68                |
| Non-Miners     | 1.29±1.03                 | 13.59±2.43        | 40.77±7.29    | 12.7±11.5                 | 2.37±1.82                |

aData derived from [12]

From the Table 2 shows the data of mercury contamination on exposure group at average, Nearly all of the subjects in the exposed areas, both miners and non-miners, were decisive for proteinuria (miners, 92.6% and non-miners, 72.4%). This result was similar to findings of proteinuria in patients exposed to products containing mercury [13]. Likewise, proteinuria is a clinical indication of mercury intoxication with elemental, inorganic and ethyl mercury [14]. Raised concentration of mercury contamination on urinary (69.39 ± 62.41 µg/L) and hair (2.77 ± 1.68 µg/g) in the miners show that a diseased process in the kidney may befall due to mercury exposure [12].

General causes of urinary mercury excretion were elemental and organic mercury exposure, as miners were straight exposed to mercury vapor throughout the smelting process [15,16]. Once inhaled,
mercury vapor is disbanded rapidly into the blood and might accumulate in other organs e.g. brain, kidney, placenta thyroid and others [17,18]. Notable differences in urinary levels between miners and non-miners show that a possible route of exposure may be ingestion of inorganic mercury within contaminated food or water.

Given in the Table 2 also shows the average of the hemoglobin concentration of miners (12.74 ± 2.39 g/dL) was lower than that of either non-miners (13.59 ± 2.43 g/dL) or the normal condition for men (13–18 g/dL) [19]. The outcomes of this former study also indicated correspondence between the smoking habits of miners and hemoglobin concentration. Nevertheless, while the normal level for male smokers is used (13.3 d/dL), formerly the Hb contents of the miners were below normal [12]. Found that he Hb amounts of miners (38.21 ± 7.18%) were below than that of non-miners (40.77 ± 7.29%) as well as the normal value ranged from 40–50% [12].

Except for the hair mercury level, all parameters covered in the former study revealed significant contrasts among the two groups. The targeted persons in the miner group were men, and most of them in the non-miner group were women. The outcomes of the study found that mercury in men’s hair was higher than that in women’s [13].

4.2. Discussion

Based on the secondary mineral assemblage, the paragenesis of the mineral can be elucidated within 3 assemblage zones which also simplified as hydrothermal alteration zone. The first assemblage zone is Propilitic that comprises of chlorite-calcite-albite±epidote soon after that alunite-pyrophyllite±diaspore deposited after propilitic alteration then the first mineralization process was the deposition of pyrite and chalcopyrite following tennantite-tetrahedrite. Then, ore mineralization happened at the crosscutting vein which incised of deposition of enargite continued with gold. If the time passed by, there was also deposition of hematite caused by the oxidation process on pyrite which crosscutting the ore mineralization that has been deposited before.

In general, pyrite is the most abundant mineral in the phase of advance argillic and argillic. Furthermore, the ore minerals deposited in the massive silica in the advance argillic zone, which also this zone is really near the surface so the local miners can easily take the ores without using proper tools and safety wear. This will affect the health and environment vicinity of Sekotong’s ASGM.

On the environmental issue, we found out the soils were highly contaminated with the mercury caused by the amalgamation of gold extraction which will damage the environment if there will not rehabilitation on the affected area. The plantation of indigenous plant species and the related mycorrhiza for remediation of mercury-contaminated soils is necessarily needed to enhance the quality of life, especially on the environmental issue.

The last important thing is the health-hazardous regarding of the activity of local miners surround the ASGM in Sekotong, the effect will not only infected the miners themselves but also their family including next generation of their children or even their spouses because the contamination of the mercury will not be ended easily as long as the mining activity still undergoes within the area.

5. Conclusion

To summarize, the liaised geological prospects on ASGM in Sekotong promising on the growth of economic sectors driving to jobs, incomes, and opportunities for social improvement. In contrast, there are also risks of contamination in soil and water environment through mining activity and high Hg concentration observed in the human body in a short time of ASGM activity that affected not only miners but also risking their families.

The technology functioned by the ASGM miners to recover gold from the rock is generally proper; amalgamation is no longer used, and cyanidation is both efficient and safe if used accurately. Environmental risk and health-hazardous are approximately manifest at the end of the mining cycle when cyanidation tailings are released into the environment with no strategy to contain or maintain the contaminant freight of the waste.
The health and safety record of mining should be governed and improved. But the single most prominent environmental risk apparent for the ASGM sector in Lombok is the uncontrolled outflow of tailing into the environment throughout the current ASGM areas to monitor the congregations of mercury in soil and water. Environmental monitoring will set unacceptable risk and allow for excellent implementation of remedial actions before an insurgent disaster befalls. A programmed health assessment on ASGM in Sekotong also must be done within the activities of mining in the area. In this study, all the related aspects consisted of geological, environmental and health aspects are clearly discussed for better enhancement for local people to be more patiently consider about this important issue for making a better world.

References
[1] Krisnayanti BD and Anderson CW 2012 Environmental impact assesment: illegal/informal gold mining in Lombok 69
[2] Santoso B and Sari RRN 2018 Suara Electronic Report
[3] Gunardi R 2015 Evaluasi Sumber Daya/cadangan Bahan Galian Untuk Pertambangan Sekala Kecil, Daerah Pulau Lombok, Provinsi Nusa Tenggara Barat
[4] Mangka and Andi 1994 Peta Geologi Lembar Lombok
[5] Claudia D and Basuki NI 2015 Paragenesa Alterasi dan Mineralisasi serta Model Konseptual Epithermal High Sulfidation di Daerah Sekotong, Kabupaten Lombok Barat, Nusa Tenggara Barat
[6] Ismawati Y 2017 Preliminary report on suspected mercury poisoning in 3 ASGM hotspots of Indonesia: Case reports Bombana-Southeast Sulawesi, Sekotong-West Lombok, and Cisitu-Lebak 16 Feb-6 March 2015 J Balifokus 4-15
[7] Silitoed, RH 1997 Characteristic and controls of largest porphyry Cu-Au and epithermal gold deposit J of Australian Earth Science
[8] Yin RK 2009 Case study research design and methods 4
[9] Utomo WH, Suntari R , Novi A, Suhartini, and Handayanto E 2014 Rehabilitation of Artisanal Small-Scale Gold Mining Land in West Lombok, Indonesia: Exploration of Indigenous Plant Species and The Associated Mycorrhiza For Phytomycoremediation of Mercury Contaminated Soils J American-Eurasian of Sustainable Agriculture 8 34-41
[10] Corbett GJ and Leach TM 1990 Southwest Pacific Au-Cu Systems SEG Special Publication 6
[11] Deng L, Mou, and Zhu F 2010 Photo-induced transformations of Hg(II) species in the presence of Nitzschia hantzschiana, ferric ion, and humic acid. J of Environmental Sciences 22 76-83.
[12] Krisnayanti BD, Anderson CW, Utomo WH, Feng X, Handayanto E, Mudarinsa N, Ikram H, and Khususiah 2015 Effect of Mercury Exposure on Renal Function and Hematological Parameters among Artisanal and Small-scale Gold Miners at Sekotong, West Lombok, Indonesia J Health Pollution 9 25-32
[13] Li SJ, Zhang SH, Chen HP, Zeng CH, Zheng CX, Li LS, and Liu ZH 2010 Mercury-induced membranous nephropathy: clinical and pathological features. Clin J Am Soc Nephrol 5 3 439-44.
[14] Clarkson TW 2002 The three modern faces of mercury Environ Health Perspect 2002 110 1 11-23.
[15] Abdenmou C, Khelili K, Boulaoud MS, Nezzal A, Boubsil S, and Slimani S 2002 Urinary markers of workers chronically exposed to mercury vapor. Environ 89 3 245-249
[16] Burbure CD, Buchet JP, Leroyer A, Nisse C, Haguenero JM, Mutti A, Smerhovsky Z, Cikrt M, Ochocka MT, Razniewska G, Jakubowski M, and Bernard A 2006 Renal and neurologic effects of cadmium, lead, mercury, and arsenic in children: evidence of early effects and multiple interactions at environmental exposure levels Environ Health Perspect 114 4 584-90.
[17] Park JD and Zheng W 2012 Human exposure and health effects of inorganic and elemental mercury J Prev Med Public Health 45 6 344-352
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