Abstract

Medical geology is the science that examines the relationships between natural geological factors and human health problems. With weathering, rocks break down to form the soils on which crops, and animals are raised. Much of the dust and some of the gases contained in the atmosphere are of geological origin, and soil and water support the crops and animals that constitute the food chain. Therefore, human health is linked directly to geology through the food chain and inhalation. The clearest example of this relationship is when geological materials contain too little (deficiency) or excessive (toxicity) trace elements, which can influence human health. Such deficiencies or toxicities can arise from natural or anthropogenic activities.

The mercury in the urban environment comes from various sources, including occupational and industrial activities, fuel combustion, and waste incineration. Urban populations are exposed directly through the inhalation of mercury vapor, or indirectly via the soil, fish, and edible plants. People living in gold mining towns experience high inorganic mercury levels when mercury vapor is emitted during the burning of amalgam as well as gold dorè in gold shops. These activities occur in Makassar, Indonesia, where a group of urban people established an artisanal waste recycling industry, in which they use mercury to recover the fine gold particles contained in the waste from goldsmiths' activities. Here, it is designate this process 'urban artisanal gold mining' (UAGM) because it is similar to the artisanal and small-scale gold mining (ASGM) that occurs in gold mining areas.

The main purposes of this study were to investigate UAGM as a new source of mercury exposure and its potential environmental and health problems in Makassar, South Sulawesi, Indonesia. The material and method to characterize of UAGM process and socio demographic that using depth interview by questioners, chemical analyses, including particle-induced X-ray emission (PIXE), were used to investigate the concentrations of mercury and other heavy metals in scalp hair, sediments, and window dust house. A health examination of all gold workers was performed by a professional physician following World Health Organization (WHO) procedures.

The UAGM workers included two groups: goldsmiths and gold smelters. The goldsmiths designed and manufactured gold jewelry, and the gold smelters recovered the fine gold particles contained in the waste generated by the goldsmiths' work. This waste included working-place dust, sludge, used gypsum molding, used clay bowls, trash, acid, and various kinds of solvents. With the exception of the ore excavation stage, the recovery process in UAGM is similar to the gold extraction stage in ASGM. However, rather than excavating gold deposits or secondary ores, the gold smelters collect the waste from goldsmiths and recover the fine gold particles from the waste. The processes involved in its extraction include crushing, milling, amalgamation, smelting, and refining. It is estimated that 100–300 kg mercury/year is used in the amalgamation process. Mercury that has been reused several times is released from a pond or trommel into a tailing reservoir before it enters the drainage system of the house, from where it flows into the main city drains. Mercury vapor is also emitted into the atmosphere during the burning of amalgam (Hg–Au). Because the UAGM activities are performed in open areas, mercury potentially contaminates the waterways, air, and soil over extensive areas.

After investigating the characteristics of the UAGM processes, to characterize the sociodemographic of the gold workers. Approximately 125 gold workers, including males and females, were involved in UAGM. Of these, 78 %–84 % were in working age (18–65 years) and had worked actively in this occupation for 5–30 years. They had an average income of US$350/month (US$12/day). The inhabitants the educational level tend to be proportional with the income and in contrast with the gold workers, the educational level tend to be not proportional. The gold workers

were predominantly elementary and junior high school. This indicates that the work was conducted with traditional management and without technological practices.

The tailings of UAGM flow into the drainage system, and ultimately into a tributary of the Tallo River, before entering the downstream waterways. Mercury concentrations were high detected in the tailings systems. The average of Hg concentration in tailing is 352.8 µg/g and the others aquatic system such as drainage, river, fish pond and beach shows are 15.6, 13.1, 23.6, and 15.0 µg/g, respectively. This indicates Aquatic system receiving water from tailing of UAGM shows elevated mercury level in the sediment of river, fish pond and beach. Some sediments taken from power plant and industrial sites also show elevated mercury level. To investigate the mercury vapor released into the atmosphere, samples of the atmospheric dust deposited on house windows were analyzed. The Hg concentration in windows dust in smelting area is higher than Hg concentration in residential area, because of mercury enrichment due to mercury emission from UAGM process. The average of Hg concentration in windows dust in smelting area is 306 µg/g, while in residential area is 35 µg/g. In residential area detected of Hg pollution due to most likely attributed by coal combustion from urban power plant, industrial emission, and automobile traffic. While the other heavy metals including lead (Pb) was also detected in the atmospheric window dust house in UAGM and residential area. The minimum lead concentration in UAGM area is 269 µg/g, and the maximum concentration is 1679 µg/g, whereas in residential area the minimum lead concentration is 99 µg/g, and the maximum concentration is 3310 µg/g. This indicates the UAGM site enriched by burning goldsmiths' waste using kerosene/gasoline, and the residential site due to most likely attributed by coal and fuel combustion from power plant and urban transportation.

To investigate mercury exposure among the UAGM workers, it analyzed their scalp hair with PIXE to determine the total mercury concentrations and compared them with those of the general Makassar population, who were used as the control group. The average hair mercury concentrations of the gold workers (8.4 µg/g) were significantly higher than that of the control group (2.8 µg/g). Gold smelters directly handle liquid mercury and are also exposed to it during the amalgamation and smelting processes, whereas goldsmiths are exposed to mercury when refining the gold dorè, which still contains mercury. The result also demonstrated a significant and positive correlation between the period of work (working years) and total mercury concentration in hair (Spearman, $r = 0.49$ $P = 0.000$). In other words, the longer they worked, the greater their exposure to mercury. Another positive and significant correlation between the period of work (working years) and total mercury concentration when the gold workers were categorized into directly (10.8 µg/g) and indirectly (5.6 µg/g) exposed groups (Spearman, $r = 2.7$; $P < 0.000$). In term of mercury level, most of the gold workers displayed high mercury levels (> 5 µg/g, threshold limit of human biomonitoring), Mercury concentration in scalp hair of gold workers are also affected by atmospheric dust in their working place. This relation is significant (*Spearman*, $r = 0.49$, $P < 0.000$) which clearly indicates that the gold workers had been exposed to mercury during their work and within their environment.

The health examinations showed that 85% of the gold workers suffered neurological symptoms, such as tremors, and 40%–60% experienced restricted fields of vision, slow reflexes, sensory disturbances, rigidity, and ataxia. These results also showed that the length of their work experience (working years) correlated reasonably well with the summed positive findings for 10 neurological symptoms (Spearman, $r = 0.59$, $P < 0.000$). The inhabitants of Makassar (control group) also showed mercury concentrations in their hair (0–12 µg/g) and slight symptoms of mercury poisoning. The symptoms most frequently suffered by control group were tremor of the tongue, eyelid, finger, or nose, pouring, and posture holding, with occurrence rates of up to 62%, whereas irregular eye movement, limited visual field, abnormal knee jerk reflex, and abnormal biceps reflex were detected in about 44% of subjects.

In this medical geological study, it is investigated mercury toxicity in the urban environment in Makassar. The researcher found that UAGM contributed to the environmental mercury contamination in atmosphere by checking windows dust as an indicator of atmosphere deposited pollution and health problems among gold workers. ASGM is usually undertaken in the countryside, and the gold is further processed in a mining town. However, a gold-mining-like process, designated UAGM, is conducted in the center of the city, and the amalgamation and smelting processes involved have become a new source of pollution in the urban area. Although UAGM consumes only 300 kg of mercury per annum (compared with ASGM, which consumes approximately 1000 tonnes of mercury per annum), it may present a greater risk because of the high population density around UAGM sites. Therefore, not only gold workers, but also the urban population and their environment, are exposed to mercury contamination.

The mercury toxicity in Makassar city has reached an alarming level, particularly within the UAGM site. To ameliorate the impact of mercury pollution, it is essential to construct a network involving all the elements of the community: national and local governments, industries, stakeholders, researchers, educational institutions, NGOs, and civil society. It is anticipated that each element of this network system will be linked by studies and monitoring/evaluation programs conducted by researchers and supported by governments through the development of environmental policies and this network should develop an appropriately sustainable program of preventing mercury pollution.