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学 位 論 文 要 旨
Dissertation Summary

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論 文 名 : Medical Geology Study of an Urban Artisanal Gold Mining Area in Makassar, South Sulawesi, Indonesia

インドネシア共和国南スラウェシ州のマカッサル市における小規模都市金鉱山に関連する医療地質学的研究

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 the characteristics of UAGM, the sociodemographic characteristics of the gold workers, their exposure to environmental mercury, and the health problems related to mercury poisoning. In-depth interviews were undertaken with the workers to document their demographic characteristics, and the gold recovery and jewelry manufacture processes were observed. Chemical analyses, including particle-induced X-ray emission (PIXE), were used to determine the concentrations of mercury and other heavy metals in scalp hair, sediments, and household dust. A health examination of all gold workers was performed by a professional physician following World Health Organization 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. Much of the gold is collected from the dust on the windows of their houses (2318–5263 μg/g). 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, the researcher characterized the sociodemographic of the gold workers. Approximately 400 gold workers, including males and females, were involved in UAGM. Of these, 78 %–84 % were in working age (25–60 years) and had worked actively in this occupation for 10–30 years. They had an average income of US$350/month (US$12/day), which was slightly higher than the income of ASGM workers in Kalimantan, who earn about US$74–223/month. The educational backgrounds of the gold workers were predominantly elementary and junior high school. Their incomes did not correlate significantly with their educational level (Spearman, $r = 0.11$; $P = 0.43$), indicating that the work was conducted with traditional management and without technological practices.

Because most of these workers had been exposed to mercury for long periods of time (>10 years), a study of the environment and the gold workers themselves was required to establish how severely they had been affected. Environmental exposure to both liquid mercury and mercury vapor is likely in this case. Liquid mercury is discharged into the tailings and drainage systems, and mercury vapor is released into the atmosphere during the gold refining and amalgam burning processes. These processes directly expose the gold workers to mercury through inhalation.

The tailings of UAGM flow into the drainage system, and ultimately into a tributary of the Tallo River, before entering the downstream waterways. High mercury concentrations were detected in the tailings and drainage systems. Very high mercury concentrations (79 and 627 μg/g) were detected in the sediments at two tailing sites, and the mercury concentrations in the other drainage sites averaged 16 μg/g (7–30.5 μg/g). To investigate the mercury vapor released into the atmosphere, samples of the atmospheric dust deposited on house windows were analyzed. Atmospheric window dust was collected from five houses inside the UAGM site. Two of the five gold workers' houses had excessive levels of mercury, reaching 636 μg/g, indicating that the individuals who worked and lived at the UAGM site were subjected to high mercury exposure. The other three were occupied by individuals who did not work with gold. The dust samples had mercury concentrations of 120 and

101 μg/g, which were three times higher than the concentrations in samples from other areas of the city. Therefore, mercury exposure via atmospheric deposition might constitute widespread contamination. This deposited mercury can contaminate edible plants or poison children through its inadvertent ingestion. The aquatic systems near the UAGM site were also enriched with elemental mercury, which was detected in sediments taken from a beach, a fish pond, and a river, with average concentrations of 15, 24, and 14 μg/g, respectively. Elemental mercury in these aquatic systems can be transformed to its most dangerous form, methylmercury, which then readily enters the food chain. These results clearly demonstrate that mercury is present within the environment, especially inside and near the UAGM site. Therefore, it investigated the exposure of the gold workers to mercury and assessed their health problems arising from mercury poisoning.

Other heavy metals, including lead (Pb) and silver (Ag), gold (Au) were also detected in the atmospheric window dust house. Several anthropogenic activities, such as chemical industries, coal combustion at a steam power plant, and fuel combustion by transport vehicles, are undertaken at different locations in the city, which also potentially introduce mercury and heavy metals into the atmosphere. The chemical analysis of the house window dust showed that varying concentrations of mercury, Pb, and As were deposited throughout the city. On average, the Pb concentrations were higher at the UAGM site (676 μg/g) than at other locations (573 μg/g), and As was three times higher (30 μg/g) at the UAGM site. This enrichment is probably attributable to the burning of gasoline at the UAGM site.

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 mean hair mercury concentrations of both the gold smelters (16.3 μg/g) and goldsmiths (11.1 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, $r = 0.57$ $P = 0.000$). 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 (6.6 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*, $r = 0.71$, $P = 0.001$) 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 44 %–56 % 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. Industries must control the environmental impact of their production processes; educational institutions, NGOs, and society can implement public health management strategies; and this network should develop an appropriately sustainable program of preventing mercury pollution.