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Exposure and human risk assessment of toxic heavy metals on abandoned metal mine areas

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Abstract: In order to assess the risk of adverse health effects on human exposure to arsenic and heavy metals influenced by past mining activities, environmental geochemical surveys were undertaken in the abandoned metal mine areas (Dongil Au-Ag-Cu-Zn, Okdong Cu-Pb-Zn, Songcheon Au-Ag, Dongjung Au-Ag-Pb-Zn, Dokok Au-Ag-Cu and Hwacheon Au-Ag-Pb-Zn mines). Arsenic and other heavy metals were highly elevated in the tailings from the Dongil, the Songcheon and the Dongjung mines. High concentrations of heavy metals except As were also found in tailings from the Okdong, the Dokok and the Hwacheon mines. These significant concentrations can impact on soils and waters around the tailing dumps. Risk compounds deriving from mine sites either constitute a toxic risk or a carcinogenic risk. The hazard index (H.I.) of As in the Dongil, the Okdong, the Songcheon and the Hwacheon mine areas was higher value more than 1.0. In the Okdong and the Songcheon mine areas, H.I. value of Cd exceeded 1.0. These values of As and Cd were the highest in the Songcheon mine area. Therefore, toxic risks for As and Cd exist via exposure (ingestion) of contaminated soil, groundwater and rice grain in these mine areas. The cancer risk for As in stream or ground water used for drinking water from the Songcheon, the Dongil, the Okdong, the Dongjung and the Hwacheon mine areas was $3E$-3, $8E$-4, $7E$-4, $2E$-4 and $1E$-4, respectively.

1. Introduction

Mining can be an important source of toxic heavy metals in the environment owing to mining activities such as processing, transportation of ores, disposal of tailings and waste waters around mines (Adriano, 1986). These activities often produce acid wastes that can cause severe geochemical changes downstream from these facilities (Filipek et al., 1987). In a typical metal mine district, massive sulfide ores in inactive mines and mine tailings are weathering and oxidizing at an accelerated rate due to atmospheric exposure. Thus, elevated levels of heavy metals discharged from mine waste materials are to be found in nearby streams, agricultural soils and food crops (Davies and Ballinger, 1990; Merrington and Alloway, 1994).

In this study, to investigate the contamination levels of heavy metals and assess the risk of adverse health effects on human exposure to heavy metals influenced by past mining activities, environmental geochemical surveys were undertaken around some abandoned metal mine areas (Dongil Au-Ag-Cu-Pb-Zn, Okdong Cu-Pb-Zn, Songcheon Au-Ag, Dongjung Au-Ag-Pb-Zn, Dokok Au-Ag-Cu and Hwacheon Au-Ag-Pb-Zn mines).

2. Materials and methods

Sampling of tailings, soils, crop plants and waters in the vicinity of the Dongil, the Okdong, the Songcheon, the Dongjung, the Dokok and the Hwacheon mines was carried out in 2001 and 2002. Soils were sampled from agricultural land around the mine sites. Rice samples were taken from paddy fields. Stream or ground waters used as a drinking water were collected around the tailings in these mine areas. After appropriate sample preparation, these samples were analyzed for As, Cd, Cu, Pb and Zn by ICP-AES and ICP-MS. Risk assessment of toxic heavy metals has been performed with chemical analytical data for environmental media.

3. Results

Arsenic and other heavy metals were highly elevated in tailings from the Dongil (8,720 As mg/kg, 5.9 Cd mg/kg, 3,610 Cu mg/kg, 5,850 Pb mg/kg, 630 Zn mg/kg), the Songcheon (24,080 As mg/kg, 8.2 Cd mg/kg, 130 Cu mg/kg, 3,830 Pb mg/kg, 2,410 Zn mg/kg) and the Dongjung (3,620 As mg/kg, 12.2 Cd mg/kg, 144 Cu mg/kg, 5,140 Pb mg/kg, 3,060 Zn mg/kg) mines. Also high concentrations of heavy metals except As were found in tailings from the Okdong (53.6 Cd mg/kg, 910 Cu mg/kg, 1,590 Pb mg/kg, 5,720 Zn mg/kg), the Dokok (98.2 Cd mg/kg, 2,550 Cu mg/kg, 4,200 Pb mg/kg, 18,020 Zn mg/kg) and the Hwacheon (12.4 Cd mg/kg, 580 Pb mg/kg, 1,300 Zn mg/kg)

mines. These significant concentrations can impact on soils and waters around the tailing dumps.

Elevated levels of As, Cd, Cu, Pb and Zn were also found in agricultural soils from these mine areas. In particular, As concentration in agricultural soils from the Dongil, the Songcheon and the Dongjung mines was higher more than the permissible level in soils. This level means the threshold of the element concentrations in soils above that crop produced are considered as unsafe for human health. Cadmium was elevated in agricultural soils from the Okdong and the Dongjung mines, Cu from the Dongil and the Songcheon mines, and Pb from the Songcheon, the Dongjung and the Hwacheon mines. Arsenic, Cd and Zn in stream water used for drinking water in the Songcheon mine area were higher than the permissible levels (0.05 As mg/L, 0.01 Cd mg/L and 1.0 Zn mg/L) in Korea. In the Dongil mine, As in groundwater used for drinking water exceeded the permissible level (0.01 mg/L) suggested by WHO.

Risk assessment is the process of characterizing the adverse health effects of human exposure to environmental hazards (Fig. 1). Risk compounds deriving from mine sites either constitute a toxic risk or a carcinogenic risk. Toxic risks are indicated in terms of a hazard quotient (H.Q.). H.Q. is ADD (average daily dose)/RfD (reference dose). A toxic risk exists for H.Q.>1. To calculate the hazard index (H.I.) the ADD from three identified pathways (soil, groundwater and food (rice grain) pathways) compared to the relevant RfD obtained from the US-EPA database *IRIS* is summed. The hazard index of As in the Dongil, the Okdong, the Songcheon and the Hwacheon mine areas was higher value more than 1.0. In the Okdong and the Songcheon mine areas, H.I. value of Cd exceeded 1.0 (Table 1). The carcinogenic risk for As in stream or ground water used for drinking water from the Songcheon, the Dongil, the Okdong, the Dongjung and the Hwacheon mine areas was 3*E*-3, 8*E*-4, 7*E*-4, 2*E*-4 and 1*E*-4, respectively.

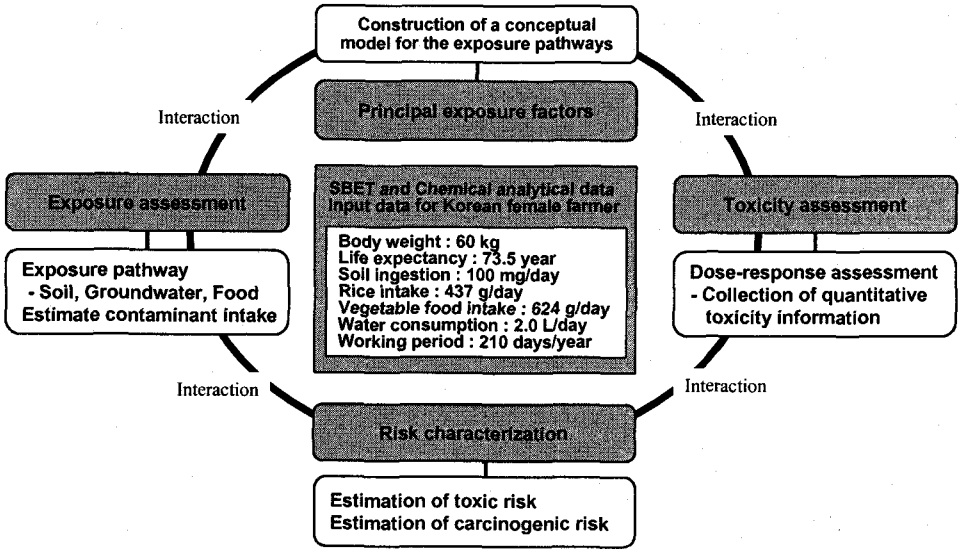

Fig. 1. Human risk assessment process.

Table 1. Hazard indices of As, Cd and Zn for toxic (non-cancer) risk.

Mine	As	Cd	Zn
Dongil mine	3.1	0.9	0.4
Okdong mine	3.3	2.2	0.2
Songcheon mine	7.1	4.4	0.2
Dongjung mine	0.4	0.1	0.0
Dokok mine	0.1	0.0	0.0
Hwacheon mine	2.5	0.5	0.3

4. Conclusions

Elevated levels of As, Cd, Cu, Pb and Zn were found in tailings from the Dongil, the Songcheon and the Dongjung mines. Heavy metals except arsenic in tailings from the Okdong, the Dokok and the Hwacheon mines were also elevated. These significant concentrations can impact on soils and waters around the tailings by surface erosion, rain and wind action and redeposition.

From the results of the risk assessment, the hazard index (H.I.) values of As and Cd were the highest in the Songcheon mine area. Therefore, toxic risks for As and Cd exist via exposure (ingestion) of contaminated soil, water and rice grain in this mine site. By the result of As analysis for contaminated water consumption, the carcinogenic risks exceed the range (1 by 100,000 to 1,000,000) required for remedial actions in the Songcheon, the Dongil, the Okdong, the Dongjung and the Hwacheon mine sites. Thus, a significant human health risk is present from the consumption of locally ground or stream water in these mine sites.

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