Risk assessment modelling and bioavailability of As and toxic heavy metals around abandoned mine sites

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In order to estimate the bioavailability of As and heavy metals from soils, and to assess the risk for adverse health effects on human exposure around abandoned mine sites in Korea, environmental geochemical surveys were undertaken in the Da-Duk Au-Pb-Zn and the Kil-Kok Au-Ag mines. After appropriate preparation, tailings and soil samples were analysed for As, Cd, Cu, Pb and Zn by ICP-AES and crop plants by ICP-MS at the British Geological Survey (BGS). The solutions extracted from soil samples by the SBET (simple bioavailability extraction test) method were analysed for As, Cd, Cu, Pb and Zn by ICP-AES at the BGS.

Elevated levels of 8782 mg/kg As, 8.3 mg/kg Cd, 489 mg/kg Cu, 3638 mg/kg Pb and 919 mg/kg Zn are found in tailings from the Da-Duk mine. Also, Cd, As, Cu and Zn are elevated in tailings from the Kil-Kok mine. Mean concentrations of As, Cd, Pb, Cu and Zn in soils are significantly higher than those in world average soil, especially for As and Pb which exceed the tolerable level. Toxic element concentrations in stream sediments from the Da-Duk mine decrease with distance from the tailings due to a dilution effect. Away from the Kil-Kok mine adit, element concentrations in sediments abruptly decrease due to topographic isolation. Tailings effluent in the Da-Duk mine contains low pH, high conductivity, and high concentrations of Al, Mn, Fe, As, Zn and SO_4, which indicates the distinctive features of acid mine waters. In particular, maximum value of As in tailings effluent is 1003 g/L. Arsenic and Cd in rice grains and stalks around the Da-Duk mine are elevated. In the Da-Duk mine, the BAC of Cd, Cu, Pb and Zn in plant species decrease in the order of sesame leaves > chinese cabbage > bean leaves > red peppers > rice stalks > rice grains. However, a high BAC of As is found in rice stalks and that of Cd in chinese cabbage.

The post-ingestion bioavailability of As and toxic heavy metals in some paddy and farmland soils has been also investigated using the SBET method. The method utilises synthetic leaching fluids closely analogous to those of the human stomach. The quantities extracted from paddy soils in the Da-Duk mine after 1 hour indicated 15.9 % As, 65.4 % Cd, 46.2 % Cu, 39.4 % Pb and 29.4 % Zn bioavailability and for farmland soils, 12.5 % As, 24.9 % Cd, 31.3 % Cu, 29.3 % Pb and 19.4 % Zn bioavailability. Also, in the Kil-Kok mine, average stomach absorptions of As, Cd, Cu, Pb and Zn are 7.2, 24.3, 15.7, 21.8 and 9.8 % of total farmland soils, respectively. The highest bioavailability values for toxic elements are found in paddy soils under submerged conditions. Arsenic bioavailability is relatively lower than other heavy metals.

Key words : Risk assessment modelling, Bioavailability, SBET, Toxic risk, Carcinogenic risk

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This indicates that As is soluble across a wide pH range in contrast to other heavy metals which are typically soluble only at low pH. The results of the SBET indicate that regular ingestion (inhalation and transmission from dirty hands) of soils by the local population could pose a potential health threat due to long-term toxic element exposure.

To perform the risk assessment modelling SBET results for soil and chemical analysis data for vegetables and a groundwater sample for As, Cd and Zn have been used. Lead and Cu data are also available, but the assessment does not consider these elements further because of the lack of reference dose information. Risk assessment modelling is subdivided into three stages, i.e. hazard identification, exposure assessment and dose-response assessment. In order to assess exposure it is necessary to calculate the average daily dose (ADD) of contaminant via the three identified pathways (soil, groundwater and food pathways). The results of ADDs for As, Cd and Zn with pathway are shown in Table 1. Toxic risks are defined for non-carcinogenic exposures, and indicated in terms of a Hazard Quotient. Carcinogenic risks are statements of probability. Individual excess risk is an estimate of the probability that an individual will get cancer from an exposure, not the probability of dying from it. The results of carcinogenic and toxic risk for arsenic from rice consumption indicate that the carcinogenic risk ranges from four in a thousand to seven in a thousand. The US-EPA considers risks of greater than one in one million (1x10-6) as significant. Clearly the results of this study indicate that further work in the Da-Duk mine area is required to assess the situation and if necessary review the exposure calculations after a more systematic data collection exercise and reassessment of exposure and soil arsenic distribution.

Table 1. Results of ADD (average daily dose) values for As, Cd and Zn with exposure pathways (unit in mg/kg-day).

Pathway		As	Cd	Zn
Soil (arable)		4.33 X 10-5	1.41 X 10-6	1.93 X 10-4
Groundwater		1.09 X 10-4	n. d.	3.68 X 10-3
Food	Rice grain	4.78 X 10-3	1.27 X 10-3	0.15
	Chinese cabbage	3.18 X 10-3	3.64 X 10-3	0.53