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Evaluation of human exposure to arsenic due to rice ingestion in the vicinity of abandoned Myungbong Au–Ag mine site, Korea

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Step 1 : Hazard Identification

1. Introduction

Mining can be a significant source of As and heavy metal contamination of the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines (Adriano, 2001). In typical metal mine districts, massive stockpiles of sulfide containing refuse and tailings in the inactive mines are weathered and oxidized due to long-term atmospheric exposure. The acidic mine drainage, with elevated levels of heavy metals, are discharged to contaminate the downstream water bodies, and subsequently agricultural soils and food crops. The fugitive metals in the receiving water and soil may pose a potential health risk to the residents in the vicinity of the mines (Davies and Ballinger, 1990; Merrington and Alloway, 1994). There is a need to accurately quantify the toxicological risk to the resident populations in the contaminated environments. Current assessment models derive the total human exposure (Kolluru et al., 1996; Kimmel et al., 1999; Akagi et al., 2000; Alcock et al., 2000; Green et al., 2000; Lee et al., 2000; Paustenbach, 2002; Sekhar et al., 2003; Lee et al., 2004) by evaluating the fate and transport of toxic elements through exposure pathways such as drinking water, food intake, dust inhalation and hand-to-mouth soil ingestion.

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Aim of the study

In this study, to assess the risk of adverse health effects on human exposure to As by past mining activities, an environmental geochemical survey was undertaken in the abandoned Myungbong Au–Ag mine area in Korea.

Step 2 : Choice or building of Toxicological Reference Values (TRV)

Table 2
Reference dose and slope factor for As

Element	RfD (mg/kg-d)	SF $(mg/kg\text{-}d)^{-1}$
As[a]	3×10^{-4}	1.5

[a] US EPA IRIS database (http://www.epa.gov/iriswebp/iris/index.html).

Step 3 : Exposure assessment

The average daily dose (ADD) of the contaminant via the identified pathways (i.e. soil ingestion, rice grain and drinking water pathways) indicates the quantity of chemical substance ingested per kilogram of body weight per day (Kolluru et al., 1996; Paustenbach, 2002) that:

$$\mathrm{ADD} = \frac{C \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT} \times 365} \quad (1)$$

Where C is the concentration of the contaminant in the environmental media (mg/kg or mg/L), IR is the ingestion rate per unit time (mg/day or L/day), ED is the exposure duration (years), EF is the exposure frequency (days/year), BW is the body weight of the receptor (kg), and AT is the averaging time (years), equal to the life expectancy for carcinogen, and 365 is the conversion factor from year to days. The principal exposure factors that have been taken into account to carry out the risk assessment calculations are shown in Table 1.

Table 1
Exposure factors for an adult Korean farmer

Factor/ parameter	Symbol	Units	Residential/ agricultural	Data source
Exposure duration	ED	years	30	US EPA, 1997
Exposure frequency	EF	days/ year	350	US EPA, 1997
Averaging time	AT			
Carcinogens	AT_C	years	76.5	KNSO, 2001
Non-carcinogens	AT_{NC}	years	30	US EPA, 1997
Body Weight	BW	kg	60	MOCIE, 1997
Ingestion rate				
Soil	IR_S	kg/day	100×10^{-6}	US EPA, 1997
Drinking water	IR_W	L/day	2.0	US EPA, 1997
Rice grain	IR_r	kg/day	0.358	KNSO, 2005

1 ADD soil ?

2 ADD water ?

3 ADD rice ?

Table 3
Range and mean concentration of As in tailings, soil, groundwaters and rice grains from the Myungbond Au–Ag mine

Sample type		Mean	Range	S.D.**
Tailings (mg/kg) (N* = 3)		2383	1946–3090	618
Soils (mg/kg)	Paddy soil (N = 5)	71.8	25–131	45
	Natural value of Korea[a]	9.6	6.1–13.0	–
	World's natural soil[b]	6.0	–	–
Groundwaters (mg/L) (N = 2)		0.008	0.007–0.009	0.001
Rice grains (mg/kg)	Rice grains (N = 5)	0.41	0.24–0.72	0.184
	Natural value of Korea[c]	0.09	0.02–0.15	–
	World's natural soil[d]	–	0.11–0.20	–

*N = no of samples , **S.D. = standard deviation.
[a]Ahn (2000), [b]Bowen (1979), [c]Rhu et al. (1988), [d]Kabata-Pendias and Pendias (1984).

Expression of the daily exposure dose

- ADD = Average Daily Dose

$$ADD = \frac{C \times IR \times EF}{BW \times 365}$$

$\times ED / AT$

Only taken into account for risk calculation!

$$\text{Daily exposure, } D = \frac{C \times Q \times F}{BW \times 365}$$

$$\frac{mg/kg \times kg/day \times days}{kg \times days}$$

Daily dose of exposure via soil ingestion ?

- ADD soil = 11,5 x 10^{-5} mg/kg/day

$$\text{ADD soil} = \frac{C \times IR \times EF}{BW \times 365}$$

$$\frac{mg/kg \times kg/day \times days}{kg \times days}$$

$$\frac{71{,}8 \times 100 \times 10^{-6} \times 350}{60 \times 365}$$

x ED / AT

Only taken into account for risk calculation!

Daily dose of exposure via water ingestion ?

- ADD water = $2{,}56 \times 10^{-4}$ mg/kg/day

$$\text{ADD water} = \frac{C \times IR \times EF}{BW \times 365}$$

$$\frac{mg/L \times L/day \times days}{kg \times days}$$

$$\frac{0{,}008 \times 2 \times 350}{60 \times 365}$$

x ED / AT

Only taken into account for risk calculation!

Daily dose of exposure via rice ingestion ?

- ADD rice = $2,3 \times 10^{-3}$ mg/kg/day

$$\text{ADD rice} = \frac{C \times IR \times EF}{BW \times 365}$$

x ED / AT

Only taken into account for risk calculation!

$$\frac{mg/kg \times kg/day \times days}{kg \times days}$$

$$\frac{0,41 \times 0,358 \times 350}{60 \times 365}$$

Step 4 : Risk characterization (threshold effect)

2.2.3. Risk characterization

Toxic risks refer to the non-carcinogenic harms incurred due to the exposures and the extent of the harm is indicated in terms of a hazard quotient (HQ) that:

$$HQ = ADD/RfD \quad (2)$$

The reference dose is the daily dosage that enables the exposed individual to sustain this level of exposure over a prolonged time period without experiencing any harmful effect. Toxic risk estimates are based on a comparison of actual exposure to the reference dose for the particular chemical involved. The RfD for chemicals is derived from toxicological data. When more than one potential toxicant or exposure pathway is present, the interactions must be considered. The HQs may then be summed to arrive at the overall toxic risk, the hazard index (HI) (Kolluru et al., 1996; Paustenbach, 2002) where:

$$HI = \Sigma HQ_i, \qquad i = 1 \ldots n. \quad (3)$$

If the calculated HI is less than 1.0, the non-carcinogenic adverse effect due to this exposure pathway or chemical is assumed to be negligible.

1 HQ soil ?

2 HQ water ?

3 HQ rice ?

4 Hazard index (HI) ?

Risk index for threshold effects ?

- Calculation of risk for non-carcinogenic effects: HQ

$$HQ = \frac{ADD\ (mg/kg/day)}{RfD\ (mg/kg/day)} \times ED / ATnc = \times 30 / 30$$

$$HQ\ soil = \frac{11{,}5 \times 10^{-5}}{3 \times 10^{-4}} = 0{,}38$$

$$HQ\ water = \frac{2{,}56 \times 10^{-4}}{3 \times 10^{-4}} = 0{,}85$$

$$HQ\ rice = \frac{2{,}3 \times 10^{-3}}{3 \times 10^{-4}} = 7{,}66$$

HI = HQ soil + HQ water + HQ rice = 8,89

Step 4 : Risk characterization (non-threshold effect)

The cancer risks are expressed in terms of the probability one may develop cancer at a given lifetime exposure level. The cancer risk probability is determined from the slope factor of the dose–response curve in the low-dose region where the relationship between the exposure dose (measured in mg/kg-day) and response (measured in terms of probability of developing cancer) is assumed to be linear. Mathematically, the SF denotes the probability of developing cancer per unit exposure level of mg/kg-day. The lifetime exposure level (ADD_{life}) is arrived by prorating the exposure incurred over the exposure duration over the expected life span. Cancer risk is then calculated as follows (Kolluru et al., 1996; Paustenbach, 2002):

$$\text{Cancer risk} = ADD_{life} \times SF \tag{4}$$

This equation applies to a linear low-dose cancer risk model that is valid for risks below 0.01.

1 Cancer risk soil ?

2 Cancer risk water ?

3 Cancer risk rice ?

4 Comparison with acceptable threshold (acceptable risk of 1 in 10,000) ?

Risk index for non-threshold effects?

- Calculation of risk for carcinogenic effects: Cancer risk (Cr) or Individual Excess Risk (IER)

$$Cr = ADD \times SF \times (ED / ATc)$$

$$Cr = mg/kg/day \times (mg/kg/day)^{-1} \times (years / years)$$

Cr soil = $11{,}5 \times 10^{-5} \times 1{,}5 \times (30 / 76{,}5)$ = $6{,}7 \times 10^{-5}$ = $\mathbf{0{,}67 \times 10^{-4}}$

Cr rice = $2{,}3 \times 10^{-3} \times 1{,}5 \times (30 / 76{,}5)$ = $1{,}3 \times 10^{-3}$ = $\mathbf{13 \times 10^{-4}}$

Cr water = $2{,}56 \times 10^{-4} \times 1{,}5 \times (30 / 76{,}5)$ = $\mathbf{1{,}5 \times 10^{-4}}$