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Modeling of risk assessment and remedial goal around closed metal mining areas

Ilwon Ko, Cheol-Hyo Lee, Ju-Young Kim*, Kwang-Pyo Lee, Kyoung-Woong Kim*

Environmental Research Center, OIKOS Co., Ltd.
**Arsenic Geoenvironment Lab. (NRL), Department of Environmental Sci. & Eng., GIST (iwko@oikos.co.kr)*

<요 약 문>

국내 폐금속광산 일대에서 비소 및 중금속의 발암 및 비발암 위해성을 근거로 복원 기준치를 설정하였다. 폐금속광산일대의 주요한 노출 경로는 부지내 폐광석과 광미로부터 직접적인 오염물 흡입과 지하수를 통한 부지내 및 외 섭취의 경로로 구분된다. 지하수의 오염원은 폐광석과 광미 침출로부터의 오염과 갱구 유출로부터의 오염 및 지질매체 자체에 의한 오염이 설정되었다. 높은 오염 수준에 대해서 높은 오염성분감소비와 폐광산일대의 다양한 배경농도로부터 복원기준치를 설정 했을때, 토양 및 지하수의 복원기준치는 비소 위해도의 영향이 매우 큰 것으로 평가되었다. 비소의 높은 독성은 복원 기준치를 매우 낮게 형성했고, 위해도가 낮은 아연과 카드늄은 높게 설정되었다. 궁극적으로 오염성분 감소비에 따른 복원기준치 설정은 오염성분의 노출 경로 차단이 복원 목표치를 현실화 시킬 수 있음을 보여주었다.

주요어 : 폐금속광산, 위해성평가, 비소 및 중금속, 복원기준치, 노출경로

1. Introduction

There is no reasonable regulation standard in Korea for the remediation of the soil and groundwater contaminated with arsenic and heavy metals that is used for drinking or for industry and agriculture (Ko et al., 2003). The possibility of potential harmful effects on human health is variable and risk based corrective action (RBCA) has suggested the remedial goals of target contaminants for the remediation of soil and groundwater (ASTM, 1998). RBCA is based on the potential risk posed by contaminated site and the corrective action goals are provided with acceptable remediation level to reduce these risks (ASTM, 1995). This study suggests the order of urgent remediation of mine area in Korea based on the risk assessment.

2. Modeling of risk assessment and remedial goal

RBCA decision was carried out using RBCA tool kit for chemical releases (Version 1.3;

Groundwater service, Inc.). The exposure parameters were adjusted with physiological and statistical values suitable for Korean people such as mean body weight, life time, exposure frequencies of various activities and etc. (Lee et al., 2003; USEPA, 1997). Target elements are As, Cd and Zn based on the database of RBCA tool kit. Despite the lack of reference dose for chronic oral exposure from integrated risk information system (IRIS), only three elements were considered. The RBCA decision was used for the chemical data of soil and groundwater as a contaminant source and those of groundwater apart from a contaminant source. In addition, the groundwater transport was modeled with dilution attenuation factor (DAF) using the location and chemical data from groundwater sampling.

3. Results and Discussion

3.1 Exposure assessment from the mine areas

The source media, transport mechanism, exposure media and receptors were chosen for the specific environmental condition of mine areas (ASTM, 1995). In this study, the target area of risk assessment as a source media includes uncovered contaminant-including wastes as well as contaminant plume from the mine tailings or waste rocks. The chemical analysis data of mine tailings and leachates for the exposure assessment were used to determine the magnitude of exposure, which is the qualitative or quantitative magnitude for potential health risk. Exposure pathways are characterized of two patterns of direct contact with mine wastes such as tailings and waste rocks and affected groundwater. Particularly, affected groundwater is assumed to be two types of a contaminant plume of leaching from mine waste and waste water from mine pit. The mines are located at the small valley and surface water is developed with shallow and variable water level, and then groundwater is expected to be affected from the surface water.

3.2 Remedial goals of the contaminated mine areas

Arsenic is carcinogenic toxic chemical and Cd and Zn are considered as noncarcinogenic toxic chemicals (USEPA, 1997; ASTM, 1998). The overall hazard quotients were calculated from the sum of individual indices for Cd and Zn and for As, the cancer risk was also calculated (USEPA, 1989). The media available for human contact are soil and groundwater on-site and potential future receptors are on-site workers. Both hazard quotient and cancer risk of on-site groundwater was more than those of soil. The off-site risk significantly reduced except for the Dongil mine (7.3E-6 for cancer risk and 2.0 for hazard quotient). Therefore, the Dongil mine needs the urgent remedial action. Because the risk associated with off-site exposures was related with the migration of the contaminant plume to residential areas, the chemical data of groundwater and sampling location from the contaminant plume became significant in enhancing risk values. However, the risk of the on-site soil exposure seemed to reduce the risk due to the low frequency of dermal and ingestion.

Risk-based remedial goals were set up during data evaluation of the baseline risk assessment as the identification of arsenic and heavy metals of potential concerns. Table 1 shows the calculated proposed remedial goals based on the site-specific risk levels. The organic contaminants zero background level, but the concentrations of heavy metals have the background level (ASTM, 1998). Cleanup criteria level was calculated with sum of the background level and site specific target level (SSTL). The degree of remedial work can be also summarized by the concentration reduction factor (CRF). CRF is represented by the contaminant concentration divided by target concentration for remedial cleanup. An increase in CRF values means the lower remedial goal level for the reduction of baseline risk. Although the CRF values were higher than those of groundwater due to the high contents of contaminants in mine tailings, the cleanup criteria levels of mine tailings were higher than the maximum concentration level (MCL). However, the levels of groundwater (4.1 µg As/L) were a little lower than the legally enforced level based on MCL (50 µg As/L in Korean regulation; 10 µg As/L in WHO). For the remediation of soil and groundwater, As was the highest values of CRF, particularly, for the Songcheon mine due to the highest contents of As (133,900 mg As/kg). Despite the highest health risk of the Dongil mine, the CRF of As was intermediate order in the CRF values of As in both soil and groundwater: Songcheon > Dongjung > Dongil > Myoungbong > Dukeum. In addition, the CRF values of Zn and Cd were also suggested for Dongil, Dongjung and Songcheon mine. Characteristically, Dongjung mine had the CRF value of Cd in the groundwater because mine leachates of waste rock and tailings as a contaminant source of groundwater had the highest value of about 20 µg Cd/L. Therefore, health risk and remedial goal levels in the mine areas are ascribed to the direct on-site exposure from wasterocks and tailings and off-site exposure from the contaminant transport in mine leachates such as a contaminant source.

Table 1. Proposed remedial goals as a cleanup criteria level with respect to each contaminant in mine area.

Mines	Elements	Background level		Site specific target level (SSTL)		Cleanup criteria level		CRF	
		Soil (mg/kg)	Groundwater (µg/L)	Soil (mg/kg)	Groundwater (µg/L)	Soil (mg/kg)	Groundwater (µg/L)	Soil	Groundwater
Dukeum	As	8.2	4	2.8E-3	5.7E-2	8.2	4.1	45000	25
	Zn	101	2.2	920	2800	1021	2802	<1	<1
	Cd	0.8	0.2	0	17	0.8	17	<1	<1
Dongil	As	6.7	4	3.1E-2	1.4	6.7	5.4	490000	600
	Zn	34	23	1800	340	1834	363	1.5	<1
	Cd	0.3	0.2	37	4	37	4.2	15	<1
Dongjung	As	5.2	4	2.8E-3	5.7E-2	5.2	4.1	850000	49
	Zn	26.3	3.1	1200	9200	1226	9203	1.1	<1
	Cd	0.4	0.2	1.0E-5	18	0.4	18	<1	1.1
Myoungbong	As	7.8	4	2.8E-3	5.7E-2	7.8	4.1	360000	300
	Zn	23	6.1	5.4	9	28	15	<1	<1
	Cd	0.4	0.2	1.3	1.0E-2	1.7	0.2	<1	<1
Songcheon	As	7.5	4	2.8E-3	5.7E-2	7.5	4.1	47000000	6500
	Zn	55	0.2	1200	22	1255	22	2.8	<1
	Cd	2.3	0.2	1.0E-5	1.0E-2	2.3	0.2	<1	<1

4. Conclusions

1) Health risk and remedial goal levels in the mine areas are ascribed to the direct on-site exposure from wasterocks and tailings and off-site exposure from the contaminant transport in mine leachates such as a contaminant source.

2) Based on the exposure health risk of hazard quotient and cancer risk of As, Cd and Zn, the

Dongil mine needs the urgent remedial action. The risk associated with off-site exposures was significantly related in enhancing risk values through the contaminant migration from the contaminant plume to residential areas.

3) Despite the highest health risk of the Dongil mine, the CRF of As was intermediate order in the CRF values of As in both soil and groundwater: Songcheon > Dongjung > Dongil > Myoungbong > Dukeum. In addition, Dongjung mine had the CRF value of Cd in the groundwater because mine leachates of waste rock and tailings as a contaminant source of groundwater had the highest value of about 20 µg Cd/L.

4) Due to the high contents of contaminants in mine tailings, their cleanup criteria levels were higher than the maximum concentration level (MCL). However, the levels of groundwater were a little lower than the legally enforced level based on MCL.

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