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Derivation of Ecological Protective Concentration using the Probabilistic Ecological Risk Assessment applicable for Korean Water Environment: (I) Cadmium

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Probabilistic ecological risk assessment (PERA) for deriving ecological protective concentration (EPC) was previously suggested in USA, Australia, New Zealand, Canada, and Netherland. This study suggested the EPC of cadmium (Cd) based on the PERA to be suitable to Korean aquatic ecosystem. First, we collected reliable ecotoxicity data from reliable data without restriction and reliable data with restrictions. Next, we sorted the ecotoxicity data based on the site-specific locations, exposure duration, and water hardness. To correct toxicity by the water hardness, EU's hardness corrected algorithm was used with slope factor 0.89 and a benchmark of water hardness 100. EPC was calculated according to statistical extrapolation method (SEM), statistical extrapolation method$_{\text{Acute to chronic ratio}}$ (SEM_{ACR}), and assessment factor method (AFM). As a result, aquatic toxicity data of Cd were collected from 43 acute toxicity data (4 Actinopterygill, 29 Branchiopoda, 1 Polychaeta, 2 Bryozoa, 6 Chlorophyceae, 1 Chanophyceae) and 40 chronic toxicity data (2 Actinopterygill, 23 Branchiopoda, 9 Chlorophyceae, 6 Macrophytes). Because toxicity data of Cd belongs to 4 classes in taxonomical classification, acute and chronic EPC (11.07 μg/*l* and 0.034 μg/*l*, respectively) was calculated according to SEM technique. These values were included in the range of international EPCs. This study would be useful to establish the ecological standard for the protection of aquatic ecosystem in Korea.

Key words: Ecological protective concentration (EPC), Probabilistic ecological risk assessment (PERA), cadmium, Statistical extrapolation method (SEM), Assessment factor method (AFM)

INTRODUCTION

Probabilistic ecological risk assessment (PERA) is a technique to overcome the limitation of Deterministic ecological risk assessment (DERA) that determines if there is potential risk or not, and it is extensive approach to qualify and quantify risk on the multispecies based on species sensitivity distribution (SSD) (George *et al*., 2003). Developed countries, including USA, Australia, New Zealand, Canada, and Netherland, presented criteria or guideline for protecting the ecosystem with PERA technique (ANZECC and ARMCANZ, 2000a; CCME, 1999; RIVM, 2001; USEPA, 2009). In addition, there were reports, papers, and guidelines according to PERA in Korea. For example, the report that derives the water quality criteria for protecting the ecosystem using PERA from Australia and New Zealand was suggested by Ministry of Environment and National Institute of Environmental Research of Korea (2006), and An *et al*. (2009) proposed PERA for Korean water environment. Especially, Korean established rule No. 415 institutionally reflected the PERA in 2010.

Along with improving the awareness to manage the chemicals with the PERA, institutionalization of the relevant guideline and the performance of the relevant project were conducted (ME, 2004, 2007). Up to now, Korean government withheld criteria, guidelines, or standards for each chemical from the public. However, environmental and health policy for focusing on receptors interests ecosystem as well as human health. The study present the case study that establishs the water quality standards for protecting the ecosystem based on PERA approach. Prior to performing the stringent guidelines or standards through technical and economical analyses, ecological protective concentration (EPC) based on the scientific data is needed to present first. Case study of EPC is needed to conduct based on the PERA applicable for Korean water environment. Our purpose in this study was to suggest EPC of cadmium (Cd) based on the PERA applicable for Korean water environment pre-

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sented by An *et al*. (2009).

MATERIALS AND METHODS

Selection of test chemicals. We selected Cd as a test chemical to derive the Korean EPA. According to An et al. (2009), toxicity of some heavy metals (e.g. Cd, Cu, Cr3+, Ni, Pb, Ag, and Zn) is different based on water hardness. Therefore hardness correction procedure is needed to induce the accuracy of ecotoxicity data. Especially, Cd and Pb were substances for the protection of human health in Korea. Along with Integrated Risk Information System (IRIS), carcinogenic classification of Cd and Pb are B1 (Probable human carcinogen - based on limited evidence of carcinogenicity in humans) and B2 (Probable human carcinogen - based on sufficient evidence of carcinogenicity in animals), respectively. Some papers presented toxicity values of Cd were more sensitive than Pb. Ninety six hours NOECs of *Selenastrum capricornutum* were 0.02 mg/*l* for Cd and 0.06 mg/*l* for Pb (Chao and Chen, 2000). Forty eight hours LC50s of *Daphnia pulex, Ceriodaphnia reticulata* and *Simocephalus vetulus* were 0.068, 0.066 and 0.024 mg/*l* for Cd and 5.1, 0.53 and 4.5 mg/*l* for Pb (Mount and Norberg, 1984). Therefore Cd was selected as a test chemical because it is more toxic than Pb based on the human health toxicity and ecotoxicity.

Collection of ecotoxicity data. Reliable ecotoxicity data was collected from reliable data without restriction (e.g. toxicity data based on the Good Laboratory Practice) and reliable data with restrictions (e.g. SCI(E) papers), according to Klimisch *et al*. (1997) and An *et al.* (2009). These references were from the US EPA's ECOTOXicology Database (ECOTOX; http://www.epa.gov/ecotox), Australia and New Zealand's TOX-2000 Database, ECB's International Uniform Chemical Information Database (IUCLID), USEPA's ambient water quality criteria reports (ANZECC and ARMCANZ, 2000b; ECB, 2000; USEPA, 1980, 1985, 1996, 2001, 2005).

Sorting of ecotoxicity data based on the site-specific locations, exposure duration, and water hardness. To induce Korean aquatic ecosystem through consideration of mutual relation among Korean organisms, we sorted the ecotoxicity data based on the site-specific locations. We utilized the research papers and illustrated books of Korean organisms (An *et al*., 2007a, 2007b, 2008; Kim, 1982; Kim and Park, 2002; KIWE, 2000; ME, 1968, 1996; Nam *et al*., 2007; NIER, 2004). Ecotoxicity data included domestic species that live in the Korean aquatic ecosystem and introduced species that settle down in the Korean water environment but excluded domestic species that locally live in the Korean aquatic ecosystem. Also, we sorted the acute and chronic exposure duration with life cycle of species based on the papers (An *et al*., 2007a, 2008; Nam *et al*., 2007). According to Nam *et al*. (2007), fish toxicity data included lethality, embryo and sac-fry stages, early-life stage, and juvenile growth toxicity test, and these data were classified by the endpoints. Acute and chronic duration of lethality toxicity test was categorized as 14 days, and duration of embryo and sac-fry stages test was maintained with the time from embryo to sac-fry. Chronic duration of early-life stage test was the time from embryo to adult, and chronic duration of juvenile growth toxicity test was until adult appears. Cladoceran reproductive toxicity data were assessed in the time that they reproduce at least third broods and lethality and immobilization toxicity test data were different according to life cycle of species (An *et al*., 2007a). Along with An *et al*. (2008a), acute and chronic duration of green algae growth inhibition toxicity data were divided by 72 hours. Aquatic toxicity of some heavy metals differs according to water hardness. So, correction of water hardness is needed to replace water hardness presented in the test with the benchmark of water hardness. In this study, we corrected the toxicity values from the EU's hardness corrected algorithm; hardness corrected toxicity value = toxicity value presented in the test X (the benchmark of water hardness/ water hardness presented in the test)$^{\text{slope factor}}$ (EU, 2007). At this time, 0.89 is used as a slope factor (ANZECC and ARMCANZ, 2000a) and 100 are used as a benchmark of water hardness (An *et al*., 2008b).

Calculation of ecological protective concentration. We utilized the domestic PERA techniques (e.g. Statistical extrapolation method (SEM), Statistical extrapolation method$_{\text{Acute to chronic ratio}}$ (SEM_{ACR}), and Assessment factor method (AFM) presented by An *et al*. (2009). It is based on the PERA techniques to protect the ecosystem in developed countries (e.g. USA, Australia, New Zealand, Canada, and Netherland). These techniques are used as related sufficiency of toxicity data. SEM is applied to sufficient acute median lethal concentration (LC50) values, acute median effective concentration (EC50) values, or chronic no-observed-effective concentration (NOEC) values and used the fifth percentile hazard concentration (HC5) from species sensitivity distribution (SSD) presented by E_TX program. At this time, the data should include at least 4 classes in taxonomical classification (e.g. Actinopterygill, Branchiopoda, Chlorophyceae, Maxillapoda, Insects, Bivalvia, Gastropoda, Secernentea, Polychaeta, Monocotyldoneae, Chanophyceae, and etc.). SEM_{ACR} is applied to the case where chronic toxicity data were insufficient but acute toxicity data were sufficient. At this time, HC5 calculated from the acute LC50 and EC50 was divided by acute to chronic ratio (ACR), and ACR was derived from the acute and chronic toxicity values of the same species. AFM is applied to the insufficient acute and chronic toxicity data. The lowest acute LC50,

Table 1. Assessment factor (AF) for deriving the concentration for protection of aquatic ecosystem

Available data	Assessment factor	Reference
Acute L(E)C50 or QSAR estimate from a set of data on one or two aquatic species	1000	OECD, 1995
Acute L(E)C50 or QSAR estimate from a set of data at least consisting of algae, crustaceans and fish	100	OECD, 1995
One long-term NOEC (either fish or daphnia)	100	EC, 2003
Two long-term NOECs from species representing two trophic levels (fish and/or daphnia and/or algae)	50	EC, 2003
Long-term NOECs from at least three species (normally fish, daphnia and algae) representing three trophic levels	10	EC, 2003

EC50, or chronic NOEC were divided by assessment factor (AF) presented in Table 1.

RESULTS

Aquatic toxicity data of Cd were collected 43 acute toxicity data (4 Actinopterygill, 29 Branchiopoda, 1 Polychaeta, 2 Bryozoa, 6 Chlorophyceae, 1 Chanophyceae) and 40 chronic toxicity data (2 Actinopterygill, 23 Branchiopoda, 9 Chlorophyceae, 6 Macrophytes) as listed in Table 2, 3 and 4. Actinopterygill toxicity data were tested with *Cyprinus carpio*, *Gasterosteus aculeatus* and *Lepomis macrochirus* and their adverse effects were lethality and vertebral column damage. Branchiopoda toxicity data were conducted with *Ceriodaphnia dubia*, *Ceriodaphnia reticulata*, *Daphnia pulex*, *Moina macrocopa*, *Simocephalus serrulatus* and *Simocephalus ventulus* and lethal and reproductive effects were tested in 2~4 and 7~70 days. Polychaeta and Bryozoa toxicity data were only assessed in acute exposure duration and lethal effect were tested with *Branchiura sowerbyi*, *Lophopodella carteri* and *Pectinatella magnifica*. Chlorophyceae toxicity data were conducted with *Chlorella vulgaris*, *Selenastrum capricorntum* and *Ankistrodesmus falcatus* and acute and chronic growth inhibition effects were assessed in 1~2 and 4~14 days. Chanophyceae toxicity data were only tested in acute exposure duration and growth inhibition effects were conducted with *Microcystis aeruginosa* for 1 day. Macrophytes toxicity data were only tested in chronic exposure duration and *Lemna paucicostata* were assessed in 7 days for investigating change of number of fonds.

Table 2. The present condition of aquatic toxicity data for cadmium selected in this study

Classification	Toxicity data	
	Acute	Chronic
Actinopterygill	4	2
Branchiopoda	29	23
Polychaeta	1	0
Bryozoa	2	0
Chlorophyceae	6	9
Macrophytes	0	6
Chanophyceae	1	0
Total	43	40

The EPC of Cd for acute and chronic toxicity effects was calculated according to SEM technique because of toxicity data belong to 6 classes (Actinopterygill, Branchiopoda,

Table 3. List of acute toxicity data for cadmium

Scientific name (Common name)	Exposure duration (d)	Endpoint	Hardness (mg $CaCO_3/l$)	Toxicity value (μg/*l*)	Hardness corrected toxicity value (μg/*l*)	Species mean acute value (μg/*l*)	References
Class Actinopterygill							
Cyprinus carpio (Common carp)	-	L(E)C50	100	4,300	4,300	8,575	USEPA(1980, 1985, 1996, 2001)
Cyprinus carpio (Common carp)	-	L(E)C50	100	17,100	17,100		USEPA(1980, 1985, 1996, 2001)
Gasterosteus aculeatus (Threespine stickleback)	-	L(E)C50	115	6,500	5,740	11,149	USEPA(1980, 1985, 1996, 2001)
Gasterosteus aculeatus (Threespine stickleback)	-	L(E)C50	107	23,000	21,656		USEPA(1980, 1985, 1996, 2001)

Table 3. Continued

Scientific name (Common name)	Exposure duration (d)	Endpoint	Hardness (mg $CaCO_3$/*l*)	Toxicity value (μg/*l*)	Hardness corrected toxicity value (μg/*l*)	Species mean acute value (μg/*l*)	References
			Class Branchiopoda				
Ceriodaphnia dubia (Water flea)	4	LC50	17	17	82		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	2	LC50	83	50	59		Diamond et al.(1997)
Ceriodaphnia dubia (Water flea)	2	EC50	90	54	59		Bitton et al.(1996)
Ceriodaphnia dubia (Water flea)	-	L(E)C50	80	55	66		USEPA(1980, 1985, 1996, 2001)
Ceriodaphnia dubia (Water flea)	-	L(E)C50	90	56	61		USEPA(1980, 1985, 1996, 2001)
Ceriodaphnia dubia (Water flea)	2	LC50	17	63	305	114	Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	2	LC50	83	107	127		Diamond et al.(1997)
Ceriodaphnia dubia (Water flea)	2	LC50	83	160	190		Diamond et al.(1997)
Ceriodaphnia dubia (Water flea)	2	LC50	83	213	253		Diamond et al.(1997)
Ceriodaphnia dubia (Water flea)	2	LC50	290	220	89		Schubauer-Berigan et al.(1993)
Ceriodaphnia dubia (Water flea)	2	LC50	290	560	217		Schubauer-Berigan et al.(1993)
Ceriodaphnia reticulata (Water flea)	2	LC50	45	66	134		Mount and Norberg.(1984)
Ceriodaphnia reticulata (Water flea)	-	L(E)C50	120	110	94	98	USEPA(1980, 1985, 1996, 2001)
Ceriodaphnia reticulata (Water flea)	-	L(E)C50	240	184	84		USEPA(1980, 1985, 1996, 2001)
Ceriodaphnia reticulata (Water flea)	2	EC50	230	184	88		Elnabarawy et al.(1986)
Daphnia pulex (Water flea)	-	L(E)C50	57	47	78		USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	-	L(E)C50	85	66	76		USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	2	LC50	45	68	138		Mount and Norberg.(1984)
Daphnia pulex (Water flea)	-	L(E)C50	85	70	81	102	USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	-	L(E)C50	54	70	122		USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	-	L(E)C50	120	80	68		USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	-	L(E)C50	85	99	114		USEPA(1980, 1985, 1996, 2001)

Table 3. Continued

Scientific name (Common name)	Exposure duration (d)	Endpoint	Hardness (mg $CaCO_3$/*l*)	Toxicity value (μg/*l*)	Hardness corrected toxicity value (μg/*l*)	Species mean acute value (μg/*l*)	References
Daphnia pulex (Water flea)	-	L(E)C50	120	100	85	102	USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	2	EC50	230	319	152		Elnabarawy et al. (1986)
Daphnia pulex (Water flea)	-	L(E)C50	240	319	146		Elnabarawy et al.(1986)
Moina macrocopa (Water flea)	-	L(E)C50	82	71	85	85	USEPA(1980, 1985, 1996, 2001)
Simocephalus serrulatus (Water flea)	-	L(E)C50	11	7	50	50	USEPA(1980, 1985, 1996, 2001)
Simocephalus serrulatus (Water flea)	-	L(E)C50	44	25	51		USEPA(1980, 1985, 1996, 2001)
Simocephalus ventulus (Water flea)	2	LC50	45	24	49	49	Mount and Norberg.(1984)
Class Polychaeta							
Branchiura sowerbyi (Tbificid worm)	-	L(E)C50	5	240	3,278	3,278	USEPA(1980, 1985, 1996, 2001)
Class Bryozoa							
Lophopodella carteri (Bryozoan)	-	L(E)C50	205	150	79	79	USEPA(1980, 1985, 1996, 2001)
Pectinatella magnifica (Bryozoan)	-	L(E)C50	205	700	370	370	USEPA(1980, 1985, 1996, 2001)
Class Chlorophyceae							
Chlorella vulgaris (green algae)	2	EC50	-	5,100	-	-	USEPA(1980, 1985, 1996, 2001)
Chlorella vulgaris (green algae)	2	EC50	-	15,720	-		USEPA(1980, 1985, 1996, 2001)
Selenastrum capricorntum (green algae)	2	EC50	-	109	-	1,845	USEPA(1980, 1985, 1996, 2001)
Selenastrum capricorntum (green algae)	1	EC50	16	341	1,845		Chen and Lin(1997)
Selenastrum capricorntum (green algae)	1	EC50	-	341	-		Chen et al (1997)
Selenastrum capricorntum (green algae)	1	EC50	-	2	-		USEPA(1980, 1985, 1996, 2001)
Class Chanophyceae							
Microcystis aeruginosa (Blue-green algae)	1	EC50	-	1	-	-	USEPA(1980, 1985, 1996, 2001)

Polychaeta, Bryozoa, Chlorophyceae, Chanophyceae) and 4 classes (Actinopterygill, Branchiopoda, Chlorophyceae, Macrophytes) in taxonomical classification. Species mean acute (chronic) value (SMA(C)V), geometric mean calculated from toxicity values of same species, was used as input data to run program, and SMAV and SMCV of Cd were calculated from 12 and 7 species, respectively. Acute and chronic SSD of Cd was presented in Fig. 1 and Fig. 2, and acute and chronic HC5 were calculated as 11.07 (1.3~40.2) μg/*l* and 0.034 (0.0002~0.4) μg/*l*, respectively.

Table 4. List of chronic toxicity data for cadmium

Scientific name (Common name)	Exposure duration (d)	Endpoint	Hardness (mg $CaCO_3/l$)	Toxicity value (μg/*l*)	Hardness corrected toxicity value (μg/*l*)	Species mean chronic value (μg/*l*)	References
Class Actinopterygill							
Lepomis macrochirus (Bluegill)	-	Chronic value	207	50	26	26	USEPA(1980, 1985, 1996, 2001)
Cyprinus carpio (Common carp)	47	LOEC (vertebral column damage)	18	10	46	46	ECB(2000)
Class Branchiopoda							
Ceriodaphnia dubia (Water flea)	8	NOEC (Reproduction)	-	0	-	27	ANZECC and ARMCANZ(2000b)
Ceriodaphnia dubia (Water flea)	7	NOEC (Reproduction)	17	1	5		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	10	NOEC (Reproduction)	17	1	5		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	14	NOEC (reproduction)	17	1	5		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	7	NOEC (Survival)	17	10	48		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	10	NOEC (Survival)	17	10	48		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	14	NOEC (survival)	17	10	48		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	10	LOEC (survival)	17	13	63		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	10	LOEC (reproduction)	17	4	19		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	7	LOEC (survival)	17	13	63		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	7	LOEC (reproduction)	17	4	19		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	14	LOEC (survival)	17	13	63		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	14	LOEC (reproduction)	17	4	19		Suedel et al.(1997)
Ceriodaphnia dubia (Water flea)	-	Chronic Value	20	14	58		Jop et al.(1995)
Ceriodaphnia dubia (Water flea)	-	NOEC (survival)	22	19	73		Jop et al.(1995)
Daphnia pulex (Water flea)	21	NOAEL (reproduction)	-	0.003	-	0.1	USEPA(1980, 1985, 1996, 2001)
Daphnia pulex (Water flea)	14	LOEL (reproductive impairment)	230	0.2	0.1		Elnabarawy et al.(1986)
Daphnia pulex (Water flea)	70	NOEC (GRO)	-	2	-		ANZECC and ARMCANZ(2000b)
Daphnia pulex (Water flea)	70	NOEC (Mortality)	-	2	-		ANZECC and ARMCANZ(2000b)

Table 4. Continued

Scientific name (Common name)	Exposure duration (d)	Endpoint	Hardness (mg $CaCO_3$/*l*)	Toxicity value (μg/*l*)	Hardness corrected toxicity value (μg/*l*)	Species mean chronic value (μg/*l*)	References
Daphnia pulex (Water flea)	70	NOEC (reproduction)	-	2	-	0.1	ANZECC and ARMCANZ(2000b)
Daphnia pulex (Water flea)	7	NOEC (Mortality)	-	5	-		Goerke et al.(1990)
Daphnia pulex (Water flea)	14	NOEC (reproduction)	-	8	-		Elnabarawy et al.(1986)
Ceriodaphnia reticulata (Water flea)	7	LOEL(Reproductive impairment)	230	0.2	0.1	0.1	Elnabarawy et al.(1986)
Class Chlorophyceae							
Ankistrodesmus falcatus (Green algae)	14	NOEC (Growth)	-		-	271	ANZECC and ARMCANZ(2000b)
Ankistrodesmus falcatus (Green algae)	14	NOEC (Growth)	-	6	-		ANZECC and ARMCANZ(2000b)
Ankistrodesmus falcatus (Green algae)	4	NOEC (Individual)	-	10	-		Baer et al.(1999)
Scenedesmus acutus (Green algae)	14	NOEC (Growth)	-	8	-		ANZECC and ARMCANZ(2000b)
Selenastrum capricornutum (Green algae)	14	NOEC (Growth)	-	17	-		ANZECC and ARMCANZ(2000b)
Selenastrum capricornutum (Green algae)	4	NOEC (cell density)	-	20	-		Chao et al.(2000)
Selenastrum capricornutum (Green algae)	14	NOEC (Growth)	-	32	-		ANZECC and ARMCANZ(2000b)
Selenastrum capricornutum (Green algae)	4	NOEC (total cell volume)	-	50	-		Chao et al.(2000)
Selenastrum capricornutum (Green algae)	4	NOEC (biomass)	15	50	271		ECB(2000)
Class Macrophytes							
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	120	5	4	9	ECB(2000)
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	120	10	9		ECB(2000)
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	700	10	2		ECB(2000)
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	120	10	9		ECB(2000)
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	120	100	85		ECB(2000)
Lemna paucicostata (Duck weed)	7	NOEC (No. of fonds)	700	50	9		ECB(2000)

DISCUSSION

The EPCs of Cd were presented by US EPA, Australia, New Zealand, Canada, EC, and the Netherland. The acute EPC was only suggested 2 μg/*l* in national recommended water quality criteria of US EPA (USEPA, 2009). Other

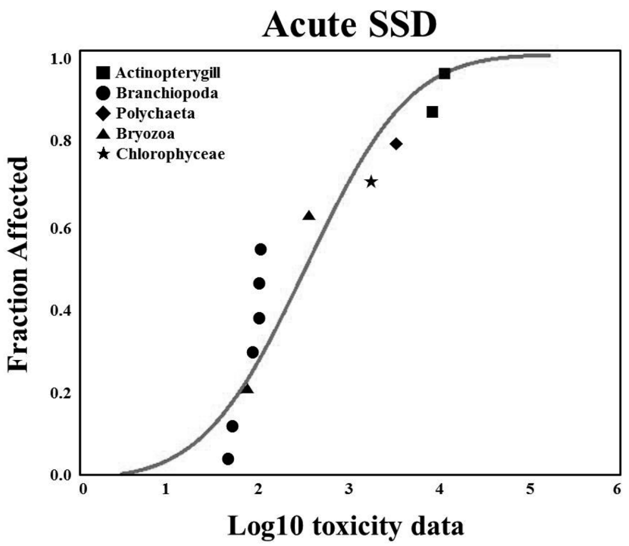

Fig. 1. Acute species sensitivity distribution for cadmium.

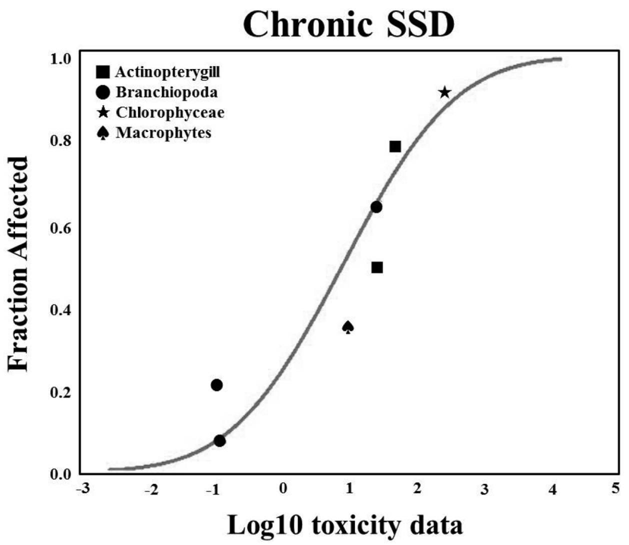

Fig. 2. Chronic species sensitivity distribution for cadmium.

international EPCs was presented as chronic value including 0.25 μg/*l* for US EPA, 0.2 μg/*l* for Australia and New Zealand, 0.017 μg/*l* for Canada, 0.19 μg/*l* for EC and 0.34 μg/*l* for the Netherland (ANZECC and ARMCANZ, 2000a; CCME, 1999; EC, 2007; USEPA, 2009). EPCs of US EPA were calculated at a total hardness of 100 mg/*l* as $CaCO_3$ according to equation for freshwater dissolved metals criteria that are hardness-dependent. Equations for freshwater dissolved metals criteria of US EPA were as follows; $0.973[e^{\{1.0166[\ln(hardness)]-3.924\}}]$ for acute EPC and $0.938[e^{\{0.7409[\ln(hardness)]-4.719\}}]$ for chronic EPC. At this time, 1.0166 and 0.7409 were pooled slopes generated from pooled data set, where every variable is adjusted relative to its mean and −3.924 and −4.719 were intercepts calculated from ln (half of final acute value) − [pooled slope * ln (hardness)] (USEPA, 2001, 2009). EPC of Australia and New Zealand is high reliability trigger value that is applied to statistical distribution method at 95% protection by BurrliOZ software. Seventy-three chronic toxicity data of Cd were available and these were fish, amphibians, crustaceans, insects and algae, and were adjusted to 30 mg/*l* as $CaCO_3$ surface water hardness (ANZECC and ARMCANZ, 2000a). Canadian EPC is derived by multiplying LOEL of 0.17 μg/*l* for *D. magna* by safety factor of 0.1 (CCME, 1999). EPC of EC is 0.09 μg/*l*; derived from 44 chronic toxicity data at 95% protection by EtX software, dividing by assessment factor of 2. These toxicity data were tested with 19 fish and amphibians, 22 invertebrates and 8 primary producers. The standard value of hardness is 50 mg/*l* as $CaCO_3$ (EC, 2007). Dutch EPC were derived from statistical distribution method at 95% protection by EtX software and 45 NOEC values includes 14 pisces, 6 crustaceans, 1 annelids, 2 molluscs, 1 rotifera, 2 protozoa, 6 macrophyta, 9 algae, 2 cyanophyta and 2 bacteria (RIVM, 2001). The confidential limits (0.0002~0.4 μg/*l*) of chronic EPC (0.034 μg/*l*) calculated in this study were included the range of international chronic EPC (0.017~1.79). However chronic EPC (0.034 μg/*l*) calculated in this study were more sensitive than US EPA, Australia and New Zealand, EC and the Netherland using the statistical distribution method, except for Canada. Chronic toxicity data of Cd selected from this study were mainly included sensitive crustaceans while these countries have a variety of chronic toxicity data. Therefore we expected lower toxicity value for crustaceans affected deduction of HC5. Recommended technique for deriving the EPC can be applicable to hazardous chemicals. This study would be useful to establish the ecological standard for the protection of aquatic ecosystem in Korea.

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