

Supplementary information

Figure S1. Pairwise mean comparison of physiological sensitivity values for each taxon of the eleven heavy metals expressed as S_{As} , S_{Cd} , S_{Co} , S_{Cr} , S_{Cu} , S_{Fe} , S_{Hg} , S_{Ni} , S_{Pb} , S_{Se} and S_{Zn} . Histograms display the distribution of standardized sensitivity values for each heavy metal. The upper panel shows the Pearson correlation coefficient (r) and the number of pairwise comparisons (n), while the lower panel presents the plotted values for each pair of heavy metals.

Table S1. Summary of Acute Toxicity Test Results for Selected Freshwater Species Exposed to Copper

Table S2. Summary of results for the fixed factors of the mixed effect model

Table S3. Physiological sensitivity (S) values for As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Se and Zn for each taxonomic level

Table S4. Summary of site-specific environmental parameters, macroinvertebrate community indices^c, and toxicity values in the Upper Nakdong River

Table S5. Information on benthic macroinvertebrate species found in the upper Nakdong River

Reference

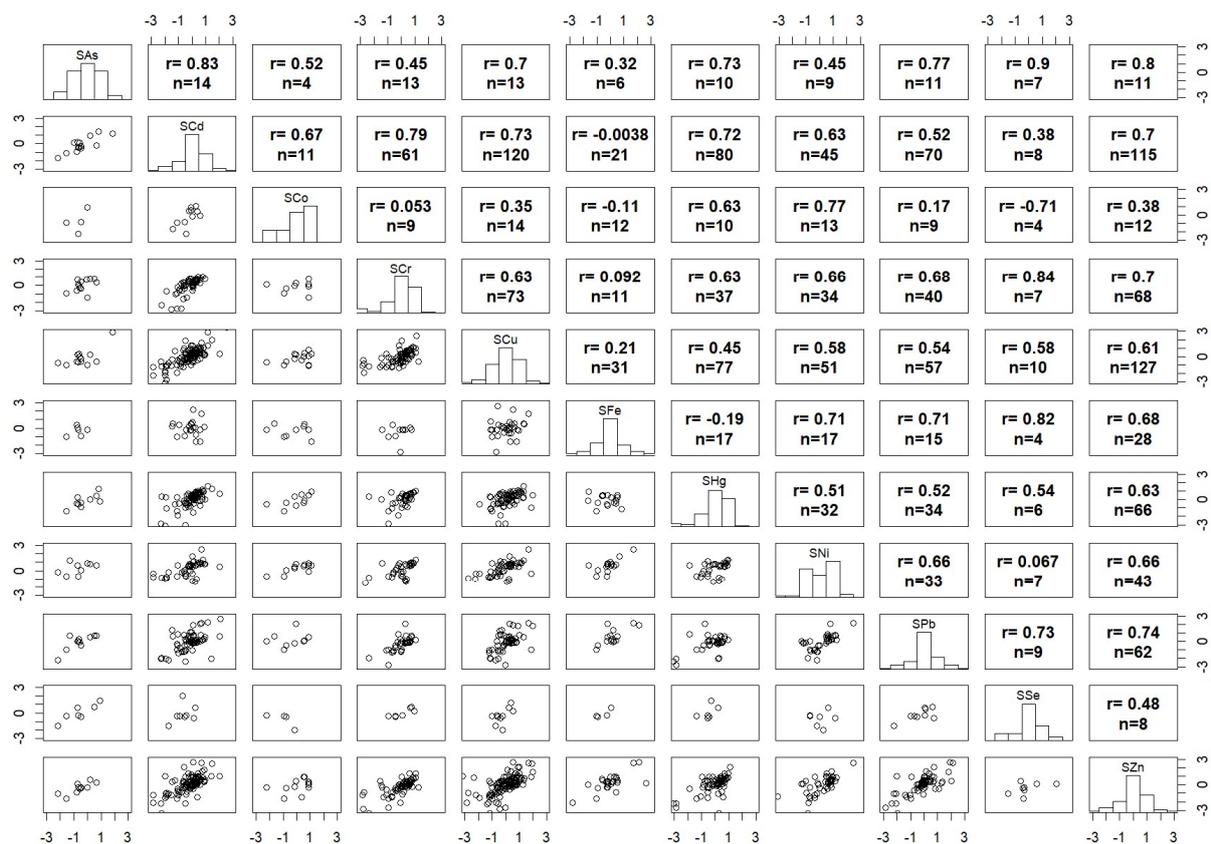


Figure S1. Pairwise mean comparison of physiological sensitivity values for each taxon of the eleven heavy metals expressed as S_{As} , S_{Cd} , S_{Co} , S_{Cr} , S_{Cu} , S_{Fe} , S_{Hg} , S_{Ni} , S_{Pb} , S_{Se} and S_{Zn} . Histograms display the distribution of standardized sensitivity values for each heavy metal. The upper panel shows the Pearson correlation coefficient (r) and the number of pairwise comparisons (n), while the lower panel presents the plotted values for each pair of heavy metals.

Table S1. Summary of Acute Toxicity Test Results for Selected Freshwater Species Exposed to Copper

Chemical	Class	Order	Family	Genus	Species	Duration	Criterion	Test endpoint	Value (ug/L)	Test method ref.
Cu	Bivalvia	Pteriomorphia	Mytilidae	Limnoperna	<i>L. fortunei</i>	4d	LC50	mortality	306.05	2
Cu	Gastropoda	Architaenioglossa	Pleuroceridae	Semisulcospira	<i>S. gottschei</i>	4d	LC50	mortality	150.07	11
Cu	Bivalvia	Veneroida	Corbiculidae	Corbicula	<i>C. leana</i>	4d	LC50	mortality	95.70	2
Cu	Malacostraca	Amphipoda	Gammaridae	Gammarus	<i>G. sobaegensis</i>	4d	LC50	mortality	15.68	10
Cu	Branchiopoda	Anostraca	Moinidae	Moina	<i>M. macrocopa</i>	1d	LC50	mortality	10.18	8
Cu	Crustacea	Cyclopoida	Cyclopidae	Acanthocyclops	<i>A. vernalis</i>	4d	LC50	mortality	115.48	8
Cu	Gastropoda	Basommatophora	Lymnaeidae	Radix	<i>R. auricularia</i>	4d	LC50	mortality	163.70	11
Cu	Gastropoda	Architaenioglossa	Ampullariidae	Pomacea	<i>P. canaliculata</i>	4d	LC50	mortality	16.55	11
Cu	Branchiopoda	Anostraca	Branchiidae	Branchinella	<i>B. kugenumaensis</i>	1d	LC50	mortality	10.64	8
Cu	Rotifera	Monogononta	Brachionidae	Brachionus	<i>B. calyciflorus</i>	1d	LC50	mortality	31.74	1
Cu	Diptera	Chironomidae	Chironomidae	Glyptotendipes	<i>G. tokunagai</i>	4d	LC50	mortality	492.20	9
Cu	Diptera	Chironomidae	Chironomidae	Chironomus	<i>C. flaviplumis</i>	4d	LC50	mortality	327.80	9
Cu	Trichoptera	Hydropsychidae	Hydropsychidae	Lepidostoma	<i>L. albardanum</i>	4d	LC50	mortality	8.20	3, 5
Cu	Trichoptera	Hydropsychidae	Hydropsychidae	Hydropsyche	<i>H. orientalis</i>	4d	LC50	mortality	12.30	3, 5
Cu	Insecta	Ephemeroptera	Baetidae	Baetis	<i>B. fuscatus</i>	4d	LC50	mortality	40.20	3, 4, 6
Cu	Insecta	Ephemeroptera	Ephemeridae	Ephemera	<i>E. orientalis</i>	4d	LC50	mortality	53.70	3, 4, 6
Cu	Insecta	Ephemeroptera	Heptageniidae	Epeorus	<i>E. pellucidus</i>	4d	LC50	mortality	70.40	3, 4, 6
Cu	Insecta	Odonata	Aeshnidae	Anax	<i>A. parthenope</i>	4d	LC50	mortality	155.20	3
Cu	Insecta	Odonata	Gomphidae	Sieboldius	<i>S. albardae</i>	4d	LC50	mortality	370.70	3
Cu	Insecta	Odonata	Gomphidae	Ophiogomphus	<i>O. obscurus</i>	4d	LC50	mortality	420.70	3

Table S2. Summary of results for the fixed factors of the mixed effect model^a

Fixed effect	Estimate	MCMC mean	HPD 95% Cis		p(MCMC)
			-	+	
S _{As(spe)}	0.03	0.03	-0.37	0.43	0.55
S _{Cd(spe)}	0.09	0.09	-0.21	0.39	0.73
S _{Co(spe)}	0.36	0.36	-0.09	0.81	0.94
S _{Cr(spe)}	0.32	0.32	0.01	0.64	0.98
S _{Cu(spe)}	0.22	0.22	-0.08	0.52	0.93
S _{Fe(spe)}	0.07	0.06	-0.30	0.43	0.64
S _{Hg(spe)}	0.18	0.18	-0.14	0.49	0.86
S _{Ni(spe)}	0.49	0.48	0.15	0.82	0.97
S _{Pb(spe)}	0.14	0.14	-0.17	0.46	0.81
S _{Se(spe)}	0.32	0.32	-0.11	0.74	0.93
S _{Zn(spe)}	0.26	0.25	-0.05	0.56	0.95

^aParameters are presented by model estimate calculated (Estimate), mean estimate across Markov Chain Monte Carlo (MCMC) samples (MCMC mean), lower (l) and upper (h) 95% highest posterior density (HPD) confidence intervals (CIs), and p values based on the posterior distribution (p(MCMC)).

Table S3. Physiological sensitivity (S) values for As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Se and Zn for each taxonomic level^b

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Clitellata	Crassiclitellata	Aeolosomatidae	Aeolosoma	<i>A. headleyi</i>		-0.45		0.30	0.78						0.28	0.29
Clitellata	Hirudinida	Erpobdellidae	Erpobdella	<i>E. octoculata</i>		0.20					0.36				0.19	0.20
Clitellata	Hirudinida	Erpobdellidae	Erpobdella	<i>N. obscura</i>		-0.97								2.25	-0.03	-0.03
Clitellata	Hirudinida	Hirudinidae	Poecilobdella	<i>P. viridis</i>					0.93		0.94					0.93
Clitellata	Lumbriculida	Lumbriculidae	Lumbriculus	<i>L. variegatus</i>		-0.27	0.69	0.78	0.00	-0.36	0.50	0.22	0.29		0.28	0.28
Clitellata	Lumbriculida	Lumbriculidae	Styodrilus	<i>S. heringianus</i>		-0.18					0.25					0.04
Clitellata	Lumbriculida	Lumbriculidae	Trichodrilus	<i>T. tenuis</i>		-0.70										-0.70
Clitellata	Rhynchobdellida	Glossiphoniidae	Glossiphonia	<i>G. complanata</i>		0.00										0.00
Clitellata	Tubificida	Naididae	Branchiura	<i>B. sowerbyi</i>		0.21	1.48		-0.05	2.87	0.28				-1.11	0.24
Clitellata	Tubificida	Naididae	Dero	<i>D. digitata</i>					-0.64							-0.64
Clitellata	Tubificida	Naididae	Ilyodrilus	<i>I. frantzi</i>							-0.09					-0.09
Clitellata	Tubificida	Naididae	Limnodrilus	<i>L. hoffmeisteri</i>		-0.74			-0.49		0.27				-1.29	-0.62
Clitellata	Tubificida	Naididae	Nais	<i>N. communis</i>							-0.48					-0.48
Clitellata	Tubificida	Naididae	Nais	<i>N. elinguis</i>		0.17			0.22	-0.06		0.82	0.54		1.09	0.38
Clitellata	Tubificida	Naididae	Nais	<i>N. sp.</i>		0.37		0.89	0.29		0.99	0.78			0.91	0.84
Clitellata	Tubificida	Naididae	Pelosclex	<i>P. ferox</i>		-0.61					0.00					-0.30
Clitellata	Tubificida	Naididae	Pristina	<i>P. leidyi</i>		-1.04										-1.04
Clitellata	Tubificida	Naididae	Quistadrilus	<i>Q. multisetosus</i>		0.07					0.87					0.47
Clitellata	Tubificida	Naididae	Rhyacodrilus	<i>R. montanus</i>		-0.34					-0.21					-0.28
Clitellata	Tubificida	Naididae	Spirosperma	<i>S. nikolskyi</i>		0.26					1.17					0.72
Clitellata	Tubificida	Naididae	Tubifex	<i>T. tubifex</i>	0.26	-0.34		0.22	-0.47		0.38	0.23	0.22		0.20	0.22
Clitellata	Tubificida	Naididae		<i>Tubificidae</i>		0.25			0.40		0.16		-0.10		0.30	0.25
Clitellata				<i>Oligochaeta</i>		-0.38					-0.24					-0.31

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Polychaeta	Phyllodocida	Nereididae	Hediste	<i>H. diversicolor</i>		2.37			0.11						1.47	1.47
Polychaeta	Phyllodocida	Nereididae	Nereis	<i>N. diversicolor</i>											0.17	0.17
Arachnida				<i>Acarina</i>		1.98										1.98
Branchiopoda	Anostraca	Streptocephalidae	Streptocephalus	<i>S. proboscideus</i>	-0.83	-0.65		-0.54	-0.14	0.14	-0.23				-0.88	-0.54
Branchiopoda	Anostraca	Streptocephalidae	Streptocephalus	<i>S. rubricaudatus</i>		-0.02		0.06	0.41						-0.31	0.02
Branchiopoda	Anostraca	Streptocephalidae	Streptocephalus	<i>S. texanus</i>		-0.07		-0.15	0.32						-0.38	-0.11
Branchiopoda	Anostraca	Thamnocephalidae	Thamnocephalus	<i>T. platyurus</i>		0.00		-0.15	1.16		0.42				-0.15	0.00
Branchiopoda	Diplostraca	Bosminidae	Bosmina	<i>B. longirostris</i>					-0.41							-0.41
Branchiopoda	Diplostraca	Chydoridae	Alonella	<i>Alonella sp.</i>	1.22											1.22
Branchiopoda	Diplostraca	Chydoridae	Chydorus	<i>C. sphaericus</i>					-0.11						-0.73	-0.42
Branchiopoda	Diplostraca	Daphniidae	Ceriodaphnia	<i>C. affinis</i>										-1.08		-1.08
Branchiopoda	Diplostraca	Daphniidae	Ceriodaphnia	<i>C. dubia</i>	-1.43	-0.81	-1.22	-0.81	-0.73	-1.25	-1.39	-1.31	-1.05	-0.30	-1.48	-1.22
Branchiopoda	Diplostraca	Daphniidae	Ceriodaphnia	<i>C. reticulata</i>	-0.66	-0.13		-0.48	-0.04				-0.43		-0.69	-0.45
Branchiopoda	Diplostraca	Daphniidae	Ceriodaphnia	<i>C. rigaudi</i>		-1.06		-2.21	-0.42						-1.15	-1.11
Branchiopoda	Diplostraca	Daphniidae	Ceriodaphnia	<i>Ceriodaphnia sp.</i>					0.35							0.35
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. ambigua</i>					-0.91							-0.91
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. carinata</i>		-0.51		0.93	-1.37				-0.46		-1.17	-0.51
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. cucullata</i>		-0.55					-1.17					-0.86
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. galeata</i>					-0.19							-0.19
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. hyalina</i>		-0.65	-0.51	-0.62	-0.65		-0.89	-0.05	-0.75		-1.26	-0.65
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. longispina</i>					-0.01							-0.01
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. lumholtzi</i>		-0.24			-0.28						-0.10	-0.24
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. magna</i>	-0.60	-0.69	-1.00	-0.65	-0.63	-1.16	-0.77	-0.67	-0.85	-0.55	-0.66	-0.67
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. obtusa</i>				-0.76								-0.76
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. pulex</i>	-0.77	-0.51	-1.64	-0.05	-0.74	-0.41	-0.97	-1.25	-0.24	-0.45	-0.49	-0.51
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. pulicaria</i>			-0.43		-0.36			-0.38		-1.80		-0.40

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>D. similis</i>				-0.75	-1.22		-1.09		-1.76		-1.50	-1.22
Branchiopoda	Diplostraca	Daphniidae	Daphnia	<i>Daphnia sp.</i>		-0.83			-0.70		-0.88		-1.25		-1.14	-0.88
Branchiopoda	Diplostraca	Daphniidae	Moinodaphnia	<i>M. macleayi</i>		-0.76		-2.12	-0.74							-0.76
Branchiopoda	Diplostraca	Daphniidae	Scapholeberis	<i>Scapholeberis sp.</i>					-0.38							-0.38
Branchiopoda	Diplostraca	Daphniidae	Simocephalus	<i>S. serrulatus</i>	-1.07	-0.12										-0.59
Branchiopoda	Diplostraca	Daphniidae	Simocephalus	<i>S. vetulus</i>	-0.67	-0.71		-0.30	0.25				0.02			-0.30
Branchiopoda	Diplostraca	Leptodoridae	Leptodora	<i>L. kindtii</i>		-0.35			0.23						-0.12	-0.12
Branchiopoda	Diplostraca	Macrotrichidae	Echinisca	<i>E. triserialis</i>		-0.62										-0.62
Branchiopoda	Diplostraca	Moinidae	Moina	<i>M. macrocopa</i>		-0.96		-0.16	-0.23		-0.52	0.10	0.05		-0.48	-0.23
Branchiopoda	Diplostraca	Sididae	Diaphanosoma	<i>D. brachyurum</i>		-0.66		-2.12	-0.39						-1.05	-0.86
Branchiopoda	Diplostraca	Sididae	Pseudosida	<i>P. ramosa</i>		-0.86		-0.83								-0.84
Branchiopoda	Diplostraca	Sididae	Sida	<i>S. crystallina</i>				-0.02								-0.02
Hexanauplia	Calanoida	Diaptomidae	Diaptomus	<i>D. forbesi</i>		-1.03	-1.51			0.55			0.44			-0.30
Hexanauplia	Calanoida	Diaptomidae	Diaptomus	<i>Diaptomus sp.</i>	1.21											1.21
Hexanauplia	Calanoida	Diaptomidae	Eudiaptomus	<i>E. padanus ssp. padanus</i>				0.52								0.52
Hexanauplia	Calanoida	Diaptomidae	Heliodiaptomus	<i>H. viduus</i>		-0.59							-0.66		-0.62	-0.62
Hexanauplia	Calanoida	Diaptomidae	Notodiaptomus	<i>N. conifer</i>				-0.26	0.16							-0.05
Hexanauplia	Cyclopoida	Cyclopidae	Acanthocyclops	<i>A. viridis</i>		-1.07										-1.07
Hexanauplia	Cyclopoida	Cyclopidae	Cyclops	<i>C. abyssorum ssp. prealpinus</i>				0.52								0.52
Hexanauplia	Cyclopoida	Cyclopidae	Cyclops	<i>Cyclops sp.</i>				0.33	1.36		0.76				-0.09	0.55
Hexanauplia	Cyclopoida	Cyclopidae	Cyclops	<i>C. strenuus</i>							0.67					0.67
Hexanauplia	Cyclopoida	Cyclopidae	Cyclops	<i>C. viridis</i>					-0.18	1.09					-0.03	-0.03
Hexanauplia	Cyclopoida	Cyclopidae	Eucyclops	<i>Eucyclops sp.</i>	1.44											1.44
Hexanauplia	Cyclopoida	Cyclopidae	Megacyclops	<i>M. viridis</i>		-1.07										-1.07
Hexanauplia	Cyclopoida	Cyclopidae	Mesocyclops	<i>M. hyalinus</i>		-0.06							0.20		-0.49	-0.06
Hexanauplia	Cyclopoida	Cyclopidae	Mesocyclops	<i>M. pehpeiensis</i>				-0.28	-0.03			-0.16			-0.76	-0.22

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Hexanauplia	Cyclopoida	Cyclopidae	Thermocyclops	<i>T. oblongatus</i>											-0.87	-0.87
Hexanauplia	Harpacticoida	Ameiridae	Nitokra	<i>N. spinipes</i>	-0.58	-0.40		0.39	-0.20		-1.31				-0.61	-0.49
Hexanauplia	Harpacticoida	Canthocamptidae	Attheyella	<i>A. crassa</i>				-0.05								-0.05
Hexanauplia	Harpacticoida	Canthocamptidae	Bryocamptus	<i>B. echinatus</i>				-0.54								-0.54
Hexanauplia	Harpacticoida	Canthocamptidae	Bryocamptus	<i>B. minutus</i>				-0.08								-0.08
Hexanauplia	Harpacticoida	Canthocamptidae	Bryocamptus	<i>B. pygmaeus</i>				-0.09								-0.09
Hexanauplia	Harpacticoida	Canthocamptidae	Bryocamptus	<i>B. zschokkei</i>				-0.37							-1.26	-0.82
Hexanauplia	Harpacticoida	Canthocamptidae	Canthocamptus	<i>Canthocamptus sp.</i>					0.38							0.38
Hexanauplia	Harpacticoida	Parastenocarididae	Parastenocaris	<i>P. germanica</i>		0.49									-0.08	0.21
Insecta	Coleoptera	Dytiscidae		<i>Dytiscidae</i>									-0.32			-0.32
Insecta	Diptera	Ceratopogonidae	Culicoides	<i>C. furens</i>		-0.32		0.02	1.57		-0.53	-1.08	-1.02		0.49	-0.32
Insecta	Diptera	Chironomidae	Chironomus	<i>C. crassiforceps</i>					0.68							0.68
Insecta	Diptera	Chironomidae	Chironomus	<i>C. decorus</i>					0.53					0.16		0.34
Insecta	Diptera	Chironomidae	Chironomus	<i>C. dilutus</i>	-1.29							0.85	0.28			0.28
Insecta	Diptera	Chironomidae	Chironomus	<i>C. javanus</i>		0.47			1.41	0.87		1.91	1.08		1.88	1.24
Insecta	Diptera	Chironomidae	Chironomus	<i>C. luridus</i>					1.02							1.02
Insecta	Diptera	Chironomidae	Chironomus	<i>C. maddeni</i>					1.09							1.09
Insecta	Diptera	Chironomidae	Chironomus	<i>C. plumosus</i>		-0.27		0.46	0.81		1.21	-0.03	0.07		0.87	0.46
Insecta	Diptera	Chironomidae	Chironomus	<i>C. ramosus</i>					0.36							0.36
Insecta	Diptera	Chironomidae	Chironomus	<i>C. riparius</i>		0.01			-0.46		-0.97	0.84	0.58	-0.55	0.42	0.01
Insecta	Diptera	Chironomidae	Chironomus	<i>Chironomus sp.</i>	0.50	0.93		1.28	0.81		-0.60	0.63	0.27		1.13	0.72
Insecta	Diptera	Chironomidae	Chironomus	<i>C. tentans</i>		-0.80			0.50		-0.86		-0.14			-0.47
Insecta	Diptera	Chironomidae	Chironomus	<i>C. zealandicus</i>	0.79											0.79
Insecta	Diptera	Chironomidae	Clunio	<i>C. gerlachi</i>		0.17			0.84		0.43				1.03	0.63
Insecta	Diptera	Chironomidae	Gymnometriocnemus	<i>G. mahensis</i>		0.17			0.84		0.50				0.84	0.67
Insecta	Diptera	Chironomidae	Larsia	<i>Larsia sp.</i>		0.19			0.85		0.57				0.86	0.71

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Malacostraca	Decapoda	Astacidae	Austropotamobius	<i>A. pallipes</i>									-0.73			-0.73
Malacostraca	Decapoda	Astacidae	Austropotamobius	<i>A. pallipes ssp. pallipes</i>		-0.76	0.65		-0.57	0.63	-1.86	0.18	-0.16		1.68	0.01
Malacostraca	Decapoda	Atyidae	Caridina	<i>C. africana</i>					0.00							0.00
Malacostraca	Decapoda	Atyidae	Caridina	<i>C. laevis</i>					-0.06							-0.06
Malacostraca	Decapoda	Atyidae	Caridina	<i>C. nilotica</i>		-1.88			-0.42	0.16			1.33		0.24	0.16
Malacostraca	Decapoda	Atyidae	Caridina	<i>C. rajadhari</i>		-0.06					-0.99					-0.52
Malacostraca	Decapoda	Atyidae	Caridina	<i>Caridina sp.</i>					0.29							0.29
Malacostraca	Decapoda	Atyidae	Neocaridina	<i>N. denticulata</i>		-0.83		0.14	-0.41		-0.47				-0.39	-0.41
Malacostraca	Decapoda	Atyidae	Paratya	<i>P. australiensis</i>		0.67			0.69						1.67	0.69
Malacostraca	Decapoda	Atyidae	Paratya	<i>P. compressa ssp. improvisa</i>		-0.57			-0.26						-0.43	-0.43
Malacostraca	Decapoda	Cambaridae	Cambarus	<i>C. robustus</i>					0.45							0.45
Malacostraca	Decapoda	Cambaridae	Orconectes	<i>O. limosus</i>		-0.49	0.76		0.21	0.99	-1.25	0.47	-0.03		1.74	0.34
Malacostraca	Decapoda	Cambaridae	Orconectes	<i>O. rusticus</i>				1.79								1.79
Malacostraca	Decapoda	Cambaridae	Orconectes	<i>Orconectes sp.</i>					0.08							0.08
Malacostraca	Decapoda	Cambaridae	Procambarus	<i>P. clarkii</i>	1.68	1.16			3.26							1.68
Malacostraca	Decapoda	Cambaridae	Procambarus	<i>Procambarus sp.</i>	0.88	1.35					1.73					1.35
Malacostraca	Decapoda	Carcinidae	Carcinus	<i>C. maenas</i>				1.28	2.75							2.01
Malacostraca	Decapoda	Diogenidae	Clibanarius	<i>C. africanus</i>		0.54			0.44				2.10		1.05	0.80
Malacostraca	Decapoda	Dotillidae	Ilyoplax	<i>I. gangetica</i>							-0.52					-0.52
Malacostraca	Decapoda	Gecarcinucidae	Barytelphusa	<i>B. cunicularis</i>					2.21		0.61					1.41
Malacostraca	Decapoda	Gecarcinucidae	Barytelphusa	<i>B. guerini</i>		-0.10										-0.10
Malacostraca	Decapoda	Palaemonidae	Macrobrachium	<i>M. carcinus</i>					-0.75						-1.51	-1.13
Malacostraca	Decapoda	Palaemonidae	Macrobrachium	<i>M. hendersodayanus</i>		-1.62			0.65		-1.05				0.53	-0.26
Malacostraca	Decapoda	Palaemonidae	Macrobrachium	<i>M. kistmensis</i>		-0.08			0.29		-0.35					-0.08
Malacostraca	Decapoda	Palaemonidae	Macrobrachium	<i>M. lamarrei</i>		-0.60		-1.15	-0.25		-0.22				-0.31	-0.31
Malacostraca	Decapoda	Palaemonidae	Macrobrachium	<i>M. lanchesteri</i>		-0.24			0.89				-0.09		1.05	0.40

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Bivalvia	Unionida	Unionidae	Epioblasma	<i>E. triquetra</i>					-0.32							-0.32
Bivalvia	Unionida	Unionidae	Fusconaia	<i>F. masoni</i>		-0.75										-0.75
Bivalvia	Unionida	Unionidae	Hyriopsis	<i>H. cumingii</i>				0.62								0.62
Bivalvia	Unionida	Unionidae	Lamellidens	<i>L. marginalis</i>		1.21			1.40		2.23					1.40
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. abrupta</i>					-1.75							-1.75
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. cardium</i>					-0.85							-0.85
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. fasciola</i>					-1.17		-0.66					-0.91
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. rafinesqueana</i>					-1.87							-1.87
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. siliquoidea</i>					-1.87							-1.87
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. straminea ssp. claibornensis</i>		-1.31			-1.54			-1.43			-0.94	-1.37
Bivalvia	Unionida	Unionidae	Lampsilis	<i>L. teres</i>		-1.37			-0.97							-1.17
Bivalvia	Unionida	Unionidae	Lasmigona	<i>L. subviridis</i>		-1.39			-0.89							-1.14
Bivalvia	Unionida	Unionidae	Leptodea	<i>L. fragilis</i>					-0.95							-0.95
Bivalvia	Unionida	Unionidae	Leptodea	<i>L. leptodon</i>					-2.00							-2.00
Bivalvia	Unionida	Unionidae	Ligumia	<i>L. recta</i>					0.57							0.57
Bivalvia	Unionida	Unionidae	Ligumia	<i>L. subrostrata</i>					-0.89							-0.89
Bivalvia	Unionida	Unionidae	Medionidus	<i>M. conradicus</i>					-1.25							-1.25
Bivalvia	Unionida	Unionidae	Megaloniaias	<i>M. nervosa</i>					-0.87							-0.87
Bivalvia	Unionida	Unionidae	Obliquaria	<i>O. reflexa</i>					1.60							1.60
Bivalvia	Unionida	Unionidae	Obovaria	<i>O. subrotunda</i>					-0.10							-0.10
Bivalvia	Unionida	Unionidae	Parreysia	<i>P. cylindrica</i>					0.88		1.20				1.48	1.20
Bivalvia	Unionida	Unionidae	Parreysia	<i>P. favidens</i>		0.53			0.98		1.08					0.98
Bivalvia	Unionida	Unionidae	Potamilus	<i>P. ohioensis</i>					-1.57							-1.57
Bivalvia	Unionida	Unionidae	Ptychobranchus	<i>P. fasciolaris</i>					-0.35							-0.35
Bivalvia	Unionida	Unionidae	Pyganodon	<i>P. grandis</i>					-0.68							-0.68
Bivalvia	Unionida	Unionidae	Unio	<i>U. elongatulus</i>					0.05		-0.10					-0.03

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Gastropoda		Lymnaeidae	Radix	<i>R. plicatula</i>		0.35										0.35
Gastropoda		Pachychilidae	Brotia	<i>Brotia sp.</i>		0.53			-0.38							0.08
Gastropoda		Physidae	Aplexa	<i>A. hypnorum</i>	0.16						0.07			1.56		0.16
Gastropoda		Physidae	Physa	<i>P. gyrina</i>		0.20				-0.92						-0.36
Gastropoda		Physidae	Physa	<i>P. heterostropha</i>				1.66	-0.54						-0.38	-0.38
Gastropoda		Physidae	Physa	<i>P. integra</i>				-1.26							-1.53	-1.40
Gastropoda		Physidae	Physa	<i>Physa sp.</i>									0.48	0.48		0.48
Gastropoda		Physidae	Physella	<i>P. acuta</i>					0.34	-0.57	0.57				0.28	0.31
Gastropoda		Physidae	Physella	<i>P. gyrina</i>					-2.58							-2.58
Gastropoda		Physidae	Physella	<i>P. heterostropha</i>				0.84							-0.50	0.17
Gastropoda		Physidae	Physella	<i>Physella sp.</i>					-0.67							-0.67
Gastropoda		Planorbidae	Biomphalaria	<i>B. alexandrina</i>					0.63	0.09					0.32	0.32
Gastropoda		Planorbidae	Biomphalaria	<i>B. glabrata</i>		-0.98		0.06	-0.02							-0.02
Gastropoda		Planorbidae	Bulinus	<i>B. globosus</i>					0.67							0.67
Gastropoda		Planorbidae	Bulinus	<i>B. truncatus</i>					0.95							0.95
Gastropoda		Planorbidae	Gyraulus	<i>Gyraulus sp.</i>		0.13							0.12		0.48	0.13
Gastropoda		Planorbidae	Helisoma	<i>H. duryi</i>					0.85							0.85
Gastropoda		Planorbidae	Indoplanorbis	<i>I. exustus</i>					0.21	-0.55	0.67				0.29	0.25
Gastropoda		Planorbidae	Isidorella	<i>I. newcombi</i>					0.38							0.38
Gastropoda		Planorbidae	Physastra	<i>P. gibbosa</i>					-1.27						1.13	-0.07
Gastropoda		Planorbidae	Planorbarius	<i>Planorbarius sp.</i>					1.48	0.48					0.78	0.78
Gastropoda		Planorbidae	Planorbella	<i>P. campanulata</i>											0.02	0.02
Gastropoda		Planorbidae	Planorbella	<i>P. trivolvris</i>			0.69	-0.03	-1.34	-0.36		-0.96			-0.01	-0.20
Gastropoda		Planorbidae	Planorbis	<i>P. planorbis</i>					0.41							0.41
Gastropoda		Pleuroceridae	Elimia	<i>E. livescens</i>				-1.06	-0.73				-1.19		-1.30	-1.13
Gastropoda		Pleuroceridae	Leptoxis	<i>L. dilatata</i>											-0.17	-0.17

Class	Order	Family	Genus	Taxon	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	HM
Rhabditophora	Tricladida	DugesIIDae	Girardia	<i>G. tigrina</i>		0.48	-0.29	0.14	0.28	-0.36	-0.54	0.42	2.13		0.25	0.25
Rhabditophora	Tricladida	Planariidae	Polycelis	<i>P. felina</i>		0.96										0.96
Eurotatoria	Philodinida	Philodinidae	Philodina	<i>P. acuticornis</i>				0.59	0.69						-0.33	0.59
Eurotatoria	Philodinida	Philodinidae	Philodina	<i>P. roseola</i>	-0.29			0.60								0.15
Eurotatoria	Philodinida	Philodinidae	Philodina	<i>Philodina sp.</i>				-0.23								-0.23
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. calyciflorus</i>	-0.80	0.14		0.49	0.37	-0.16	0.46	0.15	-0.32	0.44	-0.06	0.15
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. havanaensis</i>		0.00									-0.10	-0.05
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. koreanus</i>					0.76							0.76
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. patulus</i>		0.02			0.61		0.50					0.50
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. plicatilis</i>					-0.03		0.85				0.11	0.11
Eurotatoria	Ploima	Brachionidae	Brachionus	<i>B. rubens</i>		-0.59			-0.48							-0.54
Eurotatoria	Ploima	Lecanidae	Lecane	<i>L. hamata</i>				-0.07	-0.25							-0.16
Eurotatoria	Ploima	Lecanidae	Lecane	<i>L. luna</i>				-0.14	-0.57							-0.35
Eurotatoria	Ploima	Lecanidae	Lecane	<i>L. quadridentata</i>				-0.06	-0.16	-2.23					-1.81	-0.98
Rotifera				<i>Rotifera</i>					0.55							0.55

^bS_{metal} is the median of the eleven heavy metal sensitivity values for each taxonomic level. S values in the higher taxonomic levels equal the S values in the lower taxonomic levels, when only one lower taxon is present. Negative values indicate more sensitive taxa and positive values indicate less sensitive taxa.

Table S4. Summary of site-specific environmental parameters, macroinvertebrate community indices^c, and toxicity values in the Upper Nakdong River

Site		SPEAR _{metal} ⁻ 2012 (Malaj et al., 2012)	SPEAR _{metal} ⁻ 2024 (This study)	Community indices				Toxic values				Environmental parameters							
Names	Season			Community indices				Fresh water		Sediment		Temp	DO	pH	Alkalinity	Conductivity	NTU	TOC	DOC
				TR	EPT	H'	BMI	Sum of HQ	MAX HQ	mPELq	Hardness								
ST1	Spring	0.77	0.45	26	13	2.20	76.29	0.12	0.06	0.93	34.67	5.40	15.53	9.12	59.00	335.50	1.57	1.53	0.93
ST1	Fall	0.85	0.54	22	14	2.54	80.74	0.20	0.09	1.41	189.63	20.40	10.51	8.65	72.00	412.30	0.74	1.95	1.07
ST2	Spring	0.49	0.29	14	11	1.90	88.10	2.66	1.39	6.55	31.17	5.90	13.60	9.13	49.00	367.90	1.70	1.54	0.94
ST2	Fall	0.47	0.14	11	9	1.90	86.40	4.40	3.11	2.58	171.17	20.30	9.58	8.34	64.00	449.80	0.81	1.17	1.29
ST3	Spring	0.50	0.36	13	11	1.80	88.40	4.65	2.46	5.06	29.38	3.90	12.88	8.01	48.00	353.30	0.75	1.56	0.95
ST3	Fall	0.66	0.29	10	7	1.40	88.70	4.48	2.77	2.13	173.94	20.30	9.20	8.26	65.00	448.90	0.50	0.90	1.15
ST4	Spring	0.60	0.37	17	12	2.27	76.34	2.74	1.50	3.86	27.70	4.00	13.20	7.67	44.00	326.60	0.85	1.70	1.05
ST4	Fall	0.64	0.37	10	9	1.66	92.50	1.34	0.87	2.15	148.54	22.40	8.69	8.78	62.00	391.10	0.42	2.64	2.07
ST5	Spring	0.78	0.67	30	20	2.44	85.01	2.26	1.29	2.66	24.25	3.70	13.42	7.69	44.00	287.10	0.55	1.52	0.93
ST5	Fall	0.51	0.53	17	11	1.85	80.27	0.75	0.50	1.69	125.99	23.10	9.50	8.86	50.00	327.30	3.32	2.21	1.69
ST6	Spring	0.52	0.44	23	17	2.22	90.17	0.88	0.44	2.15	20.21	4.20	13.14	7.45	43.00	202.60	23.34	2.99	1.88
ST6	Fall	0.75	0.59	22	17	2.77	86.40	0.30	0.16	2.04	92.08	25.00	8.79	8.92	46.00	244.70	1.15	1.56	1.50
ST7	Spring	0.58	0.45	51	32	2.54	82.20	0.69	0.36	0.56	19.98	4.80	13.21	7.54	31.00	212.00	17.87	2.51	1.57
ST7	Fall	0.67	0.56	45	31	2.64	82.78	0.23	0.09	1.00	89.81	25.40	10.35	9.08	43.00	230.90	1.35	3.50	2.52
UT1	Spring	0.73	0.49	42	24	2.78	70.86	0.18	0.13	1.83	23.41	6.00	12.74	8.17	93.00	289.00	1.37	1.12	0.67
UT1	Fall	0.70	0.47	43	26	2.65	80.15	0.19	0.08	1.97	144.44	19.70	9.33	8.39	91.00	318.80	1.45	1.90	1.92
UT2	Spring	0.84	0.77	24	19	2.74	95.70	0.21	0.11	1.11	9.63	3.60	13.38	8.39	20.00	110.30	1.28	0.83	0.48
UT2	Fall	0.76	0.79	19	15	2.04	92.86	0.21	0.09	1.00	43.75	19.40	9.13	8.46	40.00	112.30	0.43	2.49	1.99
UT3	Spring	0.63	0.60	41	31	2.80	88.47	0.19	0.07	1.23	5.17	5.60	12.64	8.65	19.00	54.90	1.63	5.42	3.46
UT3	Fall	0.73	0.66	28	21	2.66	86.61	0.17	0.07	1.47	21.43	20.50	9.08	8.39	20.00	64.90	1.33	3.10	2.31
UT4	Spring	0.65	0.61	87	65	3.51	92.29	0.06	0.02	0.42	4.26	3.60	12.68	7.85	17.00	41.20	2.31	3.39	2.14
UT4	Fall	0.71	0.56	63	47	3.18	90.84	0.12	0.04	0.46	14.00	18.70	8.95	8.44	18.00	46.90	0.50	2.47	2.41
UT5	Spring	0.70	0.69	54	35	2.85	88.76	0.20	0.07	1.24	9.67	3.00	13.22	7.76	27.00	98.40	1.95	4.76	3.03
UT5	Fall	0.70	0.59	37	27	2.83	91.96	0.27	0.12	0.80	32.06	21.60	8.93	8.64	29.00	91.20	0.45	2.73	2.12
UT6	Spring	0.81	0.77	63	42	2.91	87.87	0.19	0.07	0.43	10.95	3.60	13.22	7.76	18.00	159.30	4.27	1.22	0.73
UT6	Fall	0.83	0.74	58	39	2.70	89.59	0.10	0.05	0.63	26.75	23.00	9.29	8.59	18.00	82.00	0.31	2.44	1.96
UT7	Spring	0.68	0.63	66	46	3.32	93.36	0.13	0.08	0.42	11.74	3.20	13.28	7.82	18.00	68.20	1.68	2.88	1.81
UT7	Fall	0.76	0.71	63	44	3.04	89.06	0.10	0.04	0.36	21.90	20.30	9.67	8.75	15.00	70.50	0.34	1.89	1.69
UT8	Spring	0.72	0.50	55	35	2.82	80.85	0.13	0.08	0.65	12.80	4.20	13.35	7.84	56.00	111.90	21.49	12.81	8.24
UT8	Fall	0.76	0.54	49	31	2.68	73.93	0.18	0.13	1.35	76.90	26.60	10.59	9.03	61.00	186.70	4.98	8.53	4.27
UT9	Spring	0.68	0.52	53	34	2.91	78.92	0.17	0.09	0.19	18.24	4.90	13.29	7.29	40.00	173.10	13.96	10.48	6.74
UT9	Fall	0.69	0.55	49	29	2.77	77.02	0.15	0.09	0.44	70.11	24.90	10.70	9.50	41.00	191.30	1.18	2.91	1.54
UT10	Spring	0.74	0.59	37	29	2.89	90.43	0.04	0.03	0.16	7.87	5.50	12.80	7.44	36.00	95.20	8.89	8.41	5.40
UT10	Fall	0.82	0.77	23	15	2.58	85.70	0.05	0.03	0.20	53.09	21.00	6.12	8.48	47.00	120.40	1.01	2.38	1.93
UT11	Spring	0.80	0.57	65	41	2.85	78.42	0.13	0.10	0.14	16.90	6.40	13.04	7.90	57.00	144.30	17.55	5.70	3.64
UT11	Fall	0.79	0.61	58	31	2.79	71.58	0.18	0.11	0.16	89.59	26.60	8.71	8.84	57.00	246.10	1.38	5.11	5.07

c The macroinvertebrate community indices include taxa richness (TR), Shannon diversity (H'), Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), Benthic Macroinvertebrate Index (BMI), and the SPEAR index for metals. The SPEAR index was calculated using both the existing taxon-specific metal sensitivity from SPEAR_{metal-2012}(Malaj et al., 2012) and the newly updated sensitivity from SPEAR_{metal-2024}(This study).

Species_name	ST1		ST2		ST3		ST4		ST5		ST6		ST7		UT1		UT2		UT3		UT4		UT5		UT6		UT7		UT8		UT9		UT10		UT11												
	Spr ng	Fa ll																																													
<i>Ceratopogonidae sp.</i>															11							4	4			7	4			4	7			4	4			4	4								
<i>Chaetogaster limnaii</i>																70	19						126																								
<i>Chaoborus KUa</i>																																							7								
<i>Cheumatopsyche KUa</i>											19		4	12	60		8																					15			4						
<i>Cheumatopsyche KUb</i>														156	8		15										15														7		52				7
<i>Cheumatopsyche brevilineata</i>	429	34	104	44	63	19	8	8	15	138	189	16	1737	511	300	1319		4	59			41	30	19	38	97	90	37	30	870	792	718	774							578	262						
<i>Chironomidae spp.(red type)</i>			4							4			93	22	248	944							22	30			44	11	11	22	1047	614	370	259							1151	132					
<i>Chironomidae spp.(non-red type)</i>	1150	97		226		174	69	16	364	15	53	27	786	488	1478	574	8		105	8	168	271	288	429	566	138	392	38	1198	1460	1108	861	171	27	1272	811											
<i>Chloroperlidae sp.</i>																			8																												
<i>Choroterpes (Euthraulus) altioculus</i>												12		26				4			4		4	152	489	44	78				11		161	124					44	155							
<i>Cincticostella levanidovae</i>			15		4						4		4		23	4	37		75		89	15			89	4	181	123				11					8	22									
<i>Cincticostella orientalis</i>																		4		12		167	122			30		7		4		11															
<i>Cinygmula grandifolia</i>																							19				7	4		4																	
<i>Cinygmula hirasana</i>																			4																												
<i>Cloeon dipterum</i>																																														23	
<i>Corbicula (Corbiculina) fluminea</i>																																														15	
<i>Crocothemis servilia mariannae</i>																																26															
<i>Culicidae sp.</i>																																														4	
<i>Davidius lunatus</i>															4			7	4	23	4	26	4	7		4	11	12														15					
<i>Dicranota KUa</i>																							11				7			4																	
<i>Dolichopodidae sp.</i>	8																						8				7				4																
<i>Drunella aculea</i>																4	37		30		268	30	49		330	30	171	59	19	7	7			4	4												
<i>Drunella ishiyamana</i>	19									4			4					7			93	8	323	375	152	245	4	571	78	52		75															
<i>Drunella triacantha</i>																			100		4	152	8			4	56								4												
<i>Dugesia japonica</i>													7	30	78	70						26	67			19	30	15	56	122	170	48	26								178	45					
<i>Dugesia sp.</i>	422	38					8						26	12	182	90	7		153	23	185	8	12	8	19	12	23		86		4				90	4	148	44									
<i>Ecdyonurus bajkovae</i>		4	4											7	4	19	19	8			4	30	89			189	97	48	15	59	48	4									4	22					
<i>Ecdyonurus dracon</i>	8												7	4								67		15		15	33	19	19													15		7			
<i>Ecdyonurus joernensis</i>										48		34	15	311	135				67				11										4	7						4	53	19					
<i>Ecdyonurus kibunensis</i>		37						4	4	16		4	137	226	59	122	52	37	19	138	334	209	1167	311	2536	1588	474	790	200	255	141	118	189	12	407	79											
<i>Ecdyonurus levis</i>	15	41	19		4			4	41			38	61	105	241	108	12								33	56	196	11	7		159	300	100	97			7	67	337								

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