Supplementary materials

Table S1 Detection limits for different dissolved heavy metals

Elements	As	Pb	Cr	Zn	Ni	Cd	Cu
Detection limits（ug/L）	0.057	0.009	0.002	0.057	0.006	0.011	0.074

Table S2 Toxicity distribution and Exposure concentration distribution of heavy metals

	Toxicity		Exposure concentration			
	Distribution	Parameter	Upstream		Mid-downstream	
			Distribution	Parameter	Distribution	Parameter
Cd	Log-normal	a=0, μ=387716692.68, σ=37759740313976.00	Beta	Min=0, Max=6.69, Alpha=0.61，Beat=2.68	Beta	Min= -0.09，Mean=0，Max=8.33
Pb	Log-normal	a=0, μ=28466332.46, σ=81594898747.03	Beta	Min= -0.04，Mean=0，Max=3.59	Trigonometric	Min= -0.03，Mean=0，Max=2.58
Cr	Log-normal	a=0, μ=28466332.46, σ=81594898747.03	Log-normal	a=0, μ=1.17, σ=3.45	Gamm	a=0.05, Scale =0.43, Shape =1.24
As	Log-normal	a=9.99, μ=832983.82, σ= 321838453.62	Log-normal	a=0, μ=5.10, σ=2.35	Log-normal	a=0, μ=3.53, σ=2.37
Ni	Log-normal	a=0, μ=28466332.46, σ=81594898747.03	Log-normal	a=0, μ=0.83, σ=0.72	Beta	Min= -0.06, Mean=0, Max=5.31
Cu	Log-normal	a=0, μ=387716692.68, σ=37759740313976	Log-normal	a=0, μ=1.73, σ=2.16	Log-normal	a=0, μ=3.46, σ=2.79
Zn	Log-normal	a=99.69,μ=204769.98, σ=8096474.31	Log-normal	a=2.37, μ=29.56, σ=44.27	Log-normal	a=0, μ=25.7, σ=19.49

Table S3 Descriptive statistics of physicochemical factors in the Yangtze River Basin

Physicochemical factors		Min	Mean	Max	SD	CV(%)	Class III[a]
Upstream	T (℃)	1.33	13.37	21.08	5.34	39.95	-
	pH	7.35	8.22	8.57	0.25	3.03	6-9
	DOC (mg/L)	954.30	2724.24	3957.00	747.27	18.88	-
	TP	38.17	82.75	206.69	40.08	48.43	200
	TN	362.09	1464.64	4438.07	961.04	65.62	1000
Mid-downstream	T (℃)	13.50	17.47	22.70	2.78	15.93	-
	pH	6.46	7.50	8.03	0.33	4.44	6-9
	DOC (mg/L)	2160.00	3674.66	6800.00	902.95	13.28	-
	TP	56.39	170.53	930.88	138.05	80.95	200
	TN	856.75	2969.18	13153.94	2160.22	72.75	1000

[a] the threshold values of Class III of the Environmental Quality Standards for Surface Water (GB 3838-2002)

Table S4 Descriptive statistics of dissolved heavy metal contents in the Yangtze River Basin (ug/L)

Elements		As	Pb	Cr	Zn	Ni	Cd	Cu
Upstream	Min	1.57	0.00	0.05	3.27	0.00	0.00	0.00
	Mean	5.07	0.38	1.57	30.39	0.82	1.16	1.75
	Max	10.15	3.12	8.30	280.50	3.27	5.31	12.09
	SD	2.19	0.60	1.90	48.40	0.66	1.29	2.24
	CV(%)	43.14	159.30	120.69	159.27	81.11	111.68	128.02
Mid-downstream	Min	0.68	0.00	0.06	4.16	0.00	0.00	0.65
	Mean	3.53	0.26	0.59	25.42	0.87	1.18	3.38
	Max	11.62	2.22	1.47	124.00	4.57	7.17	9.52
	SD	2.27	0.47	0.42	20.49	1.08	1.55	2.28
	CV(%)	64.45	181.43	71.80	80.60	124.39	130.92	67.54
Standard value	I[a]	50	10	10	50		1	10
	II[a]	50	10	50	1000	20	5	1000
	III[a]	50	50	50	1000		5	1000
	Drinking water[b]	10	10	50	1000	20	5	1000
	World average[c]	0.62	0.08	0.70	0.60	0.80	0.08	1.48

[a] the threshold values of ClassⅠ、Ⅱand III of the Environmental Quality Standards for Surface Water (GB 3838-2002)

[b] standards for drinking water quality (GB 5749-2022)

[c] Gaillardet J, Viers J, Dupré B (2003). Trace elements in river waters. Treatise Geochem, 5, 225–272

Table S5 Comparison of dissolved heavy metals in the surface water of the Yangtze River Basin with other studies (ug/L)

Site	As	Pb	Cr	Zn	Ni	Cd	Cu	References
Yangtze River basin (Upstream)	5.07	0.38	1.57	30.39	0.82	1.16	1.75	This study
Yangtze River basin (Mid-downstream)	3.53	0.26	0.59	25.42	0.87	1.18	3.38	This study
Huaihe River	5.11	2.01	2.75	325.32	3.95	61.74	52.32	(Yang et al., 2018)
Pearl River	-	0.08	1.70	3.61	1.89	0.04	1.09	(Geng et al., 2015)
Liao River	2.65	1.66	2.00	25.00	-	0.50	5.00	(Liu, 2011)
Yellow River	0.12	0.25	5.13	6.63	5.37	0.03	5.07	(Xiao et al., 2019)
Tarim River	3.07	0.45	0.43	7.11	1.79	0.02	1.22	(Xiao et al., 2014)
Hai River	2.18	0.05	5.46	2.90	1.40	0.03	0.84	(Gao et al., 2019)
Le'an River	1.17	29.20	4.62	35.62	9.41	1.75	40.59	(Wu et al., 2023)
Bijiang	4.27	-	2.08	37.71	13.36	0.08	0.30	(Li et al., 2024)
Yarlung Zangbo River	2.34	0.18	4.90	2.51	2.89	0.07	2.05	(Xiao et al., 2023)
Karatoya Riverr (Bangladesh)	58.07	3.53	6.91	19.40	11.56	0.10	3.87	(Siddique et al., 2023)

Table S6 Seasonal changes of dissolved heavy metals in the Yangtze River basin (ug/L)

Sites	Time	As	Pb	Cr	Zn	Ni	Cd	Cu	References[a]
Yangtze lakes	Wet season	-	0.90	0.18	7.30	3.03	0.05	1.79	(Wang et al.,
	Normal season	-	2.10	0.27	10.19	4.61	0.12	3.50	2022)
	Dry season	-	1.64	0.20	7.56	4.12	0.08	2.15	
Yangtze River	Wet season	1.96	0.08	-	0.27	-	0.02	0.29	(Hu et al.,
Estuary	Normal season	1.38	0.11	-	0.54	-	0.03	0.46	2022)
	Dry season	2.33	0.06	-	0.18	-	0.03	0.40	
Nanjing	Wet season	1.94	0.00	0.58	4.72	0.41	0.73	0.92	(Huang et al.,
	Normal season	2.35	0.02	0.30	1.72	0.68	0.04	2.36	2024)
	Dry season	1.79	-	1.99	0.21	0.00	0.42	1.54	
Fu river	Wet season	-	8.76	2.09	1.43	-	0.29	17.64	(Guo et al.,
	Dry season	-	34.49	3.66	3.60	-	0.05	3.12	2023)
Han river	Wet season	-	4.27	-	-	6.13	3.18	46.35	(Li and Zhang,
	Normal season	3.81	-	6.67	-	1.18	0.26	0.94	2010)
	Dry season	23.94	26.12	10.51	-	0.14	0.57	0.66	
Yangtze river	Normal season	3.40	-	4.84	1.99	-	0.01	0.98	(Liang et al.,
	Dry season	4.08	-	4.91	2.10	-	0.01	1.06	2023)
Jiaxing River	Wet season	1.10	3.21	0.21	7.06	1.73	0.03	1.80	(Ding et al.,
Network	Normal season	1.29	7.91	2.08	22.66	0.60	-	1.22	2020)
Nanfeihe River	Wet season	9.30	0.40	5.70	-	-	15.50	11.10	(Wang et al.,
	Dry season	0.70	53.30	24.10	-	-	12.80	156.80	2017)
Ningbo	Wet season	-	12.00	7.00	39.00	35.00	3.00	-	(Xu et al.,
	Dry season	-	10.00	45.00	60.00	37.00	1.00	-	2023)
Qingjiang river	Wet season	1.00	6.00	0.00	13.00	0.00	-	30.00	(Liu et al.,
	Dry season	2.00	7.00	0.00	270.00	0.00	-	6.00	2021)
Niyang River	Wet season	-	-	-	6.60	-	4.50	3.50	(Lu et al.,
	Normal season	-	-	-	41.80	-	4.60	35.00	2019)
	Dry season	-	-	-	21.90	-	3.30	11.60	
Taipu Rive	Wet season	-	58	8.5	115	14	1.5	30	(Yao et al.,
	Dry season	-	57	9	64	16	3	16	2014)
Wusong River	Wet season	-	71	8	53	29	4	17	
	Dry season	-	81	11	158	32	4	44	
Yangtze Estuary	Normal season	1.54	1.37	-	-	-	0.075	3.98	(Wu,
	Wet season	1.4	0.44	-	-	-	0.057	3.07	2005)
	Dry season	1.12	1.32	-	-	-	0.072	3.03	
Three Gorges	Normal season	2.57	0.53	0.49	128.03	-	0.05	1.74	(Zhao et al.,
Reservoir	Wet season	1.54	1.64	0.45	128.55	-	0.03	1.74	2017)
Taihu	Wet season	-	6	0.35	-	-	0.24	1.06	(Rajeshkumar et
	Normal season	-	2.28	0.33	-	-	0.13	0.11	al., 2018)
	Dry season	-	5.06	2.84	-	-	0.74	0.34	
Southeastern	Wet season	2.56	0.7	1.42	36.35	1.66	0.09	2.64	(Xu et al.,
hilly area	Dry season	1.47	0.51	2.67	52.43	2.71	0.51	3.09	2020)
Fengle river	Wet season	1.95	0.16	0.14	51.65	1.09	-	2.88	(He et al.,

Normal season	0.98	0.54	1.51	4.49	2.15	0.05	22.74	2023)
Dry season	-	0.21	1.20	221.42	1.27	0.40	24.28	

[a] The literature screening criteria were as follows:

(a) Studies must include water sampling conducted in at least two distinct seasons.

(b) Studies must specify the research location (city/geographical coordinates).

(c) Surface water collection, sample preparation, and testing must employ nationally/industrially certified technical standards and methods.

(d) Studies must report the mean values of heavy metal concentrations in surface waters.

Table S7 Seasonal variation of dissolved heavy metals in the Yangtze River Basin (ug/L)

Elements	Time	N	Mean	SD	P[a]	
					Intra-group	Multiple comparison
All elements	Wet season	94	10.54	21.84	<0.05	Wet season -Normal season >0.05
	Normal season	59	5.86	17.99		Normal season -Dry season <0.05
	Dry season	86	19.61	45.19		Dry season -Wet season >0.05
As	Wet season	10	2.28	2.57	>0.05	Wet season -Normal season >0.05
	Normal season	8	2.16	1.04		Normal season -Dry season >0.05
	Dry season	9	4.16	7.51		Dry season -Wet season >0.05
Pb	Wet season	16	10.85	21.37	>0.05	Wet season -Normal season >0.05
	Normal season	9	1.65	2.50		Normal season -Dry season >0.05
	Dry season	14	19.84	26.59		Dry season -Wet season >0.05
Cr	Wet season	14	2.47	3.27	>0.05	Wet season -Normal season >0.05
	Normal season	9	2.13	2.27		Normal season -Dry season <0.05
	Dry season	12	9.53	13.07		Dry season -Wet season <0.05
Zn	Wet season	13	35.69	42.67	>0.05	Wet season -Normal season >0.05
	Normal season	8	26.43	43.42		Normal season -Dry season >0.05
	Dry season	12	71.78	93.45		Dry season -Wet season >0.05
Ni	Wet season	10	9.21	12.77	>0.05	Wet season -Normal season >0.05
	Normal season	5	1.84	1.66		Normal season -Dry season >0.05
	Dry season	9	10.36	14.62		Dry season -Wet season >0.05
Cd	Wet season	16	2.08	3.91	>0.05	Wet season -Normal season >0.05
	Normal season	11	0.49	1.37		Normal season -Dry season >0.05
	Dry season	15	1.80	3.31		Dry season -Wet season >0.05
Cu	Wet season	16	10.74	13.85	>0.05	Wet season -Normal season >0.05
	Normal season	11	6.64	11.39		Normal season -Dry season >0.05
	Dry season	15	18.27	40.15		Dry season -Wet season >0.05

[a] One-way ANOVA was performed to analyze the differences

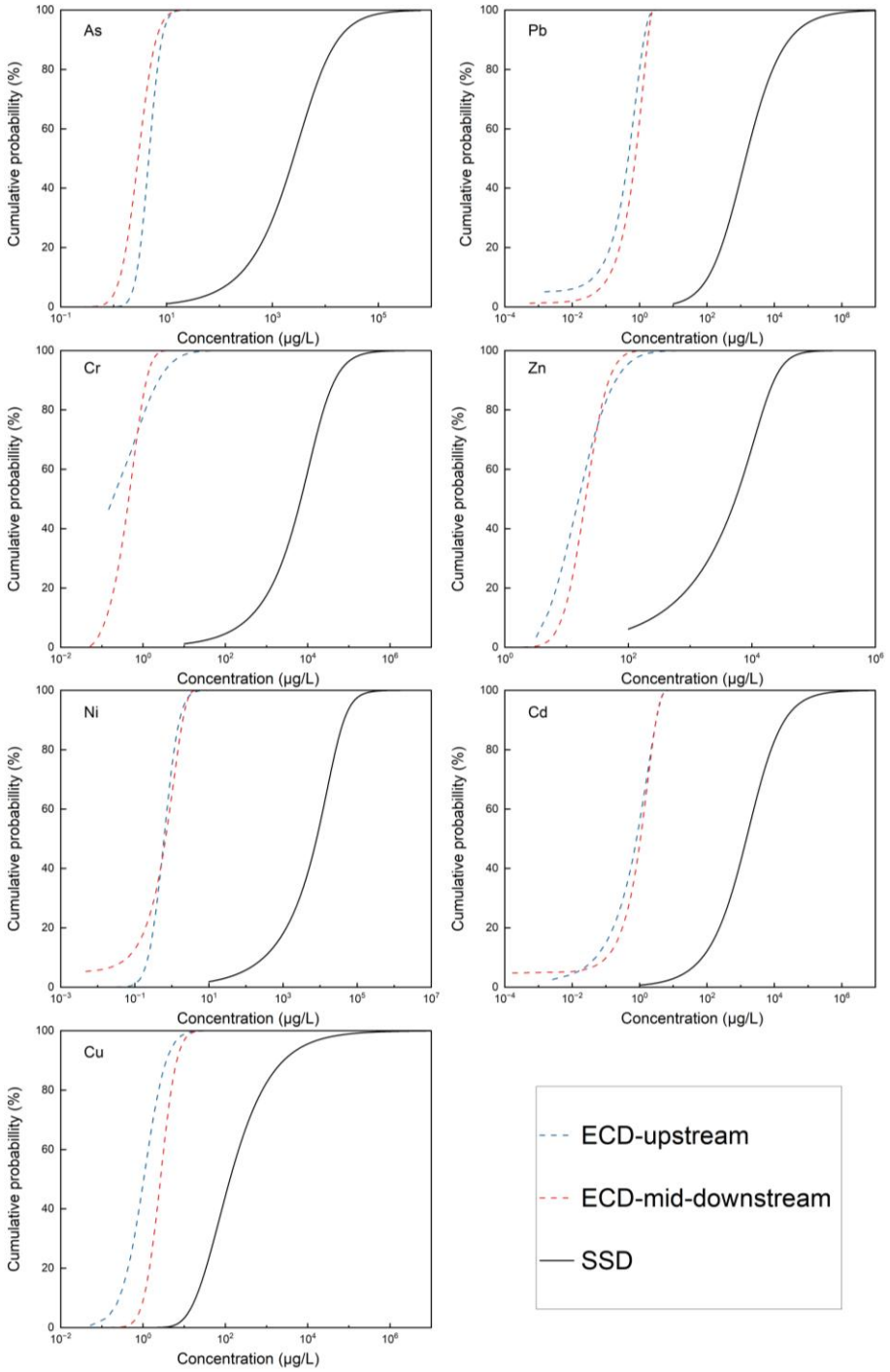

Fig. S1 The cumulative probability distribution of toxicity data and concentration of dissolved heavy metals

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