Bioaccumulation and Potential Risk Assessment of Heavy Metals in Tropical Bamboo Plantations of *Dendrocalamus brandisii* under Two Cultivation Patterns in Yunnan, China

Qian Cheng [1,2,†], Peitong Dou [1,†], Changyan Bao [1,*], Zhiming Zhang [1], Yurong Cao [1] and Hanqi Yang [1,3,*]

[1] Institute of Highland Forest Science, Chinese Academy of Forestry, Bailongsi, Panlong District, Kunming 650233, China
[2] College of Landscape Architecture, Nanjing Forestry University, Nanjing 210037, China
[3] Key Laboratory of Breeding and Utilization of Resource Insects, National Forestry and Grassland Administration, Kunming 650233, China
* Correspondence: baochangyan@caf.ac.cn (C.B.); yanghanqikm@caf.ac.cn (H.Y.)
† These authors contributed equally to this work.

Tables

Table S1. The classification of the contamination degree according to the value of P_i and P_N.

Level	P_i	Contamination Assessment
1	$P_i \leq 1$	No
2	$1 < P_i \leq 2$	Slight
3	$2 < P_i \leq 3$	Mild
4	$3 < P_i \leq 5$	Medium
5	$P_i > 5$	Serious

Table S2. I_{geo} and pollution status of heavy metals

I_{geo}	**Class**	**Pollution status**
$I_{geo} \leq 0$	0	Unpolluted
$0 < I_{geo} \leq 1$	1	Unpolluted-moderate
$1 < I_{geo} \leq 2$	2	Moderate
$2 < I_{geo} \leq 3$	3	Moderate-heavy
$3 < I_{geo} \leq 4$	4	Heavy
$4 < I_{geo} \leq 5$	5	Heavy-extreme
$5 < I_{geo}$	6	Extreme

Table S3. Grades of the potential ecological risk index

E_r^i	Risk grade	RI	Risk grade
$E_r^i < 40$	Low risk	$RI < 150$	Low risk
$40 \leq E_r^i < 80$	Moderate risk	$150 \leq RI < 300$	Moderate risk
$80 \leq E_r^i < 160$	Moderate-high risk	$300 \leq RI < 600$	High risk
$160 \leq E_r^i < 320$	High risk	$RI \geq 600$	Extremely high risk
$E_r^i \geq 320$	Extremely high risk		

Table S4. Input parameters to characterize the daily exposure dose of toxic metals via various exposure pathways (US EPA, 1996, 2011; MEPPRC, 2014; Li et al., 2014; He et al., 2016).

Parameter		Value	Unit
Daily bamboo shoot intake (FIR)	Adult	255	g/d
	Children	163	
Ingestion rate (R_{ing})	Adult	100	mg/day
	Children	200	
Inhalation rate (R_{inh})	Adult	14.5	m^3/day
	Children	7.5	
Exposure frequency (EF)	-	90	day/a
Exposure duration (ED)	Adult	24	a
	Children	6	
Exposed skin area (SA)	Adult	5075	cm^2
	Children	2448	
Skin adherence factor (AF)	Adult	0.07	mg/m^2*day
	Children	0.2	
Dermal absorption factor (ABS)	-	0.001	unitless
Particle emission factor (PEF)	-	1.36E+09	m^3/kg
Average exposure time (AT)	-	ED*365	day
Average bodyweight (BW)	Adult	56.8	Kg
	Children	15.9	

Table S5. Values of the reference dose (RfD; mg/kg/day) and the slope factor (SF; per mg/kg/day) for HMs (US EPA, 2013; Zhao et al., 2019; RunHong et al., 2021; Luo et al., 2022; Liu et al., 2023).

	RfD (mg/kg/day)				SF (per mg/kg/day)		
	bamboo	soil			ingestion	inhalation	dermal
		ingestion	inhalation	dermal			
Cr	1.50E+00	3.00E-03	2.86E-05	6.00E-05	5.00E-01	4.20E+01	2.00E+01
Mn	1.40E-01	4.60E-02	-	1.84E-03	-	-	-
Ni	2.00E-02	2.00E-02	9.00E-05	5.40E-03	1.70E+00	8.40E-01	4.25E+01
Cu	4.00E-02	4.00E-02	4.00E-02	1.20E-02	-	-	-
Zn	3.00E-01	3.00E-01	3.00E-01	6.00E-02	-	-	-
As	3.00E-04	3.00E-04	-	1.23E-04	1.50E+00	1.51E+01	3.66E+00
Cd	1.00E-03	1.00E-03	2.86E-06	2.50E-05	-	6.30E+00	-
Pb	3.60E-03	3.00E-03	3.52E-03	5.25E-04	8.50E-03	4.20E-02	-

Table S6. Uncertain parameters of this study's HMs concentrations in soils and bamboo shoots.

Heavy metals		Probabilistic distribution	Parameters (mg/kg) N(mean,SD) TRI(min,mode,max) LN(mean,SD)
Bamboo	Cr	Triangular	TRI(0.08,0.57,1.87)
	Mn	Triangular	TRI(0.97,4.71,17.77)
	Ni	Lognormal	LN(0.31,0.34)
	Cu	Triangular	TRI(1.15,1.87,14.50)
	Zn	Normal	N(5.04,1.17)
	As	Lognormal	LN(0.03,0.03)
	Cd	Lognormal	LN(0.01,0.02)
	Pb	Lognormal	LN(0.06,0.08)
Soil	Cr	Triangular	TRI(31.56,66.26,458.30)
	Mn	Triangular	TRI(117.45,505.58,2235.27)
	Ni	Lognormal	LN(35.94,46.33)
	Cu	Lognormal	LN(42.72,49.98)
	Zn	Lognormal	LN(72.44,86.11)
	As	Lognormal	LN(29.55,49.34)
	Cd	Triangular	TRI(0.05,0.20,1.51)
	Pb	Triangular	TRI(6.54,17.73,177.60)

Table S7. Parameters for human health risk assessment by Monte Carlo simulation (Wang et al., 2022; Tan, 2023).

Parameter	Unit	Type	Children	Adult
EF	day/year	Triangular	TRI (60, 90, 100)	
R_{ingest}	mg/day	Triangular	TRI (65, 100, 160)	TRI (5, 31, 54)
AF	mg/cm^2	Lognormal	LN (0.64, 1.2)	LN (0.48, 0.54)
ED	years	Uniform	U (0, 6)	U (7, 55)
FiR	g/day	Triangular	TRI (146, 163, 213)	TRI (219, 255, 266)

Table S8. Coefficient of variation of heavy metal content indifferent areas in soil.

Area	pH	Cr	Mn	Ni	Cu	Zn	As	Cd	Pb
LA	13.70 %	33.60 %	68.70 %	61.80%	69.00%	60.60%	67.10%	63.50 %	115.90 %
SF	13.40 %	78.80 %	75.70 %	121.20 %	128.00 %	128.50 %	187.30 %	88.20 %	71.20%
ALL	13.50 %	74.10 %	72.80 %	128.90 %	117.00 %	118.90 %	167.00 %	83.20 %	97.80%

LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

Table S9. potential ecological risk index and evaluation of ecological risk index of single heavy metals in study area.

Area		LA	SF	Mean(n=74)	Standard deviation(n=74)	Max(n=74)	Min(n=74)
E_r^i	Cr	2.07±0.69	3.21±2.53	2.69	2.0	14.10	1.00
	Mn	0.89±0.60	0.98±0.76	0.94	0.7	3.60	0.20
	Ni	2.41±1.47	5.78±6.96	4.23	5.5	31.20	0.80
	Cu	3.73±2.54	5.35±6.92	4.61	5.4	45.90	1.10
	Zn	0.62±0.38	0.97±1.24	0.81	1.0	8.10	0.20
	As	12.87±8.44	18.77±35.63	16.06	26.8	211.10	4.40
	Cd	28.14±17.51	37.85±33.79	33.39	27.8	207.90	6.60
	Pb	3.12±3.60	2.64±1.89	2.86	2.8	21.90	0.80
RI		53.86±28.14	75.55±58.81	65.59	48.2	306.00	22.00

LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

Table S10. Heavy metals content in bamboo shoots (n=74).

Area	LA	SF	Mean	Standard deviation	Max	Min	limit
Cr	0.63±0.37	0.54±0.36	0.58	0.37	1.87	0.08	0.5
Mn	7.12±5.27	5.66±3.95	6.31	4.61	17.77	0.97	-
Ni	0.30±0.18	0.32±0.43	0.31	0.34	2.77	0.07	-
Cu	3.57±3.48	2.88±2.67	3.19	3.06	14.5	1.15	-
Zn	5.17±1.03	4.94±1.28	5.04	1.17	8.17	3	-
As	0.02±0.02	0.03±0.04	0.03	0.03	0.22	0	0.5
Cd	0.01±0.02	0.01±0.02	0.01	0.02	0.08	0	0.05
Pb	0.05±0.03	0.07±0.11	0.06	0.08	0.62	0.02	0.1

LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

Table S11. Coefficient of variation of heavy metal content in different areas in bamboo shoots.

Area	Cr	Mn	Ni	Cu	Zn	As	Cd	Pb
LA	59.40%	74.10%	62.30%	97.50%	20.00%	139.60%	184.00%	52.70%
SF	66.90%	69.80%	133.20%	92.90%	25.90%	126.10%	155.00%	149.80%
All	63.30%	73.10%	109.40%	96.00%	23.30%	136.10%	169.70%	131.70%

LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

Figure

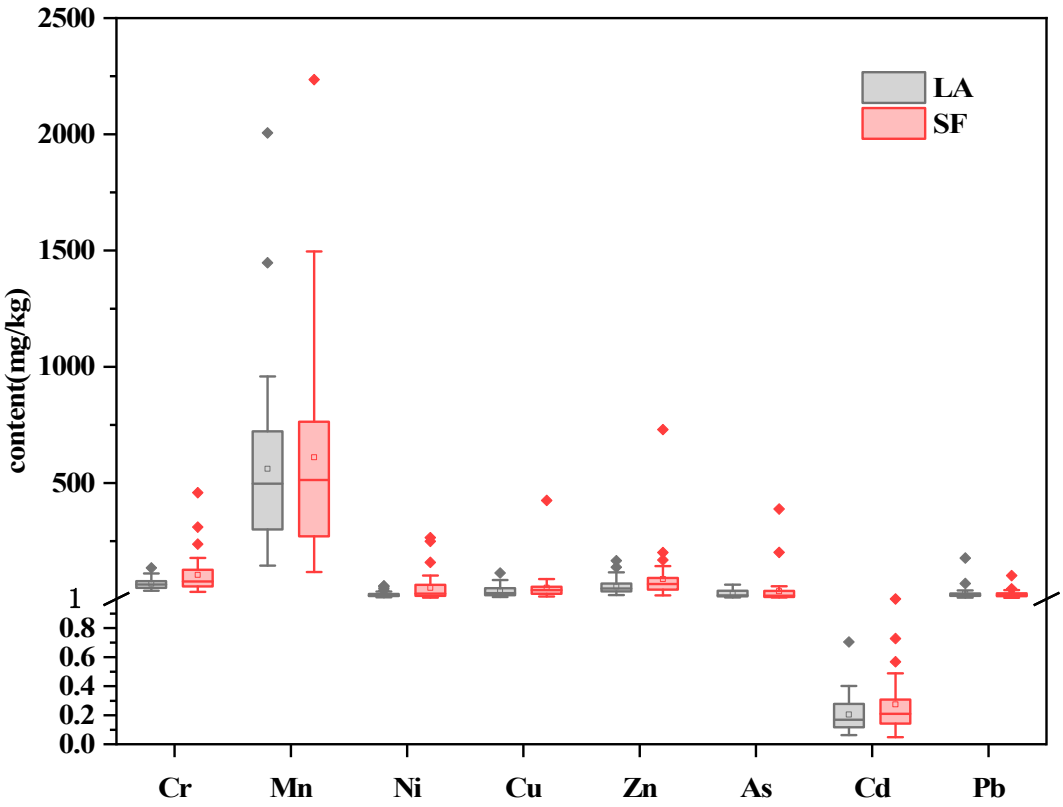

Figure S1. Heavy metal content of Cr、Mn、Ni、Cu、Zn、As、Cd and Pb from different bamboo shoot areas. LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

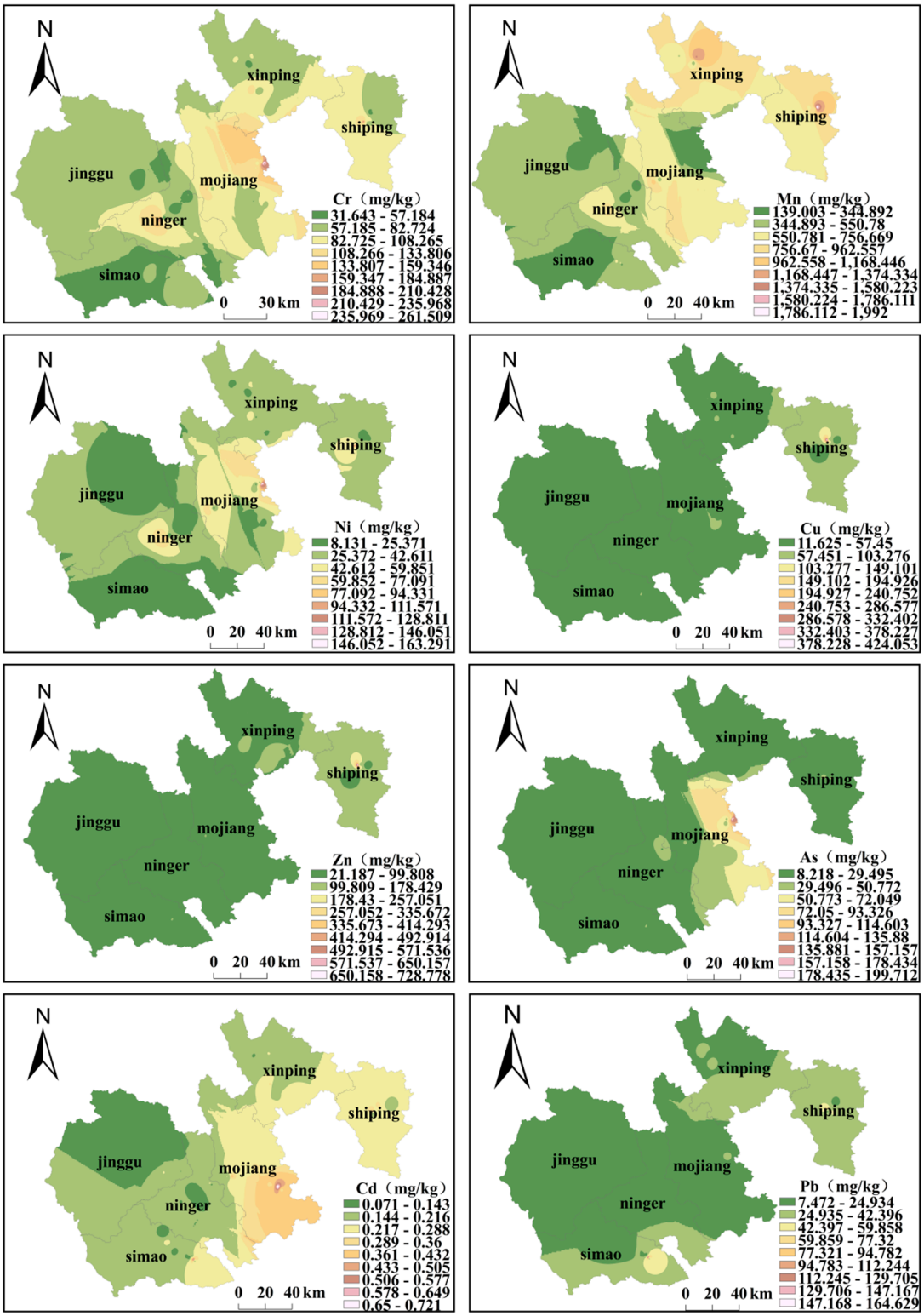

Figure S2. Spatial distribution of heavy metals content in research area. LA, bamboo forests of the large-area intensive afforestation pattern; SF, bamboo forests of the small-scale farmer management pattern.

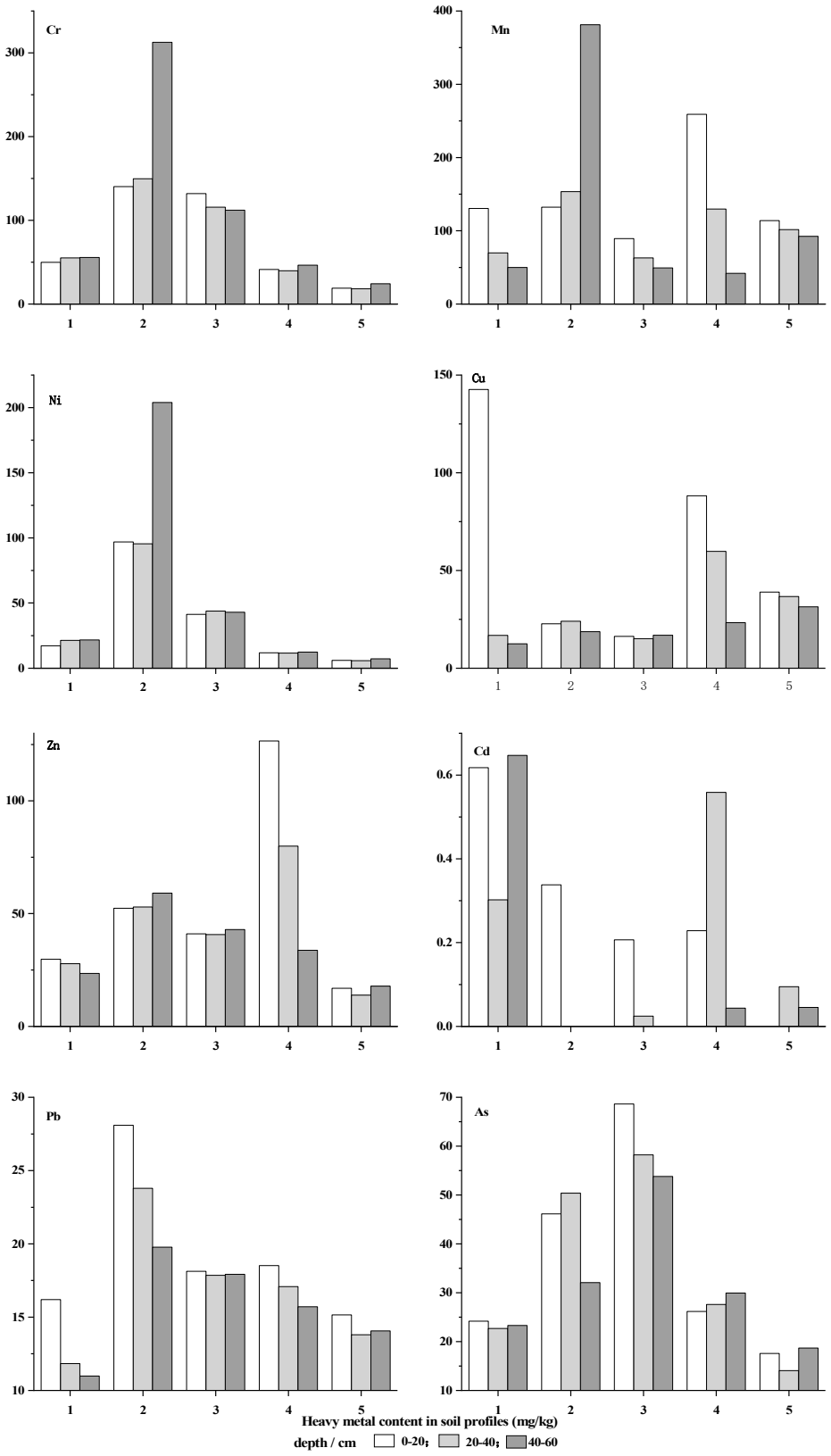

Figure S3. Heavy metal content in soil profiles (mg/kg).

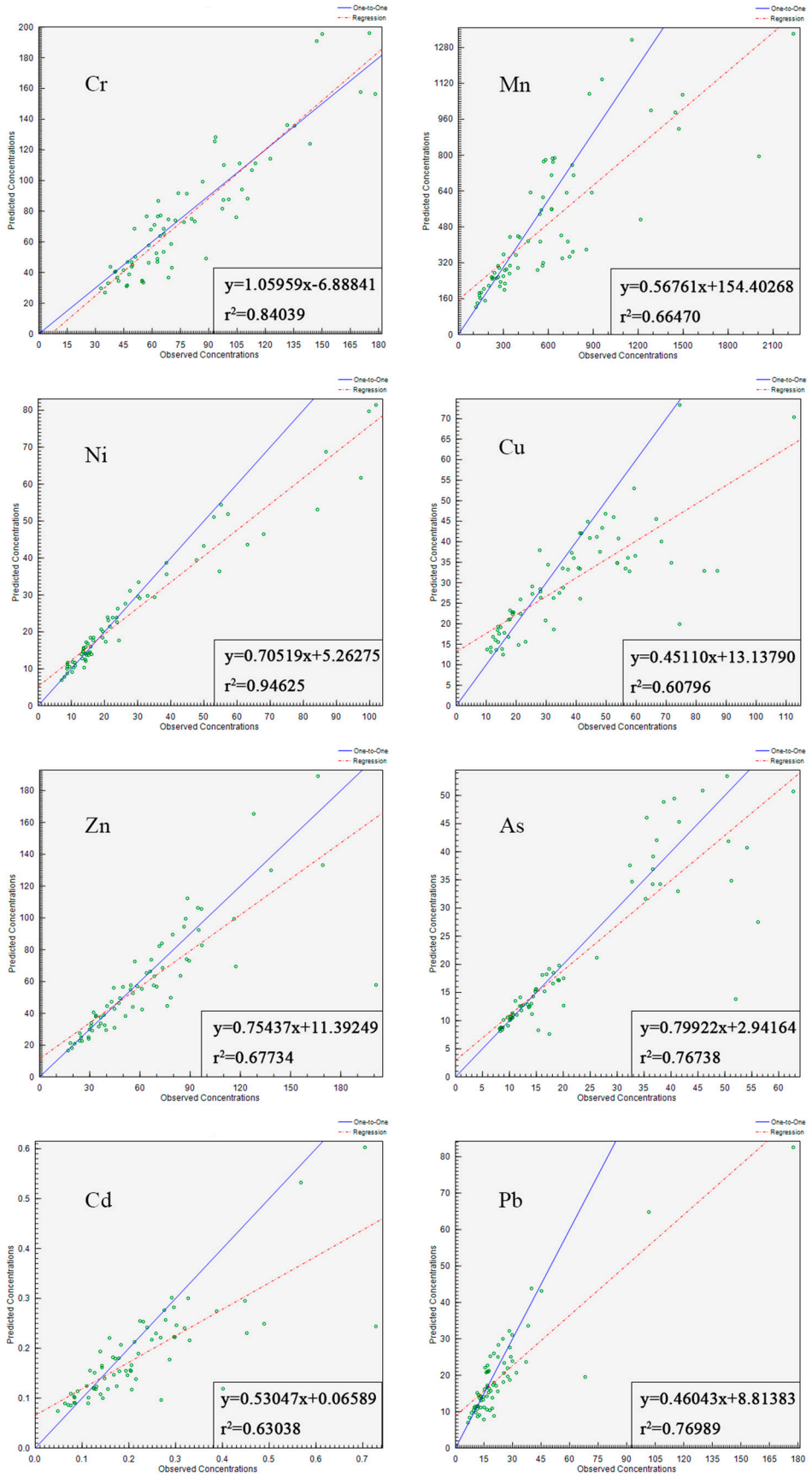

Figure S4. Fitting coefficients (r2) ofmeasured and predicted HMs concentrations in soil.

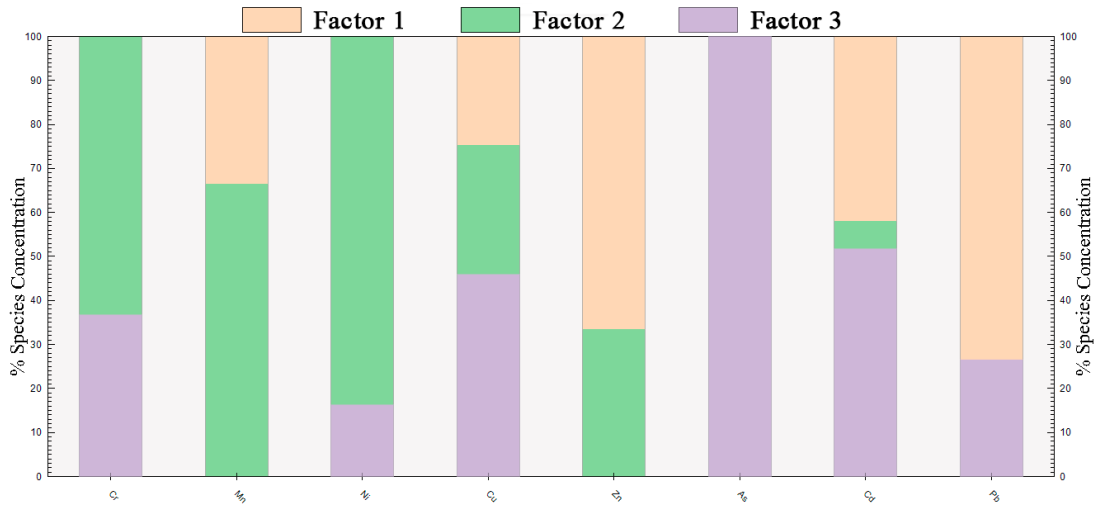

Figure S5. Contribution of heavy metal elements in each factor.

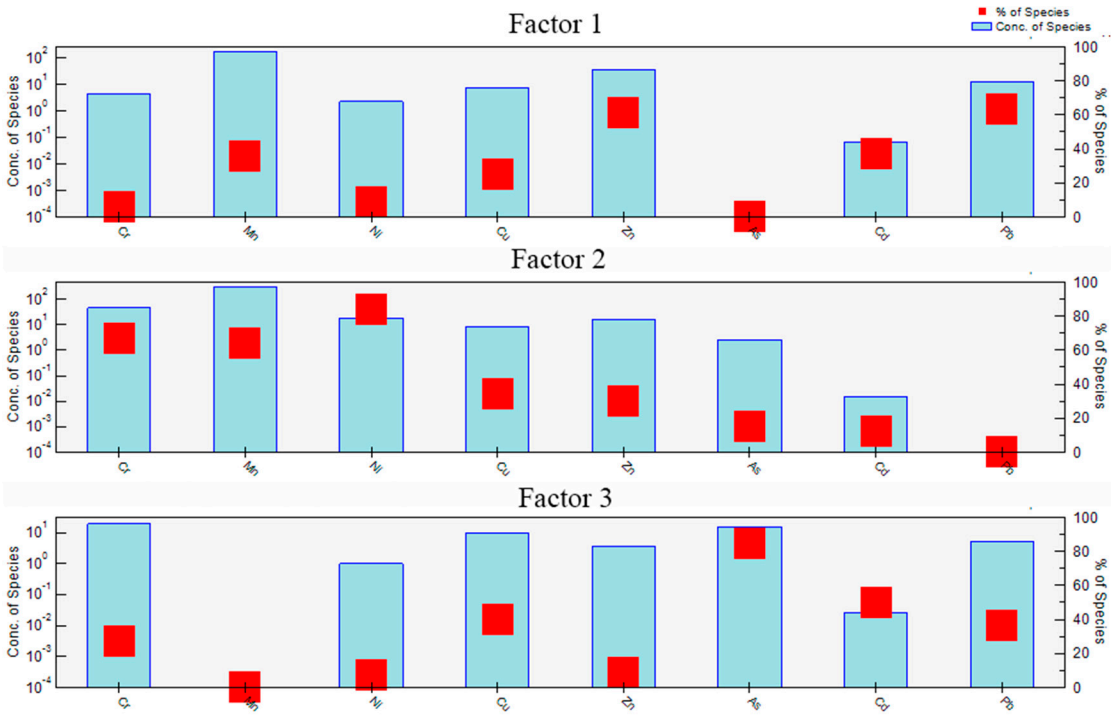

Figure S6. Profile of three factors and contribution of each HM to soil contamination.

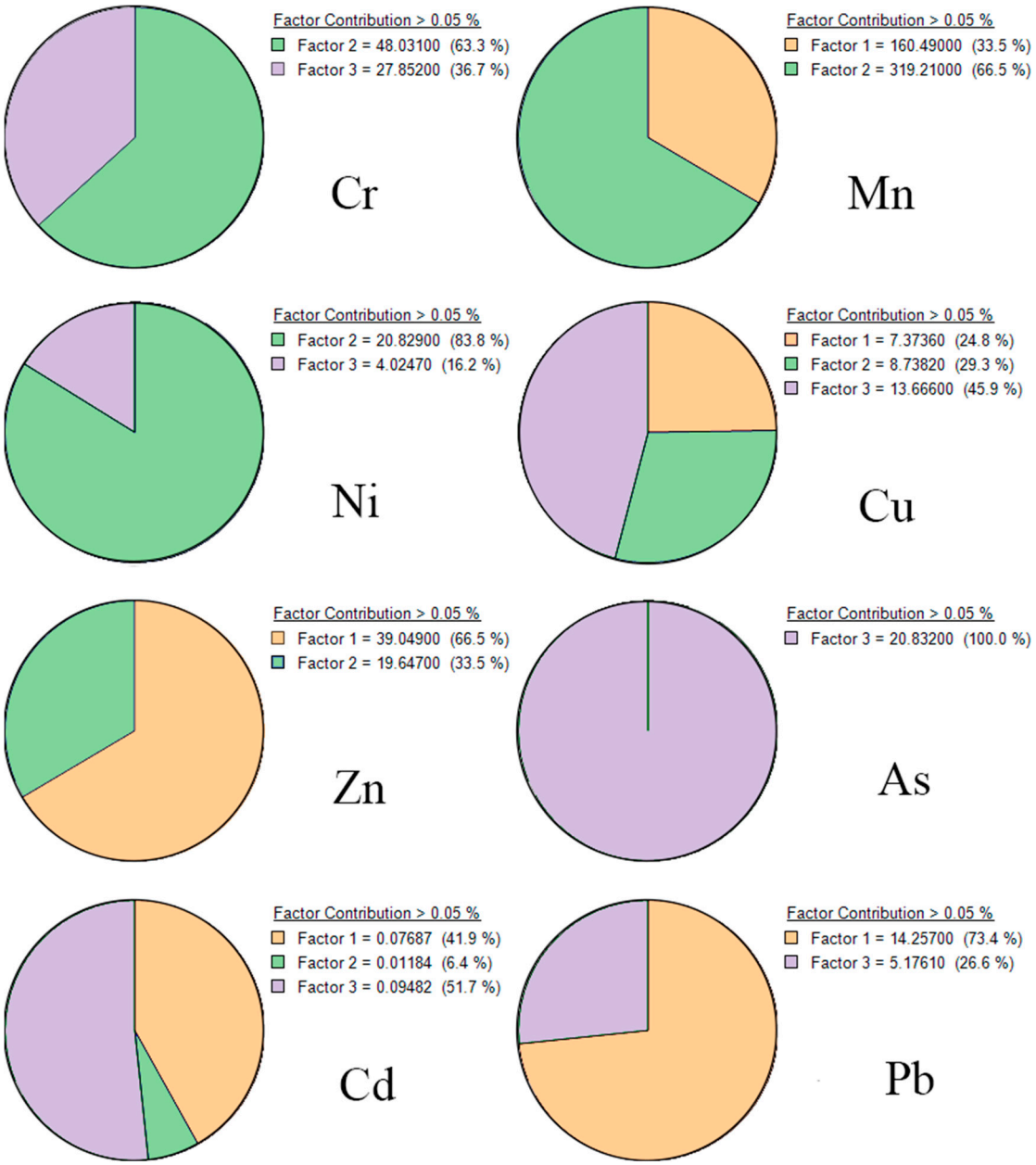

Figure S7. Factor contribution of heavy metals in soil by PMF model.

He, yu-na, Zhao, li-yun, Yu, dong- mei, 2016. Vegetable and fruit intake status of adult residents in China from 2010 to 2012. Chin. J. Prev. Med. 50, 221–224. https://doi.org/10.3760/cma.j.issn.0253-9624.2016.03.006

Li, Z., Zhang, Ya-rong, Wang, J., Chen, C., Zhang, Yu-mei, Wang, P., 2014. A survey on dietary types and intake of children aged 3-12 in China. China Food Nutr. 20, 78–82.

Liu, Z., Du, Q., Guan, Q., Luo, H., Shan, Y., Shao, W., 2023. A Monte Carlo simulation-based health risk assessment of heavy metals in soils of an oasis agricultural region in northwest China. Sci. Total Environ. 857, 159543. https://doi.org/10.1016/j.scitotenv.2022.159543

Luo, H., Wang, Q., Guan, Q., Ma, Y., Ni, F., Yang, E., Zhang, J., 2022. Heavy metal pollution levels, source apportionment and risk assessment in dust storms in key cities in Northwest China. J. Hazard. Mater. 422, 126878. https://doi.org/10.1016/j.jhazmat.2021.126878

MEPPRC, 2014. Technical Guidelines for Risk Assessment of Contaminated Sites, HJ25.3-2014.

RunHong, M., Cheng, J., Tang, F., Yue, J., Li, Z., Ni, Z., 2021. Heavy metals in bamboo shoots from Southeastern China and risk assessment. Food Addit. Contam. Part B 14, 264–270. https://doi.org/10.1080/19393210.2021.1947900

Tan, C., 2023. An integrated approach for quantifying source apportionment and source-oriented health risk of heavy metals in soils near an old industrial area. Environ. Pollut.

US EPA, 2013. Region IX, Regional Screening Levels (formerly PRGs). San Francisco, CA 94105.

US EPA, 2011. Exposure Factors Handbook: 2011 Edition, 2011, National Center for Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency; Washington, 20460, (EPA/600/R-09/052F).

US EPA, 1996. Soil Screening Guidance: Technical Background Document. Superfund US EPA.

Wang, B., Gao, F., Qin, N., Duan, X., Li, Y., Cao, S., 2022. A comprehensive analysis on source-distribution-bioaccumulation-exposure risk of metal(loid)s in various vegetables in peri-urban areas of Shenzhen, China. Environ. Pollut. 293, 118613. https://doi.org/10.1016/j.envpol.2021.118613

Zhao, R., Guan, Q., Luo, H., Lin, J., Yang, L., Wang, F., Pan, N., Yang, Y., 2019. Fuzzy synthetic evaluation and health risk assessment quantification of heavy metals in Zhangye agricultural soil from the perspective of sources. Sci. Total Environ. 697, 134126. https://doi.org/10.1016/j.scitotenv.2019.134126