Supplementary Material

Input Flux and the Risk of Heavy Metal(Loid) of Agricultural Soil in China: Based on Spatiotemporal Heterogeneity from 2000 to 2021

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2.1 Data collection and database building

With comprehensive consideration, the following factors need to be taken into account in our study: atmospheric deposition, fertilizer, livestock and poultry manure, irrigation water, while factors that have a low impact such as agrochemical or are not applied universally such as industrial waste and sludge are not considered for the fewer contributions to the quantities of total input.

The relevant publications were collected from Web of Science (WOS) and China National Knowledge Infrastructure (CNKI) with the following search term: *soil AND (agricultural OR farmland OR cropland) AND (heavy metal* OR trace element* OR As OR Cd OR Cr OR Cu OR Hg OR Ni OR Pb OR Zn) AND (flux* OR inventory OR input* OR source*) AND (atmospheric deposition OR fertilizer OR irrigation OR manure) AND (China OR Chinese).*

The 109 publications used to create the database are listed in the references[1-109].

Table S1. Descriptive statistics of heavy metal input fluxes in China (mg/m^2/yr)

Source		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Total
Atmospheric deposition	N	164	235	149	143	125	91	199	141	271
	n	1516	1947	1024	924	1455	777	1621	903	
	Min	0.04	0.03	0.14	0.56	0.003	0.19	0.42	3.4	
	Max	8.69	1.73	34.34	34.3	0.144	15.51	59.3	231.52	
	Mean	2.73	0.49	10.62	11.49	0.037	4.99	19.93	63.82	
	SD	2.09	0.38	8.08	7.68	0.031	3.49	13.53	45.79	
Fertilization	N	91	149	72	78	96	18	110	75	156
	n	764	1450	477	458	770	274	869	444	
	Min	0.051	0.001	0.14	0	0	0.35	0.0054	0.27	
	Max	2.04	0.319	3.24	5.45	0.09	3.57	10.78	22	
	Mean	0.58	0.05	0.99	1.03	0.012	0.82	0.75	5.18	
	SD	0.44	0.07	0.76	1.07	0.018	0.8	1.32	5	
Irrigation	N	81	146	68	78	78	39	111	80	167
	n	3360	1780	870	893	804	682	1000	931	
	Min	0	0	0	0	0	0	0	0.021	
	Max	8.82	0.47	13	7.55	0.468	5.31	7.03	55.35	
	Mean	1.82	0.09	2.27	1.68	0.05	0.79	1.29	8.21	
	SD	2.1	0.12	3.29	1.69	0.086	1.44	1.75	11.4	

Note: N (Sites); n (Samples)

Table S2. Comparison of researches on atmospheric deposition fluxes of heavy metals in China ($mg/m^2/yr$)

	This study (2000-2020)			Peng [110] (2008-2018)			Ni and Ma [111] (2006-2015)			Wang [112] (1995-2015)		
	n	WM	RSD	n	Mean	RSD	n	Mean	RSD	n	Mean	RSD
As	1516	2.67	77%	574	3.39	68%	755	3.37	67%	254	2.54	99%
Cd	1947	0.49	78%	625	0.59	80%	762	0.41	88%	310	0.37	256%
Cr	1024	10.77	76%	577	22.32	76%	763	16.14	72%	226	10.38	264%
Cu	924	11.54	67%	527	16.23	141%	764	11.56	74%	232	10.99	90%
Hg	1455	0.039	84%	553	0.07	71%	750	0.09	202%	262	0.07	230%
Ni	777	5.06	70%	364	8.61	133%	376	8.08	122%	159	4.79	170%
Pb	1621	20.64	68%	608	26.29	67%	768	19.19	72%	319	21.81	175%
Zn	903	64	72%	617	108.75	88%	766	72.90	124%	279	78.87	206%

Note: n (Samples); WM (Weighted mean); RSD (Relative standard deviation)

2.2 Weighted average calculation

Table S3. Agricultural utilization rate of livestock and poultry manures in China

Region	Utilization rate	References
Hubei	30%	[113]
Lanzhou, Gansu	40%	[114]
Cenxi, Guangxi	60%	[115]
Guizhou	40%	[116]
Jilin, Hebei, Sichuan, Zhejiang, Anhui	80%	[117]
Zhengzhou, Henan	61%	[118]
Yinchuan, Ningxia	60%	[119]
Liaozhong, Liaoning	64%	[120]
Jinzhou, Liaoning	80%	[121]
Taixing, Jiangsu	50%	[122]
Luochuan, Shanxi	60%	[123]
Inner Mongolia, Liaoning, Jilin, Heilongjiang	50%	[124]
Jilin, Hebei, Sichuan, Zhejiang, Anhui	63%	[125]
Average	57%	
Utilization rate used in this study	21%	

The planting area of grain crops accounts for 70% of the total arable land in China, and the manure is applied more to cash crops, protected vegetable fields, and orchards than to grain crop fields. Therefore, according to the amount of manure applied per unit area and the total amount of excrement produced, the utilization rate of grain crop fields was calculated as 21%.

Table S4. Parameters of livestock and poultry excrements

	Excretion parameters [126] (kg/day)	Water contents [127] (%)
Chicken	0.37	53.64
Pig	3.14~3.65	84.2
Sheep	2.25	61.1
Cattle	18.71~25.015	81.1
Horse	16.16	75.1
Donkey	13.9	71.4
Mule	13.9	72.1
Rabbit	0.37	76.74

2.4 Soil environment risk assessment

Table S5. Assessment standards of soil environmental capacity

Level	P_i	Risk level	Description
I	$P_i>1$	No risk	High capacity
II	$0.7\leq P_i<1$	Mild risk	Medium capacity
III	$0.3\leq P_i<0.7$	Moderate risk	Low capacity
IV	$0\leq P_i<0.3$	Severe risk	Alert
V	$P_i<0$	Extreme risk	Overload

Table S6. Risk screening values for soil contamination of agricultural land (mg/kg) [128]

Element	pH≤5.5	5.5<pH≤6.5	6.5<pH≤7.5	pH>7.5
As	30	30	25	20
Cd	0.3	0.3	0.3	0.6
Cr	150	150	200	250
Cu	50	50	100	100
Hg	0.5	0.5	0.6	1
Ni	60	70	100	190
Pb	70	90	120	170
Zn	200	200	250	300

3.1 Zoning of heavy metal input flux

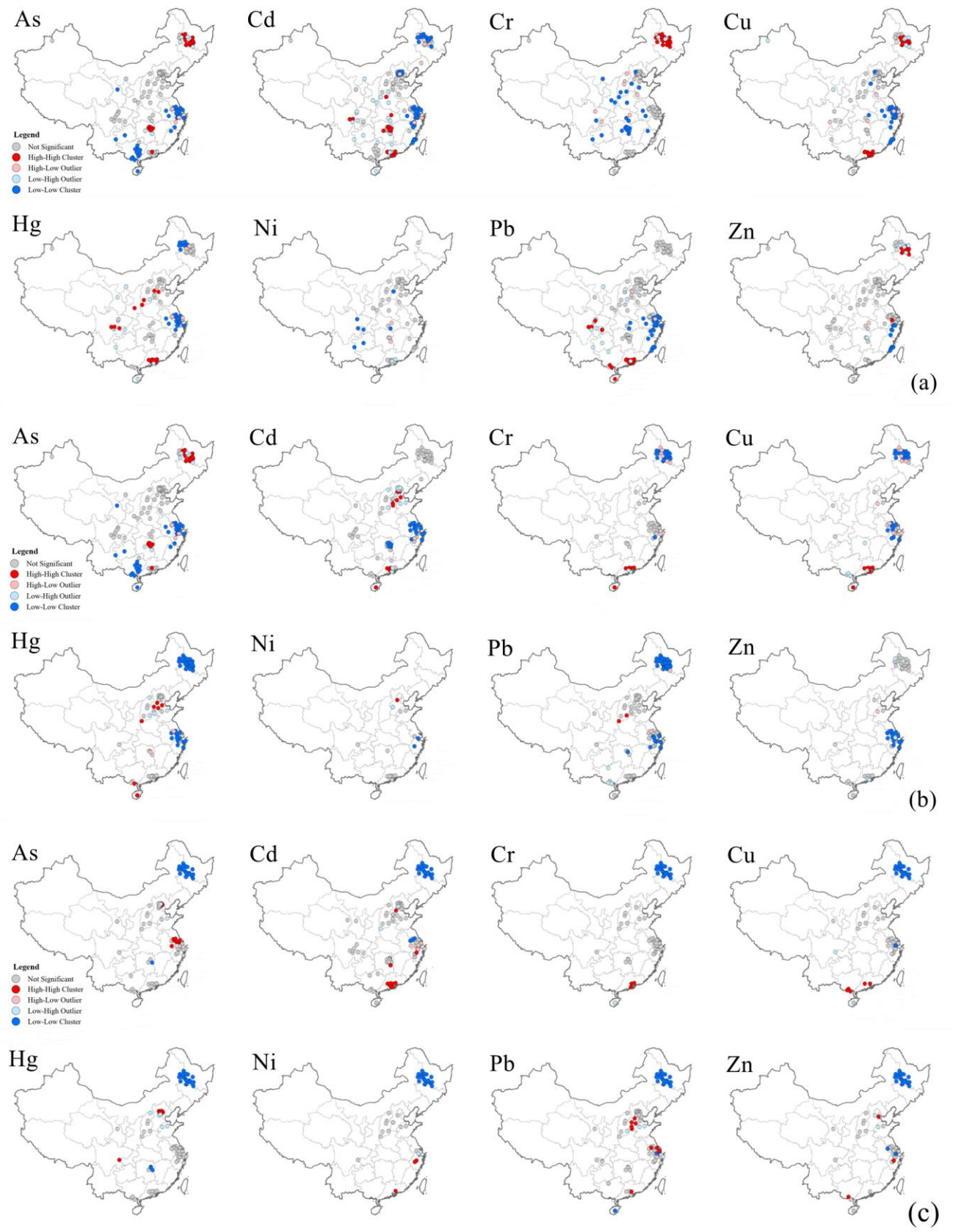

Figure S1. The LISA of heavy metal input flux via atmospheric deposition (a), fertilizer (b), irrigation (c)

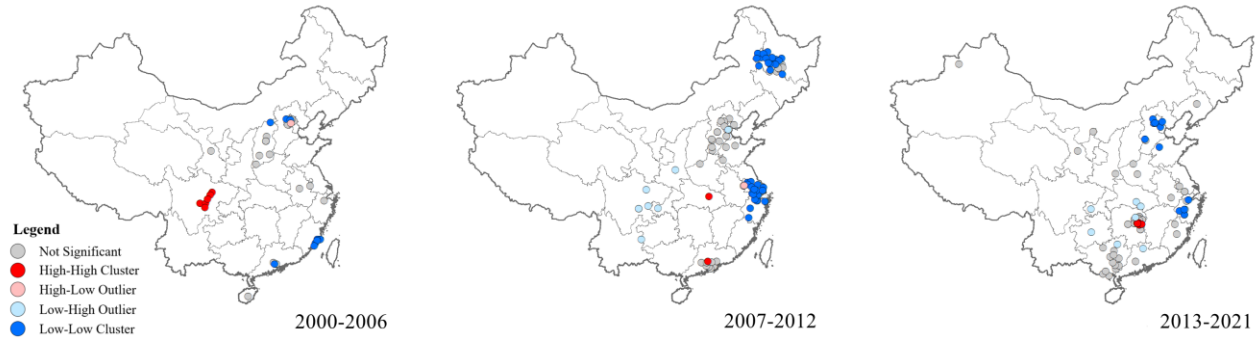

Figure S2. The LISA of Cd input flux via atmospheric deposition in different periods

3.2.3 Manure

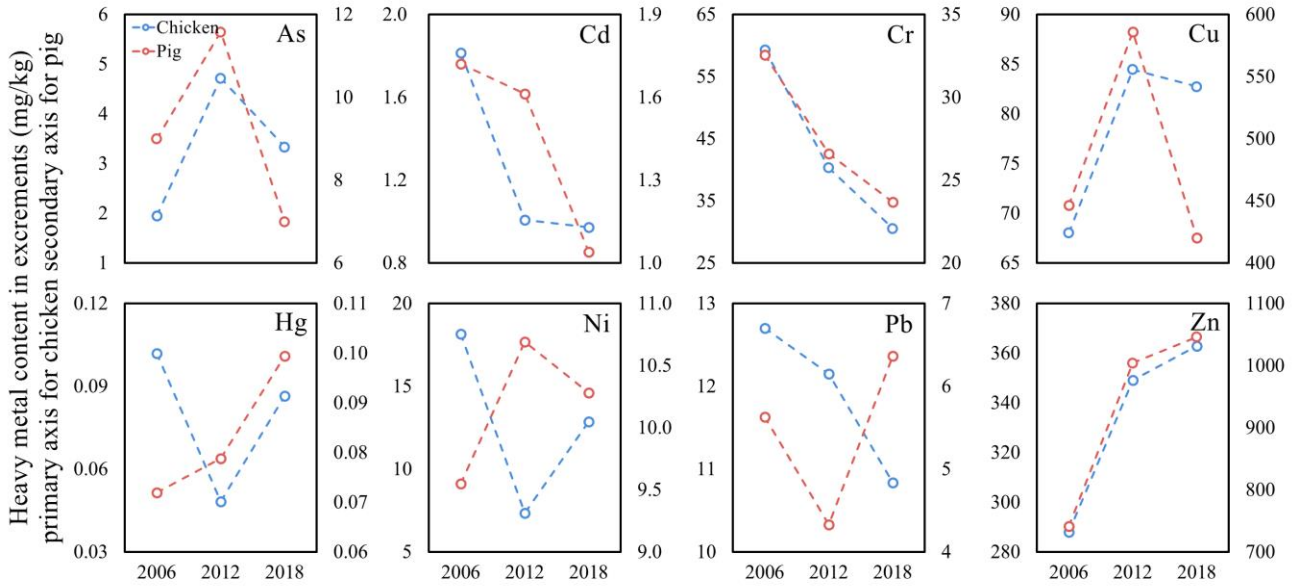

Figure S3. Heavy metal content in livestock and poultry excrements (2000-2021)

References

1. Yang, C.; Sun, G.; Zhang, C.; Chen, Y.; Yang, W.; Shang, L. A New Geochemical Method for Determining the Sources of Atmospheric Particles: A Case Study from Gannan, Northeast China. Atmosphere-Basel 2019, 10, doi:10.3390/atmos10100632.
2. Hu, W.; Huang, B.; Shi, X.; Chen, W.; Zhao, Y.; Jiao, W. Accumulation and health risk of heavy metals in a plot-scale vegetable production system in a peri-urban vegetable farm near Nanjing, China. Ecotox. Environ. Safe. 2013, 98, 303-309, doi:10.1016/j.ecoenv.2013.09.040.
3. Yi, K.; Fan, W.; Chen, J.; Jiang, S.; Huang, S.; Peng, L.; Zeng, Q.; Luo, S. Annual input and output fluxes of heavy metals to paddy fields in four types of contaminated areas in Hunan Province, China. Sci. Total Environ. 2018, 634, 67-76, doi:10.1016/j.scitotenv.2018.03.294.
4. Jiang, W.; Hou, Q.; Yang, Z.; Yu, T.; Zhong, C.; Yang, Y.; Fu, Y. Annual input fluxes of heavy metals in agricultural soil of Hainan Island, China. Environ. Sci. Pollut. R. 2014, 21, 7876-7885, doi:10.1007/s11356-014-2679-0.
5. Hou, Q.; Yang, Z.; Ji, J.; Yu, T.; Chen, G.; Li, J.; Xia, X.; Zhang, M.; Yuan, X. Annual net input fluxes of heavy metals of the agro-ecosystem in the Yangtze River delta, China. J. Geochem. Explor. 2014, 139, 68-84, doi:10.1016/j.gexplo.2013.08.007.

6. Yang, Y.; Xiao, C.; Wang, F.; Peng, L.; Zeng, Q.; Luo, S. Assessment of the potential for phytoremediation of cadmium polluted soils by various crop rotation patterns based on the annual input and output fluxes. J. Hazard. Mater. 2022, 423, 127-183, doi:10.1016/j.jhazmat.2021.127183.
7. Feng, W.; Guo, Z.; Peng, C.; Xiao, X.; Shi, L.; Zeng, P.; Ran, H.; Xue, Q. Atmospheric bulk deposition of heavy metal(loid)s in central south China: Fluxes, influencing factors and implication for paddy soils. J. Hazard. Mater. 2019, 371, 634-642, doi:10.1016/j.jhazmat.2019.02.090.
8. Feng, W.; Guo, Z.; Xiao, X.; Peng, C.; Shi, L.; Ran, H.; Xu, W. Atmospheric deposition as a source of cadmium and lead to soil-rice system and associated risk assessment. Ecotox. Environ. Safe. 2019, 180, 160-167, doi:10.1016/j.ecoenv.2019.04.090.
9. Xing, W.; Yang, H.; Ippolito, J.A.; Zhao, Q.; Zhang, Y.; Scheckel, K.G.; Li, L. Atmospheric deposition of arsenic, cadmium, copper, lead, and zinc near an operating and an abandoned lead smelter. J. Environ. Qual. 2020, 49, 1667-1678, doi:10.1002/jeq2.20151.
10. Cao, X.; Tan, C.; Wu, L.; Luo, Y.; He, Q.; Liang, Y.; Peng, B.; Christie, P. Atmospheric deposition of cadmium in an urbanized region and the effect of simulated wet precipitation on the uptake performance of rice. Sci. Total Environ. 2020, 700, 134513, doi:10.1016/j.scitotenv.2019.134513.
11. Wong, C.S.C.; Li, X.D.; Zhang, G.; Qi, S.H.; Peng, X.Z. Atmospheric deposition of heavy metals in the Pearl River Delta, China. Atmospheric environment (1994) 2003, 37, 767-776, doi:10.1016/S1352-2310(02)00929-9.
12. Liang, J.; Feng, C.; Zeng, G.; Zhong, M.; Gao, X.; Li, X.; He, X.; Li, X.; Fang, Y.; Mo, D. Atmospheric deposition of mercury and cadmium impacts on topsoil in a typical coal mine city, Lianyuan, China. Chemosphere 2017, 189, 198-205, doi:10.1016/j.chemosphere.2017.09.046.
13. Zhang, Y.; Zhang, S.; Zhu, F.; Wang, A.; Dai, H.; Cheng, S.; Wang, J.; Tang, L. Atmospheric heavy metal deposition in agro-ecosystems in China. Environ. Sci. Pollut. R. 2018, 25, 5822-5831, doi:10.1007/s11356-017-0892-3.
14. Cao, Z.; Yang, Y.; Lu, J.; Zhang, C. Atmospheric particle characterization, distribution, and deposition in Xi'an, Shaanxi Province, Central China. Environ. Pollut. 2011, 159, 577-584, doi:10.1016/j.envpol.2010.10.006.
15. Pan, Y.P.; Wang, Y.S. Atmospheric wet and dry deposition of trace elements at 10 sites in Northern China. Atmos. Chem. Phys. 2015, 15, 951-972, doi:10.5194/acp-15-951-2015.
16. Pan, Y.; Liu, J.; Zhang, L.; Cao, J.; Hu, J.; Tian, S.; Li, X.; Xu, W. Bulk Deposition and Source Apportionment of Atmospheric Heavy Metals and Metalloids in Agricultural Areas of Rural Beijing during 2016–2020. Atmosphere-Basel 2021, 12, 283, doi:10.3390/atmos12020283.
17. Ma, Y.; Tang, Y.; Xu, H.; Zhang, X.; Liu, H.; Wang, S.; Zhang, W. Bulk/wet deposition of trace metals to rural, industrial, and urban areas in the Yangtze River Delta, China. Ecotox. Environ. Safe. 2019, 169, 185-191, doi:10.1016/j.ecoenv.2018.11.002.
18. Fu, Y.; Li, F.; Guo, S.; Zhao, M. Cadmium concentration and its typical input and output fluxes in agricultural soil downstream of a heavy metal sewage irrigation area. J. Hazard. Mater. 2021, 412, 125203, doi:10.1016/j.jhazmat.2021.125203.
19. Tang, Y.; Han, G. Characteristics of major elements and heavy metals in atmospheric dust in Beijing, China. J. Geochem. Explor. 2017, 176, 114-119, doi:10.1016/j.gexplo.2015.12.002.
20. Chen, L.; Zhou, S.; Wu, S.; Wang, C.; Li, B.; Li, Y.; Wang, J. Combining emission inventory and isotope ratio analyses for quantitative source apportionment of heavy metals in agricultural soil. Chemosphere 2018, 204, 140-147, doi:10.1016/j.chemosphere.2018.04.002.
21. Chen, L.; Zhou, S.; Wu, S.; Wang, C.; He, D. Concentration, fluxes, risks, and sources of heavy metals in atmospheric deposition in the Lihe River watershed, Taihu region, eastern China. Environ. Pollut. 2019, 255, 113301, doi:10.1016/j.envpol.2019.113301.
22. Cai, K.; Li, C. Ecological risk, input flux, and source of heavy metals in the agricultural plain of Hebei Province, China. Int. J. Env. Res. Pub. He. 2022, 19, 2288, doi:10.3390/ijerph19042288.
23. Abuduwailil, J.; Zhaoyong, Z.; Fengqing, J. Evaluation of the pollution and human health risks posed by heavy metals in the atmospheric dust in Ebinur Basin in Northwest China. Environ. Sci. Pollut. R. 2015, 22, 14018-14031, doi:10.1007/s11356-015-4625-1.
24. Yang, Y.; Li, Y.; Dai, Y.; Wang, M.; Chen, W.; Wang, T. Historical and future trends of cadmium in rice soils deduced from long-term regional investigation and probabilistic modeling. J. Hazard. Mater. 2021, 415, 125746, doi:10.1016/j.jhazmat.2021.125746.
25. Xie, Y.; Zhu, J.; Liu, S.; Pan, S.; Ji, X. Input and output of cadmium (Cd) for paddy soil in central south China: fluxes, mass balance, and model predictions. Environ. Sci. Pollut. R. 2020, 27, 21847-21858, doi:10.1007/s11356-020-08519-4.
26. Yan, X.; Zhao, W.; Yang, X.; Liu, C.; Zhou, Y. Input–output balance of cadmium in typical agriculture soils with historical sewage irrigation in China. J. Environ. Manage. 2020, 276, 111298, doi:10.1016/j.jenvman.2020.111298.
27. Shi, T.; Ma, J.; Wu, F.; Ju, T.; Gong, Y.; Zhang, Y.; Wu, X.; Hou, H.; Zhao, L.; Shi, H. Mass balance-based inventory of heavy metals inputs to and outputs from agricultural soils in Zhejiang Province, China. Sci. Total Environ. 2019, 649, 1269-1280, doi:10.1016/j.scitotenv.2018.08.414.

28. Huang, S.; Tu, J.; Liu, H.; Hua, M.; Liao, Q.; Feng, J.; Weng, Z.; Huang, G. Multivariate analysis of trace element concentrations in atmospheric deposition in the Yangtze River Delta, East China. Atmos. Environ. 2009, 43, 5781-5790, doi:10.1016/j.atmosenv.2009.07.055.
29. Cai, K.; Li, C.; Song, Z.; Gao, X.; Wu, M. Pollution and health risk assessment of carcinogenic elements As, Cd, and Cr in multiple media—A case of a sustainable farming area in China. Sustainability-Basel 2019, 11, 5208, doi:10.3390/su11195208.
30. Xia, X.; Yang, Z.; Cui, Y.; Li, Y.; Hou, Q.; Yu, T. Soil heavy metal concentrations and their typical input and output fluxes on the southern Song-nen Plain, Heilongjiang Province, China. J. Geochem. Explor. 2014, 139, 85-96, doi:10.1016/j.gexplo.2013.06.008.
31. Liu, J.; Wang, D.; Song, B.; Chen, Z.; Zhang, X.; Tang, Y. Source apportionment of Pb in a rice-soil system using field monitoring and isotope composition analysis. J. Geochem. Explor. 2019, 204, 83-89, doi:10.1016/j.gexplo.2019.05.009.
32. Hu, W.; Wang, H.; Dong, L.; Huang, B.; Borggaard, O.K.; Bruun Hansen, H.C.; He, Y.; Holm, P.E. Source identification of heavy metals in peri-urban agricultural soils of southeast China: An integrated approach. Environ. Pollut. 2018, 237, 650-661, doi:10.1016/j.envpol.2018.02.070.
33. Qiu, K.; Xing, W.; Scheckel, K.G.; Cheng, Y.; Zhao, Z.; Ruan, X.; Li, L. Temporal and seasonal variations of As, Cd and Pb atmospheric deposition flux in the vicinity of lead smelters in Jiyuan, China. Atmos. Pollut. Res. 2016, 7, 170-179, doi:10.1016/j.apr.2015.09.003.
34. Li, Y.; Zhou, S.; Jia, Z.; Liu, K.; Wang, G. Temporal and spatial distributions and sources of heavy metals in atmospheric deposition in western Taihu Lake, China. Environ. Pollut. 2021, 284, 117465, doi:10.1016/j.envpol.2021.117465.
35. Liao, S.; Jin, G.; Khan, M.A.; Zhu, Y.; Duan, L.; Luo, W.; Jia, J.; Zhong, B.; Ma, J.; Ye, Z. et al. The quantitative source apportionment of heavy metals in peri-urban agricultural soils with UNMIX and input fluxes analysis. Environmental Technology & Innovation 2021, 21, 101232, doi:10.1016/j.eti.2020.101232.
36. Wang, F.; Peng, L.; Zhou, X.; Zeng, Q.; Luo, S. Typical sources of Cd to paddy fields in different contaminated areas and their impacts on Cd accumulation in topsoil and rice in Changzhutan, China. Environ. Res. 2021, 193, 110523, doi:10.1016/j.envres.2020.110523.
37. Ye, L.; Huang, M.; Zhong, B.; Wang, X.; Tu, Q.; Sun, H.; Wang, C.; Wu, L.; Chang, M. Wet and dry deposition fluxes of heavy metals in Pearl River Delta Region (China): Characteristics, ecological risk assessment, and source apportionment. J. Environ. Sci.-China 2018, 70, 106-123, doi:10.1016/j.jes.2017.11.019.
38. Zhong, C. A regional eco-geochemical assessment in agroecosystem of main basins in Shanxi Province (in Chinese), China University of Geosciences, Beijing, Beijing.
39. Tang, Q.; Yang, Z.; Zhang, B.; Feng, H.; Wang, H. A study of elements flux and sources from atmospheric bulk deposition in the Chengdu economic region (in Chinese). Earth Science Frontiers 2007, 213-222.
40. Zhou, Y.; Shen, W.; Li, Y.; Dou, L.; Li, W.; Lai, Q.; Du, H.; Zhong, L.; Liang, T. A study of prediction and early-warning forecast on geochemical accumulation of soil heavy metals based on flux model in Pearl River Delta economic zone (in Chinese). Advances in Earth Science 2012, 27, 1115-1125.
41. Dong, T.; Yang, H.; Li, H.; Qiao, Y.; Su, D. Accumulation characteristics of heavy metals in the soil with wheat-corn rotation system in north China (in Chinese). Journal of Agricultural Resources and Environment 2014, 31, 355-365.
42. Wang, Z. An analysis of the input flux and source of elements in dry and wet atmospheric deposition of southwest plain of Shandong: A case study of Juye County (in Chinese). Geophysical and Geochemical Exploration 2020, 44, 839-846.
43. Zheng, X.; Zheng, G.; Luo, J.; Zhang, Y.; Yan, X.; Wei, H.; Wang, C.; Wang, J.; Liu, X. An early warning study on the ecological geochemistry prediction of atmospheric deposition of northern Qianqiang City, Hubei Province (in Chinese). Resources Environment & Engineering 2018, 32, 21-29.
44. Yang, Z.; Hou, Q.; Yu, T.; Chen, J.; Xia, X.; Huang, Y.; Li, K. An example of eco-geochemical assessment for agroecosystems: A study of cd in Chengdu economic region (in Chinese). Earth Science Frontiers 2008, 23-35.
45. Tang, S.; Jiang, K.; Huang, J.; Qin, J.; Long, J.; Hou, H.; Peng, P. Analysis of cadmium balance source in soil-rice system in a certain area of Xiangxiang City (in Chinese). J. Soil Water Conserv. 2020, 34, 365-371.
46. Jiang, K. Analysis of cadmium interception effect and soil cadmium balance in rrigation wetland of paddy field system in central Hunan (in Chinese), Central South University of Forestry and Technology, Changsha.
47. Shi, T.; Yang, B.; Ma, G.; Yang, J.; Cao, Y. Analysis of environmental geochemical characteristics of atmospheric dry deposition in Shizuishan area (in Chinese). Ningxia Engineering Technology 2020, 19, 270-273.
48. Wang, R.; Zou, X.; Zhao, J.; Zhang, Y. Analysis on farmland soil erosion and deposition features in Beijing Plain (in Chinese). J. Soil Water Conserv. 2011, 25, 20-24, 29.
49. Li, D.; Shi, D.; Shen, R.; Hu, S.; Yang, J.; Li, Z.; Pan, L. Analysis on source apportionment of atmosphere particulates in Jianghan Plain,China (in Chinese). Geoscience 2008, 22, 915-921.
50. Liang, Y. Analysis on the source of heavy metal and the safety of rice in the typical farmland in the suburb of Changsha (in Chinese), Hunan Normal University, Changsha.

51. Chen, X.; Yang, Z.; Chen, Y.; Yang, Q.; Wang, L.; Wei, X. Arsenic input flux in farmland soil of 9 counties in the middle east of Guangxi (in Chinese). Geoscience 2019, 33, 525-534.
52. Dong, W.; Guo, B.; Lin, Y.; Liu, S.; Song, J. Assessment of input-output patterns of cd and pb of typical heavy metal polluted agricultural land in Quzhou (in Chinese). Journal of Nuclear Agricultural Sciences 2020, 34, 1061-1069.
53. Bao, L.; Yang, L.; Dong, J.; Zhou, J. Atmospheric deposition characteristic and its influence on the earth surface in western Chongqing agricultural area (in Chinese). Environmental Pollution & Control 2016, 38, 41-46.
54. Wu, C.; Qi, S.; Su, Q.; Fang, M.; Wang, W. Atmospheric deposition of heavy metals to Xinghua Bay, Fujian Province (in Chinese). Environ. Chem. 2006, 781-784.
55. Zhang, G. Atmospheric wet and dry deposition and its impacts on agricultural soils in northern China (in Chinese), Gansu Agricultural University, Lanzhou.
56. Shi, G. Biogeochemical cycles of toxic metals in farmland soil-plant system (in Chinese), East China Normal University, Shanghai.
57. Xu, Y.; Huang, B.; Shi, X.; Yu, D.; Wang, H.; Chang, Q.; Zhou, L. Budget of heavy metals in small-sized vegetable farming system in a typical peri-urban agricultural area (in Chinese). Soils 2008, 249-256.
58. Xiao, M.; Yang, W.; Zhang, Z.; Lv, X.; Chi, D. Cadmium accumulation in soil and risk prediction in the Qaidam Basin (in Chinese). Journal of Plant Nutrition and Fertilizer 2014, 20, 1271-1279.
59. Tang, Q.; Yang, Z.; Zhang, B.; Jin, L.; Liu, A. Cadmium flux in soils of the agroecosystem in the Chengdu economic region, Sichuan, China (in Chinese). Geological Bulletin of China 2007, 869-877.
60. Chen, X.; Yang, Z.; Chen, Y.; Yang, Q.; Wang, L.; Wei, X. Cadmium input flux in farmland soil of 9 counties in the middle east of Guangxi (in Chinese). Geophysical and Geochemical Exploration 2019, 43, 415-427.
61. Zhang, Z. Characteristics of heavy metals and environmental effects in farmland - Maize in Baiyin area, Gansu Province (in Chinese), Chang'an University, Xi'an.
62. Lu, H.; Li, J.; Chen, H.; Li, J.; Ni, W. Crop yields and heavy metal balance in soil-tomato system as affected by application of livestock and poultry manure (in Chinese). J. Soil Water Conserv. 2014, 28, 237-242.
63. Wang, C.; Xia, X.; Zhao, X.; Zheng, W.; Zhou, G.; Hu, X.; Ji, S. Distribution and migration regularity of soil heavy metal pollution along the Xiaoqing watershed, Shandong Province (in Chinese). Geology in China 2012, 39, 530-538.
64. Wang, H.; Li, J.; Sun, Z.; Zhao, X. Distribution characteristics and sources analysis of heavy metals in atmospheric dustfall in Panxian County of Guizhou Province (in Chinese). Journal of Guizhou University (Natural Sciences) 2014, 31, 124-127.
65. Dai, Y. Distribution characteristies and primary investigation on source apportionment of soil-vegetable heavy metals in Chongqing (in Chinese), Southwest University, Chongqing.
66. Lei, S.; Wu, G.; Wang, X. Distribution of heavy metals in soil and spring wheat in Baiyin district (in Chinese). Gansu Metallurgy 2007, 86-88.
67. Cong, Y.; Chen, Y.; Yang, Z.; Hou, Q.; Wang, H. Dry and wet atmospheric deposition fluxes of elements in the plain area of Beijing Municipality, China (in Chinese). Geological Bulletin of China 2008, 257-264.
68. Cong, Y.; Zheng, P.; Chen, Y.; Hou, Q. Ecological risk assessments of heavy metals in soils of the farmland ecosystem of Beijing, China (in Chinese). Geological Bulletin of China 2008, 681-688.
69. Zhang, N. Effects of air settlement on heavy metal accumulation in soil (in Chinese). Soil and Environmental Sciences 2001, 10, 91-93.
70. Lai, M.; Yang, Z.; Wang, H.; Zhou, J.; Wang, J. Effects of atmospheric fallouts on heavy metal elements accumulation in soils in farmland areas in the Taiyuan Basin, Shanxi, China and sources of fallouts (in Chinese). Geological Bulletin of China 2008, 27, 240-245.
71. Lu, H. Effects of fertilizer management on macronutrient and heavy metal balance in soil-crop systems (in Chinese), Zhejiang University, Hangzhou.
72. Kong, W.; Ni, W. Effects of integrated fertilization with commercial organic manure and chemical fertilizers on heavy metal balance in soil-rice cropping system (in Chinese). Chinese Journal of Rice Science 2006, 517-523.
73. Sun, C.; Chen, Z.; Bi, C.; Liu, Y.; Zhang, C.; Wang, D.; Shi, G.; Ye, M. Evaluation on environmental quality of heavy metals in agricultural soils of Chongming Island, Shanghai (in Chinese). Acta Geographica Sinica 2009, 64, 619-628.
74. Zhang, N.; Chen, J.; Chang, X. Factors affecting heavy metal accumulation in soil of sewage irrigation area (in Chinese). Soils 2002, 90-93.
75. Zhang, M.; Yang, D. Flows and mass balance of heavy metals in two typical farming systems in Shaoxing Plain, Zhejiang Province, China (in Chinese). Ecology and Environmental Sciences 2010, 19, 320-324.
76. Ma, W.; Zhang, M. Flows and mass balance of heavy metals in typical tea ecological systems in Zhejiang Province, China (in Chinese). Journal of Tea Science 2011, 31, 362-370.
77. Lu, H.; Ye, W.; Zhang, G.; Li, J.; Ni, W. Heavy metal balance in soil-pakchoi system as affected by application of commercial organic manure (in Chinese). Chinese Journal of Soil Science 2014, 45, 1511-1516.

78. Hou, J.; Shen, Y.; Cao, S.; Cheng, X.; Wang, W. Heavy metal flux research in Tianjin suburb vegetable farmland (in Chinese). Journal of Anhui Agricultural Sciences 2013, 41, 5764-5773.
79. Zheng, X.; Wang, J.; Wei, L.; Zheng, G.; Hu, R.; Tang, S.; Liu, X.; Liu, D.; Xu, Z. Heavy metals and pH in dry and wet deposition in a certain area of Honghu City (in Chinese). Urban Environment & Urban Ecology 2016, 29, 18-20, 27.
80. Jian, Y. Heavy metals fluxes and their source and sink patterns in a small watershed of Minjiang River (in Chinese), Sichuan Agricultural University, Ya'an.
81. Xu, H.; Wu, D.; Li, G.; Wu, L.; Ye, C.; Guo, B.; Ma, J.; Ye, Z.; Liu, D. Input and output balance of cadmium(cd) in cultivated land with moderate pollution in Songyang County (in Chinese). Journal of Zhejiang A&F University 2021, 38, 1231-1237.
82. Zhu, P.; Liu, Y.; Chen, L.; Gao, S.; Zhang, J.; Yang, W.; Li, Y.; Liu, K. Input pattern of sources for pb, cd and zn in the agricultural ecological system in the lower reaches of Minjiang River (in Chinese). Journal of Agro-Environment Science 2013, 32, 1814-1820.
83. Xie, G.; Ying, J.; Zhang, M. Mass balance of heavy metals in typical pear orchard ecological system affected by fertilization and atmospheric deposition (in Chinese). Chinese Agricultural Science Bulletin 2019, 35, 88-94.
84. Shi, Y. Modeling and mapping of critical loads for heavy metals in suburb agro-ecosystem of Taihu basin (in Chinese), Nanjing University, Nanjing.
85. Yan, X. Pollution characterization of heavy metals in air, soil and precipitation in Xi'an (in Chinese), Xi'an University of Architecture and Technology, Xi'an.
86. Jiang, W. Potential hazardous element geochemistry in agro-ecosystem of areas around Beibu Gulf (in Chinese), China University of Geosciences, Beijing, Beijing.
87. Wu, C.; Qi, S.; Fang, M.; Su, Q. Precipitation characteristics of heavy metal in dustfall to Quanzhou Bay of Fujian Province (in Chinese). Research of Environmental Sciences 2006, 27-30.
88. Shi, T. Prediction and early-warning forecast on heavy metals and their pollution status in agricultural soils in Zhejiang Province, China based on input-output inventory (in Chinese), Northwest A&F University, Xianyang.
89. Xu, H.; Li, D.; Yang, J.; Zhang, X.; Zhu, L. Preliminary study on flux of atmospheric dry and wet deposition of heavy metal elements in Yunmeng County, Hubei Province (in Chinese). Resources Environment & Engineering 2015, 29, 816-821.
90. Song, Z.; Chen, Y.; Cui, X.; Luan, W.; Li, S. Research on as flux in soils of the Hebei Plain, China (in Chinese). Earth and Environment 2011, 39, 167-173.
91. Liu, H. Research on geochemical background and flux for cadmium, mercury and lead in soil environment in the piedmont region of Taihang Mountain (in Chinese), Hebei GEO University, Shijiazhuang.
92. Li, B. Research on the current status of wetland and grassland eco-environment in the western part of Jilin Province (in Chinese), Jilin University, Changchun.
93. Jin, G. Researeh on source apportionment of heavy metals in farmland soil at small scale (in Chinese), Zhejiang A&F University, Hangzhou.
94. Zhao, X. Risk assessment in the hilly region of Sichuan central section (in Chinese), Chengdu University of Technology, Chengdu.
95. Wang, L.; Song, Z.; Gong, D.; Jia, W.; Sun, S.; Geng, N.; Ru, S.; Sun, M.; Zhang, G. Security early warning of cadmium in non-environmental pollution vegetable soil in Hebei Plain (in Chinese). Chinese Agricultural Science Bulletin 2016, 32, 126-132.
96. Wang, W.; Cao, S.; Li, G.; Zhang, Y. Sedimentation flux and its evaluation of dry and wet atmospheric deposition of heavy metal elements in north Tianjin (in Chinese). Environmental Science and Management 2017, 42, 46-51.
97. Dai, Y.; Fu, K.; Yang, Y.; Wang, M.; Chen, W. Simulation cadmium(cd) accumulation in typical paddy soils in South China (in Chinese). Environmental Science 2021, 42, 353-358.
98. Zhang, X. Soil environmental quality monitoring in the Yangtze River Delta (in Chinese), China University of Geosciences, Beijing, Beijing.
99. Li, Y. Source/sink pattern on lead (pb), zinc (zn) and cadium (cd) in different planting modes in the lower reaches of Minjiang (in Chinese), Sichuan Agricultural University, Ya'an.
100. Xiong, Z. Studies on pollution characteristics and risk assessment of heavy metal in Hebei's farmland soil - A case of cadmium and nickel (in Chinese), Chinese Academy of Agricultural Sciences.
101. Nan, M. Study on atmospheric dry and wet deposition fluxes and geochemical classification in Lianyuan area (in Chinese). City Geography 2016, 97-99.
102. Chen, Y.; Hu, H. Study on heavy metal pollution sources in the watershed of Jianghuai River in Hefei (in Chinese), Geoscience Science and Technology Forum of six Provinces and one City in East China in 2007, Hefei, China: Hefei, China, 2007.
103. Han, H. Study on land quality geochemical assessment of prime farmland protection area in Qingyang (in Chinese), China University of Geosciences, Beijing, Beijing.

104. Xiong, A.; Chen, Y.; Dai, Y.; Hou, J.; Yi, T. Study on lead flux in vegetable-based soil in Chongqing suburb based on heavy metals flow (in Chinese). Environmental Impact Assessment 2016, 38, 92-96.
105. Zhang, G. Study on the influences of atmospheric deposition on the heavy metal pollution in the farmland over the Bohai Sea region and corresponding preventions (in Chinese), Gansu Agricultural University, Lanzhou.
106. Li, S.; Luan, W.; Song, Z.; Cui, X.; Wu, X. The distribution and source of atmospheric dustfall in the southern plain of Hebei Province (in Chinese). Geology in China 2010, 37, 1769-1774.
107. Huang, Y. The exploring of heavy metal pollution source apportionment in various scale of agricultural soils (in Chinese), Zhejiang University, Hangzhou.
108. Wang, X.; Liang, B. The geochemistry characteristics of the atmospheric dust from the Chinese herbal origin area (in Chinese). Science and Technology of West China 2012, 11, 35-36, 30.
109. Cai, J. The research on the analysis and fluctuation rule of cadmium pollution sources in the typical paddy fields - A case study of Changsha County (in Chinese), Hunan University, Changsha.
110. Peng, H.; Chen, Y.; Weng, L.; Ma, J.; Ma, Y.; Li, Y.; Islam, M.S. Comparisons of heavy metal input inventory in agricultural soils in North and South China: A review. Sci. Total Environ. 2019, 660, 776-786, doi:10.1016/j.scitotenv.2019.01.066.
111. Ni, R.; Ma, Y. Current inventory and changes of the input/output balance of trace elements in farmland across China. PLoS One 2018, 13, e199460, doi:10.1371/journal.pone.0199460.
112. Wang, M.; Yuan, M.; Su, D. Characteristics and spatial-temporal variation of heavy metals in atmospheric dry and wet deposition of China. China Environmental Science 2017, 37, 4085-4096.
113. Luo, J. Strengthen the construction of rural environmental policies and laws in Hubei and promote the construction of new socialist countryside.
114. Li, X. Old and new pollution is intertwined with rural environment worries. Lanzhou Daily 2010.
115. Liang, T. Cenxi, Guangxi - Five Actions out of the acceleration of green development. Farmers' Daily 2022.
116. Wang, W.; Chen, L.; Fan, C.; Qin, S. The status and utilization counter measures of Guizhou manure resources. Southwest China Journal of Agricultural Sciences 2010.
117. Qiu, H.; Luan, J.; Kong, X.; Jing, Y. Estimation of nitrogen utilization efficiency in China's agricultural production. Journal of Qingdao Agricultural University (Natural Science) 2014.
118. Gao, T.; Chang, M.; Fu, T.; Shi, P.; Zhao, F. Calculation of comprehensive utilization rate of feces in large-scale dairy farms, The 7th National Congress and Symposium of Animal Ecology Branch of Chinese Society of Animal Science and Veterinary Medicine, 2008.
119. Liang, X. The new scene in the field, the 'iron bulls' showing their talents. Yinchuan Daily 2022.
120. Lu, J.; Wang, Z.; Chi, F.; Bing, L.; Wang, M. Present Situation, Potential and countermeasures of Livestock Manure Recycling in the Circular Agriculture: A Case in Liaozhong County. Ecological Economy 2015, 31, 107-113.
121. Yao, P.; Yu, Z.; Yao, Z. Investigation and control measures on pollution of livestock and poultry breeding in Jinzhou City, Proceedings of National High-level Forum on Comprehensive Prevention and Control of Agricultural Non-point Source Pollution, 2008.
122. Ye, G.; Fan, B.; Zhou, L.; Zhang, C.; Wang, Z. Status and countermeasure of comprehensive utilization of agricultural waste in Taixing City. Modern Agricultural Science and Technology 2014.
123. Xing, L.; Yang, S.; Liu, H. Evaluation of agricultural sustainable development in main apple production areas in Weibei, Shaanxi Province: Taking Luochuan, Xunyi and Baishui county as examples. Journal of China Agricultural University 2019, 24, 213-222.
124. Yang, Z.; Lu, W.; Long, Y. Atmospheric dry and wet deposition of heavy metals in Changchun City, China. Research of Environmental Sciences 2009, 22, 28-34.
125. Mo, H.; Qiu, H.; Wang, J.; Bai, J. The methods of disposal of livestock and poultry waste and its influencing factors. Journal of Agricultural Resources and Environment 2011, 28, 59-64.
126. Bao, W.; Liu, J.; An, J.; Xie, G. Value-taking of livestock and poultry excreta factor in China. Journal of China Agricultural University 2018, 23, 1-14.
127. Bao, W.; Liu, J.; An, J.; Xie, G. Discussion on value-taking of relative parameters for assessment of livestock and poultry excrement resource in China. Transactions of the Chinese Society of Agricultural Engineering 2018, 34, 314-322.
128. MEE Soil environmental quality risk control standard for soil contamination of agricultural land (GB15618-2018). Ministry of Ecology and Environment of the PRC 2018.