Article

Current Situation of Agricultural Soil Pollution in Jiangsu Province: A Meta-Analysis

Rui Zhang [1,2], Tao Chen [3,4], Lijie Pu [1,2,5,*], Lu Qie [1,2], Sihua Huang [1,2] and Dejing Chen [1,2]

[1] School of Geography and Ocean Science, Nanjing University, Nanjing 210023, China
[2] The Key Laboratory of the Coastal Zone Exploitation and Protection, Ministry of Natural Resources, Nanjing 210023, China
[3] College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, China
[4] Key Laboratory of Plant Nutrition and the Agri-Environment in Northwest China, Ministry of Agriculture and Rural Affairs, Yangling 712100, China
[5] School of Environmental Engineering, Nanjing Institute of Technology, Hongjing Road 1, Nanjing 211167, China
* Correspondence: ljpu@nju.edu.cn; Tel.: +86-025-8359-4209

Figure caption:

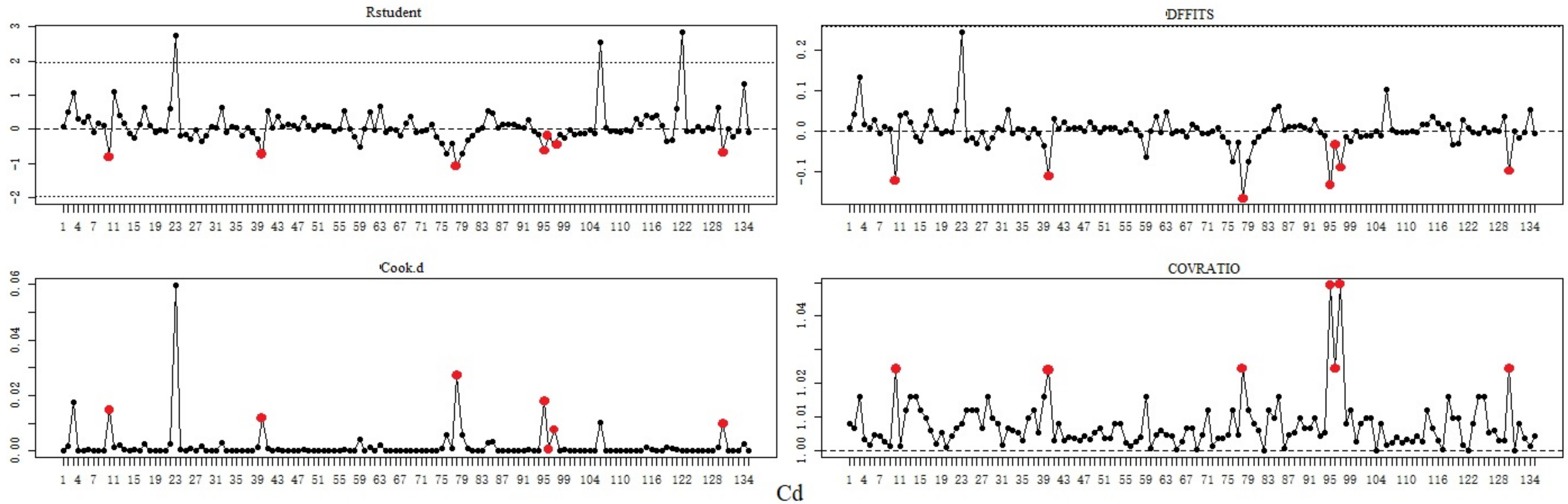
Figure S1. The Outlier selection by sensitivity analysis.
Figure S2. The annual subgroup analysis of the ecological risk index.

Table caption:

Table S1 The Shapiro-Wilk test of weights and mean concentrations.
Table S2 The weighted mean values (mg/kg) of heavy metals calculated by the four datasets.
Table S3 The risk control standard for the environmental quality of other countries (mg/kg).
Table S4 Concentration projections in optimistic scenario.
Table S5 Concentration projections in no-mutation scenario.

Method introduction:

1. Potential ecological risk index.
2. Concentration projection model.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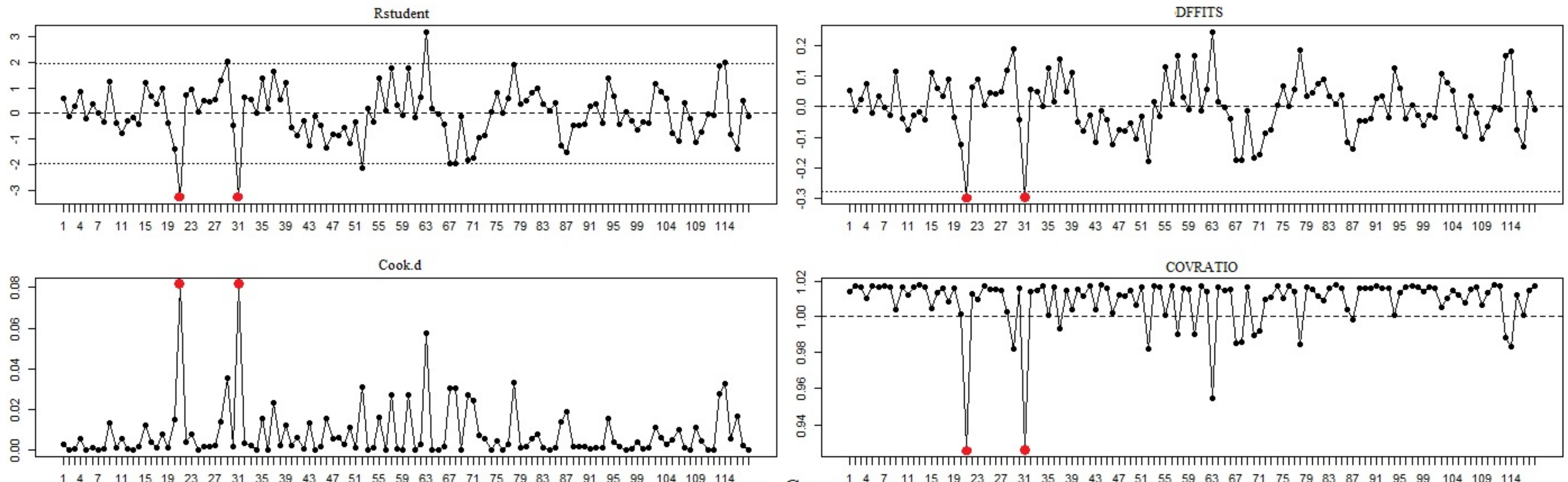
Cd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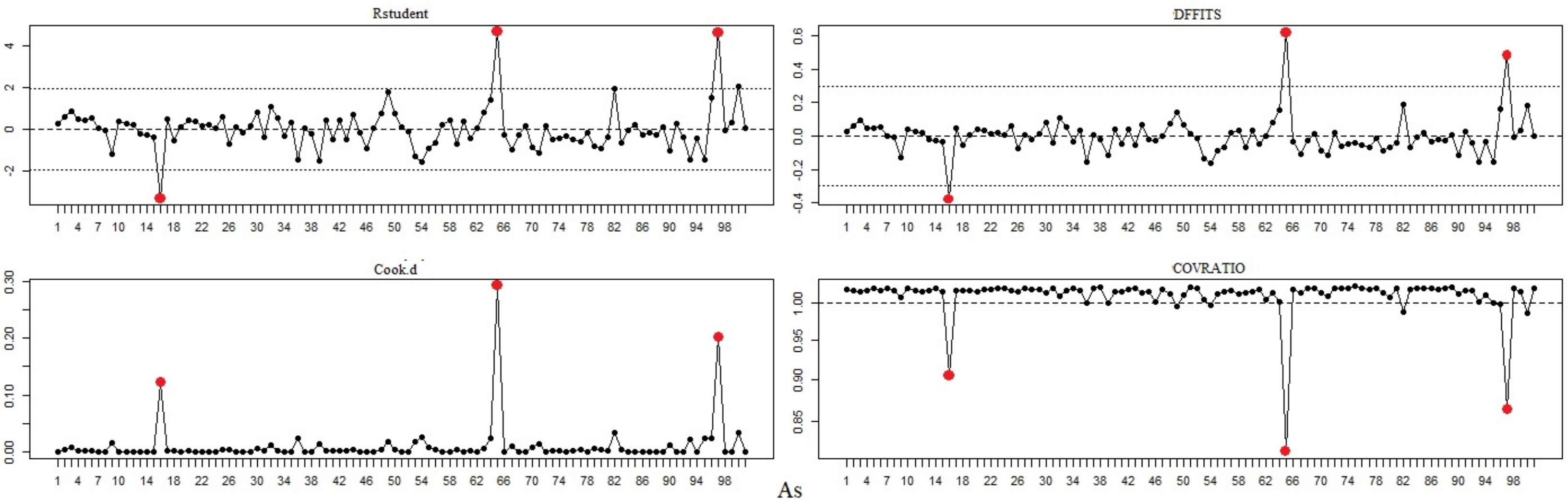
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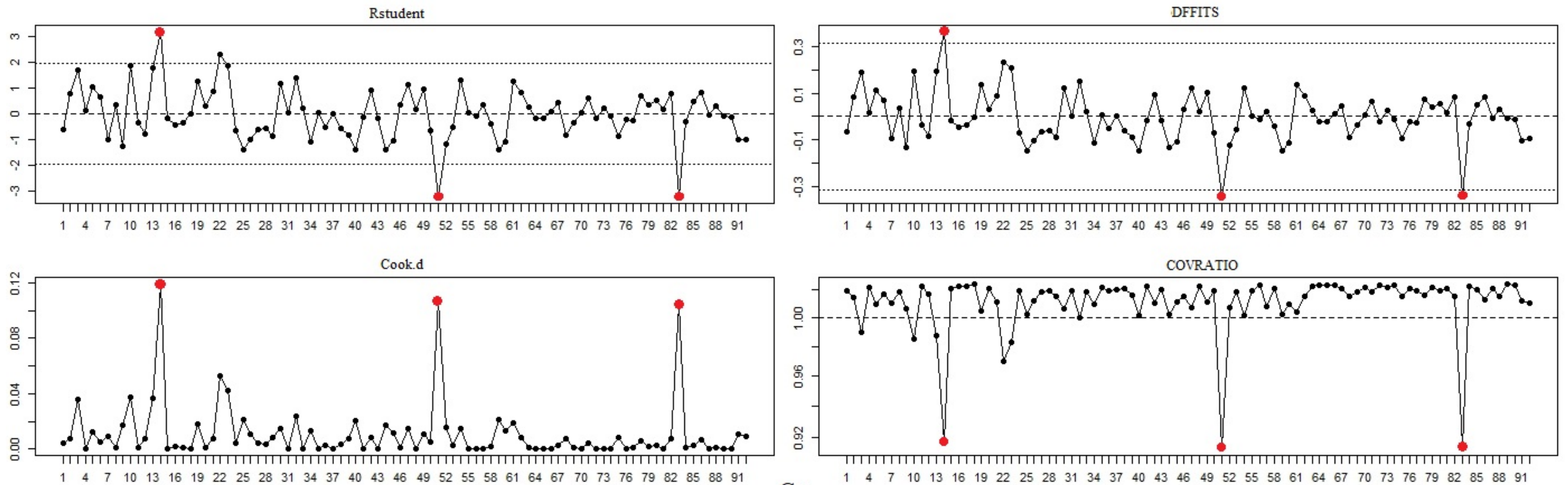
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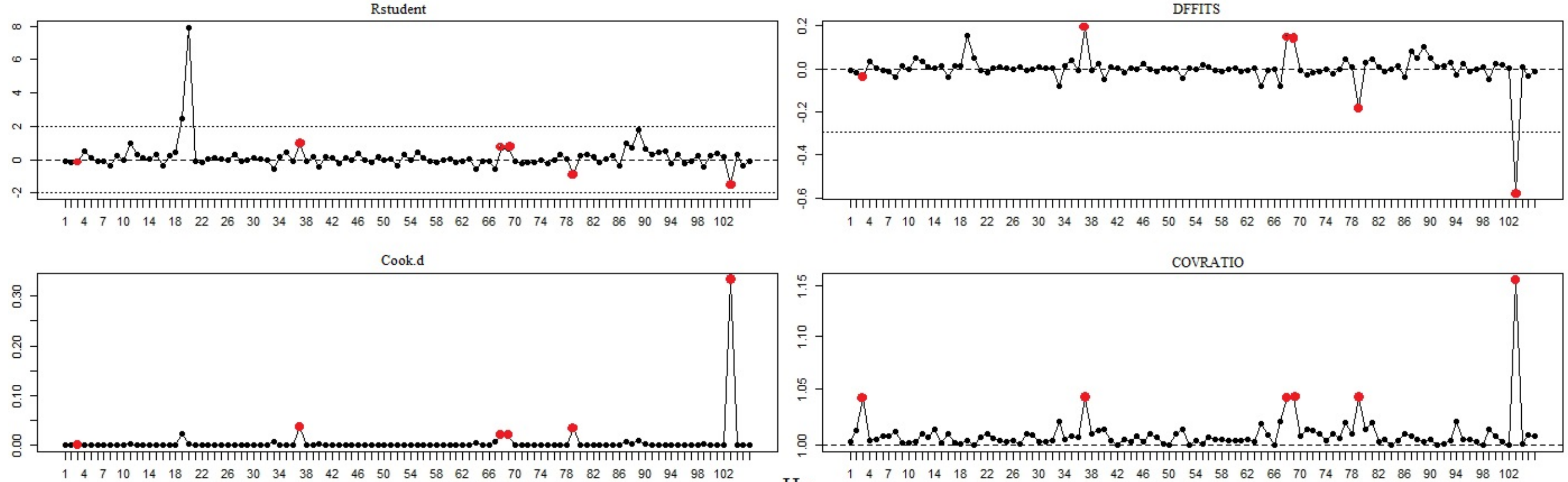
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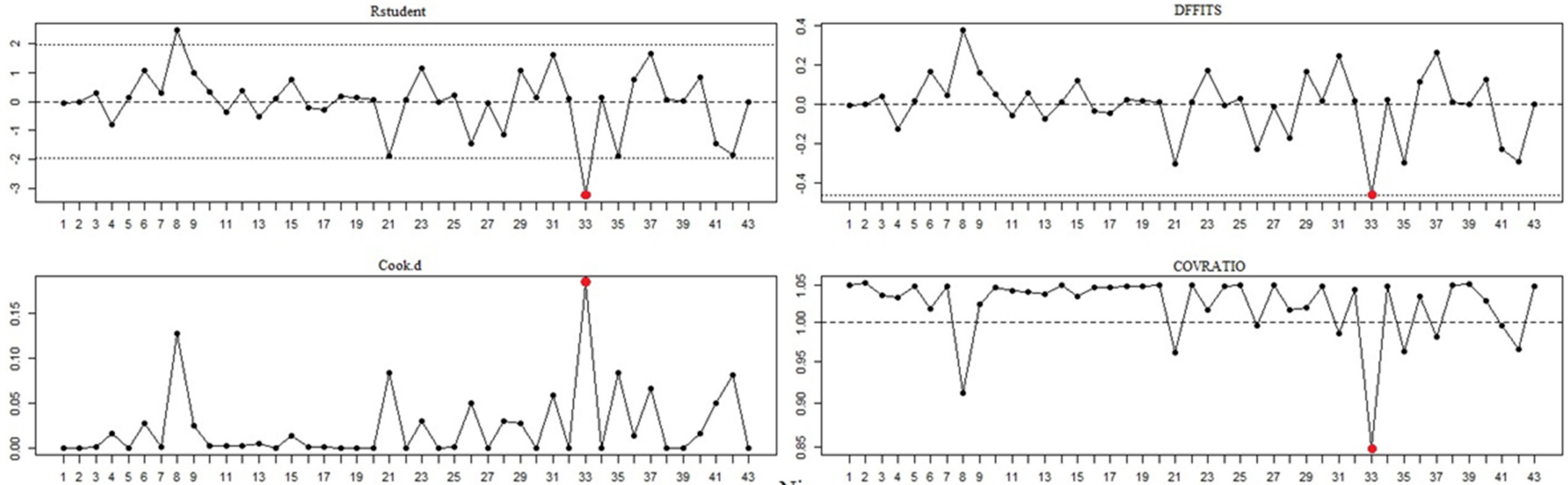
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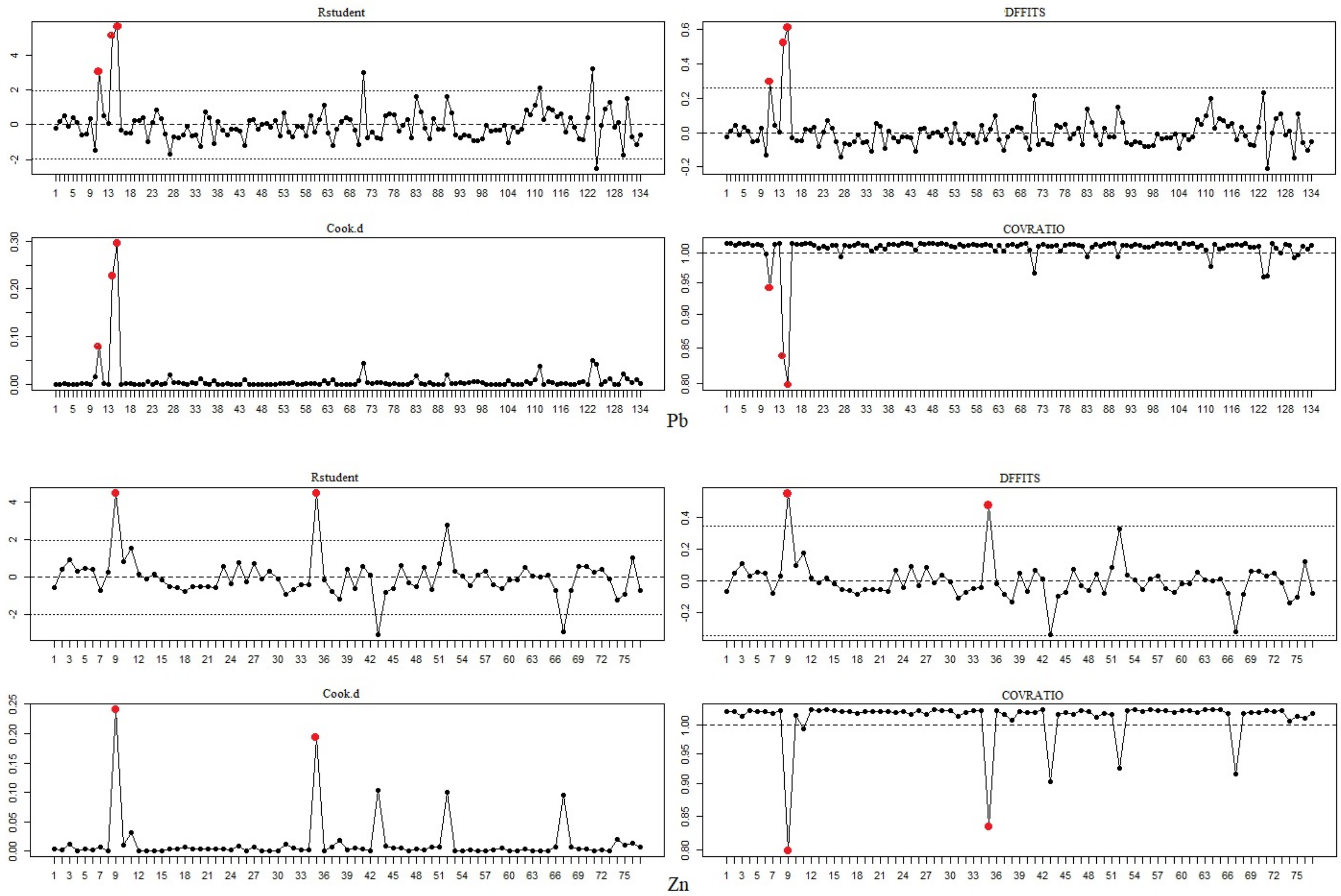

Figure S1 The Outlier selection by sensitivity analysis.

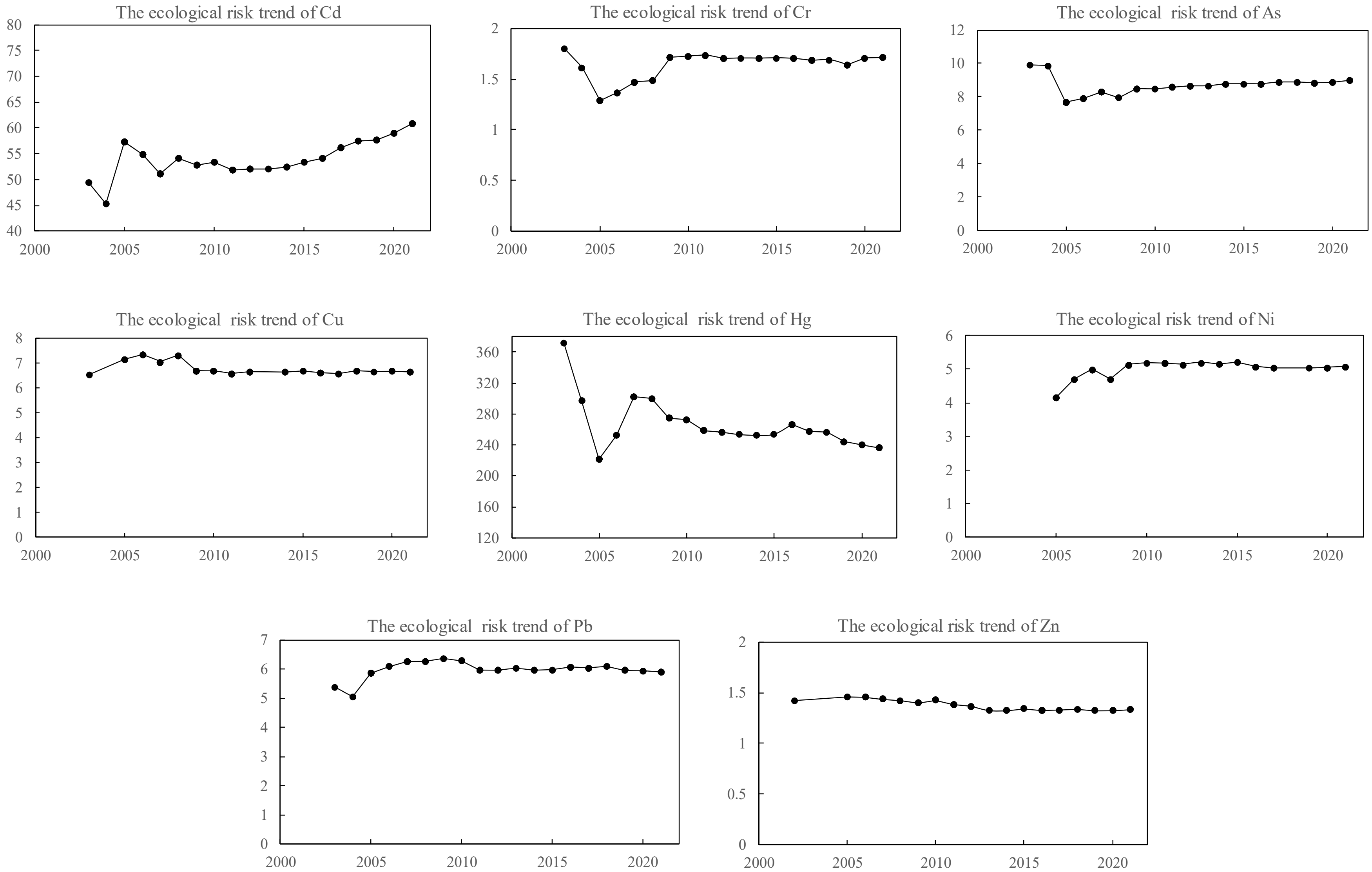

Figure S2 The annual subgroup analysis of the ecological risk index.

Table S1 The Shapiro-Wilk test of weights and mean concentrations.

	p value			
	C_i	W_i	W_i^*	C_i^*
Cd	0.0002	0.0001	0.0535	0.0498
Cr	0.2849	0.0003	0.0487	0.0518
As	0.0007	0.0002	0.0534	0.0631
Cu	0.0025	0.0002	0.0489	0.0491
Hg	0.0002	0.0005	0.0712	0.0642
Ni	0.0021	0.0003	0.2383	0.0302
Pb	0.0009	0.0003	0.0449	0.0530
Zn	0.0001	0.0004	0.0921	0.0471

When $p > 0.05$, the group showed a normal distribution.

C_i: The mean concentration of individual heavy metals in each research.

W_i: The weight in each research.

W_i^*: The natural logarithm of the weight.

C_i^*: The natural logarithm of recalculated mean.

Table S2 The weighted mean values (mg/kg) of heavy metals calculated by the four datasets.

	Cd	**Cr**	**As**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
All data	0.267	65.024	8.979	30.940	0.314	31.251	29.600	85.131
Excluded outliers	0.186	64.548	8.979	30.191	0.147	31.251	29.151	80.841
Normal farmlands	0.146	64.466	8.862	38.418	0.113	31.295	27.554	76.557
Risk farmlands	0.201	67.437	9.509	34.794	0.237	35.807	34.257	93.749

Table S3 The risk control standard for the environmental quality of other countries (mg/kg).

	Cd	**Cr**	**As**	**Cu**	**Ni**	**Hg**	**Pb**	**Zn**	**Reference**
China	0.60	300	25	100		0.60	140	250	This study
Japan	150	250	150	/	/	150	150	/	[51] [86]
Republic of Korea	12	15	75	450	50	12	600	900	[51] [87]
UK	1.80	/	43	/	230	26	/	/	[51] [88]
Canada	3	250	20	150	100	0.80	200	500	[51] [89]
Denmark	0.50	500	20	500	3	0.5	40	500	[51] [90]
Australia	3	50	20	100	70	1	100	200	[51] [91]
Russia	0.76	3.80	4.50	3.50	2.60	0.76	55	16	[51] [92]

Table S4 Concentration projections in optimistic scenario.

	Cd		Cr		As		Cu		Hg		Ni		Pb		Zn	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Suzhou	0.13	0.10	60.72	60.72	9.01	9.01	29.90	24.00	0.24	0.17	29.35	24.33	28.86	22.35	81.38	65.34
Wuxi	0.17	0.12	61.44	61.44	8.98	8.98	30.23	24.27	0.13	0.09	27.18	27.18	32.87	25.46	74.63	59.92
Changzhou	0.14	0.11	66.08	47.70	8.02	8.02	26.64	21.39	0.15	0.11	29.75	29.75	23.34	18.07	64.81	52.03
Nanjing	0.26	0.19	71.64	51.71	9.56	7.45	33.68	27.04	0.11	0.08	34.63	28.71	30.43	23.57	91.20	73.22
Zhenjiang	0.19	0.14	75.17	75.17	9.38	9.38	27.93	22.43	0.11	0.08	30.92	25.63	26.94	20.86	80.84	64.91
Nantong	0.17	0.12	53.77	53.77	7.24	7.24	21.97	21.97	0.12	0.08	23.13	23.13	24.46	18.94	67.26	54.01
Yangzhou	0.12	0.09	67.80	67.80	9.62	9.62	20.81	16.71	0.09	0.06	26.43	26.43	23.08	17.87	72.03	57.83
Taizhou	0.11	0.08	72.63	72.63	7.17	7.17	22.20	17.82	0.06	0.04	30.30	30.30	23.77	18.41	66.99	53.79
Xuzhou	0.27	0.20	66.82	66.82	10.14	7.90	24.52	19.69	0.07	0.05	28.86	23.92	23.04	17.84	66.32	53.25
Lianyungang	0.12	0.09	58.61	58.61	9.65	9.65	28.69	23.03	0.09	0.06	36.89	30.58	26.25	20.33	69.81	56.05
Yancheng	0.13	0.09	67.27	67.27	8.00	8.00	22.08	22.08	0.04	0.03	30.61	30.61	18.44	18.44	65.99	52.99
Huaian	0.11	0.08	70.89	70.89	9.27	7.23	23.67	19.00	0.03	0.02	35.06	29.06	23.94	23.94	61.17	49.11
Suqian	0.09	0.09	75.10	75.10	10.78	8.40	21.66	17.39	0.02	0.02	32.20	26.69	24.70	24.70	59.50	59.50

Table S5 Concentration projections in no-mutation scenario.

	Cd		**Cr**		**As**		**Cu**		**Hg**		**Ni**		**Pb**		**Zn**	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Suzhou	0.15	0.12	60.72	60.72	9.01	9.01	32.83	26.94	0.31	0.24	29.65	24.63	30.96	24.45	89.06	73.02
Wuxi	0.20	0.15	61.44	61.44	8.98	8.98	33.27	27.31	0.17	0.13	27.18	27.18	36.25	28.84	80.16	65.45
Changzhou	0.16	0.13	66.19	47.81	8.02	8.02	28.54	23.29	0.20	0.15	29.75	29.75	23.67	18.40	67.21	54.43
Nanjing	0.31	0.25	73.55	53.63	9.74	7.63	37.83	31.19	0.14	0.11	36.60	30.67	33.03	26.17	102.01	84.03
Zhenjiang	0.22	0.17	75.17	75.17	9.38	9.38	30.24	24.74	0.14	0.10	31.72	26.42	28.42	22.35	88.35	72.42
Nantong	0.19	0.15	53.77	53.77	7.24	7.24	21.97	21.97	0.15	0.11	23.13	23.13	25.15	19.63	70.45	57.19
Yangzhou	0.13	0.10	67.80	67.80	9.62	9.62	20.86	16.76	0.11	0.08	26.43	26.43	23.32	18.12	76.73	62.54
Taizhou	0.12	0.09	72.63	72.63	7.17	7.17	22.69	18.31	0.07	0.05	30.30	30.30	24.24	18.88	70.09	56.89
Xuzhou	0.33	0.26	66.82	66.82	10.51	8.27	25.75	20.92	0.09	0.07	29.00	24.06	23.27	18.08	69.21	56.14
Lianyungang	0.14	0.11	58.61	58.61	9.65	9.65	31.24	25.59	0.11	0.08	39.57	33.26	27.51	21.58	73.81	60.05
Yancheng	0.14	0.11	67.27	67.27	8.00	8.00	22.08	22.08	0.04	0.03	30.61	30.61	17.20	17.20	68.78	55.77
Huaian	0.12	0.09	70.89	70.89	9.36	7.32	24.62	19.96	0.03	0.02	37.16	31.16	23.94	23.94	62.41	50.35
Suqian	0.09	0.09	75.10	75.10	11.36	8.98	21.98	17.71	0.02	0.02	33.40	27.89	24.70	24.70	59.50	59.50

1. Hakanson's ecological risk index

The Hakanson's potential ecological risk index (RI) focuses on the toxicity and ecological effects of heavy metals and evaluates the potential ecological risk. The calculation formula used to calculate RI is as follows:

$$E_i = T_i \times \frac{C_i}{B_i} \quad \text{(S1)}$$

$$\mathrm{RI} = \sum E_I \quad \text{(S2)}$$

Where C_i is the measured value, mg/kg, B_i is the soil background value of element i in Jiangsu Province [29], and E_i is the single potential ecological risk index. RI is the total potential ecological risk index.$T_i$is the toxicity response factor, and the values for each element is Hg=40>Cd=30>As=10>Cu=Ni=Pb=5>Cr=2>Zn=1.

According to Hakanson's ecological risk grading rules [39], the pollution index of potential ecological risk classification is as follows:

	low	Medium	Strong	Very strong	Extremely strong
E_i	<40	40<E<80	80<E<160	160<E<320	>320
RI	<150	150<E<300	300<E<600	>600	

2. Cumulative prediction model

Based on the current accumulation trend of eight heavy metals and soil remediation in Jiangsu, the concentrations of heavy metals in 2030 and 2050 were predicted under two scenarios: no mutation scenario and optimistic scenario. Setting the year 1973 as a year of zero soil heavy metal pollution, the economy of Jiangsu province developed rapidly since then. As of 2010, soil accumulation of heavy metals had accelerated for 37 years. The year 1973 was determined as a year of zero soil heavy metal pollution, and since then, the economy of Jiangsu has developed rapidly. As of 2010, the accumulation of heavy metals in soil had accelerated for 36 years. After realizing that the soil environment was strongly disturbed by human activities, Jiangsu has initiated a series of soil pollution control efforts. Therefore, the accumulation of heavy metals in soils of Jiangsu accelerated before 2010, and then accumulated at a uniform rate. The acceleration and occurrence rate in heavy metal cumulative prediction model are calculated as follows:

$$\mathrm{A} = \frac{2(C_0 - C_B)}{t_1^2 + 2t_1t_2} \quad \text{(S3)}$$

$$\mathrm{V} = \mathrm{A}t_i \quad \text{(S4)}$$

Where A is the accumulation acceleration; C_b is the soil background value of Jiangsu Province (mg/kg); $C_0$is the weighted average values of soil heavy metals in Jiangsu (mg/kg); and V is the current pollution rate (mg/kg/year). t_1 indicates the years of accelerated accumulation of heavy metals (1973-2010), and t_2 indicates the years of uniform accumulation (2010-2021). The heavy metal concentrations were calculated for different scenarios as follows:

Optimistic scenario:

$$C(t)=\begin{cases} C_o K^t; & C_0 > C_b \\ C_0; & C_0 \le C_b \end{cases}$$

No mutation scenario:

$$C(t)=\begin{cases} C_o K^t + VK\frac{(1-K^t)}{(1-K)}; & C_0 > C_b \\ C_0; & C_0 \le C_b \end{cases}$$

where C(t) is the predicted concentration of heavy metals (mg/kg) after *t* years, and K is the annual residual rate of soil heavy metals. The annual residual rates of eight heavy metals were calculated based on the soil pollution risk screening value (GB-15618-2018) which takes 100 years to purify to the soil background value in Jiangsu province through natural action [71,86].

K values are shown in the table:

	Cd	**Cr**	**Ni**	**Hg**	**Cu**	**As**	**Pb**	**Zn**
K（%）	0.9856	0.9846	0.9911	0.9826	0.9896	0.9882	0.9879	0.9896

Reference

86. Chen, P. Overview on the formation process and current situation of soil environmental quality standard system of Japan. *Envi. Susta. Develop.* **2014**, 6, 154–159. https://doi.org/10.3969/j.issn.1673-288X.2014.06.042.
87. RKME (Republic of Korea's Ministry of the Environment). Soil Pollutant and Soil Environment Standard. Ministry of the Environment, Republic of Korea. (in Korean). 2010. (accessed on 25 November 2022).
88. European Environmental Agecy (EEA) Progress in management of contaminated sites (CSI 015/LSI 003). 2007. http://www.eea.europa.eu/data-and-maps/indicators. (accessed on 25 November 2022).
89. New Zealand Ministry foe the Environment (NZME). Users' Guide: National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health. Wellington: Ministry for the Environmental.www.esdat.net. **2012**. (accessed on 25 November 2022).
90. Carlon, C. Derivation Methods of Soil Screening Values in Europe. A Review and Evaluation of National Procedures Towards Harmonization. European Commission, *Joint Res. Centre, Ispra. p*. 2007, 306.
91. Zarcinas, B. A, Pongsakul, P., Mclaughlin, M. J., Cozens, G. Heavy metals in soils and crops in Southeast Asia. 2. Thailand. *Envir. Geo. Health.* **2004**, 26, 359–371. https://doi.org/10.1007/s10653-005-4670-7.
92. Vodyanitskii, Y. N. Standards for the contents of heavy metals in soils of some states. *Annals of Agr. Sci*. **2016**, 14, 257–263. https://doi.org/10.1016/j.aasci.2016.08.011.