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A Review on Heavy Metal Pollution of Agricultural Land Soil in the Yangtze River Delta and Relevant Pollution Control Strategy

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Abstract: The Yangtze River Delta is an important industrial and agricultural production base in China. Attention should focus on the heavy metal pollution of agricultural land in the Yangtze River Delta to promote the healthy development of the social economy and to ensure the safety of the ecological environment. In this study, the accumulation and pollution status of typical heavy metals in agricultural land soils in different regions of the Yangtze River Delta were analysed. The main reasons accounting for the pollution were systematically discussed, according to data on heavy metal content reported in the literature over the past 20 years. The analysis revealed that due to industrial "three wastes" emissions, transportation, and the extensive use of fertilizers, pesticides, and agricultural films, Cd accumulation and pollution in the soil of agricultural land across the entire Yangtze River Delta is the most serious, followed by Cu, Hg, and Pb pollution; specifically, Taizhou (in Zhejiang Province) has a compound pollution problem of Cd, Hg, and Cu, while Tongling (in Anhui Province) has a compound pollution problem of Cd, Pb, and Cu. To meet the urgent need for the prevention and control of heavy metal pollution in the Yangtze River Delta and considering the main causes of pollution, some suggestions are proposed. These include source control, rapid and dynamic monitoring, hierarchical management of agricultural land, research and development of new technologies for soil remediation, and legislation on the prevention and control of agricultural land soil pollution. It is hoped that this research can provide a reference for improving the soil ecological environment in the Yangtze River Delta and promoting the sustainable development of high-quality and efficient agriculture.

Keywords: agricultural land; heavy metal; pollution; prevention; Yangtze River Delta

1 Introduction

The Yangtze River Delta, which includes Shanghai, and Jiangsu, Zhejiang, and Anhui Provinces, is an important agricultural production base and a well-known commodity grain base in China. Both the annual average agricultural output and the total grain output account for more than 12% of those of the country [1]. However, in recent years, the soil environment of agricultural land in the Yangtze River Delta has not been promising. The *National Survey Communique on Soil Pollution Status* noted prominent environmental pollution of cultivated land

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in this region, mostly by inorganic heavy metal [2]. Heavy metal pollution of agricultural land soil has an important impact on the quality and yield of agricultural products, poses a serious threat to human health and the ecological environment, and severely restricts the sustainable development of the agricultural economy.

Research on the soil heavy metal pollution of agricultural land in the Yangtze River Delta area has mainly involved sampling over a small area followed by laboratory analyses [3–5]. However, owing to limitations of the soil environment at the sampling point, and the number of samples, the small amounts of heavy metal data obtained are not representative and do not comprehensively reflect the status of heavy metal pollution in the Yangtze River Delta. To fully understand the status and main sources of heavy metal pollution in agricultural land in the Yangtze River Delta region, and to provide guidance for the effective prevention and control of heavy metal pollution, in this study, based on the heavy metal content data in the literature related to heavy metals in agricultural land soils in the Yangtze River Delta region and published in the past 20 years, the accumulation and pollution of typical heavy metals in agricultural land soils in the Yangtze River Delta region have been comprehensively analyzed, and the main reasons for the accumulation and pollution of heavy metals in agricultural land in the Yangtze River Delta have been systematically explored. On this basis, recommendations for the prevention and control of heavy metal pollution of agricultural land in the Yangtze River Delta region are proposed to address the causes of pollution, in order to provide references for improving the soil ecological environment in the Yangtze River Delta region and promote the sustainable development of high-quality and efficient agriculture.

2 Typical heavy metal pollution status of agricultural land soil in the Yangtze River Delta

Articles relating to heavy metals in agricultural soils of the Yangtze River Delta region, and published in the past 20 years were collected. Data on the content of typical heavy metals, including Cd, Ni, Cu, As, Hg, Pb, Cr, and Zn, in different regions were summarized. Then, by comparing the average content of heavy metals with the soil background values of local provinces and cities [6], according to the accumulation coefficient of heavy metals, the accumulation of typical heavy metals in agricultural land of different regions was analyzed. Taking the secondary standard value of the environmental quality of soil inorganic pollutants for agricultural land ($5.5 < pH < 6.5$) in the *Soil Environmental Quality Standards (Revised) (GB 15618—2008)* [7] as the basis for evaluation, according to the individual pollution index method and the corresponding classification standards listed in *National Technical Regulations on Evaluation of Soil Pollution Status* [8], the pollution status of typical heavy metals in agricultural land in different regions were evaluated.

2.1 Typical heavy metal pollution status of agricultural land soil in Shanghai

Compared with the background soil value for Shanghai, the accumulation of heavy metal Hg in the soil of agricultural land in Shanghai was the highest. The accumulation coefficients of heavy metal Hg in Jiading, Minhang, Qingpu, Jinshan, Songjiang, Baoshan, and Pudong New Districts were relatively higher, and the degree of heavy metal Pb accumulation in Jiading District was also high. The accumulation of heavy metals Cd, Cu, As, Hg, Pb, Cr, and Zn in other regions was lower, and the average heavy metal contents were close to the soil background values reported for Shanghai (Fig. 1). According to the single pollution index of typical heavy metals in the soil of agricultural lands from different regions in Shanghai (Fig. 2), pollution of heavy metals Cd, Cu, As, Cr, and Zn were not found in agricultural land soils in all regions. However, the soil of agricultural land in Jiading District is slightly polluted by heavy metals Hg and Pb, and that of agricultural land in Minhang, Qingpu, and Jinshan Districts is slightly polluted by heavy metal Hg. Therefore, attention should be paid to the prevention and control of heavy metal Hg pollution in the soil of agricultural land in Jiading, Minhang, Qingpu, and Jinshan Districts, and of heavy metal Pb in soil of agricultural land in Jiading District.

2.2 Status of typical heavy metal pollution in the soil of agricultural land in Jiangsu Province

Compared with the background soil values for Jiangsu Province, the degree of heavy metal Cd accumulation in the soil of agricultural land in Nanjing was the highest, followed by the heavy metals Cu, Zn, and Pb. There was also some accumulation of the heavy metal Cd in the soil of agricultural land in Suzhou City, while the accumulation of heavy metals Cd, Ni, Cu, As, Hg, Pb, Cr, and Zn in other regions was not high (Fig. 3). The single pollution index of typical heavy metals in the soil of agricultural land in different regions of Jiangsu Province (Fig. 4) indicated there is no pollution of heavy metals Ni, Cu, As, Pb, Cr, and Zn in this region. However, the heavy metal Cd in Nanjing, and Hg in Suzhou are both considered level II, with slight pollution. Therefore, attention

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should focus on preventing and controlling the pollution of heavy metals Cd and Hg in the soil of agricultural lands in these two regions in order to prevent their continuous accumulation and ensuing problems arising from serious pollution of these heavy metals.

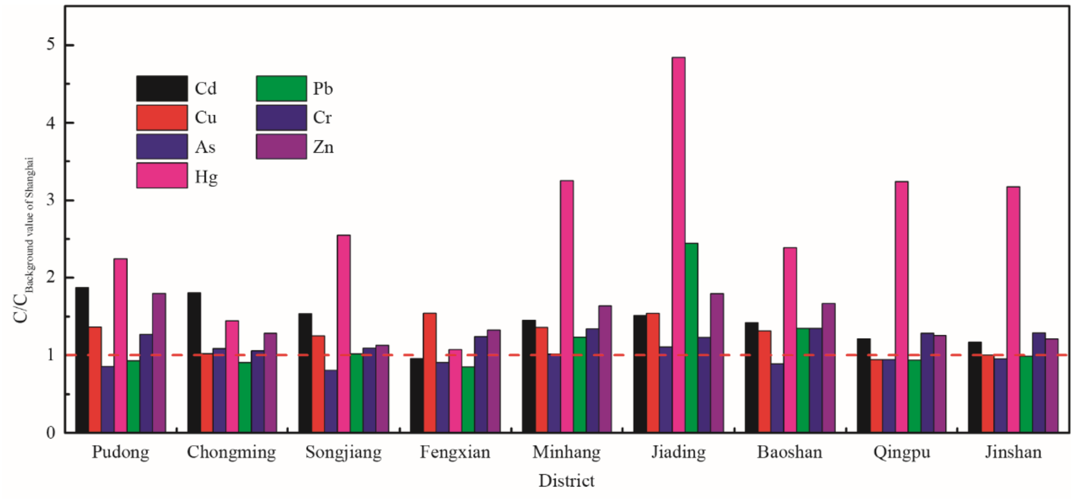

Fig. 1. Accumulation coefficient of heavy metals in the soil of agricultural land in different districts of Shanghai.

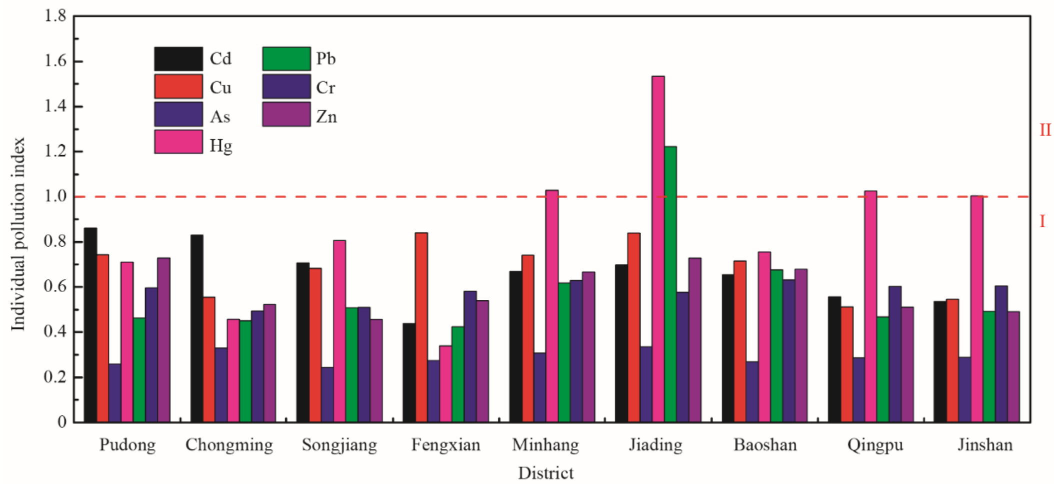

Fig. 2. Individual pollution index of heavy metals in the soil of agricultural land in different districts of Shanghai.

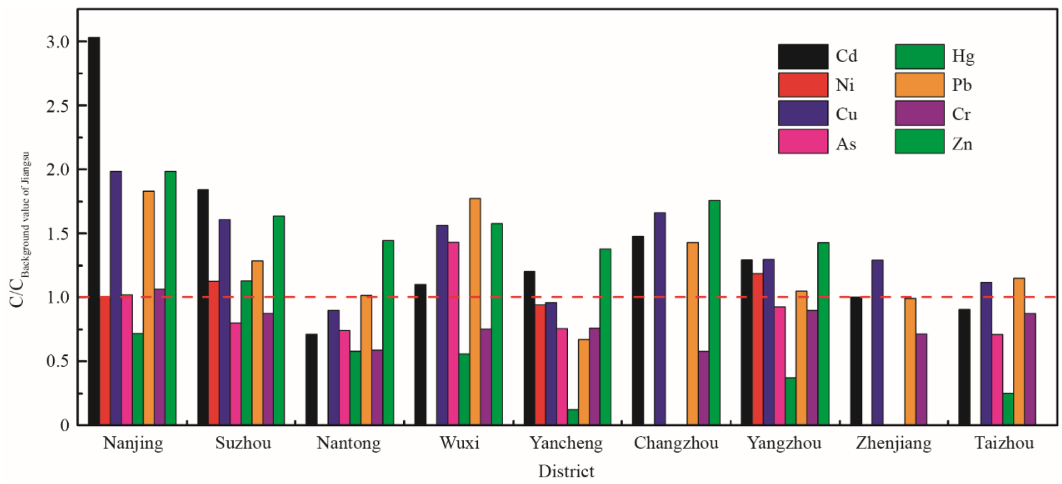

Fig. 3. Accumulation coefficient of heavy metals in the soil of agricultural land in different districts of Jiangsu.

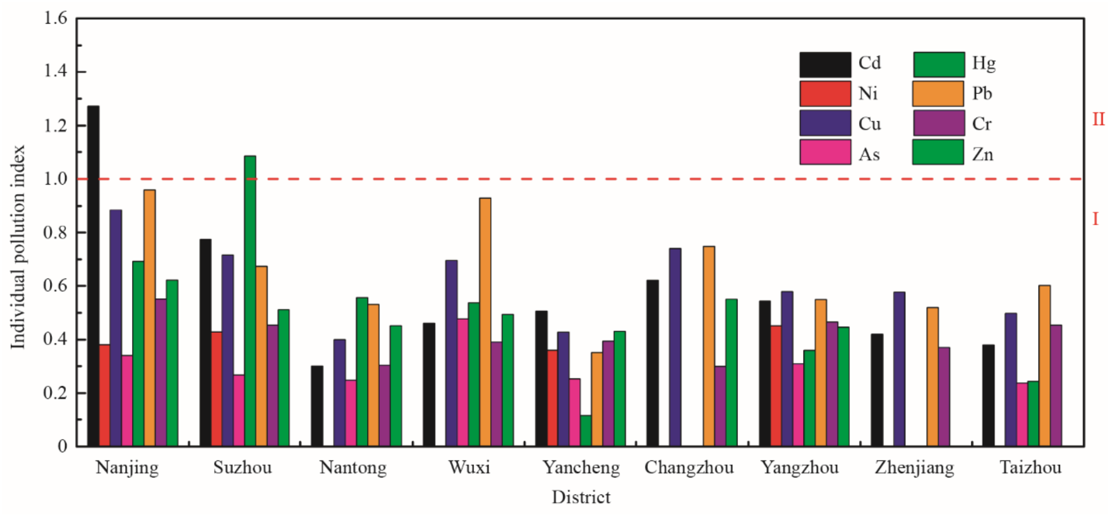

Fig. 4. Individual pollution index of heavy metals in the soil of agricultural land in different districts of Jiangsu.

2.3 Typical heavy metal pollution status of agricultural land soil in Zhejiang Province

Compared with the soil background value of each heavy metal element in the soil of agricultural land in Zhejiang Province, the accumulation of heavy metal Cd in the soil of agricultural land in Zhejiang Province is the most serious, followed by the heavy metal Hg. In terms of regional distribution, the accumulation degrees of heavy metals Cu, As, and Zn in Taizhou, Cu in Jiaxing and Shaoxing, Cu and Pb in Jinhua, and Zn in Hangzhou were all higher. However, there was no obvious accumulation of heavy metals Ni, Cu, As, Pb, Cr, and Zn in the soil of agricultural land in other regions of Zhejiang Province (Fig. 5). The individual pollution index of typical heavy metals in the soils of agricultural land in different regions of Zhejiang Province (Fig. 6) indicated that there is no pollution of Ni, As, Pb, Cr, and Zn in these regions. However, there was level II (slight) pollution of the heavy metal Cd in the soil of agricultural land in Hangzhou, Ningbo, and Jinhua; Cu in the soil of agricultural land in Taizhou; and Hg in the soil of agricultural land in Hangzhou, Taizhou, and Shaoxing. There was level IV (moderate) pollution of the heavy metal Cd in the soil of agricultural land in Taizhou. Heavy metal pollution of agricultural land in Taizhou City is serious, and there is a compound pollution problem of the heavy metals Cd, Cu, and Hg. The soil of agricultural land in Hangzhou City is also affected by compound pollution of the heavy metals Cd and Hg. Therefore, more attention should be paid to the prevention and control of soil heavy metal pollution in agricultural land in Taizhou, Hangzhou, Shaoxing, Jiaxing, and Jinhua.

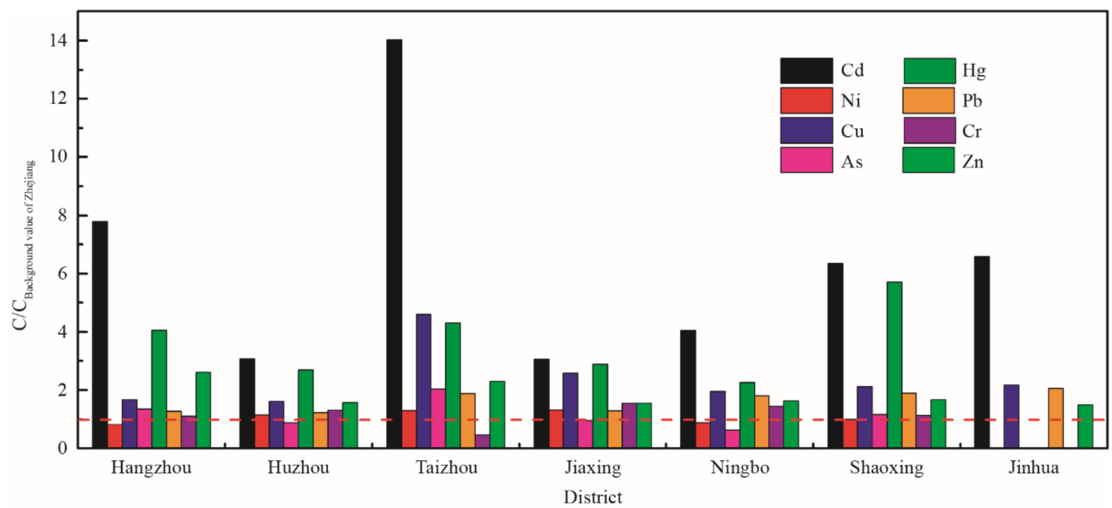

Fig. 5. Accumulation coefficient of heavy metals in the soil of agricultural land in different districts of Zhejiang.

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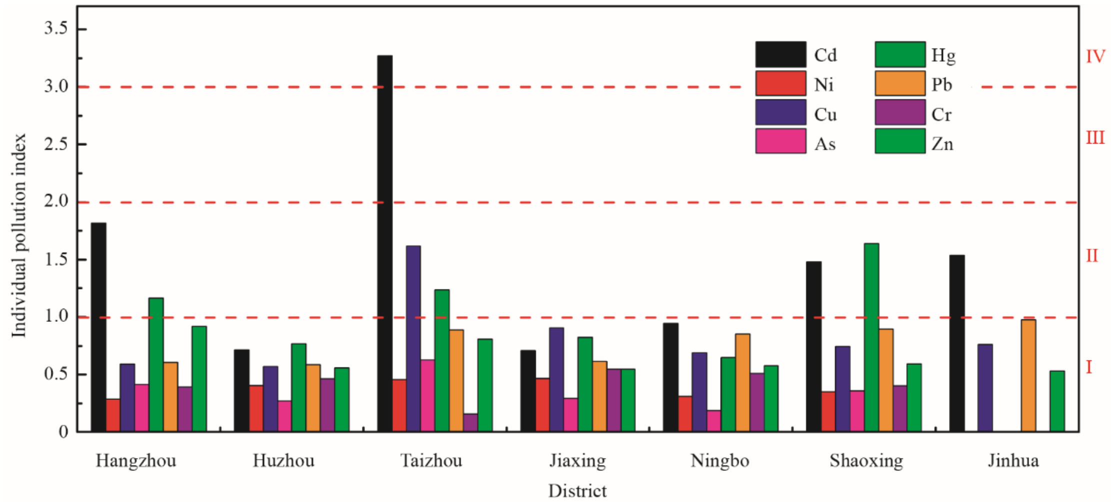

Fig. 6. Individual pollution index of heavy metals in the soil of agricultural land in different districts of Zhejiang.

2.4 The status of typical heavy metal pollution in the soil of agricultural land in Anhui province

Compared with the background soil values of Anhui Province, accumulation of the heavy metal Cd in the soil of agricultural land in Anhui Province is the most serious, followed by the heavy metals Cu and Hg. In terms of regional distribution, there is serious accumulation of the heavy metals Cd and Cu in the soil of agricultural land in Tongling. In addition, there is also a certain degree of accumulation of the heavy metals Hg, Pb, and Zn. In the soil of agricultural land in Wuhu, accumulations of the heavy metals Cu, Cd, Hg, and As are higher. Accumulation of the heavy metals Cd and As in the soil of agricultural land in Chaohu, and the heavy metal Cd in the soil of agricultural land in Hefei City are also higher. However, there is no obvious accumulation of heavy metals in the soil of agricultural land in other regions (Fig. 7). The individual pollution index of typical heavy metals in the soils of agricultural land in different regions of Anhui Province (Fig. 8) indicates they are not polluted with the heavy metals Ni, As, Hg, Cr, and Zn. However, there was slight pollution (level II) of the heavy metal Pb in the soil of agricultural land in Tongling, with moderate pollution (level IV) of the heavy metals Cd and Cu. There was light pollution (level III) of the heavy metal Cu in the land of agricultural soil in Wuhu, and severe pollution (level V) of the heavy metal Cd in the soil of agricultural land in Chuzhou. Heavy metal pollution of agricultural land in Tongling is the most serious, and there is a compound pollution problem of the heavy metals Cd, Cu, and Pb. Therefore, the prevention and control of heavy metal pollution in Tongling agricultural land should be strengthened. In addition, the pollution of single heavy metals Cd or Cu in the soil of agricultural land in Chuzhou City and Wuhu City should also be considered.

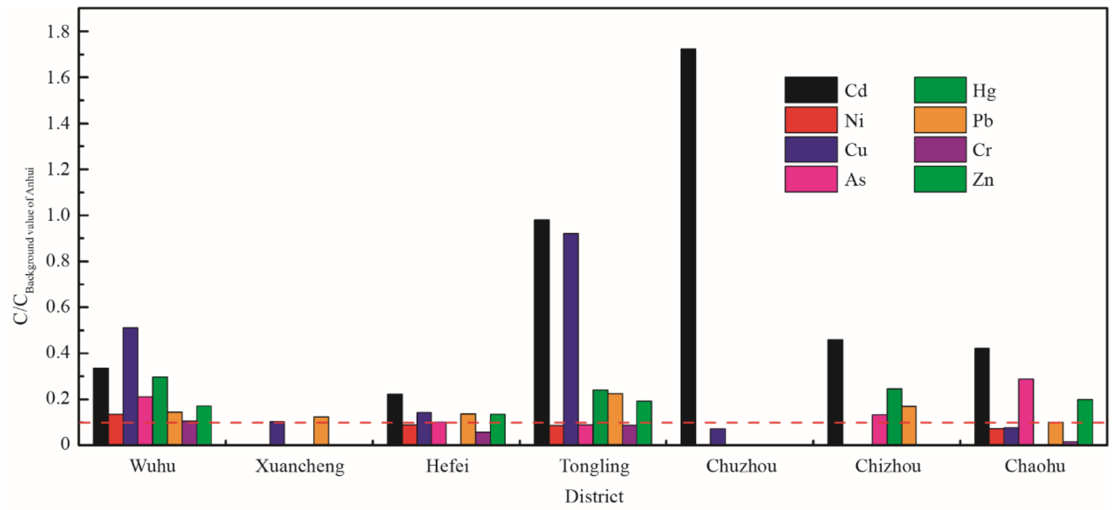

Fig. 7. Accumulation coefficient of heavy metals in the soil of agricultural land in different districts of Anhui.

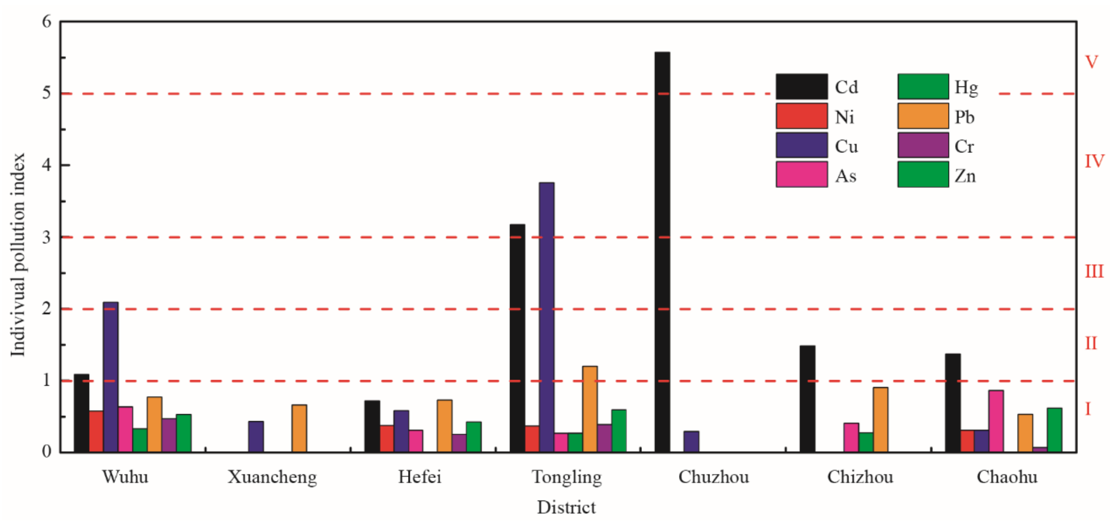

Fig. 8. Individual pollution index of heavy metals in the soil of agricultural land in different districts of Anhui.

3 Analysis on the source of heavy metal pollution of agricultural land in the Yangtze River Delta

Articles published in the past 20 years and related to heavy metals in agricultural land in the Yangtze River Delta were collected. The coefficients of variation (CV) of the typical heavy metals Cd, Ni, Cu, As, Hg, Pb, Cr, and Zn were summarized, and the average CV values for different heavy metal elements were determined (Fig. 9). In terms of regional distribution, all the CV of the heavy metals Cd and Pb in Jiangsu Province and of the heavy metal Hg in Shanghai exceeded 100%. And all the CV of the heavy metal Hg in Jiangsu Province, the heavy metals Cd and Hg in Zhejiang Province, and the heavy metals Cd, Cu, and Hg in Anhui Province exceeded 50%. This indicates that there is strong spatial differentiation for the heavy metals Cd, Pb, Hg, and Cu in the soil of agricultural land in the Yangtze River Delta region, and the contents of heavy metals in different regions are quite different. Heavy metals in the soil of agricultural land throughout the Yangtze River Delta are significantly affected by human activities. Man-made pollution sources, such as industrial "three wastes" (exhaust gas, wastewater, solid waste) emissions, transportation pollution, excessive use of chemical fertilizers, pesticides, manure, and agricultural membranes, are the main means through which heavy metals enter the soil of agricultural land in the Yangtze River Delta.

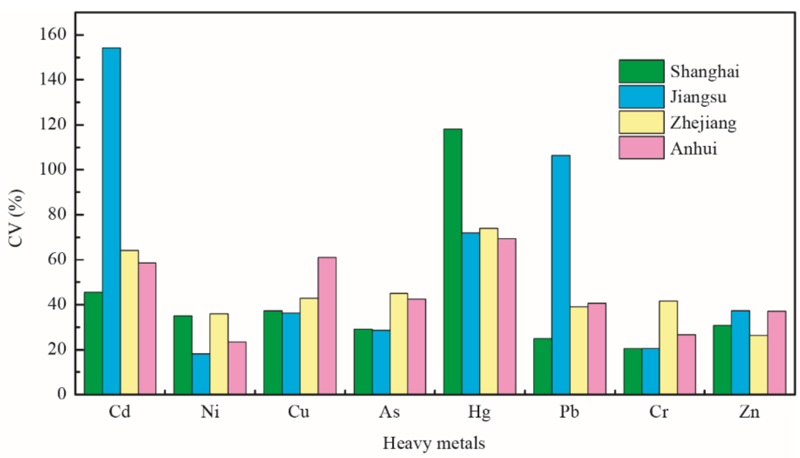

Fig. 9. Variation coefficients of typical heavy metals in agricultural soils from different regions of the Yangtze River Delta.

3.1 Industrial "three wastes" emissions

The Yangtze River Delta region is an important industrial production base in China, with many industries, such as steel, smelting, electroplating, chemicals, mining, electronics, textiles, printing and dyeing, and automobile manufacturing. In 2018, the total industrial production value of this region reached 10.436951 trillion CNY

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(accounting for 34.2% of the national total), and the number of industrial enterprises above the designated size reached 113 800 (accounting for 30.03% of the national total) [1]. The output of the main products of the industrial manufacturing industry (Table 1) has obvious advantages.

Table 1. The output of industrial products in the Yangtze River Delta in 2018.

Industrial products	Shanghai	Jiangsu	Zhejiang	Anhui	Whole nation	Proportion
Nitrogen, phosphorus, and potassium fertilizers (× 10^4 t)	1.02	168.04	19.92	217.15	5418.00	7.50%
Chemical pesticides (× 10^4 t)	1.06	80.20	21.75	10.95	208.28	54.71%
Primary form of plastic (× 10^4 t)	335.39	930.78	926.21	14.25	8558.02	25.78%
Chemical fiber (× 10^4 t)	39.70	1370.47	2282.30	39.61	5011.09	74.48%
Cement (× 10^4 t)	414.52	14 717.81	12 323.46	13 248.19	220 770.68	18.44%
Pig iron (× 10^4 t)	1476.75	6796.05	873.75	2422.01	77 105.44	15.00%
Crude steel (× 10^4 t)	1630.09	10 422.10	1266.51	3103.87	92 800.90	17.70%
Steel (× 10^4 t)	1983.32	12 146.72	3048.69	3194.95	110 551.65	18.43%
Metal cutting machine (× 10^4)	0.60	8.49	11.97	2.84	48.86	48.92%
Integrated circuit (× 10^4)	233.48	564.24	65.36	1.25	1739.47	49.70%
Household appliances (× 10^4)	330.53	4160.73	2493.90	6536.30	34 096.09	39.66%

Source: *China Statistical Yearbook 2019*.

The strong industrial production capacity of the Yangtze River Delta region has been accompanied by severe issues associated with environmental heavy metal pollution. Possible reasons for this are that many raw materials containing heavy metals such as Cd, Cr, Hg, Cu, As, Pb, and Zn are used in industrial production. The smoke and industrial dust produced by coal burning from thermal power plants, metal smelters, and cement plants, contain large amounts of the heavy metals Hg, As, Cd, Cu, and Pb. Moreover, the mining and smelting of metal mines, and the accumulation of tailings and waste residues, also release heavy metals, such as Cd, Pb, and Zn.

According to the *China Statistical Yearbook 2019*, the discharge of smoke (powder) and dust in exhaust gas in the Yangtze River Delta in 2017 was 8.72×10^5 t, and the amount of industrial solid waste generated was 3.012×10^8 t. The total discharge of wastewater was 1.475×10^{10} t, and that containing heavy metal Pb was 1.867×10^7 t, that containing the heavy metal Hg was 6.97×10^5 t, that containing the heavy metal Cd was 2.121×10^6 t, that containing the heavy metal Cr was 4.268×10^8 t, and that containing the heavy metal As was 8.729×10^6 t [1]. Therefore, the large amount of industrial "three wastes" emissions in the Yangtze River Delta region is an important way through which heavy metals enter the soil of agricultural land.

3.2 Transportation pollution

China has the largest car ownership in the world. The coatings, anti-corrosion materials, brakes, and tires of automobiles usually contain heavy metals such as Cd, Cu, Pb, Zn, and Ni. In addition, fuels and lubricants for automobiles usually contain heavy metals, such as Pb and Cu [9]. Therefore, leakage of automobile fuel and lubricating oil, emissions from automobile exhausts, mechanical wear of the tires and braking system, and the aging of the tires will release heavy metals into the surrounding environment, which then enter the soil through atmospheric deposition and gradually accumulate. Even if the content of these heavy metals is low, the increasing number of cars and associated use of fuel will increase the risk for heavy metal pollution in the soil. Relevant studies have shown [10] that pollution load from the heavy metal Cu released by the wear of automobile brake pads is the largest, followed by Zn, Pb, Cr, and Cd, while that from the heavy metal Zn released by the wear of automobile tires was the largest, followed by Pb, Cr, Cu, Ni, and Cd.

The car ownership and vehicle fuel consumption in the Yangtze River Delta region are both increasing annually. In 2018, car ownership was 8.405×10^7, and the consumption of gasoline and diesel for transportation was 3.252×10^7 t (Fig. 10). Transportation is an important cause of heavy metal pollution in agricultural land in this area. In 2013, an analysis of the heavy metal content and spatial differences in farmland soil on both sides of the Nanjing Baguazhou Highway found that the average content of Ni, Pb, Cr, and Zn in farmland soil across the road was significantly higher than the background value of heavy metals in the Baguazhou soil [11]. Research on the spatial distribution of the heavy metals Pb, Cd, Cr, and Zn in farmland soils on both sides of the Jurong, Danyang, and Suzhou sections of the Shanghai–Nanjing Expressway revealed different degrees of accumulation and large spatial variability [12]. With increasing traffic volume, the content of Pb and Cd in the farmland soil on both sides of the road increased significantly, indicating that road traffic is the main reason for the accumulation of heavy metals in farmland soil on roadsides in the Yangtze River Delta.

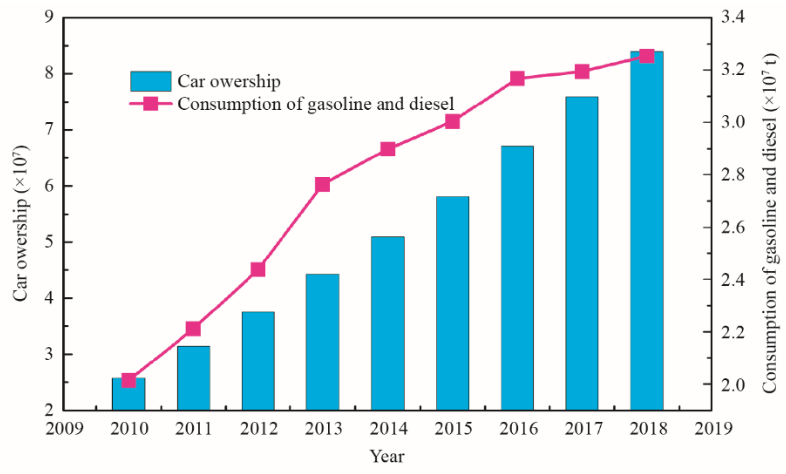

Fig. 10. Car ownership and fuel consumption in the Yangtze River Delta over time.
Source: *China Statistical Yearbook* (2011–2019).

3.3 Extensive application of chemical fertilizers, pesticides, manure, and agricultural films

Chemical fertilizers, pesticides, manure, and agricultural films are essential inputs for agricultural production. However, their long-term, large-scale, or excessive application will lead to serious heavy metal pollution in the soil of agricultural land. This is mainly because chemical fertilizers such as phosphate, nitrogen, and compound fertilizers contain high concentrations of heavy metals, such as As, Cd, Pb, Zn, Cr, and Hg; livestock and poultry manure such as pig, chicken, cow, and sheep manures contain heavy metals such as Cu, Zn, As, Cd, Cr, and Ni; pesticides such as insecticides and fungicides contain heavy metals such as Hg, Cu, Cd, and As; and heat stabilizers containing the heavy metal Cd are added to process agricultural films.

According to the *China Statistical Yearbook 2019*, the amounts of chemical fertilizers used in agricultural production in the Yangtze River Delta in 2018 was 6.904×10^6 t, of which nitrogen and compound fertilizers were used in the highest amounts, followed by phosphate and potash fertilizers. The amounts of pesticides used in agricultural production was 2.11×10^5 t, and the amount of agricultural films used was 2.985×10^5 t (Table 2) [1]. The large-scale application of chemical fertilizers, pesticides, and agricultural films has led to the accumulation of heavy metals and subsequent pollution problems in the soil of agricultural land in the Yangtze River Delta. Analysis of the characteristics of heavy metal pollution in vegetable soils in the Sanshan District of Wuhu demonstrated that long-term application of pesticides, fertilizers, and chicken manures was the main reason for the accumulation of heavy metals As and Zn in the local vegetable fields [13]. Research on the variation of heavy metals in different types of farmland soils in the Fuyang area [14] demonstrated that the application of organic fertilizers was an important reason for the high content of Cu and Zn in the soil.

Table 2. The use of agricultural products in the Yangtze River Delta in 2018.

District	Amount of agricultural fertilizer (× 10^4 t)					Amount of agricultural plastic film (× 10^4 t)	Amount of pesticide (× 10^4 t)
	Total	Nitrogen fertilizer	Phosphate fertilizer	Potash fertilizer	Compound fertilizer		
Shanghai	8.40	3.80	0.60	0.30	3.80	1.57	0.35
Jiangsu	292.45	145.60	34.00	17.20	95.70	11.61	6.96
Zhejiang	77.76	40.10	8.60	6.10	22.90	6.89	4.37
Anhui	311.75	95.61	28.24	27.90	160.10	9.78	9.42

Source: *China Statistical Yearbook 2019*.

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4 Suggestions on the prevention and control of heavy metal pollution of agricultural land soil in the Yangtze River Delta

4.1 Control the source of heavy metal pollution in agricultural land

In 2011, the *Twelfth Five-Year Plan for the Comprehensive Prevention and Control of Heavy Metal Pollution* highlighted that end-of-pipe treatment alone is unable to overcome the problem of heavy metal pollution. Therefore, attention should be paid to the prevention and control concept of “prevention first, source prevention, emphasis on process, and end treatment”, to strengthen control of the source of heavy metal pollution of agricultural land in the Yangtze River Delta.

4.1.1 Strictly control the source pollution of the “three wastes” in industry

The “three wastes” emissions from industrial production in the Yangtze River Delta are the main pollution sources of heavy metals in the soil of agricultural land. Following release of the *Notice on the Three-Year Action Plan for Winning the Blue Sky Defense War* in 2018, the three provinces and one city in the Yangtze River Delta region proposed the implementation plans for speeding up the relocation, transformation, or closure and exit of heavy-polluting enterprises in urban built-up areas. The implementation plan required that heavily polluting enterprises in the five sectors of cement, flat glass, chemical industry, coking, and steel in areas built or under construction within the administrative districts of cities and counties must be relocated or closed and withdrawn.

(1) The development, promotion, and application of new technologies for the purification and treatment of waste gas and wastewater and the recycling and reuse of solid wastes should be accelerated to reduce the amount and concentration of industrial three wastes emissions. (2) The management and control of three wastes pollution discharge from industry should be strengthened, and all industrial enterprises should be urged to strictly implement the national pollution discharge standards to prevent the phenomenon of excessive industrial three wastes discharge. The pollutant discharge standards and technical specification for pollution in relevant industries should be improved, to provide a timely basis for the supervision of industrial “three wastes” emissions. (3) The development of clean energy, environmentally friendly raw materials, and clean production technology implementation plans for key heavy metal industries should be encouraged to further promote the use of clean energy, environmentally friendly raw materials, clean production technology, advanced production technology, and equipment by industrial enterprises. The storage sites of solid wastes, such as tailings, coal gangue, and smelting slag, must be fully rectified, and industrial wastes such as electronic waste and waste tires must be treated and disposed of in an intensified manner.

4.1.2 Strictly control pollution at the source of transportation

(1) New pollution-free materials such as automotive coatings, anti-corrosion materials, brakes, tire curing agents, and accelerators should be encouraged to develop, apply, and promote, in order to reduce the use of heavy metal-containing raw materials in the automobile manufacturing process and reduce the intensity of heavy metal pollution caused by brake wear and tire aging during automobile driving. (2) Fuel quality should be promptly upgraded, and clean fuels such as unleaded gasoline should be promoted and used. The emission standards for automobile exhaust pollutants will be upgraded, along with the mandatory installation of purification devices for automobile exhausts in order to reduce the risk of heavy metal pollution in agricultural land soil by automobile fuel and exhaust emissions. (3) Supporting facilities for the prevention and control of automobile exhaust pollution should be developed to improve the ability of filtering, purification, and prevention of automobile exhaust pollutants.

4.1.3 Strictly control pollution from agricultural sources such as fertilizers, pesticides, and agricultural films

The timing and frequency of pesticide and fertilizer application in agricultural production should aim to increase the utilization rate and reduce pesticide use. Waste packaging from pesticides and fertilizers should be properly handled, and highly efficient, low-residue pesticides, and ecological organic fertilizers should be promoted and used. Research, development, and application of early warning and control systems of plant diseases and insect pests should be strengthened, and the fertilization technology of soil-testing formula and the slow and controlled release should be promoted, so that the use of agricultural fertilizers and drugs is evidence-based. The use of heavy metal-containing veterinary drugs and feed additives must be strictly regulated to reduce the heavy metal pollution of agricultural land soil caused by the application of livestock and poultry manure. Agricultural producers should be encouraged to increase their awareness of scientific fertilization, drug use, and environmental protection. In addition, training on the scientific use of fertilizers and pesticides for agricultural producers should be performed on a large scale.

When using agricultural films, it is necessary to raise awareness among agricultural producers on the long-term and serious nature of pollution from waste agricultural film, and to increase the awareness and initiative of recycling of waste agricultural film. The technology of uncovering the film at the right time should be promoted, and the crop rotation system should be used to reduce the use of agricultural films and increase their recycling rate. Research, development, and popularization of pollution-free and degradable green biofilms should be supported to reduce the use of non-degradable agricultural films and gradually eliminate the heavy metal pollution of agricultural land soil caused by agricultural film residues.

4.2 Monitoring and treatment of heavy metal pollution in agricultural land

4.2.1 Strengthen the rapid and dynamic monitoring of soil heavy metals in agricultural land

Soil pollutant monitoring provides supporting data for soil environmental supervision and pollution prevention, and is an important foundation and prerequisite for evaluating the environmental quality of soil and for pollution control. In-depth monitoring and investigations of heavy metals in the agricultural land of the Yangtze River Delta should be performed, using a traditional on-site sampling-laboratory analysis detection and analysis model of heavy metals. Non-invasive, high-precision, miniaturized, intelligent, on-site rapid monitoring and emergency monitoring technologies and equipment for soil heavy metals should be focused on research and development to avoid tedious and time-consuming on-site sampling and pre-processing procedures to eliminate disturbance to the tested soil environment. The use of new technology can reduce the cost of investigations and research on heavy metal pollution in soil, improve the timeliness of rapid screening and emergency monitoring for heavy metal pollution, and enable the rapid and accurate acquisition of heavy metal concentrations in a large area of farmland.

(1) To determine changes in the temporal and spatial distribution of heavy metal pollution in agricultural land in the Yangtze River Delta region, three-dimensional dynamic high-precision monitoring technology should be applied over a large area to assess the pollution of heavy metal in soil based on geographic information systems. In addition, hyperspectral remote-sensing technology should be implemented, and a rapid, large-scale, and three-dimensional dynamic monitoring system for heavy metal pollution of agricultural land in the Yangtze River Delta region should be established. (2) Internet and information technology should be introduced, and the fundamental role of big data in environmental monitoring should be fully utilized. An automatic monitoring network system to assess the environmental quality of agricultural land soil in the Yangtze River Delta region and a soil environmental quality monitoring database for agricultural land should be established. (3) An environmental information management platform of agricultural land soil in the Yangtze River Delta region should be formed, with reasonable sharing and scientific management of environmental monitoring data to fully assess dynamic changes in the environmental quality of agricultural land and to provide data support for the evaluation of heavy metal pollution and trends.

4.2.2 Strengthen the hierarchical management of agricultural land

According to the degree of heavy metal pollution in agricultural land in the Yangtze River Delta region, agricultural land should be managed at different levels. (1) For clean agricultural land that is not polluted by heavy metals, monitoring and management should be strengthened, and a permanent protection system should be established to maintain the normal production functions of agricultural land and ensure the quality and safety of agricultural products. (2) For agricultural land with light and moderate heavy metal pollution, the planting layout of crops should be adjusted in a targeted manner, and the crop varieties suitable for planting should be screened. A technical plan for concurrent planting and restoration should be adopted to ensure the safe use of agricultural land. (3) For agricultural land heavily polluted by heavy metals, strict controls should be implemented (such as prohibiting the cultivation of edible crops), the structure of crop planting should be adjusted, and the corresponding remediation plans for soil contaminated by heavy metals should be adopted to protect and remediate soil, and strive to restore the ecological environment quality of the farmland as soon as possible.

4.2.3 Research and develop new technologies for remediation of agricultural land soil contaminated by heavy metals

At present, remediation technologies for agricultural land soil, including physical technology, chemical technology, and biotechnology, are used to treat the soils of agricultural land that have been polluted by heavy metals. (1) Physical technologies, such as the foreign soil method, thermal desorption technology, and electric

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remediation technology, are only suitable for small, polluted areas because of their high cost and low remediation efficiency, which restricts their application and promotion. (2) Chemical remediation technologies, such as leaching technology, fixation-stabilization technology, and chemical oxidation technology, carry a risk of secondary pollution for agricultural land soil remediation due to the use of chemical reagents. (3) Bioremediation technologies, such as phytoremediation technology and microbial remediation technology, are applied because they do not change the original function of the soil and have many advantages, such as their low cost, high efficiency, simple operation, and lac of secondary environmental pollution. However, agricultural land contaminated by heavy metals is difficult to quickly repair and treat owing to the inherent characteristics of heavy metal adsorption by organisms.

In view of the advantages and disadvantages of the existing physical, chemical, and biological remediation technologies, as well as the soil environment of agricultural land in the Yangtze River Delta region and its heavy metal pollution characteristics, the research and development of new technologies for heavy metal remediation in agricultural land soil and multi-technology combined technology for the remediation of agricultural land soil should be focused on. The promotion and application of new restoration technologies for agricultural land soil in the Yangtze River Delta region should be emphasized in order to provide scientific and technological support for the soil environmental quality and safety of agricultural land in the Yangtze River Delta region.

4.3 Promote legislation on the prevention and control of soil pollution in agricultural land, and improve the legal and standards system

Soil pollution of agricultural land in the Yangtze River Delta region and China remains severe; therefore, the soil environment is deteriorating. Due to the dispersability and insufficient laws and regulations related to the prevention of soil pollution and control of agricultural land in China, on the basis of *Soil Pollution Prevention and Control Action Plan* and *Soil Pollution Prevention and Control Law of the People's Republic of China*, the targeted and highly operational special legislation of *Pollution Prevention and Control Law of Agricultural Land Soil*, should be implemented in a timely manner. In this special legislation, the implementation rules for soil environmental protection, supervision, pollution prevention, and other aspects of agricultural land are formulated, and the main body of administrative responsibility for prevention and supervision and the territorial responsibilities of governments at all levels must be clarified.

Based on the soil characteristics and production functions of agricultural land in the Yangtze River Delta, and the requirements for quality and safety of agricultural products, on the basis of the existing national standards of *Soil Environmental Quality: Agricultural Land Soil Pollution Risk Control Standards (Trial)* (GB 15618—2018), it is recommended to refine and formulate industrial and local standards and technical specifications such as agricultural land soil pollution investigation and monitoring, classification, risk assessment, planting industry structure adjustment, restoration, and governance. In addition, measures to manage the local soil environment of agricultural land should be endorsed in a timely manner, and local management regulations for agricultural production activities such as fertilizers, pesticides, livestock and poultry breeding, and irrigation water should be optimized in a timely manner. The implementation of legislation is expected to support the effective supervision and pollution prevention of agricultural land in the Yangtze River Delta region.

5 Conclusion

In the Yangtze River Delta region, accumulation and pollution of the heavy metal Cd in agricultural land soil is the most serious, and there are heavy metal Cd pollution problems in many areas. The accumulation and pollution of the heavy metal Hg is the next most serious, while the heavy metals Pb and Cu also accumulate to a low level with slight pollution in some areas. Industrial "three wastes" emissions, transportation pollution, large-scale application of chemical fertilizers, pesticides, manures, and agricultural films are the main causes of accumulation and even pollution of heavy metals such as Cd, Hg, Pb, and Cu in agricultural land in the Yangtze River Delta region.

Considering the status and specific sources of heavy metal pollution in agricultural land in the Yangtze River Delta, we recommend controlling the source of heavy metal pollution in agricultural land soil, rapid dynamic monitoring of heavy metals in agricultural land soil, graded management of agricultural land soil, research and development of new technologies for soil remediation of agricultural land contaminated by heavy metals, and legislation on the prevention and control of agricultural land soil pollution to strengthen pollution prevention, improve the ecological environment, guarantee the safe production of agricultural land, and promote the high-quality, high-efficiency, and sustainable development of regional agriculture.

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