Environmental Quality Assessment of The Agricultural Production Area Based on Heavy Metal Risk Analysis In Soils and Crops From a Typical Economic Region, Southeastern China

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**Environmental quality assessment of the agricultural production area
based on heavy metal risk analysis in soils and crops from a typical
economic region, Southeastern China**

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Abstract

Background

Heavy metal pollution in soil-crop system attracted great attention globally with rapid urbanization and intensive industrialization. Due to their accumulation and enrichment effects may pose a serious threat to food safety and human health, it is significant to assess environmental quality assessment of the agricultural production area before plantation. Numerous previous studies have been conducted to identify the total amount, distribution patterns and contamination levels of specific heavy metals in agricultural environment, while haven't taken them in both soil and crop into account. Therefore, it is necessary to establish an evaluation approach to indicate the relationship between agricultural resources and farm produce, which considering the soil-crop system quality in relation to multiple heavy metals.

Methods

The soil and crop samples were collected from 370 sampling points in Taizhou City, which is a typical agricultural region located in the central of Jiangsu Province, China. After determination of heavy metals contents, the pollution status and risks of multiple heavy metals were analyzed through both single factor pollution index and Nemero comprehensive pollution index method. Subsequently, the spatial distribution and relevant risk potentials of heavy metals in both soils and crops were illustrated by using ArcGIS 10.3. The K-means clustering algorithm was then applied to quantitatively classify the environment partition with consideration of above results as main indicators.

Results

The mean values of soil Cr, Pb, Cd, As and Hg were 66.78, 32.88, 0.23, 8.16 and 0.16 mg/kg which were much higher than their background values. Affecting by the anthropogenic activities, the average contents of soil Cd and Hg exceeded the risk screening value at a rate of 11.70% and 5.96%, respectively. The heavy metal pollution in soil and crop were inconsistent as more than 97% of the study soils were not polluted with toxic metals while 11-23% of the crop possessed safety risk with Cd and Pb. Based on the pollution assessment, approximately 83% of the study area possessed medium or higher environmental quality, which were preferable for agricultural production.

Conclusions

Our results revealed that, the spatial distribution, pollution level of the heavy metals in soil-crop system were significantly influenced by industrial activities, followed by agricultural sources and transportation emissions etc. Therefore, continuous monitoring and source control for heavy metals, especially for Cd, should be conducted to ensure the environmental quality and food security.

Introduction

Soil heavy metal pollution, which resulted from rapid urbanization and intensive industrial and agricultural production, has attracted both academic and public attentions within the last few decades. Heavy metals refer to metal (loid)s with densities larger than 5 g/cm^3 such as lead (Pb), chromium (Cr), cadmium (Cd), mercury (Hg) and arsenic (As) [1]. Due to the toxicity, non-degradability and persistence of these metals in soil, their accumulation and enrichment effects may pose a serious threat to food safety and human health [2]. In China, 16.1% of the arable land are facing different levels of heavy metal contamination and 2.6% of them are moderate or severe polluted, according to the National Communique of Soil Pollution Survey [3]. In such regions, soil heavy metals are mainly derived from anthropogenic sources, which might also threaten the surrounding aquatic life via surface runoff or leaking in underground water [4, 5]. Therefore, it is important to scientifically and precisely assess the environmental quality based on overall contamination status and pollution risk, in order to protect the agricultural ecosystems.

Prior to classify the potential risks of heavy metals in soils and determine the appropriate solution for risk control, it is vital to identify the total amount, distribution patterns and contamination levels. The total amount of soil heavy metals can provide the information on overall pollution status, which may be valuable for making police and updating threshold values [6]. Many publications have addressed that the spatial distribution of soil heavy metals were complex and significantly influenced by soil parent properties and anthropogenic activities [7, 8, 9, 10]. This is due to the different

sensitivities of heavy metals to the environmental factors such as soil and plant types, point source pollution inputs and tillage methods, especially in the industrial area [11]. Therefore, it is necessary to quantify the correlation between the studied elements in the soil or environmental variables using Pearson correlation analysis, which is helpful for source apportionment of pollutants. Contamination levels are conventionally evaluated through potential ecological risk index [12], geo-accumulation index [13], single factor pollution index [14], Nemerow comprehensive pollution index [15], enrichment factor [16] and target hazard quotient index [17]. These approaches are widely accepted and primarily focus on a single or multiple heavy metals by comparing contents of target heavy metals to their background and standard values.

Numerous previous studies have been conducted to assess the environment quality by using the statistical analysis results of above indexes, while haven't taken heavy metals in both soil and crop into account. In fact, it has been proved that not all heavy metal pollution in crops come from soil, which highlight the demand to detect the quality of soil and crop together [18]. Especially in the economically developed areas, much more attention are needed on food security as the request from the intense population. Although a few researches have been implemented to explore the in-between relationship of soil-crop quality and ecological risk, they focused on specific heavy metal combinations of given crops, regional-scale pollution data are still lacking [19, 20, 21]. Recently, the environment partition method of production area has been applied to achieve an integrated evaluation with considering the soil-crop system quality in relation to heavy metals [22]. Scientifically, this approach is more rational to

combine the soil environmental quality and agricultural product security based on geographic information systems (GIS) technique and clustering analysis [23, 24]. Besides, it also indicates the relationship between agricultural resources and farm produce, which can act as a useful tool to guide the local sustainable agriculture [25].

In this work, 370 samples that containing soil and crop information were collected in Taizhou City, a typical economic development area of southeastern China. The main objectives of this study were to: (1) investigate the overall pollution status of different soil-crop systems; (2) illustrate the spatial distribution of heavy metals and identify the relevant hotspot clusters in the study area; (3) estimate the heavy metal pollution levels and identify the correlation between different metals; and (4) classify the environmental quality based on a comprehensive analysis on soil environment quality and agricultural product security. The results of this study will provide practical references for evaluating environmental quality in similar areas with intensive agriculture, also offer reliable data basis for local government to mitigate heavy metal pollution with high risks.

Materials and methods

Description of the study area

The study area is Taizhou City (Fig. 1) which is a typical agricultural region located in the central of Jiangsu Province, China ($32^{\circ}01'57''$ - $33^{\circ}10'59''$ N, $119^{\circ}38'24''$ - $120^{\circ}32'20''$ E). It is the industrial belt of Yangtze River Delta region and coastal economic development area in Southeastern China, consists of Xinghua City, Taixing City,

Jingjiang City, Hailing District, Gaogang District and Jiangyan District with a total area of 5787 km². The area is within a subtropical humid monsoon climate zone with an annual average temperature and precipitation of about 14.4 - 15.1°C and 1037.7 mm, respectively. The main soil types in the study region are moisture soil and paddy soil which possess an average content of organic matter (OM), total nitrogen (TN), available phosphorus (AP) and available potassium (AK) of 21.4 g/kg, 1.36 g/kg, 25.2 mg/kg and 86.7 mg/kg, respectively. By the end of 2020, the total registered population of the city is 505.19 million. The overall grain production is 306.68 million tons with acre yield of 490.9 kg and wheat, rice, rape and vegetables are the major crops. According to the statistics, the crop production in the study region was steadily increased at a rate of 2.3-3.5% within last five years, ranking the first in Jiangsu Province [26]. Extensive input of chemical fertilizer, livestock and poultry manure and pesticides resulted in this satisfying agricultural production, while raised the risk of heavy metal accumulation in the soils and crops. Industrial regions that including electronics, chemical industry, medicine and smelting are mainly located in north and south of the study area (Fig. 2). Sewage and fumes emitted from these industrial factories also increase heavy metals accumulation in soils and crops.

Sample collection and analysis

Layout of sampling points

According to the requirement for layout of monitoring point, the selection of sampling sites should be typical, representative and homogeneous in order to accurately reflect

the pollution of heavy metals. The sampling sites were geo-located with a global positioning software (ArcGIS 10.3) after a four-step process that including fishnet creation, central point establishment, location calibration and coordinate system transition [27]. Then, a total of 370 sampling points were determined and their spatial distribution were shown in Fig. 1.

Soil and crop sampling

For each site, surface soil (0-20 cm) samples were collected with a stainless-steel drill in June 2019 based on “Technical Specification for Monitoring Farmland Soil Environmental Quality” [28]. Each sample was approximately 2.5 kg and was a composite of five subsamples from a nearby 10 m² area. Soil samples were air-dried, passed through a 2-mm nylon sieve after grinding. Wheat and rice were chosen as the objective crops and their grains were collected in November 2019 according to “Technical Specification for Contamination Monitoring of Agricultural Products” [29]. The sampling positions of grain were in accordance with those of soil and about 50 g of each sample was collected. Grain samples were initially cleaned by deionized water and dried to constant weight, then passed through a 200-μm nylon sieve after grinding. All the samples were stored in hermetically sealed polyethylene bags before chemical analysis.

Chemical analysis

Soil pH was measured using potentiometry at a 1:2.5 (soil:water) ratio with a pH meter (pH 700, American Thermo Scientific). For heavy metal determination, the contents of

soil and grain Cd, Pb, As and Cr were measured using inductively coupled plasma mass spectrometry (ICP-MS, 7500 Cx, American Aglient) after digestion by HCL-HF-HCLO₄-HNO₃. The content of soil and grain Hg were determined by cold vapour atomic absorption spectroscopy and hydride generation-atomic fluorescence spectrometry method, respectively. The recovery rates for Cd, Pb, As, Cr and Hg in samples with addition of standard reference solutions were between 92.6 - 106.4%. Duplicate were simultaneously analyzed with relative standard deviations less than 5.0% compared to the measurements of national standard reference materials (GBW07402, GBW10011 and GBW10011 obtained from the National Standard Detection Research Center, Beijing, China).

Data and statistical analysis

Evaluation of soil heavy metal pollution

In this research, single factor pollution index was introduced to distinguish the key accumulated heavy metals and estimate their pollution status in the study area, which was calculated using the following equation:

$$P_i = \frac{C_i}{S_i} \quad (1)$$

Where P_i is the single factor pollution index of soil heavy metal, C_i (mg/kg) is the measured value of soil heavy metal in sampling site, and S_i (mg/kg) is the pollution risk control threshold of soil heavy metal under different soil pH conditions [30].

Nemero comprehensive pollution index is a kind of weighted multi-factor environmental quality index, which gives specific consideration to the most serious

pollution factor in order to avoid the reduction of heavy metal weighted value caused by the influence of average calculation. This method is most widely used and is extended to assess the pollution levels of soil heavy metals as follows:

$$P_{com} = \frac{\bar{P}_i^2 + P_{imax}^2}{2} \quad (2)$$

Where P_{com} denotes the Nemero comprehensive pollution index of soil heavy metal, $\bar{P}_i$ denotes the average value of soil heavy metal single factor pollution index, and P_{imax} denotes the maximum value of soil heavy metal single factor pollution index. The evaluation criteria for P_i and P_{com} are given in Table 5.

Assessment of agricultural product heavy metal accumulation

The accumulation of heavy metals in agricultural product were also estimated by both single factor pollution index and Nemero comprehensive pollution index. In accordance with the crop types and relevant national standard for food safety [31], the single factor pollution index of agricultural product heavy metals (P_n) can be calculated as follows:

$$P_n = \frac{C_n}{S_n} \quad (3)$$

Where C_n and S_n refer to the detected value and safety threshold of the heavy metals in grain samples, respectively.

The Nemero comprehensive pollution index of agricultural product heavy metals (P_{ncom}) can be computed by the following formula:

$$P_{ncom} = \frac{\bar{P}_n^2 + P_{nmax}^2}{2} \quad (4)$$

Where $\bar{P}_n$ and P_{nmax} represent the average value and the maximum value of heavy metal single factor pollution index regarding to the sampling grains. The evaluation criteria for P_n and P_{ncom} are given in Table 6.

Environment partition of the production area

In this research, the soil quality was applied as the main indicator to define the environmental quality of the production area. Comprehensively considering the spatial distribution of heavy metals in soil-crop system and the yield of crop, K-means clustering algorithm was used to quantitatively classify the environment partition. Five major influencing factors were selected: (1) comprehensive pollution index of soil heavy metals (P_{com}), (2) comprehensive pollution index of rice (P_{n1com}) and (3) wheat heavy metals (P_{n2com}) and (4) yield of rice (Y_1) and (5) wheat (Y_2). The mathematical expression of K-means clustering is as follows:

$$E = \sum_{i=1}^k \sum_{x \in C_i} \|x - u_i\|_2^2 \quad (5)$$

Where the given samples in the study area were divided into K clusters according to the distance between the samples. The setup of K value is important and should be based on the prior experience of the data through cross-validation. Assuming that the cluster is divided into $C_1, C_2, \dots, C_K$ points which should be set as close together as possible, the goal is to minimize the squared error E . In the equation, u_i refers to the mean vector of the cluster C_i , also known as centroid, which can be expressed as follows:

$$u_i = \frac{1}{C_i} \sum_{x \in C_i}^k x \quad (6)$$

The location of K initialized centroids should not be too close due to their significant influence on the final clustering results and running time. Then, the minimum values of above equation can be found to partition the cluster C_i .

Data analysis

The spatial distribution of five heavy metals in soils and crops and relevant food safety risk were mapped via the inverse distance weight method in ArcGIS 10.3. Distribution map of sampling sites and industrial areas were drawn according to the data offered by Cultivated Land Quality Protection Station of Jiangsu Province and Shanghai MetroDataTech co. Ltd. using ArcGIS 10.3. The statistical and correlation analysis on the heavy metal concentrations and environmental partitions of the production areas were implemented using Excel 2016 and SPSS 20.0.

Results and discussion

Descriptive statistical analysis of soil physicochemical properties and heavy metals in soils and crops

The physicochemical properties of the surface soils in the study area are descriptively listed in Table 1. The soil pH was ranged from 3.40 to 8.28 with an average value of 6.67, indicating that the sampling soils are mainly slightly acidic to alkaline. The soil OM was ranged from 4.87 to 77.5 g/kg with majority of soils possessing more than 2% of OM. The soil had low TN (ranged from 0.25-2.49 g/kg) while the AP and AK contents were relatively higher with mean value of 25.2 and 86.7 mg/kg, respectively compared to the results of the Second National Soil Survey of China [32]. In general, the farmland soils of Taizhou City are fertile, which might attribute to the over-application of organic and chemical fertilizers in intensive agricultural production [33].

The average contents of Cr, Pb, Cd, As and Hg in the sampling soils were 66.78, 32.88, 0.23, 8.16 and 0.16 mg/kg, respectively (Table 1), which were lower than the

risk control standard values (RCV) referred to II Level Standard of Soil Environment Quality [30]. In addition, the results were consistent with the data in National Communique of Soil Pollution Survey [3] for the central region of Jiangsu Province, China, indicating that the majority of the study soils might be safe for plantation and human health. The mean values of Pb, Cd and Hg were 1.25, 1.77 and 2-fold larger than their soil background values (SBV), which maintaining high over-SBV rates of 69.1%, 88.6% and 86.2%, respectively. Therefore, soil heavy metals particularly for Cd and Hg, should receive attention as 11.70% and 5.96% of the sampling sites exceeded the RCV. Accordingly, the mean value of Cd was similar to that in Yangtze River Delta region, but higher than that in Guangzhou City (0.21 mg/kg) and Shanghai City (0.196 mg/kg) [34, 35, 36]. The average Hg was much higher than that in Hebei Province (0.034 mg/kg), Chongqing City (0.08 mg/kg) and Tianjin City (0.043 mg/kg) [37, 38]. The coefficient of variation (CV) of soil Cd and Hg were 0.49 and 0.55, respectively, suggesting a high spatial variability and an important influence of local anthropogenic activities [39]. Moreover, the contents of soil Cd and Hg were significantly correlated to those of Cr, Pb and As (Table 2), which might imply their homology to access soil environment such as atmospheric deposition, sewage irrigation and pesticide application [40].

The accumulation of different heavy metals in rice and wheat are shown in Table 3. Except for Hg, all other heavy metals could raise food safety risk due to their detected contents in crops exceeded the food safety limiting values (FSV) referred to the national standard [31] at different rates. Higher average contents of Cr and Pb were obtained,

especially for Pb, which were approximately 2-fold and 3-fold larger than the FSV in rice and wheat, respectively. These results were in accordance with Wan et al.'s [41] findings and probably due to the high contents of Cr and Pb in the study soil. Furthermore, the enrichment of Pb was comparably higher than that of Cr, which might be explained by the fact that the exchangeable Pb in soil was more easily to be absorbed by crop and transported from root to grain [42]. In regard to Cd, the over-FSV rate (12.74%) observed in rice was significantly higher than that in wheat (1.32%), with mean concentration of 0.15 mg/kg. In fact, Cd is known as the most bioavailable toxic element that easily to be transported from soil to food chain even though its background concentration is low [43]. Several researches have pointed out that the enrichment and transport capacity of rice on Cd are much stronger than other cereal crop due to the effect of transport protein OsNramp5 [44, 45, 46, 47]. Actually, the average content of Cd in rice was found to be 0.33-0.69 mg/kg in the polluted area of southern China, which was significantly higher than the safety threshold [48]. Hence, some preventive engineering measurements should be taken to mitigate the risks induced by the Cd contamination. The CV of crop heavy metals were all higher than 0.4 and the accumulation of Cd in rice and Pb in wheat were significantly correlated to Pb and Cr, respectively (Table 4), indicating the synergetic accumulation effects between these metals [49].

Spatial distribution of heavy metals in soils and crops

The spatial distribution of soil heavy metals are presented in Fig. 3. Overall, the spatial distribution of soil heavy metals was apparently different from south to north of the

study area without regular variation trend. The hotspots of high Cr distributed in the northern area of Jiangyan District, and the low-value area were relatively concentrated in the southern of Taizhou City. The high-value area of Pb were scattered distributed in Xinghua City. Compared with that of Pb, the scattered distribution of Cd was more obvious, mainly situated on the south of Xinghua and Jingjiang City. Furthermore, higher contents of As and Hg were located in the southwest and southeast of Jingjiang City. The results showed that most of the high-value areas of soil heavy metals were located in Xinghua and Jingjiang City, which had a similar distribution pattern with local industries (Fig. 2) to some extent. As reported, the spatial distribution of heavy metals in farmland soils are significantly affected by point source pollution, which mostly come from the industrial emissions or other anthropogenic activities [50]. Therefore, densest human activities, particularly industrial activities like metallurgy, nonferrous casting, electronic product processing and cotton spinning etc. resulted in the high contents of Cd, As, Cr, Hg and Pb in the study area [51]. The Ningtong Highway and Provincial Road (S28, S29, S35), with a developed transportation network and high traffic steam, crossing the study area might lead to the high levels of Pb and Cd in surroundings through exhaust gas emission and tire wear [52]. In addition, the southern study area adjoin the Yangtze River, the high concentration of Cd and As were likely due to the sewage irrigation [53].

The spatial distribution of heavy metals in crops are shown in Fig. 4. Similarly, the high-value area of five heavy metals were scattered distributed without regular variation trend. Their concentrations in paddy grain showed a positive correlation to

that of soil heavy metals, but not a linear relationship, which might be related to the inhibition mechanism of root assimilation and plant conduction of heavy metals [54]. In terms of rice, higher contents of Cr, Pb and Cd were found in north-central regions while higher contents of As and Hg were observed in south-central regions. For wheat, high-value Cr, Pb and As were distributed in south-central area, and high-value Cd and Hg were distributed in north-central area. In short, most of the hotspots with high-level heavy metals, especially for Pb and Cd which exceeded the safety threshold, were mainly situated in the central section of Taizhou City (including Jiangyan, Gaogang and Hailing District). This result might be due to the local discrepancies that central Taizhou is downtown where possesses larger population density, less industries but higher contamination load compared to the other regions [55]. In fact, except for point source pollution, the bioaccumulation of heavy metals in food crops could be significantly influenced by urbanization, agrochemical application, plant species as well as environmental and climate conditions [56]. This conclusion was consistent with previously published reports and the content of Pb and Cd in edible parts of the crops (0.62 and 0.15 mg/kg for rice and 0.386 and 0.049 mg/kg for wheat, respectively) were detected to be similar or slightly lower than the current data gathered in Southern China [57].

Heavy metal pollution assessment in the study area

Table 5 presents the heavy metal contamination degrees of sampling soils and its potential environmental risks. According to the calculated single factor pollution index (P_i) values, soil samples were free of Hg and Pb pollution due to all their P_i values were

obtained to be less than 1. The pollution levels of Cr and As were light ($1.0 < P_i \leq 2.0$), with the pollution rate of 0.75% and 0.27%, respectively. Soil Cd deserved more attention, since 2.98% of the samples reached light or moderate pollution levels. The results showed that, more than 97% of the topsoil samples were not polluted with toxic metals, demonstrating low potential environmental risk in the study area. The Nemero comprehensive pollution index (P_{com}) is able to assess the soil quality in a more complete way than the evaluation of one single element. Nevertheless, it is worth mentioning that, P_{com} excessively emphasizes the impact of the maximum studied element, which might artificially exaggerate or neglect the influence of some other factors in the evaluation process. The P_{com} values showed that, most of the sampling sites were within the safety threshold as 91.06% and 7.86% reached the security level ($P_{com} \leq 0.7$) and warning level ($0.7 < P_{com} \leq 1.0$), respectively. Apparently, the sampling soils were appropriate for food crop planting, only 1.08% of them reached light pollution level which was much lower than the data (20%) published by Ministry of Land and Resources of China [58]. In addition, the results based on P_i and P_{com} were similar, suggesting that the soil quality assessment in this work was reliable.

The heavy metal contamination levels of the sampling food crops and its potential ecological risks are shown in Table 6. The results of pollution index (P_n) suggested that both rice and wheat were not contaminated with Hg as their obtained P_n values were less than 1. The pollution rate of other four heavy metals were ranked as Cd (12.1%) > Pb (3.18%) > Cr (1.27%) > As (0.64%) and Pb (17.33%) > Cr (7.33%) > Cd (1.34%) > As (0.67%) in rice and wheat, respectively. Much higher accumulation of Cd was

observed in rice with 3.82% of the samples reached heavy pollution level ($P_n > 3.0$). Inversely, the contamination of Cd in wheat was not obvious, while had a serious-pollution rate of Cr (2.0%) and Pb (5.33%). This difference was significantly correlated to the tillage of different plants and relevant translocation mechanisms on heavy metals [59]. Generally, the pollution area of wheat was larger than that of rice, which was also reflected in the results of Nemero comprehensive pollution index (P_{ncom}). The total polluted area of wheat was 21.33% which was approximately two-fold than that of rice (11.46%). The contaminated area of rice and wheat ranked by different P_{ncom} values were in same order: light pollution > heavy pollution > moderate pollution, and more ecological hazards were observed in wheat at each pollution level. It could be seen that the soil pollution risk and crop pollution risk caused by heavy metals were inconsistent, which might be attributed to the point source pollution. Fig. 5 presents the spatial distribution of heavy metal pollution risk in crops based on the P_{ncom} values. The heavy pollution area of rice and wheat were located in the southeast of Xinghua City and west of Taixing City, respectively. These regions were close to relatively densest industries, traffic arteries and streams that increased the local inputs and bioaccumulation of heavy metals via atmospheric deposition and irrigation [53, 56]. Moreover, the discrepancies of external influences such as climate, acid rain, tillage and fertilization would alter soil properties and heavy metal morphology, ultimately increased the uptake of heavy metals by crops [33, 59, 60]. Therefore, objective environmental assessment on production area should consider the integrated aspects of soil environmental quality and agricultural product quality.

Environment partition of the production area

The environment partition of the production area in Taizhou city based on clustering analysis are shown in Table 7 and Fig. 6. According to the determined clustering indexes, the environmental quality of the production area were classified into five grades: high quality, good, medium, common and poor quality, named as 1-5. The order for the proportion of the production area with different qualities was as bellows: good (58.38%) > common (15.14%) > medium (12.16%) = high quality (12.16%) > poor quality (2.16%). The results indicated that 82.7% of the 370 sampling sites possessed medium or higher environmental quality, which was totally appropriate for the local agricultural production. The production area with poor quality was mainly located in Xinghua City, Taixing City and Jiangyan District, where were surrounded by intensive industries. Considering the pollutant inputs, it is suggested to continue to monitor soil quality in these regions and critical to organize the correlative enterprises working with other stakeholders to seek potential pathways for alleviating the risks from heavy metals pollution.

Conclusions

In this work, environment quality of the production area in Taizhou City, a typical agricultural and industrial region of Jiangsu Province, was assessed by characterizing the contamination status, spatial distribution, correlation and risk of heavy metals in soils and crops simultaneously. The results indicated that, the mean concentration of soil Cr, Pb, Cd, As and Hg were higher than the corresponding background values while

only few sampling sites were light or moderate polluted with Cd. The spatial distribution of heavy metals in soils and crops were mainly affected by the anthropogenic activities, especially industrial production. The pollution risks in soils and crops were inconsistent, serious contamination of Cd and Pb were found in rice and wheat, respectively which closed to relatively densest industries and traffic arteries. The overall environmental quality of the production area in Taizhou are preferable, regular monitoring, source control, and integrated environmental management should be continued to guarantee sustainability of local agriculture.

Abbreviations

Pb: Lead

Cr: Chromium

Cd: Cadmium

Hg: Mercury

As: Arsenic

MEPC: National Communique of Soil Pollution Survey

USEPA: United States Environmental Protection Agency

GIS: Geographic information systems

OM: Organic matter

TN: Total nitrogen

AP: Available phosphorus

AK: Available potassium

DARAJP: Department of Agriculture and Rural Affairs of Jiangsu Province

MAC: Ministry of Agriculture of China

ICP-MS: Inductively coupled plasma mass spectrometry

MEEC: Ministry of Ecological Environment of China

AFDC: Administration of Food and Drug of China

SCOC: Soil Census Office of China

RCV: Risk control standard values

MEPC: Ministry of Environmental Protection of China

SBV: Soil background values

CV: Coefficient of variation

FSV: Food safety limiting values

P_i : Single factor pollution index

P_{com} : Nemero comprehensive pollution index

MLRC: Ministry of Land and Resources of China

P_n : Pollution index

Declarations

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interest.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author's contributions

Xinyu Mao designed the study, validated methods and performed analyses, evaluated results, and prepared the manuscript. Xiaosan Jiang designed the study and developed the analyzing methods. Huaizhi Yu contributed to the sampling analysis and manuscript writing. Senmao Zhai contributed to the samples collecting and manuscript writing.

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Table Captions

Table 1 Descriptive statistical analysis of soil physicochemical properties and heavy metals in the study area

Table 2 Pearson correlation analysis of the five heavy metals in soils

Table 3 Descriptive statistical analysis of heavy metals content of agricultural products in the study area

Table 4 Pearson correlation analysis of the five heavy metals in rice and wheat, respectively in the study area

Table 5 Proportion of soil heavy metal pollution levels analyzed by single factor pollution index (A) and Nemero comprehensive pollution index (B) method, respectively

Table 6 Proportion of crop heavy metal pollution degree analyzed by single factor pollution index (A) and Nemero comprehensive pollution index (B) method, respectively

Table 7 Environment partition of the production area in Taizhou city based on clustering analysis

Table 1 Descriptive statistical analysis of soil physicochemical properties and heavy metals in the study area

Indexes	Cr	Pb	Cd	As	Hg	pH	OM	TN	AP	AK
	(mg/kg)						(g/kg)		(mg/kg)	
Maximum	807.0	123.0	1.19	24.70	0.70	8.28	77.5	2.49	49.7	475.8
Minimum	19.0	10.50	0.06	0.01	0.02	3.40	4.87	0.25	12.3	15.1
Median	66.78	32.88	0.23	8.16	0.16	6.67	21.4	1.36	25.2	86.7
Standard deviation	49.28	10.53	0.11	4.49	0.87	0.87	8.75	0.49	42.4	51.2
Variable coefficient (%)	0.74	0.32	0.49	0.55	0.55	0.13	0.38	0.30	0.82	0.34
SBV ^a	77.8	26.2	0.13	10.0	0.08	-	-	-	-	-
Over SBV rate (%)	20.9	69.1	88.6	20.9	86.2	-	-	-	-	-
RCV ^b	200	250	0.30	30	0.30	-	-	-	-	-
Over RCV rate (%)	1.40	0	11.70	0	5.96	-	-	-	-	-

Note : ^a SBV: the soil background values of soil heavy metals in Jiangsu province that obtained from Chinese Environmental Monitoring Station (1990), ^b RCV: the risk control standard values for soil heavy metals that refer to II level standard of soil environment quality (GB15618-2018)

Table 2 Pearson correlation analysis of the five heavy metals in soils

	Soil-Cr	Soil-Pb	Soil-Cd	Soil-As	Soil-Hg
Soil-Cr	1.00	-	-	-	-
Soil-Pb	0.06	1.00	—	—	—
Soil-Cd	0.13**	0.17**	1.00	—	—
Soil-As	-0.09	-0.24**	-0.05	1.00	—
Soil-Hg	-0.16**	-0.13*	-0.26**	0.15**	1.00

Note : *Significantly correlated at the 0.05 level , **Significantly correlated at the 0.01 level

Table 3 Descriptive statistical analysis of heavy metals content of agricultural products in the study area

Crop	Indexes	Cr (mg·kg ⁻¹)	Pb (mg·kg ⁻¹)	Cd (mg/kg)	As (mg/kg)	Hg (mg/kg)
Rice	Max value (mg/kg)	1.630	5.400	0.684	0.630	0.017
	Minimum value (mg/kg)	0.180	0.060	0.005	0.023	0.001
	Mean value (mg/kg)	0.480	0.620	0.150	0.099	0.005
	Standard deviation (mg/kg)	0.201	0.483	0.097	0.067	0.003
	FSV ^a	1.0	0.2	0.1	0.5	0.02
	Over FSV rate (%)	1.27	3.18	12.74	0.64	0
	Variable coefficient	0.42	0.78	0.65	0.68	0.6
Wheat	Max value (mg/kg)	4.500	2.600	0.246	0.960	0.005
	Minimum value (mg/kg)	0.263	0.041	0.02	0.006	0.001
	Mean value (mg/kg)	0.388	0.386	0.049	0.056	0.002
	Standard deviation (mg/kg)	0.253	0.157	0.028	0.035	0.001
	FSV ^a	1.0	0.2	0.1	0.5	0.02
	Over FSV rate (%)	7.28	17.22	1.32	0.66	0
	Variable coefficient	0.65	0.41	0.57	0.63	0.50

Note: ^a FSV: Food safety limiting values of heavy metals for cereal that refer to the national standard (GB2762-2017)

Table 4 Pearson correlation analysis of the five heavy metals in rice and wheat,
respectively in the study area

	Rice-Cr	Rice-Pb	Rice-Cd	Rice-As	Rice-Hg
Rice-Cr	1.00				
Rice-Pb	0.04	1.00			
Rice-Cd	0.02	0.11*	1.00		
Rice-As	0.24**	0.01	-0.02	1.00	
Rice-Hg	0.02	0.07	0.06	0.04	1.00
	Wheat-Cr	Wheat-Pb	Wheat-Cd	Wheat-As	Wheat-Hg
Wheat-Cr	1.00				
Wheat-Pb	0.18**	1.00			
Wheat-Cd	0.01	0.01	1.00		
Wheat-As	0.11*	-0.01	-0.27**	1.00	
Wheat-Hg	-0.09	-0.05	0.10	0.01	1.00

Note : *Significantly correlated at the 0.05 level , **Significantly correlated at the 0.01 level

Table 5 Proportion of soil heavy metal pollution levels analyzed by single factor
pollution index (A) and Nemero comprehensive pollution index (B) method,
respectively

	Single evaluation index	Class of pollution	Proportion of different pollution levels (%)				
			Cr	Pb	Cd	As	Hg
A	$P_i \leq 1.0$	Non-pollution	98.92	100	97.02	99.73	100
	$1.0 < P_i \leq 2.0$	Light pollution	0.75	0	2.71	0.27	0
	$2.0 < P_i \leq 3.0$	Medium pollution	0	0	0.27	0	0
	$P_i > 3.0$	Heavy pollution	0	0	0	0	0
Comprehensive evaluation index		Class of pollution	Proportion of different pollution levels (%)				
B	$P_{com} \leq 0.7$	Security level	91.06				
	$0.7 < P_{com} \leq 1.0$	Warning level	7.86				
	$1.0 < P_{com} \leq 2.0$	Light pollution level	1.08				
	$2.0 < P_{com} \leq 3.0$	Medium pollution level	0				
	$P_{com} > 3.0$	Heavy pollution level	0				

Note : P_i and P_{com} is single factor pollution index and Nemero comprehensive pollution index of
soil heavy metals, respectively

Table 6 Proportion of crop heavy metal pollution degree analyzed by single factor

pollution index (A) and Nemero comprehensive pollution index (B) method,

respectively

	Crop	Single evaluation index	Class of pollution	Proportion of different pollution levels (%)				
				Cr	Pb	Cd	As	Hg
A	Rice	$P_{n1} \leq 1.0$	Non-pollution	98.73	96.82	87.90	99.36	100
		$1.0 < P_{n1} \leq 2.0$	Light pollution	1.27	1.91	7.01	0.64	0
		$2.0 < P_{n1} \leq 3.0$	Medium pollution	0	1.27	1.27	0	0
		$P_{n1} > 3.0$	Heavy pollution	0	0	3.82	0	0
	Wheat	$P_{n2} \leq 1.0$	Non-pollution	92.67	82.67	98.66	99.33	100
		$1.0 < P_{n2} \leq 2.0$	Light pollution	4.0	8.67	0.67	0.67	0
		$2.0 < P_{n2} \leq 3.0$	Medium pollution	1.33	3.33	0.67	0	0
		$P_{n2} > 3.0$	Heavy pollution	2.0	5.33	0	0	0
B	Rice	Comprehensive evaluation index	Class of pollution	Proportion of different pollution levels (%)				
		$P_{n1com} \leq 0.7$	Security level	84.08				
		$0.7 < P_{n1com} \leq 1.0$	Warning level	4.46				
		$1.0 < P_{n1com} \leq 2.0$	Light pollution level	6.37				
		$2.0 < P_{n1com} \leq 3.0$	Medium pollution level	1.91				
	Wheat	$P_{n2com} \leq 0.7$	Security level	64.67				
		$0.7 < P_{n2com} \leq 1.0$	Warning level	14.0				
		$1.0 < P_{n2com} \leq 2.0$	Light pollution level	14.0				
		$2.0 < P_{n2com} \leq 3.0$	Medium pollution level	3.33				
		$P_{n2com} > 3.0$	Heavy pollution level	4.0				

Note : P_{n1} and P_{n2} is single factor pollution index of rice and wheat, respectively, P_{n1com} and P_{n2com} is Nemero

comprehensive pollution index of rice and wheat, respectively

Table 7 Environment partition of the production area in Taizhou city based on
clustering analysis

Clustering index	Cluster				
	2	5	3	4	1
P_{com}	0.48	0.37	0.47	0.42	0.45
P_{n1com}	0.46	0.28	0.39	0.42	0.46
P_{n2com}	0.51	0.52	0.85	0.80	0.44
Y_1	619	353	613	550	666
Y_2	427	400	421	410	436
Case number	216	8	45	56	45
Area proportion (%)	58.38	2.16	12.16	15.14	12.16

Note: Y_1 and Y_2 are the yield of rice and wheat, respectively, number 1-5 refer to the environment partition rank of the production area named high quality, good, medium, common and poor quality, respectively.

Figure captions

Fig. 1 Distribution of sampling sites in the studying area

Fig. 2 Spatial distribution of some industrial areas in Taizhou City

Fig. 3 Spatial distribution of soil heavy metals in the study area

Fig. 4 Spatial distribution of heavy metals in agricultural products in the study area

Fig. 5 Comprehensive risk map of heavy metals in rice and wheat, respectively

Fig. 6 Environment partition of the production area in Taizhou City

The study area

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