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Original Research

Risk Assessment and Legal Countermeasures for Heavy Metal Contamination of Land in Rural Areas under the Green Background

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Abstract

The study focuses on heavy metal-contaminated land in rural areas of northern China and dryland soil. Electrochemical sensors and other related methods are used to detect heavy metal content in soil. Based on the traditional heavy metal pollution soil evaluation model, an evaluation model considering comprehensive pollution factors is proposed to assess the situation of heavy metal pollution in soil. Finally, provide effective treatment suggestions based on the heavy metal pollution situation in the soil. According to the distribution of heavy metals in the sample collection area, about 94% of the areas belonged to Class I areas, and the soil quality met national safety quality requirements. The heavy metal content in crops did not exceed safety standards. The main pollutants in other areas were cadmium and nickel, with only a few areas severely polluted. Zone C and Zone D were selected as examples for analysis, with data sourced from agricultural economic data, regional statistical yearbooks, and environmental monitoring data from the region over the years. Four typical cadmium and nickel pollution areas were selected for risk assessment. In evaluating soil quality standards, Zone D was the main production area for grain crops, with densely distributed factories. The Cd content in region D was relatively high, at 0.711 mg/kg, and the soil quality belonged to level three. However, the nickel content in farmland in all four regions was within the first-level soil quality range (50 mg/kg), and there was no problem with heavy metal pollution. In addition, the average wheat yield in the four regions was calculated to be 9.249 t/hm^2, which was not significantly affected. In the comprehensive evaluation of the three indicators, the soil in the four regions was safe, but the accumulation trend of elements was slight, indicating a certain trend of heavy metal pollution in the study area.

Keywords: heavy metal, farmland, risk assessment, contamination characteristics, rule of law response

Introduction

Industrial, mineral, and exhaust emissions have greatly impacted land resources and the environment, directly leading to heavy metal

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contamination of a large amount of farmland. According to relevant statistics, in the last ten years, the annual agricultural economic losses caused by heavy metal contamination in China have exceeded 20 billion Yuan, and the pollution of grain crops has exceeded 12 million tons per year. China has a serious contamination problem, and the actual situation is that less than 9% of the world's arable land is used to feed more than 22% of the world's population in China [1]. Due to increasingly prominent environmental issues, the land area is constantly shrinking. In most rural and impoverished areas, their food mainly relies on local supply, and environmental contamination significantly impacts farmers' survival. In addition, the annual amount of garbage in Asia reaches 24.9 million tons, with the highest amount among the five continents at 57.4 million tons. According to Statista data, the global production of plastic waste exceeds 430 million tons. As one of the largest plastic waste-producing countries in the world, China's National Bureau of Statistics shows that the amount of plastic waste produced in 2022 was over 60 million tons. Plastic waste contains a large amount of heavy metals, and due to the intensification of heavy metal pollution, the per capita arable land area in China continues to decrease. [2]. This has had a huge negative impact on the ecological environment and agricultural economy. Heavy metal contamination of soil mainly refers to land pollution by toxic and harmful metals [3]. Due to the heavy metal in the soil exceeding the environmental and ecological safety standards (mainly based on regional soil quality standards), soil microbial activity and plant ecology are affected to varying degrees, hindering the healthy development of agriculture. Zhang et al. investigated metal contamination in farmland in the agricultural areas of Sihui and Shunde in Southern China, where mercury contamination was the main cause [4]. At present, there are more than 40 major heavy metals in rural areas, and the impact of different heavy metals on the ecological environment is significantly different, including cadmium (Cd), mercury (Hg), lead (Pb), zinc (Zn), chromium (Cr), etc. Heavy metal contamination greatly impacts the agricultural ecological environment, crop quality, and husbandry. Therefore, in order to effectively address the problem of heavy metal contamination in rural areas, a certain heavy metal contamination area in the north was taken as the research object to analyze the main contamination elements in rural areas. Based on the traditional assessment model, the distribution characteristics in the polluted land were analyzed, and a comprehensive indicator evaluation system was constructed to effectively evaluate heavy metal pollution in the soil. The research innovation lies in investigating metal pollution in northern farmland, providing technical support for pollution control in the northern region. Secondly, the study aims to provide a more accurate assessment of regional heavy metal pollution through practical investigations and a comprehensive scientific evaluation system. By studying the current situation of heavy metal pollution in soil in rural areas, effective improvement suggestions are proposed to promote the healthy development of agriculture and the ecological environment.

Materials and Methods

Materials

Equipment: Electron microscope, provided by Beijing Taihe Gerun Instrument Co., Ltd.; universal high-speed crusher, manufactured by Oukailaifu Industrial Company; HH-S6 electric blast drying oven, manufactured by Tianjin Test Instrument Co., Ltd.; Hitachi Z-5000 atomic absorption spectrophotometer, provided by Hitachi Corporation.

Materials: pH buffer solution (buffer solution of 4.0, 6.86, 9.18); metal element standard solution provided by the China National Center for Reference Materials Research; experimental soil was collected from multiple points in the contaminated area.

Statistical Methods

By utilizing the descriptive statistical function of SPSS, statistical measures such as

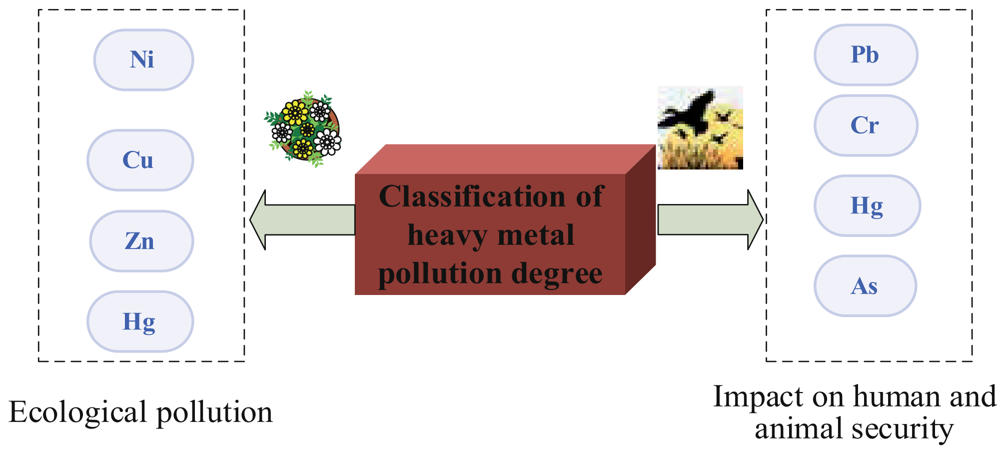

Fig. 1. Classification of the contamination impact degree for heavy metal.

the average, standard deviation, maximum, and minimum values of heavy metal content in soil can be calculated to understand the distribution characteristics of the data.

Methods

Research on Contamination Status

According to the 2014 China National Soil Contamination Survey Report, the survey scope covers the land territory of the People's Republic of China (excluding the Hong Kong Special Administrative Region, Macau Special Administrative Region, and Taiwan region), covering all cultivated land, some forest land, grassland, unused land, and construction land. The actual survey area is about 6.3 million Km^2. The survey adopted unified methods and standards and grasped the country's overall soil environmental quality situation. China's land environment is facing significant risks, and the problem of industrial waste soil is severe. Industrial, mining, agricultural, and other activities are the main reasons for excessive heavy metals in soil. The total soil exceeding the standard rate in China is 16.1%, and the proportions of mild, moderate, and severe contamination points are 11.2%, 2.3%, 1.5%, and 1.1%, respectively, mainly caused by inorganic pollution [5]. It can be seen that the current soil environmental problems in China are very serious [6]. There is no clear definition of heavy metal pollution in agricultural heavy metal pollution, but there are local standards in different regions. Metals with a natural density greater than 4.5 g/cm^3 are called heavy metals in the study area. At present, 45 types of heavy metal substances are found in nature. Common heavy metals include Hg, Cd, Pb, Cr, As, Cu, Ni, and others. Heavy metals will flow into the rural land environment. When the heavy metals in the soil exceed the standard value of environmental and ecological safety, it will cause an irreversible impact on the animals, plants, and ecology in the environment. The impact of heavy metal contamination is divided into two categories. One is the contamination of the ecological environment, and the other is the impact on human and animal life organizations, as shown in Fig. 1.

The ecological contamination caused by heavy metals destroys the soil microbial structure, impedes the absorption of nutrients by plants, and reduces the ecological contamination degradation ability. The contaminants impact the life and health of animals, including the intelligence and organ development of animals and physical defects. If animals are affected by heavy metals for a long time, various diseases can become life-threatening. The main contaminants include mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), copper (Cu), nickel (Ni), etc. It shows that heavy metal contamination poses a great threat to ecology and human health [7].

By 2022, China's arable land area was 127 million hectares, a decrease of 7 million hectares from 135 million hectares in 2015

Table 1. Contamination degree of typical farmland in northern China.

Contaminant type	Proportion of serious contamination/%				Point exceeding standard rate /%
	Slight	Light	Moderate	Serious	
Cd	5.82	0.83	0.42	0.49	7.56
Ni	4.20	1.25	0.32	0.12	5.89
As	2.10	0.42	0.29	0.10	2.91
Cu	1.58	0.32	0.11	0.05	2.06
Hg	1.19	0.24	0.10	0.09	1.62
Pb	1.12	0.19	0.12	0.11	1.54
Cr	0.89	0.12	0.05	0.01	1.07
Zn	0.71	0.09	0.05	0.02	0.87

[8]. At the same time, heavy metal pollution has seriously affected the ecology of farmland in China, and the area of arable land has been decreasing every year. If effective ecological protection measures are not taken, it will pose a serious challenge to China's food security and the physical and mental health of the people. The development of traditional industries is the main focus in northern China, and many areas have been polluted by heavy metals in recent years, causing serious impacts on agriculture and ecology [9]. In this experiment, typical heavy metal pollution areas in the north were selected for research, and 141 typical areas of farmland were investigated for heavy metal pollution in this area. Through testing and investigation, it was found that nearly 17.2% of the land in the area is polluted with heavy metals. In the survey data, the main pollution elements with the highest proportion are Cd, Ni, and Pb. At the same time, heavy metal pollution in the region is rising, posing challenges to current agricultural food safety and ecological health. The current situation of heavy metal pollution in farmland in a certain northern region is shown in Table 1 [10].

The heavy metal pollution in a certain heavy metal polluted area in the north of the experimental investigation has obvious differences and long-term characteristics. This is mainly caused by regional industrial structure, ecological conditions, soil structure, and other factors. The heavy metal pollution characteristics of different farmland also

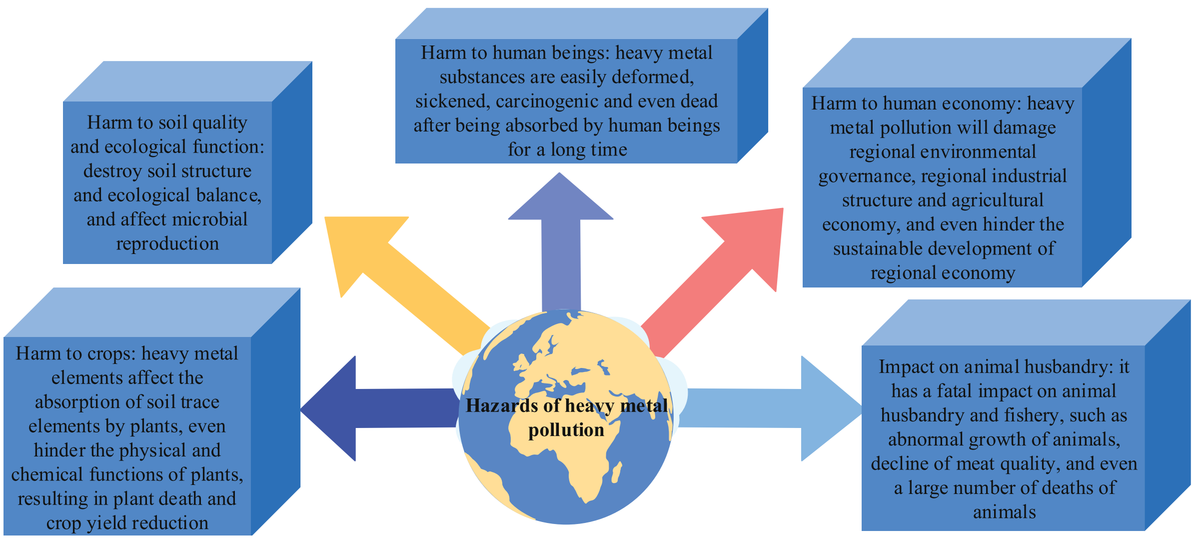

Fig. 2. Main hazards of heavy metal contamination.

impact regional ecology and food security differently. Through the analysis of the heavy metal pollution characteristics of farmland in the region, it was found that the soil with heavy metal pollution in the northern region presents alkalinity, which is of great significance for the heavy metal pollution of alkaline land in the northern region. A study was conducted on typical heavy metal pollution in the north. Fig. 2 shows the main hazards of heavy metal pollution.

Research on Contamination Characteristics

The research is about the heavy metal contamination caused by typical droughts in northern China. The areas mainly involve Hebei, Tianjin, Beijing, and others. These regions are important vegetable and grain production areas in China. They supply corn, wheat, vegetables, and other food crops to the whole country every year. The annual output of corn in this region is more than 22 million tons, and the annual output of wheat is more than 19 million tons [11]. Due to the development of the national economy, the demand for heavy metal elements in various industries is increasing, such as construction, energy, mining, and other industries. A large number of heavy metals flow into the ecological environment through enterprise contamination and gas emissions, resulting in heavy metal contamination in farmland. The soil samples of the main pollution land in this area are selected to detect the content of heavy metals in the soil. Multiple heavy metals have been found in the soil surface [12].

To further study the characteristics of soil contamination in the northern region, it is necessary to analyze the contamination sources of major heavy metal contamination elements Cd and Ni in the region. Starting from the source of contamination, it flows into the rural environment through a series of physical and chemical processes such as precipitation and dissolution, oxidation and reduction, adsorption and desorption, complexation, colloid formation, etc. The characteristics of heavy metal contamination in farmland can be better analyzed [13]. Thus, the scientific treatment of heavy metal contamination areas can be realized. Therefore, the characteristics of heavy metal contamination sources are analyzed based on the carbon sink balance theory. Four methods are mainly used, including the atmospheric sedimentation method, irrigation water method, livestock manure method, and fertilizer calculation method [14]. In the atmospheric sedimentation method, the exploration data of laboratory personnel and regional environmental monitoring data are mainly calculated. Thus, atmospheric precipitation data can be obtained. The actual calculation will remove the abnormal data of Cd and Ni high contamination settlements in the industrial contamination area and mining area. Then, in formula (1), the total deposition flux of heavy metal elements in a certain area in the north is shown [15].

$$A_a = C_i \times S \tag{1}$$

C_i represents the mean sedimentation flux of element *i* in formula (1), and *S* represents the farmland area. The unit is m^2.

The irrigation method mainly calculates the heavy metal content through agricultural irrigation. Due to the fact that the surveyed northern areas are mainly dry fields, agricultural water resources are relatively scarce. To improve agricultural water use, groundwater exploitation and water-saving irrigation technology are widely used in this region to meet the agricultural water demand. There is a lot of sewage in this area. For a long period, cheap and stable sewage is used for agricultural production [16]. In recent years, the country has strengthened the quality requirements for agricultural water, so sewage irrigation is prohibited.

In formula (2), the output flux of farmland irrigation water to farmland heavy metals is shown.

$$A_g = (S_1 \times C_{1i} + S_2 \times C_{2i}) \times W \tag{2}$$

S_1 represents the area of farmland sewage in formula (2). S_2 represents the area of groundwater used in farmland. The unit is m^2. C_{1i} represents the heavy metal content

Table 2. Characteristics of heavy metal pollution in soil in northern China.

Type name (200 samples)	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
Minimum value	0.690	0.030	5.320	0.015	3.720	8.900
Maximum value	192.000	6.180	895.000	11.800	92.000	219.400
Average value	10.150	0.149	66.200	0.045	28.800	22.900
Median value	10.600	0.160	64.900	0.046	28.100	23.600
Standard deviation	3.120	0.092	13.400	0.094	6.510	6.990
Coefficient of variation	0.310	0.601	0.241	2.070	0.229	0.101

of farmland sewage. The unit is mg/kg. C_{2i} represents the heavy metal content of groundwater used in farmland. The unit is mg/kg. W represents the water consumption per unit area of farmland, and its unit is kg/m^3.

In analyzing the main characteristics of heavy metal contamination in farmland, the impact of organic manure should also be considered. In the development of agriculture, many farmers use composted animal manure as organic agricultural fertilizer [17]. In the sampling survey of organic agricultural fertilizer, there are also many heavy metal elements in livestock manure. Heavy metals flow into farmland after agricultural fertilization. Two hundred manure farmland areas were analyzed, and the impact of manure on farmland in this area was obtained. In formula (3), the livestock and poultry manure method is used to calculate the heavy metal output flux of livestock and poultry manure to farmland.

$$A_b = f\sum_j N_j p_j (1 - f_{wj}) C_{ij} \tag{3}$$

f represents the utilization rate of excrement in formula (3). N_j represents the annual breeding quantity of type j livestock and poultry. p_j represents the excretion parameters of livestock and poultry excrement. f_{wj} represents the annual water content of type j livestock and poultry excrement. C_{ij} represents the metal element concentration in livestock and poultry excrement. In addition to livestock and poultry manure containing certain heavy metal elements, heavy metal content in agricultural fertilizer cannot be ignored. In formula (4), the output flux of Cd and Ni in agricultural fertilizer to farmland is shown.

$$A_h = \sum_j N_k C_{ik} \tag{4}$$

N_k represents the annual consumption of class k fertilizer in formula (4). The unit is Kg. C_{ik} represents the concentration of element i in class k fertilizer. In formula (5), the total output of major heavy metals Cd and Ni in farmland in a northern region is shown.

$$A_i = A_a + A_g + A_b + A_h \tag{5}$$

The output characteristics of heavy metals in polluted farmland can be obtained from formulas (1) to (4). The impact of pesticides on farmland is not considered in the actual calculation, mainly because the heavy metal content of pesticides is relatively small. The mixing of pesticides and water sources has been included in the calculation of farmland irrigation water. Using the above methods, the northern region studied was analyzed, and Table 2 shows the final data survey results.

According to the sampling survey data in Table 2, the main contaminating elements in heavy metal pollution areas in the north are Cd and Hg. Soil samples were collected from multiple cities, counties, and towns in the northern region, and there were differences in the content of heavy metal elements in different regions. However, the variation coefficients of Cd and Hg are relatively high, with a variation coefficient above 0.5, while the other heavy metal elements are below 0.5. The high coefficient of variation indicates that Cd and Hg have a high distribution in the survey area.

At the same time, referring to the evaluation standards for heavy metal contamination in Chinese soil environment monitoring, a review was conducted on the environmental quality monitoring data of the region over the years. The soil contents of As, Cd, Ni, Pb, Cr, and Hg in the survey area meet the soil quality and safety requirements. However, Cd, Cr, and Ni were higher than the national average (0.097 mg/kg, 61 mg/kg, 26 mg/kg) in monitoring deep soil in northern China [18]. It shows that the content of Cd, Cr, and Ni elements in the highly polluted areas of heavy metals in the north is higher than the environmental quality standard, which requires high attention from the relevant regional departments [19].

Risk Assessment of Heavy Metal Contamination in Farmland

Heavy metal pollution farmland soil contains a variety of harmful elements. Different types and concentrations of heavy metals have different impacts on farmland ecology. When the content of heavy metals exceeds the ecological safety standard value of the soil environment, it will cause certain damage to the regional farmland ecology. The higher the concentration of heavy metal elements, the greater the ecological damage [20]. Therefore, a risk assessment method is needed to assess farmland quality in heavy metal contamination areas. This is conducive to strengthening the governance of the regional environment and reducing the impact of heavy metals on agricultural ecology. According to the requirements of agricultural ecological supervision and protection in China, the second-level standard method of the Soil Environmental Quality Standard (GB 15168-2018) is adopted. The soil environmental quality standard is the maximum allowable content of contaminants in soil. The residual accumulation of contaminants in soil is limited to not causing obstacles to crop growth, excessive accumulation in grains or edible parts (not exceeding food hygiene standards), or affecting environmental quality such as soil and water bodies. This standard is formulated to implement the "Environmental Protection of the People's Republic of China" to prevent soil contamination, protect the ecological environment, ensure agricultural and forestry production, and maintain human health. This standard specifies the maximum allowable concentration index values of contaminants in soil and corresponding monitoring methods based on soil application functions, protection objectives, and main soil properties. This standard applies to farmland soil, vegetable fields, tea gardens, orchards, pastures, forests, nature reserves, and other areas. This method divides soil quality into three levels, from low

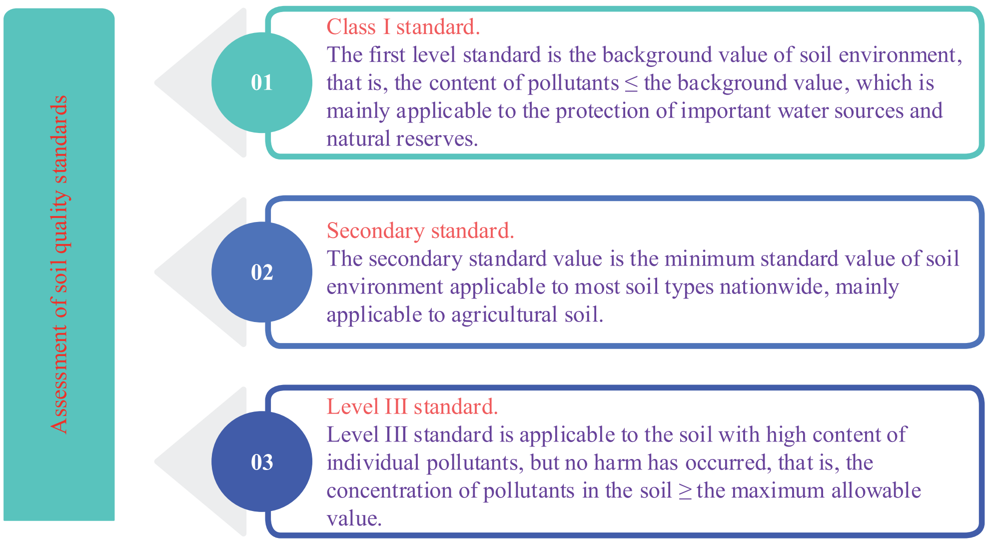

Fig. 3. Evaluation according to soil quality standards.

to high: Class I, Class II, and Class III, with the most severe standard pollution, as shown in Fig. 3 [21].

According to the soil quality level standards, 200 typical farmland samples were analyzed in the study area to determine the maximum allowable content of pollution elements in the soil. It can make standard-grade assessments of agricultural ecological quality and has important value for the quality assessment of heavy metal contamination areas. However, this method cannot consistently evaluate the quality of soil and crops [22]. Therefore, the three-indicator comprehensive method is used to evaluate the heavy metal contamination in farmland. The assessment of farmland soil quality, plant quality, and soil accumulation trends can more scientifically reflect the situation of farmland contamination. Fig. 4 shows the process of this evaluation method [23].

To evaluate heavy metal farmland, the main contamination sources should be identified first. The main contamination sources of farmland come from four aspects: farmland irrigation, livestock manure, atmospheric dust, and agricultural fertilizer. The content of metal elements in crops can be obtained through international standards (GB/T 5009) [24]. The assessment of heavy metal contamination in farmland mainly starts from three aspects: soil quality, plant quality, and soil accumulation trend. The severity of the soil mainly determines the soil quality. The trend of soil accumulation is determined by the annual increase rate of elements in the soil [25]. Plant quality is divided into two categories according to the degree of impact, including ecological risk and agricultural product quality risk [26]. Table 3 shows the types of heavy metal pollution in farmland from the above aspects.

Table 3 classifies the three aspects of heavy metal contamination in farmland. "-" is an arbitrary value, and "()" is the ecological impact. In soil quality analysis, the risk entropy is used to reflect the degree of heavy metal contamination in farmland. The calculation expression is shown in formula (6) [27].

$$T_i = \frac{C_r}{C_{rl}} \tag{6}$$

C_r represents the measured value of element i in soil in formula (6). C_{rl} represents the limit parameter of element i in soil. T_i represents the risk of element i in soil. In the environmental treatment, when the farmland is in the safety standard, the heavy metal removal rate of the

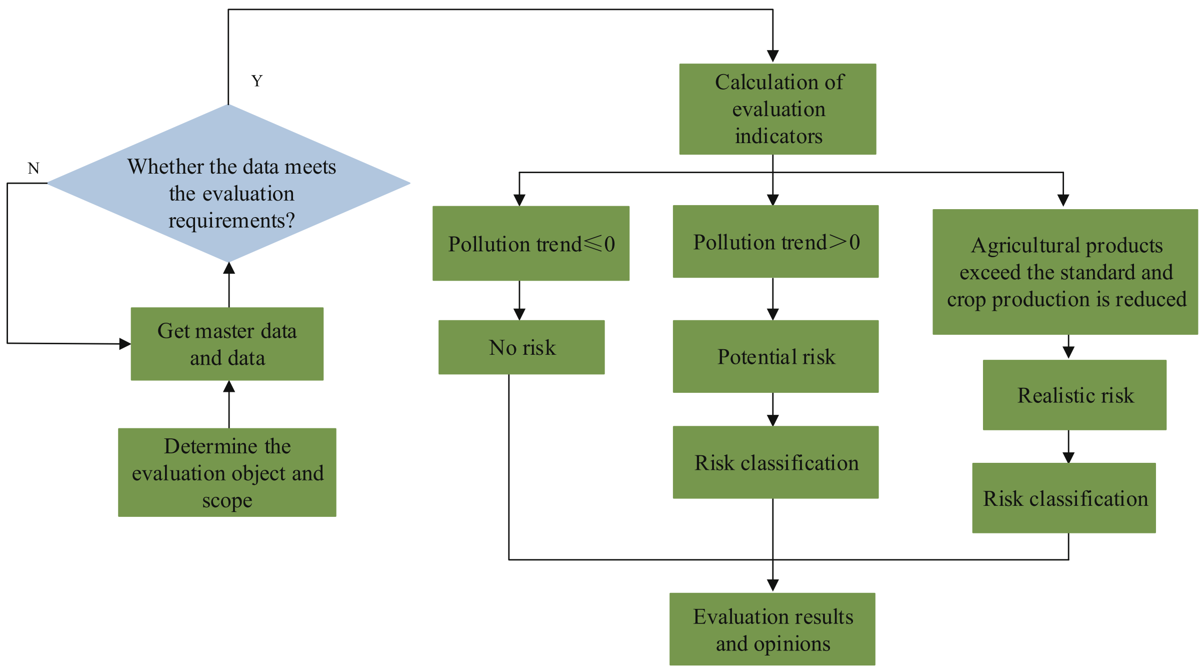

Fig. 4. Assessment process of heavy metal contents in farmland with three indicators.

Table 3. Classification of heavy metal contamination levels in farmland.

Indicator/risk type	Soil quality	Soil accumulation trend	Plant quality
Security	The content of heavy metals does not exceed the standard	≤ 0	The content of heavy metals does not exceed the standard (the crop yield is not reduced)
Potential risk	The heavy metal content does not exceed the standard	> 0	The content of heavy metals does not exceed the standard (the crop yield is not reduced)
	Heavy metal content exceeds the standard	< 0	The content of heavy metals does not exceed the standard (the crop yield is not reduced)
Realistic risk	-	-	Heavy metal content exceeds the standard
			(the crop yield reduction)

heavy metal treatment measures taken should be greater than 50% [28]. If the content of the Cd element in the soil is twice the maximum safe value, the control measures cannot effectively control soil contamination [29]. The soil accumulation trend was mainly based on the farmland contamination background and contamination years, which were used to calculate the farmland heavy metal contamination trend in formula (7).

$$Y_i = (C_{il} - C_{ib}) \times W_t / P_i \quad (7)$$

C_{il} represents the limit value of element *i* in soil in formula (7). C_{ib} represents the content of element *i* in polluted soil. W_t represents the quality of farmland soil per unit area. Y_i represents the safe life of elements in the soil. The unit is the year. In formula (8), the plant quality is mainly calculated based on the element content of agricultural products [30].

$$E_i = (C_{ia} - C_{if}) C_{il} \times 100\% \quad (8)$$

In formula (8), C_{ia} represents the average content of element *i* in agricultural products. The unit is mg/Kg. C_{if} represents the limit parameter of element *i* in agricultural products. E_i represents the over-standard condition of elements in agricultural products. From formulas (6) - (8), the risk assessment grade of heavy metals in farmland can be obtained. At the same time, referring to the survey report by Huang et al. on the concentration of heavy metal contamination in farmland in China, a more reasonable classification of different metal contents was carried out. Table 4 shows the evaluation levels of heavy metal contamination in farmland [31].

From Table 4, it can be seen that the soil risk level is divided into four levels, namely mild, moderate, high, and severe. Among them, the serious risk level is that farmland will experience problems such as plant death and severe damage to soil microbial systems. At higher risk levels, there are issues such as the impact on soil microbial systems and the

Table 4. Assessment system of heavy metal contamination in farmland.

Risk classification	Soil quality parameters/Ti	Cumulative trend/ Yi	Plant quality/Ei	Impact degree
Security	< 1	∞	< 0	Farmland is in a safe production state
Slight	1 ≤ Ti < 1.5	≥6 0	0 ≤ Ei < 50%	Normal production, with a slight impact on crop yield and quality
Secondary	1.5 ≤ Ti < 2	30 ≤ Yi < 60	50% ≤ Ei < 100%	Crop growth has been affected, and crop quality and yield have decreased significantly
Higher	2 ≤ Ti < 2.5	20 ≤ Yi < 30	100% ≤ Ei < 150%	The soil microbial system is affected, and a large number of plants die
Serious	Ti ≥ 2.5	Yi < 20	≥ 150%	Plant death and serious damage to soil microbial system

occurrence of a large number of plant deaths. At a moderate risk level, crop growth is affected, and there is a significant decrease in crop quality and yield.

Results and Discussion

Regional Overview

The study mainly takes Shijiazhuang City, Hebei Province, as the research object of soil heavy metal pollution and studies four important typical regions in the region. The four typical regions are defined as A, B, C, and D, and regions C and D are selected as the example analysis objects and environmental monitoring data of the region over the years. According to the data, the province's emissions of sulfur dioxide and smoke (powder) dust in 2017 were approximately 1.1284 million tons and 1.5854 million tons, respectively. The total amount of wastewater discharge is 3.1056 billion tons, and the main heavy metals in the wastewater are lead, mercury, cadmium, arsenic, and hexavalent chromium [32]. In recent years, heavy metal contamination in the region has intensified, and conducting soil quality testing is of great significance for regional agriculture and ecology. Among them, C and D regions are the main grain-producing areas in the province, with arable land accounting for 25.21% and yield accounting for 30.21%. At the same time, the D region has developed rapidly in industrialization in recent years, and pollution problems have gradually become prominent, which has a certain safety impact on food crops. The experiment selects areas A, B, C, and D as the example analysis sites. Sample collection mainly included collecting multiple soil experimental samples from four types of localities, a total of 500 samples weighing 500 kg, including collecting 0-20 cm of mixed soil on the surface of wheat planting farmland. Select areas adjacent to factories, areas with abnormal soil pH, and areas with differences in soil staining as soil sources for investigation. After confirming the sampling field area, the sampling plot area is divided into 1-10 according to the sampling concentration location, and sampling is carried out according to the principles of "random", "equal quantity", and "multi-point mixing" [33]. The S-shaped sampling method is used in sample collection, where soil samples are collected in the collection area in an S-shaped manner, and impurities need to be removed from the collected soil samples. It shall be dried in natural dark light and ground at the same time. The obtained soil samples were screened using standard soil screening methods, and nylon was screened and classified into four sizes of samples, including 0.149 mm, 0.25 mm, 1 mm, and 2 mm. Plant samples (only the aboveground parts were collected, excluding the root system) were separated from stems, leaves, and panicles, washed, sterilized at 105°C for 20 minutes, and dried at 70°C. Peel off the kernels, discard the glumes, retain the seeds, crush the stem and leaf combined kernels, and pass them through a 0.25 mm sieve to determine the Cd. Heavy metal content was determined in plant samples using wet digestion, and Cd content was measured using Hitachi Z-5000 atomic absorption spectrophotometer. The determination of the available heavy metal content in the soil was carried out using DTPA extraction (0.005mol/LDTPA+0.1mol/LTEA+0.01 mol/L $CaCl_2$) and atomic absorption spectrometry. Weigh 5.00 g of air-dried soil, sieve it through a 2 mm sieve, and place it in a 100 nml plastic bottle. Add 25.00ml DTPA extractant and shake at room temperature (25±2°C) at a rate of 180±20 times/minute [34]. Take it out and filter it to obtain a clear solution. Measure the content of cadmium, lead, and zinc using a Hitachi Z-5000 atomic absorption spectrophotometer. Ni content. The sampling map is shown in Fig. 5.

Comprehensive Contamination Risk Assessment

In June 2021, four locations in areas A, B, C, and D of a certain northern province were selected as experimental collection points. Referring to the national Soil Environmental Quality Standards, the distribution characteristics of heavy metals in the region were investigated. Soil characteristics are mainly influenced by two important factors:

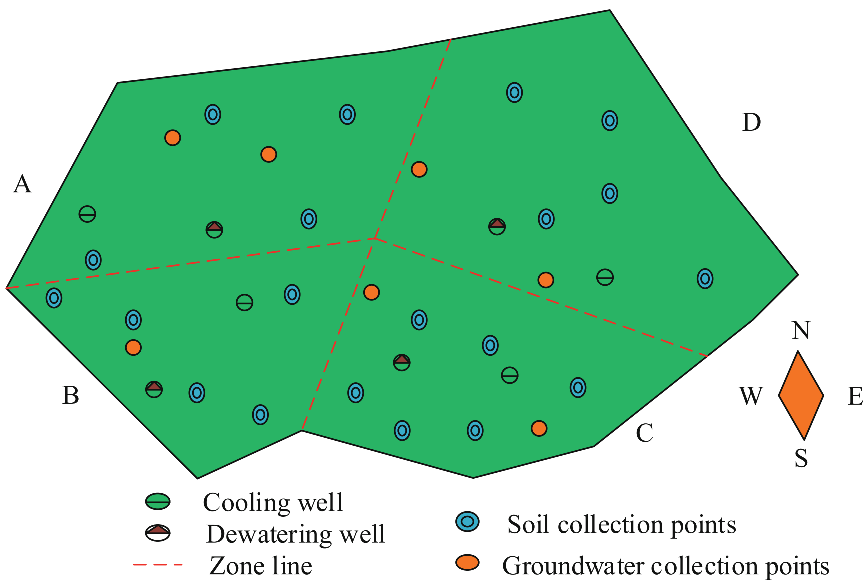

Fig. 5. Partial sampling points.

soil pH value and organic carbon content. The content of heavy metals in the soil can affect the internal charge properties of the soil, thereby affecting the pH, acidity, and alkalinity of the soil. When labeled with a pH value of 7, both high and low pH values are not conducive to soil activity and organic matter content. Organic carbon content is used to describe soil fertility. The higher the organic carbon content, the higher the soil fertility and health. Therefore, the concentration of heavy metals in soil directly affects the soil pH and organic carbon content. Therefore, it mainly analyzes the changes in the region's heavy metal content and pH values. The ratio of soil pH to water pH in this area is 1:2.5, and glass electrodes were used for measurement [35]. The ratio of soil pH to water pH in this area is 2.5:1, and glass electrodes are used for measurement. The soil organic matter was determined using the external heating potassium dichromate volumetric method. The total amount of Cd and Ni in the soil is digested using a mixture of nitric acid and hydrofluoric acid, totaling 350 g [36]. The AM600 automatic program-controlled digestion instrument was used, combined with a mixture of nitric acid and hydrogen peroxide acid, to digest the cadmium and nickel content in wheat grains. Fig. 6 shows the results.

The heavy metal contamination in four regions of a province is investigated. According to the survey results, the main contamination elements in the region are Cd and Ni. The contamination level of the sample collection area is divided into four levels. And the contamination level of heavy metals from the first level to the third level is gradually increasing. Fig. 6a) shows the first-level quality area. The main heavy metals include Cd, Ni, Pb, As, Cr, and Hg, which account for approximately 94% of the total sampling area. They belong to Class I areas, where the soil quality meets national safety quality requirements, and the heavy metal content of crops does not exceed safety standards. Fig. 6b), c), and d) show the secondary, tertiary, and super tertiary quality areas, respectively. The main contamination elements in the secondary quality area are Cd and Ni, which are concentrated in the farmland in the industrial park area. The main contamination elements in the tertiary quality area are Cd and Ni. The overall area of this area is low, accounting for 0-0.64%, mainly distributed in industrial parks and river areas. The total proportion of super tertiary quality areas is very small, mainly Cd, which causes serious damage to farmland and plants, mainly distributed in river areas. Therefore, high-quality wheat planting soil in the region was selected for research, with a total of 24 soil samples, mainly distributed in the industrial areas of farmland, rivers, and near industrial

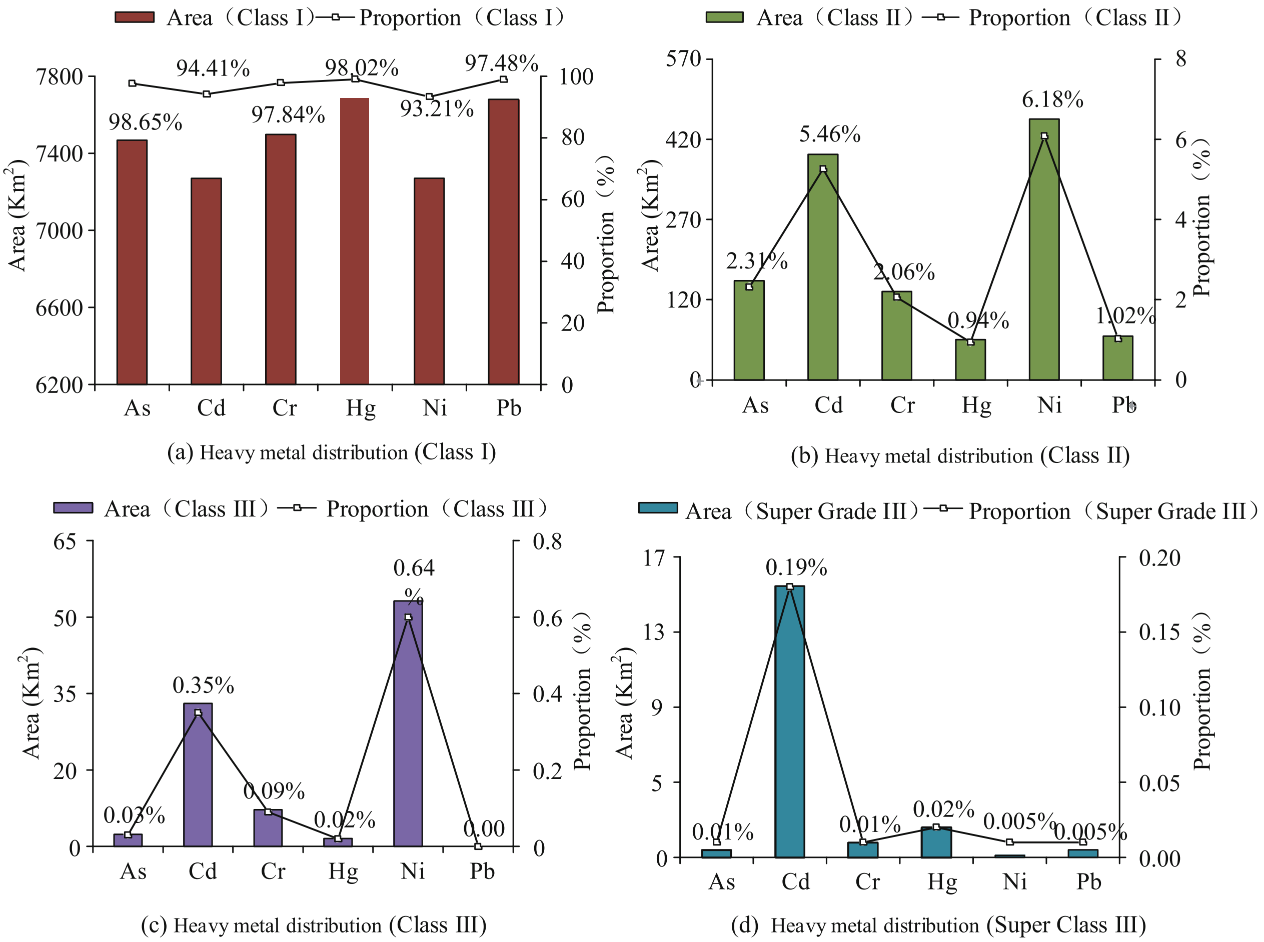

Fig. 6. Distribution results of heavy metals in the sample collection area.

green belts in four regions. The electrochemical analysis technology for analyzing the content of heavy metals in soil mainly refers to detecting heavy metals in soil through electrochemical sensors. The selected samples were subjected to metal content parameter experiments, as shown in Table 5.

Table 5 shows the test results of heavy metals in the sample area. The test samples include soil, grain, and straw. In the four regions studied, except for area D, the pH value of other regions is high. Among the four regions surveyed, the organic matter content in area C is the highest, 21.91 g/kg. The total amount of Ni in the soil was also the highest, with 34.02 mg/kg. The highest total amount of soil Cd was found in area D, with Cd 0.711 mg/kg. The content of metal elements in crops was tested, and a large amount of Cd and Ni was detected in the grain and straw of the four regions. The wheat planted in area D contains a large amount of Cd in the grain and straw, and the straw contains a large amount of Ni. This shows that heavy metal contamination in area D is more serious than in other areas. It needs to further evaluate the farmland environmental quality of the four regions. According to the risk assessment system of heavy metal contamination in farmland, the quality of farmland soil in four regions was evaluated. Fig. 7 shows the results based on the standards in Table 4.

Fig. 7a), b), and c) are the results of the assessment of soil pH, Cd, and Ni in each region. According to the statistical results of the evaluation of farmland soil quality in four regions, the Cd value in farmland soil in areas A, B, and C has remained at a stable level. According to national standards, it has not exceeded the first-level national environmental soil quality standard, and the soil quality meets the environmental quality and safety

Table 5. Average test results of soil and plant samples.

Project/sampling area	Area A	Area B	Area C	Area D
Soil pH	8.84	8.64	8.35	7.91
Soil organic matter (g/kg)	14.56	18.85	21.91	14.25
Total amount of soil Cd (mg/kg)	0.105	0.164	0.182	0.711
Total amount of soil Ni (mg/kg)	29.94	31.15	34.02	31.99
Grain Cd (mg/kg)	0.008	0.019	0.016	0.066
Straw Cd (mg/kg)	0.035	0.056	0.059	0.192
Grain Ni (mg/kg)	0.349	0.442	0.323	0.491
Straw (mg/kg)	6.801	8.216	8.801	1.450

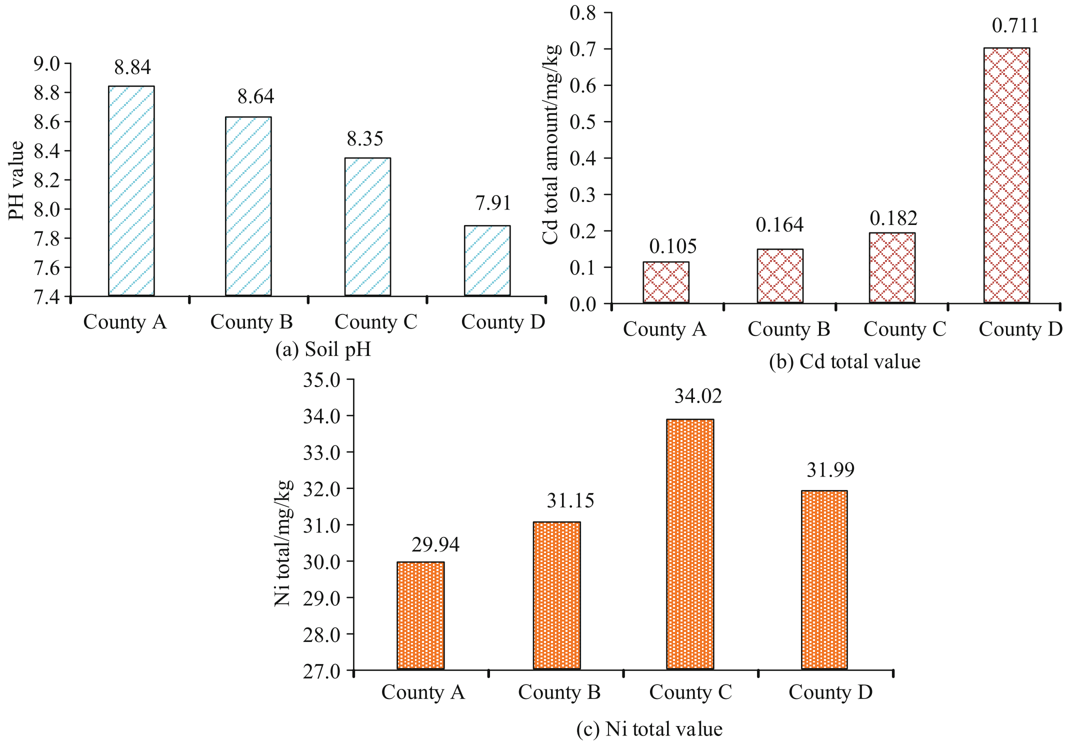

Fig. 7. Evaluation results of soil quality standards.

requirements. However, detailed analysis reveals that the Cd element in the farmland soil in area D exceeds the soil quality and safety standards. Although farmland crops can still grow, the farmland environment and crops have already been polluted. The Ni-contenting farmland in all four regions is within the first level range of soil quality (50 mg/kg), and there is no problem of heavy metal contamination. In order to further evaluate the farmland contamination in the four regions, the three-indicator comprehensive method was used to evaluate the farmland heavy metal contamination. Table 6 shows the results.

In Table 6, compared with single soil quality assessment results, the three-indicator comprehensive assessment refined the quality risk level. The development trends of soil quality, contamination elements, and crop quality are comprehensively considered. Table 7 shows that the soil quality in areas A, B, C, and D is safe. However, in the indicators of the cumulative trend of heavy metal elements, the risk assessment of the four regions is slight. Heavy metal contamination in this area

Table 6. Assessment results of heavy metal contamination, farmland land quality, and element accumulation trend.

Project type	Sampling area	Area A	Area B	Area C	Area D
Soil quality	Soil risk (SNi)	0.501	0.499	0.511	0.540
	Soil safety level	Safe	Safe	Safe	Safe
Element cumulative trend	Average annual growth rate ($g/hm^2/yr$)	103.1	102.1	103.9	104.4
	Heavy metal input (mg/kg/yr)	0.0475	0.0485	0.04244	0.047
	Safety years (yr)	621.1	637.2	569.1	610.1
	Soil safety level	Slight	Slight	Slight	Slight

has been a rising trend in recent years, and it has had a certain impact on the farmland's ecological environment. At the same time, in order to better reflect the soil conditions in the region, plant quality is reflected by crop yield. The wheat yield of the four regions in that year was calculated. The average yield of wheat in the demonstration agricultural area was 8.779 t/hm^2, while the average yield in the surveyed area was 9.249 t/m^2. According to the survey statistics, the wheat grain crop yield in the survey area has not been affected, indicating that the soil in the area basically meets the safety soil standards. Finally, the two quality evaluation methods were compared, as shown in Table 7.

Table 7 shows the comparison results of two kinds of farmland quality assessment. The soil quality standard evaluation is relatively simple compared with the three-index comprehensive evaluation method. This method only considers the soil risk and does not consider the development trend of contamination and the impact on crops. The three-index comprehensive evaluation rule fully considers the soil quality, the regional elements' development trend, and the effect of ecological crops. Compared with references [3] and [31], both adopt standard soil quality assessment methods. In practical applications, only the current impact of heavy metal pollution on the soil is considered, and future development trends are not fully considered. The proposed three-indicator evaluation methods increase the assessment of future risks, making the overall evaluation more accurate and more in line with the requirements of soil governance assessment. In general, the three-indicator comprehensive evaluation method fully takes into account the soil, plants, and external factors in the farmland environment. It can establish a more comprehensive evaluation system, which is of great significance to the restoration of the regional environment, risk early warning, and formulating environmental laws and policies.

Taking this research project as a case study, area D has certain potential risks. Therefore, relevant legal provisions have been established to strictly control pollution sources. After half a year, a comparison of the region's current environmental and ecological status has been conducted, as shown in Table 8.

Table 7. Comparison of two quality assessment methods.

Sampling area	Soil risk assessment of Cd		Soil risk assessment of Ni	
	Evaluation of soil quality standards	Soil-trend evaluation of three indices	Evaluation of soil quality standards	Soil-trend evaluation of three indices
Area A	Level one	Slight	Level one	Slight
Area B	Level one	Slight	Level one	Slight
Area C	Level one	Slight	Level one	Slight
Area D	Level three	Slight (higher potential risk)	Level one	Slight

Table 8. Comparison of environmental interventions in area D.

Index	The 1st month	The 3rd month	The 6th month	The 9th month	The 12th month
pH value	7.95	7.85	7.85	7.84	7.83
Cd (mg/kg)	0.710	0.682	0.565	0.354	0.266
Ni (mg/kg)	31.28	31.13	30.25	29.64	28.68

The results in Table 8 show that after implementing corresponding environmental management measures in area D, the Cd and Ni contents significantly decreased the following year, while the pH value decreased, closer to the safe pH value. At the same time, vegetable food in the area was tested, and the experiment showed that the local people's vegetable cultivation met safety standards.

Discussion

Heavy metal pollution can seriously impact the ecological environment and crop safety. Conducting heavy metal investigations and analyses on farmland contaminated with heavy metals will be beneficial for preventing and controlling heavy metal pollution in the region and ensuring food safety in the area. Therefore, in this context, research should be conducted on areas with heavy metal pollution in farmland. At the same time, effective methods for controlling heavy metal pollution in areas will be provided based on the survey results.

According to the experimental survey results, most farmland in the survey area has not been contaminated by heavy metals. The content of heavy metal elements in farmland near industrial parks is slightly higher than in other areas, mainly due to the emissions from factory pollution sources, with Cd and Ni being the main pollutants. Further research has found that the main element of heavy metal pollution in the study area is Cd, which causes serious damage to farmland and plants, mainly distributed in river areas. In addition, investigations were conducted on soil, grain, and straw samples, and it was found that the wheat grown in Zone D contained a large amount of Cd in its grains and straw and a large amount of Ni in its straw. The overall heavy metal content in soil and straw in other regions is at a safe level. In addition, the trend of element accumulation in farmland contaminated with heavy metals was studied. In the trend of element accumulation, the soil safety level was mild, indicating an upward trend in soil heavy metal pollution in the study area. From this, it can be seen that only Zone D in the study area has high levels of heavy metal pollution, but all regions have a trend of heavy metal pollution development. Therefore, it is necessary to take measures to treat the problem of heavy metal pollution in farmland. The following will be discussed from three aspects:

Firstly, the supervision of regional environmental sanitation must be strengthened. It is necessary to communicate with regional policies and agricultural development to ensure that farmland governance has standards and a basis. Therefore, industrial enterprises with high contamination and emissions must strengthen environmental health supervision, implement relevant environmental health protection regulations, and strictly avoid disorderly discharge from the source. Entities, including chemical enterprises, mining enterprises, raw material processing enterprises, and local governments at all levels, need to strengthen environmental hygiene supervision of high contaminating enterprises, strictly implement the principle of "whoever is responsible for water contamination shall compensate", and bear corresponding legal responsibilities. At the same time, environmental monitoring points should be set up and conducted daily for enterprises located in adjacent agricultural production areas to avoid contamination issues [37].

The second is environmental governance and compensation. For the areas that have been polluted and have a serious impact on the local agricultural ecological environment, the local governments and enterprises need to do a good job in environmental health management and actively do a good job in the relevant compensation content [38]. It includes agricultural loss compensation and environmental and ecological compensation and strictly implements the principle of "whoever pollutes, who compensates" [39]. At the same time, the government and enterprises need to strictly implement environmental health protection regulations, carry out environmental protection education in rural areas, and do a good job in environmental protection publicity to improve the regional environmental quality [40].

Finally, scientific treatment of heavy metal pollution. Considering that heavy metal pollution control is a serious issue, it is necessary to take control measures according to the degree of pollution. The main governance measures include pH physical and chemical control measures and traditional ecological restoration measures. For mildly polluted areas, crops should be planted reasonably according to the degree of soil pollution to restore ecological stability. For heavily polluted areas, pH physical or chemical measures should be taken for remediation, and the environmental quality in the area should be regularly tested. After reaching a certain standard, ecological remediation measures should be taken for restoration. Considering that the accumulation of pollutants largely depends on the type of soil, different remediation techniques need to be adopted for different soil types to treat heavy metal pollution. For example, biological remediation should be used for sandy soil, utilizing plant absorption; clay can be treated with amendments to reduce heavy metal activity; soil rich in organic matter is suitable for stabilization treatment. In addition, the accumulation of pollutants largely depends on the cultivation varieties used. The study area mainly focuses on Cd and Ni exceeding the standard. For cadmium and Cd, plants such as *Solanum nigrum*, *Calendula officinalis*, *Phytophthora infestans*, *Bidens pilosa*, and *Ricinus communis* can be planted, which have strong ability to accumulate and transport cadmium. In areas with excessive Ni, alfalfa and ryegrass can be planted, and intercropping and applying AM fungi can improve the degradation effect of Ni. These plants have a super accumulation ability for Ni.

Conclusions

Under the context of green and sustainable development, the health of the ecological environment and food safety have attracted social attention, and it is necessary to effectively control agricultural heavy metal pollution. In this regard, the study focuses on a province in northern China, where much farmland is affected by heavy metal harmful substances. Therefore, the characteristics of heavy metal pollution in rural areas of the region were studied. Through analysis, it was found that the main polluting elements in the area are Cd and Ni.

In order to further evaluate the quality of farmland in the region, a three-indicator comprehensive evaluation method was proposed, which evaluates the soil quality, element accumulation trend, and plant quality in the region.

Finally, electrochemical sensors and other relevant methods were selected to detect the content of heavy metals in soil, and four typical type localities in Shijiazhuang City, Hebei Province, were selected for example analysis. From the evaluation results, it could be seen that among the four selected regions, only the soil Cd evaluation in Zone D was level 3, while the rest were all level 1. Meanwhile, the soil safety years in the four regions were between 102.1 and 104.4, but the soil in Zone D had a high potential risk. The region needed to strengthen risk management. Simultaneously, targeting the D region, the implementation of corresponding environmental management measures resulted in a significant decrease in Cd and Ni content and pH value in the area the following year, approaching the safe pH value. Through the evaluation of heavy metal pollution in the area and the adoption of corresponding response measures, the heavy metal pollution situation in the area has been significantly improved. However, the study only focuses on heavy metals in the main areas and cannot fully represent the main pollution characteristics of the area. In the future, it is necessary to conduct investigations on a larger regional scale to improve the effectiveness of regional farmland pollution investigations.

Data Access Statement

All data generated or analyzed are included in this article.

Conflict of Interest

Both authors declare that they have no conflict of interest.

Author Contributions:

Yuchen Guo provided the concept and wrote the draft; Jianwei Guo revised the paper critically and supervised this research. Both authors have reviewed this paper and approved this submission.

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