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Original Research

Soil Heavy Metal Pollution and Ecological Risk Health Risk Assessment in Gengzhen Town, China

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Abstract

Excessive heavy metals in soil pose ecological and health risks. In order to prevent pollutants from harming human health, Gengzhen Town, Wutai County, China, was selected as the research area. The health risk assessment model (*BHR*A), potential ecological hazard index (*RI*), and land accumulation index (*Igeo*) were used to evaluate the pollution and risk of heavy metals in the soil of the research area. The assessment shows that there is slight pollution of heavy metals in the soil of Gengzhen Town, with the main influencing elements being Cd, Cr, As, Ni, and Pb; the ecological risk is mild, ranging from 69.56 to 120.49; Cr, As, and Pb pose significant non-carcinogenic health threats to children; the As element poses a carcinogenic risk to both adults and children, while the Cd element poses a carcinogenic risk only to children; The average carcinogenic risk index is between 10^{-6} and 10^{-4}, which meets China's soil health standards. It is necessary to raise awareness and draw attention. The evaluation of health risks related to heavy metals in soil is beneficial for people to reasonably prevent risks and scientifically utilize land, playing a wide-ranging guiding role.

Keywords: health risks, ecological risks, soil, heavy metals, Gengzhen area

Introduction

Heavy metal pollution in farmland is caused by excessive deposition of heavy metals in the soil from waste [1, 2]. The heavy metals that pollute farmland soil mainly include biologically toxic elements such as Cd, Hg, Cr, Pb, and metalloid arsenic, as well as toxic elements like Ni, Zn, and Cu [3]. Heavy metals in farmland soil can be transmitted into the human body through the food chain, and their accumulation to a certain extent can cause various diseases. For example, lead can damage the nervous and hematopoietic systems, while cadmium can cause kidney disease, etc. Studying its health risks can help understand the potential harm of pollution to human health and take effective measures to protect public health [4-6]. Studying heavy metal pollution in farmland soil can provide a basis for protecting the entire ecological environment, providing

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a basis for land use planning, and supporting the formulation of pollution prevention and control policies and standards. At the same time, this study involves multiple disciplines such as soil science, environmental chemistry, and toxicology, which helps promote the cross-integration and development of these disciplines. Wu and Wan [7] studied the innovation and practice of agricultural soil heavy metal pollution remediation technology in cultural and tourism contexts. It is believed that composting and biochar technology can be used to remediate soil contaminated with heavy metals, and the choice of this technology can be determined based on agricultural production, soil conditions, and social development. Liu et al. [8] studied the health risks associated with wheat grown near tailings dams in North China and concluded that long-term consumption of crops contaminated with heavy metals can lead to non-carcinogenic health risks, which are more severe for children. Cd poses a carcinogenic risk to human health. It is necessary to standardize soil remediation and crop cultivation, and scientifically prevent harm to human health. Lai et al. [9] studied the effectiveness of using passivators on cadmium in polluted soil and its impact on absorption by Chinese cabbage. Sun et al. [10] found in their research on heavy metals in soil in Datong, China, that Pb and Cu have extremely high levels of pollution, and heavy metals pose strong ecological risks. Most of the risks are mainly mild to moderate. The research on heavy metal pollution remediation, pollution characteristics, pollution prevention and control, and pollution health risk assessment provides ideas for this study and a reference for ecological and health risk research on heavy metal pollution characteristics. Based on previous research experience, this article uses internationally recognized advanced methods to determine the pollution status of heavy metals in shallow farmland soil, as well as the ecological and health risks associated with farmland soil mainly producing corn, millet, and potatoes, with the aim of protecting both ecological and human health.

Heavy metals are particularly prominent in soil inorganic pollutants, mainly because they cannot be decomposed by soil microorganisms and are easily accumulated. Accumulated heavy metals can be converted into more toxic methyl compounds, and some even accumulate in the human body at harmful concentrations through the food chain, seriously endangering human health [11]. In order to protect and improve the ecological environment, prevent and control soil pollution, safeguard public health, promote sustainable use of soil resources, advance ecological civilization construction, and promote sustainable economic and social development, the soil heavy metal pollution, ecological risks, and health risks in Gengzhen Town were studied [12].

Materials and Methods

General Situation

The Gengzhen Town research area is located in Wutai County, Xinzhou City, Shanxi Province. It is situated in the southeast of Wutai County, adjacent to Pingshan County in Hebei Province to the east, Gaohongkou Township to the south, Ru Village to the west, and Lingjing Township to the north. It is 45 km away from Wutai County and has a total area of 411 km^2. The terrain of Gengzhen Town is high on all sides and low in the middle. The terrain is mountainous. The main mountain range is Mount Wutai. The highest peak in Huangmujian is located north of Huanghualiang Village, at an elevation of 2136 m above sea level. The lowest point of the Qingshui River bed is located on the southeast side of Houchengwei Village, with an altitude of 750 m above sea level. Gengzhen Town is located in a temperate monsoon continental climate zone, with a cool climate and distinct four seasons. The annual average temperature is 8-9ºC, and the annual extreme temperature ranges from -26ºC to 37.8ºC. The annual precipitation ranges from 400 to 500 mm, and due to high temperatures and rapid evaporation, droughts often occur throughout the year. The annual sunshine hours are 2670-945 hours during the year. The cultivated land area on the map of Gengzhen is 22.56 km^2, mainly distributed in the valley areas of Gengzhen Town, Menxianshi Township, and Gaohongkou Town, which are the main areas for sample collection and analysis in this study. The main grain crops in Gengzhen Town are corn, millet, and potatoes; animal husbandry mainly focuses on raising cattle and sheep. To study the ecological and health risks of heavy metals in farmland soil and effectively support sustainable agricultural development, 38 samples of farmland soil from the Gengzhen map were collected and analyzed. Fig. 1 shows the distribution of sampling points. With the continuous economic development in Gengzhen, the mining and breeding industries surrounding the farmland soil in Gengzhen are thriving. Mining, mineral transportation, and animal husbandry pose a threat to soil safety in farmland. At the same time, with the deepening development of agriculture, the use of pesticides and fertilizers has had an impact on the soil safety of farmland in Gengzhen. Therefore, the agricultural production area in Gengzhen was selected for research, with the hope that the research results would have a positive impact on the prevention and control of heavy metal pollution, ecological health, and human health.

Methodology

In the farmland soil area, deploy 5 points in a plum blossom shape, with a distance of no less than 30 ms between each point; take 5 soil samples and mix them thoroughly to create a single sample. The sampling task

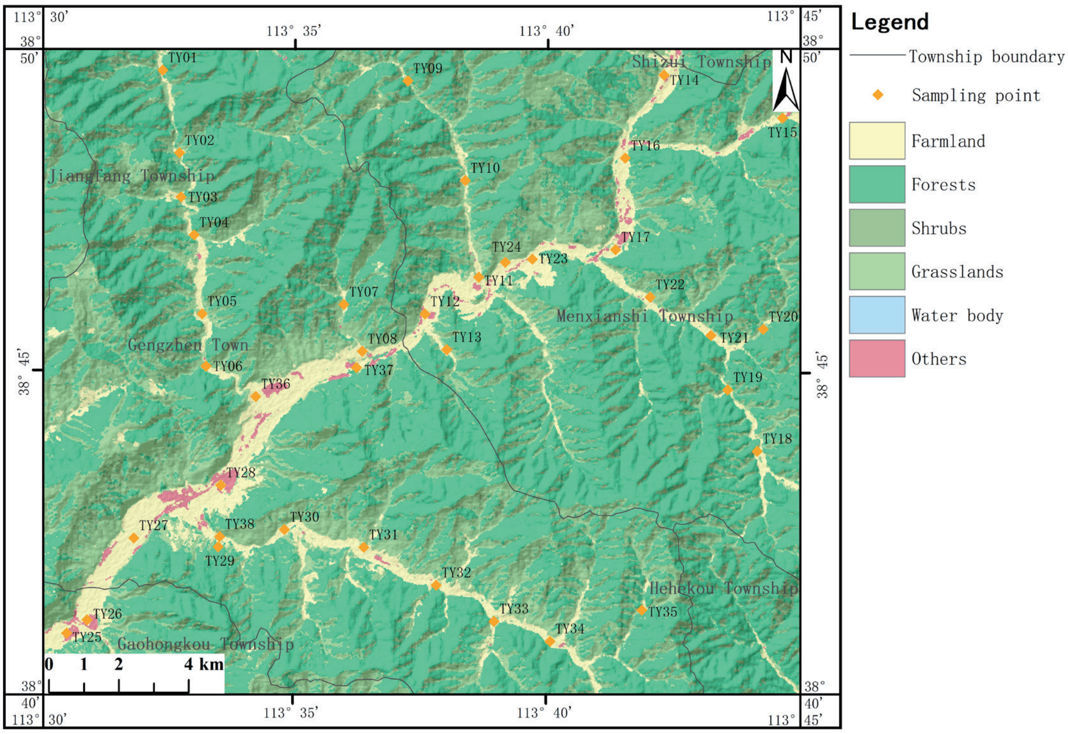

Fig. 1. Distribution map of soil sample collection points.

is divided into three sample collection teams, and all samples are collected and completed within one week. The sample collection area is a planned farmland soil area, and in order to ensure the collected samples are more representative, corresponding sample points are located in areas where different types of crops are planted. After the samples are sent to the laboratory, the testing task will be completed within one week.

The sample testing was carried out by the laboratory of the Harbin Natural Resources Comprehensive Survey Center in accordance with the "Technical Requirements for Sample Analysis of Ecological Geochemistry Evaluation" (DD 2005-03). The analysis indicators, determination methods, and detection limits are shown in Table 1. The sample is ground in an agate jar without contamination, and strict control is exercised during the sample preparation process to prevent contamination by other foreign substances. Accuracy and precision are controlled using national first-class standard substances. Four national first-class standard substances of the same category (GBW07403, GBW07404, GBW07426, GBW07427) are inserted into the sample and analyzed together with the sample. The logarithmic difference (Δ logC) between the measured value and the standard value for each element and each standard substance is calculated separately, which meets the allowable limit of logarithmic difference. The accuracy and precision qualification rate of elemental analysis is both higher

Table 1. The analytical methods, brands, and models of the analytical devices and their detection limits [mg/kg].

Indicator	Analytical method	Brand and model of analytical device	Detection limit
Zn	ICP–MS	ThermoFisher; X2	1
Cu	ICP–MS	ThermoFisher; X2	0.1
Hg	AFS	Jitian; AFS-820	0.0005
Pb	ICP–MS	ThermoFisher; X2	0.2
Cr	ICP–OES	ThermoFisher; iCAP6300	1.5
Ni	ICP–OES	ThermoFisher; iCAP6300	0.2
Cd	ICP–MS	ThermoFisher; X2	0.02
As	AFS	Jitian; AFS-820	0.2

Note: AFS is cold vapor-atomic fluorescence spectrometry, ICP–MS is inductively coupled plasma mass spectrometry, and ICP–OES is inductively coupled plasma optical emission spectroscopy.

than 97.9%; the element reporting rate is higher than 99.8%.

Regarding the pollution level of heavy metals in soil, the globally recognized German scientist Müller proposed the Land Accumulation Index method (*Igeo*) [13]; the ecological risk assessment of heavy metals in soil is carried out using the Potential Ecological Risk Index (RI) method proposed by the renowned scientist Hakanson (Sweden) [14], the health risk assessment of heavy metals in soil is carried out using the health risk assessment model proposed by USEPA, which includes two parts: exposure calculation and risk characterization

Table 2. Formula list for building evaluation models.

Number	Model formula	Remarks
1	$I_{geo} = log_2\left[\frac{C_i}{kC_n^i}\right]$	Geoaccumulation index
2	$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n}(T_r^i \times C_f^i) = \sum_{i=1}^{n}(T_r^i \times \frac{C_i}{C_n^i})$	Overall Potential Ecological Risk Index
3	$ADD_{i\text{ing}} = \frac{C_i \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6}$	Adult exposure through the oral ingestion route
4	$ADD_{i\text{inh}} = \frac{Ci \times InhR \times EF \times ED}{PEF \times BW \times AT}$	Adult exposure through the respiratory ingestion route
5	$ADD_{iderm} = \frac{C_i \times SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6}$	Adult exposure through the dermal contact ingestion route
6	$LADD_{i\text{ing}} = \frac{C_i \times EF}{AT}\left(\frac{IngR_{child} \times ED_{child}}{BW_{child}} + \frac{IngR_{adult} \times ED_{adult}}{BW_{adult}}\right) \times 10^{-6}$	Children's exposure through the oral ingestion route
7	$LADD_{i\text{inh}} = \frac{C_i \times EF}{PEF \times AT} \times \left(\frac{InhR_{child} \times ED_{child}}{BW_{child}} + \frac{InhR_{adult} \times ED_{adult}}{BW_{adult}}\right)$	Children's exposure through the respiratory ingestion route
8	$LADD_{i\text{derm}} = \frac{Ci \times EF \times SL \times ABS}{AT} \times \left(\frac{SA_{child} \times ED_{child}}{BW_{child}} + \frac{SA_{adult} \times ED_{adult}}{BW_{adult}}\right) \times 10^{-6}$	Children's exposure through the dermal contact and ingestion route
9	$HQ = \sum HQ_i = \sum \frac{ADD_{i\text{ing}} + ADD_{i\text{inh}} + ADD_{i\text{derm}}}{RfD_i}$	Non-carcinogenic risk index *HQ*
10	$CR = \sum CR_i = \sum\left(ADD_{i\text{ing}} + ADD_{i\text{inh}} + ADD_{i\text{derm}}\right) \times SF$	Cancer Risk Index *CR*

Table 3. List of meanings of symbols in building model formulas.

Symbol	The Meaning of Symbols	Symbol	The Meaning of Symbols
I_{geo}	Geoaccumulation index	E_r^i	Potential ecological risk index of heavy metal i
C_i	Concentration of heavy metal i	C_f^i	Pollution index of heavy metal i
C_n^i	Background values of heavy metal substances	T_r^i	Toxicity coefficient of heavy metal i
k	Background matrix correction factor	RI	Overall potential ecological risk index
ADD_{iderm}	Adults ingest through the skin	$LADD_{iinh}$	Children ingest through respiration
ADD_{iinh}	Adults ingest through respiration	$LADD_{iing}$	Children consume orally
ADD_{iing}	Adults consume orally	$LADD_{iderm}$	Children ingest through the skin
HQ	Non-carcinogenic health risk index for all heavy metals	CR	Health risk index for carcinogenesis of all heavy metals
HQ_i	Non-carcinogenic health risk index of heavy metal i	CR_i	Carcinogenic health risk index of heavy metal i
RfD_i	Daily average intake of non-carcinogenic heavy metals	SF	Carcinogenic slope factor

Note: The T_r^i values for Zn, Cr, Cu, Ni, Pb, As, Cd, and Hg are 1, 2, 5, 5, 5, 10, 30, and 40, respectively [21-23]; k = 1.5 [24].

Table 4. The meaning and parameters of symbols in various formulas for the exposure assessment formula.

Symbol	Parameter	Unit	Adult reference value	Child reference value
EF	Exposure frequency	$d \cdot a^{-1}$	350	350
BW	Average weight	kg	56.8	15.9
ED	Exposure years	a	25	6
AT	Average exposure time	d	Carcinogenic26280, noncarcinogenic9125	Carcinogenic26280, noncarcinogenic2190
InhR	Daily air respiration	$m^3 \cdot d^{-1}$	14.5	7.5
IngR	Daily soil intake	$mg \cdot d^{-1}$	100	200
SL	Skin adhesion coefficient	$mg\ (cm^2 \cdot d)^{-1}$	0.2	0.2
SA	Exposed skin surface area	cm^2	2415	1295
ABS	Skin absorption factor		0.001	0.001
PEF	Surface dust emission factor	$m^3 \cdot kg^{-1}$	1.36×10^9	1.36×10^9

Table 5. Classification of ecological risk assessment levels.

Ecological hazards	Slight	Medium	Strong	Very strong	Extremely strong
E_r^i	<40	40-80	80-160	160-320	≥320
RI	<150	150-300	300-600	600-1200	≥1200

Table 6. RfD and SF for oral, dermal, and respiratory exposure pathways.

Potentially harmful elements	Reference measurement RfD ($mg \cdot kg^{-1} \cdot d^{-1}$)			Carcinogen SF ($kg \cdot d \cdot mg^{-1}$)		
	Through the mouth	Skin	Breathing	Through the mouth	Skin	Breathing
Zn	3.0×10^{-1}	3.0×10^{-1}	—	—	—	—
Cu	4.0×10^{-2}	4.0×10^{-2}	—	—	—	—
Hg	3.0×10^{-4}	2.1×10^{-5}	3.0×10^{-4}	—	—	—
Pb	3.5×10^{-3}	5.3×10^{-4}	3.5×10^{-3}	—	—	—
Cr	3.0×10^{-3}	7.5×10^{-5}	2.55×10^{-5}	—	—	42
Ni	2.0×10^{-2}	8.0×10^{-4}	2.3×10^{-5}	—	—	0.84
Cd	1.0×10^{-3}	2.5×10^{-5}	1.0×10^{-5}	6.1	6.1	6.3
As	3.0×10^{-4}	3.0×10^{-4}	1.5×10^{-5}	1.5	1.5	4.3×10^{-3}

Table 7. Classification of pollution levels.

Index of geoaccumulation I_{geo}	Level	Pollution degree
$5 \le I_{geo}$	6	Extremely heavy pollution
$4 \le I_{geo} < 5$	5	Heavy to extremely heavy pollution
$3 \le I_{geo} < 4$	4	Heavy pollution
$2 \le I_{geo} < 3$	3	Medium to heavy pollution
$1 \le I_{geo} < 2$	2	Medium pollution
$0 \le I_{geo} < 1$	1	Light pollution
$I_{geo} < 0$	0	Pollution-free

[15]. The calculation formulas for constructing pollution, ecological risk, and health risk assessment models are shown in Table 2 [16]. The actual meanings of each symbol in the calculation formulas are shown in Table 3 [17]. The meanings of each symbol in the health risk assessment model formulas are shown in Table 4 [18, 19]. The hazard level classification is shown in Table 5. The RfD and SF values for mouth, skin, and respiration are shown in Table 6 [20]. The pollution classification is shown in Table 7.

Statistics

SPSS19 software was used to statistically analyze the maximum, minimum, mean, standard deviation, and coefficient of variation of 8 heavy metals in the soil of the study area. Origin software was used to perform a Pearson correlation analysis on the concentrations of heavy metals.

Results and Discussion

Distribution Characteristics of Heavy Metals in Soil

The distribution characteristics of heavy metals in soil show that the content of multiple heavy metals is higher than the background value of soil (Table 8), indicating that these heavy metals have accumulated significantly under the influence of human activities. The order of the average content is Zn>Cr>Ni>Cu>Pb>As>Cd>Hg. From the perspective of the coefficient of variation, Hg>As>Cr>Ni>Zn>Cu>Pb>Cd, the values of Hg, As, Cr, Ni, Zn, Cu, Pb, and Cd are 0.64, 0.35, 0.30, 0.2, 0.16, 0.15, 0.14, and 0.13, respectively. The coefficient of variation of Hg, As, and Cr is greater than 0.3, indicating uneven distribution in the soil, while the coefficient of variation of other elements is relatively small and evenly distributed in the soil.

Table 8. Test data and distribution patterns of heavy metals in the soil of Geng Town.

Serial Number	Zn mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Cr mg/kg	Ni mg/kg	Cd mg/kg	As mg/kg
1	93	19.3	0.06	17.9	75.7	33.5	0.2	14.7
2	100	24.9	0.21	18.6	71.6	35.2	0.24	13.2
3	75.8	21.1	0.037	17.1	75.9	37.3	0.23	7.62
4	89	20.1	0.064	18	70.1	32.7	0.22	11.7
5	87.1	21	0.047	17.7	80.1	37	0.2	10.4
6	81.9	21.7	0.022	16.3	119	49.7	0.19	4.98
7	84.2	20.2	0.079	17.1	96.1	42.1	0.23	8.95
8	98.4	23.7	0.11	17.2	103	51.1	0.2	8.77
9	91.4	23.6	0.03	15.9	99.9	45	0.2	4.85
10	98.6	16.6	0.067	16.6	69.7	37.9	0.21	6.91
11	90.5	24.7	0.031	17.7	65.3	33.8	0.27	8.3
12	68	17.7	0.046	17.5	60.7	31.9	0.2	22.2
13	91.6	27.5	0.096	18.9	66.9	33.4	0.25	17.2
14	80.8	24.5	0.044	17.9	73.6	36.1	0.2	10.2
15	75.7	25.9	0.043	17.8	52.9	29	0.26	9.56
16	70.9	22.7	0.031	17.7	60.7	31.6	0.22	14.4
17	62.1	23.9	0.029	16.9	58.5	28.8	0.21	7.72
18	66.6	22.1	0.1	17.2	59.4	29.7	0.2	10.4
19	58.9	19.8	0.038	17	52.4	25.6	0.18	12.1
20	52.3	19.4	0.034	16.8	51.5	25.3	0.17	14.6
21	70.7	24	0.062	18.2	53.5	26.5	0.23	13
22	72.4	19.8	0.067	18.5	51.3	26.7	0.23	11.7
23	67.5	24.8	0.032	17.9	57.9	29.5	0.22	8.06

24	94.5	26.3	0.029	17.8	40	26.1	0.24	7.91
25	72	24.2	0.093	17.9	46.8	26.4	0.24	11.1
26	70.2	23.9	0.034	17.7	50.1	26.5	0.22	11.2
27	75	14.6	0.029	15.9	56.9	29.3	0.19	5.46
28	74.3	25.8	0.058	17.5	61.8	33.5	0.26	8.36
29	54.5	17.8	0.045	16.4	46.5	27.6	0.19	6.52
30	77.9	25.3	0.044	18.2	45.7	28.1	0.33	10.5
31	79.1	27.5	0.13	19.4	52.4	27.6	0.23	10.6
32	96	16.5	0.041	18.2	42.5	23.9	0.23	8.02
33	74.3	21.3	0.026	18.2	47.4	29.7	0.21	6.94
34	81.7	17.8	0.1	18.2	45.9	26.6	0.22	9.26
35	80.7	18.9	0.039	17.8	43.5	29.4	0.19	7.29
36	80.5	24.1	0.061	32.6	47.2	29.2	0.19	5.74
37	68.2	24	0.058	18.2	47.3	25.2	0.24	11.3
38	62.4	22.3	0.02	17.8	47.3	29.8	0.23	11.3
Maximum value	52.3	14.6	0.02	15.9	40	23.9	0.17	4.85
Minimum value	100	27.5	0.21	32.6	119	51.1	0.33	22.2
Average value	78.12	22.09	0.06	18.01	61.76	31.8	0.22	10.08
Standard deviation	12.46	3.25	0.04	2.55	18.35	6.52	0.03	3.53
Coefficient of variation	0.16	0.15	0.64	0.14	0.3	0.2	0.13	0.35
Soil background value	75.5	26.9	0.27	15.8	61.8	32	0.13	9.8

Note: The background values of heavy metals in soil are obtained from actual investigations and statistics [23], and the coefficient of variation is dimensionless.

The Correlation between Heavy Metal Elements in Soil

Correlation analysis was conducted on 8 types of soil heavy metals to measure the degree of correlation between two variable factors. It is not simply personalized or causal, but rather to determine whether each element has the same material source by measuring the degree of correlation between variables. Use Origin2024 software to conduct correlation analysis on 8 heavy metals in the soil of the study area and generate the relevant graph as shown in Fig. 2.

From Fig. 2, it can be seen that there is a significant positive correlation between heavy metals Cr and Ni in the soil of Gengzhen, with a correlation coefficient of 0.95, indicating a close relationship between Cr and Ni. Cr undergoes corresponding changes with the increase and decrease of Ni. The line chart trends of Cr and Ni are consistent. There is a positive correlation between Cd and Cu, with a correlation coefficient of 0.52, indicating a strong relationship between Cd and Cu. Cd undergoes corresponding changes with the increase and decrease of Cu. The line chart trends of Cd and Cu are generally consistent; the correlation coefficients between Zn and Ni are 0.5, and between Zn and Cr are 0.42, indicating a positive correlation between Zn, Ni, and Cr. Both Ni and Cr increase and decrease with the increase of Zn, indicating a close-cut relationship between Zn, Cr, and Ni. Zn undergoes corresponding changes with the increase and decrease of Cr and Ni content, while Cd undergoes corresponding changes with the increase and decrease of Cu content. From the above results, it can be seen that Zn has the same material source as Ni and Cr, and Cd and Cu have the same material source.

Analysis of Soil Heavy Metal Pollution Status in Gengzhen Town

Based on the soil background values in Shanxi Province, a ground accumulation index evaluation was conducted on the pollution level of heavy metals and risk elements in the soil of Gengzhen Town (Table 9). The average pollution index of various heavy metals and risk elements follows the following pattern: Cd>Cr>As>Ni>Pb>Zn = Cu = Hg. Soil Cd pollution is the most severe, accounting for 81.58%. Next is Cr, accounting for 10.53%; As, accounting for 7.89%;

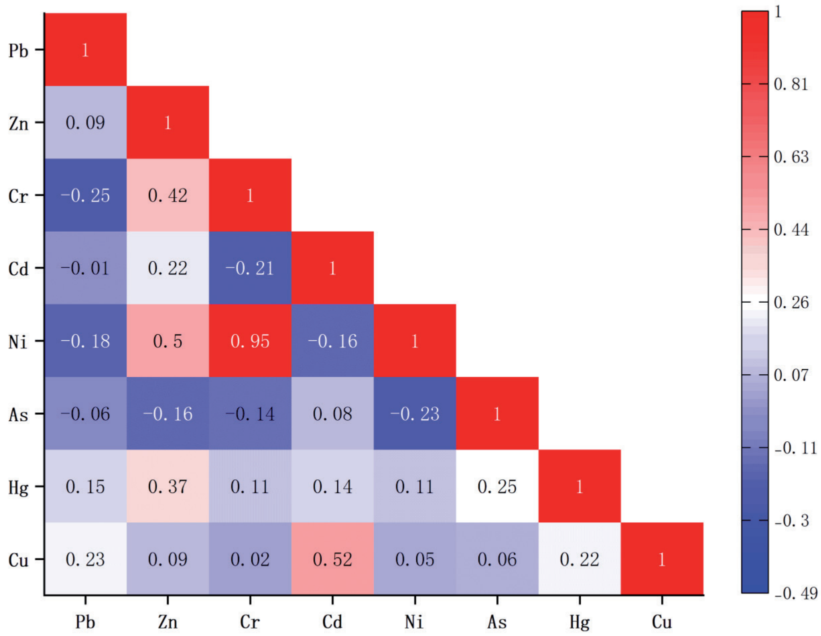

Fig. 2. Correlation map of heavy metals in surface soil of Gengzhen Town.

Ni, accounting for 10.53%; and Pb, accounting for 2.63%. From the mean, the ground accumulation indices of Cr, Pb, Zn, Ni, Cd, As, Cu, and Hg are all less than 0, indicating that they are generally pollution-free. From the maximum value, Cr, Cd, As, Pb, and Ni have light pollution points, and it is necessary to evaluate whether these elements pose ecological and health risks to human health.

The slight pollution points of Pb are located in Menxianshi Township, Cr in Gaohongkou Township and Gengzhen Town, Ni in Gaohongkou Township, Cd in Gengzhen Town, Jiangfang Township, Gaohongkou Township, Hehekou Township, Menxianshi Township, and Shizui Township, and As mainly appears in Gengzhen Town.

Potential Ecological Risks of Heavy Metals in the Soil of Gengzhen Town

The ecological risk assessment results of heavy metals in the soil of Gengzhen Town are shown in Table 10. The maximum value of the heavy metal Cd risk index is 77.34. One sample belongs to a slight ecological risk, and 37 samples belong to a moderate ecological risk; the maximum ecological risk index range for Hg, As, and Pb is less than 40, indicating a relatively low ecological risk; the maximum ecological risk index of Ni, Cu, Cr, and Zn is less than 10, indicating that the ecological risk is very low. Except for the Cd risk index greater than 40, which belongs to moderate ecological risk, the ecological risk indices of Hg, As, Pb, Ni, Cu, Cr, and Zn are all less than 40, which belong to mild ecological risk.

Table 9. Classification of soil heavy metal pollution types in Gengzhen Town.

Heavy metal	Index mean	Number of contaminated samples at all levels	
		Pollution-free	Light
Zn	-0.55	38	
Cu	-0.89	38	
Hg	-3.03	38	
Pb	-0.41	37	1
Cr	-0.64	34	4
Ni	-0.62	36	2
Cd	0.19	7	31
As	-0.62	35	3

Note: Due to heavy metal pollution not reaching the limits of moderate pollution, moderate to severe pollution, severe pollution, severe to extremely severe pollution, and extremely severe pollution, the corresponding sections have been omitted from the table.

Table 10. Classification table of potential ecological hazards in Gengzhen Town.

Hazard index		Distribution range	Sample quantity allocation situation	
			Slight	Medium
Ei	Zn	0.69~1.32	38	0
	Cu	2.71~5.11	38	0
	Hg	2.96~31.11	38	0
	Pb	5.03~10.32	38	0
	Cr	1.29~3.85	38	0
	Ni	3.73~7.98	38	0
	Cd	39.84~77.34	1	37
	As	4.95~22.65	38	0
RI		69.56~120.49	38	0

Note: Due to the potential ecological risks associated with heavy metals not reaching the limits of intensity risk, very strong risk, and extremely strong risk, the corresponding parts have been omitted from the table.

From Table 11, it can be seen that the maximum value of the total potential ecological index (RI) is less than 150, indicating that the ecological risk in Geng Town is very low.

Health Risk Assessment of Heavy Metals in the Soil of Gengzhen Town

Assessment of Heavy Metal Exposure in Gengzhen Town

The non-carcinogenic daily exposure risks of heavy metals in soil in Gengzhen Town are shown in Table 11. In the non-carcinogenic average daily exposure, the values for oral intake, skin contact, and respiratory inhalation in children are 2.68E-03, 3.47E-06, and 7.39E-08, respectively, with a total intake of 2.68E-03. The values for oral intake, skin contact, and respiratory inhalation in adults are 3.75E-04, 1.81E-06, and 4.00E-08, respectively, with a total intake of 3.77E-04. The common point among the three intake methods for adults and children is $ADD_{ing}>ADD_{derm}>ADD_{inh}$. The risk of oral intake is much higher than that of dermal intake and much higher than that of respiratory intake. Another commonality in the intake patterns of adults and children is that Zn>Cr>Ni>Cu>Pb>As>Cd>Hg, and the order of the effects of various heavy metals on adults and children is the same. One difference in the risk of ingestion between adults and children is that the risk of various heavy metals to children is much higher.

The carcinogenic daily exposure levels of heavy metals in the soil of Gengzhen Town are shown in Table 12. One common feature of carcinogenic intake in adults and children is that the order of the effects of various heavy metals is the same: Cr>Ni>As>Cd. The second commonality between carcinogenic intake in adults and children is that the order of influence of different intake methods is the same: $ADD_{ing}>ADD_{derm}>ADD_{inh.}$ Oral intake is the main route of carcinogenic exposure; the difference in carcinogenic intake exposure between adults and children is that various heavy metals have a greater impact on children's exposure than on adults.

Health Risk Assessment of Heavy Metals in the Soil of Gengzhen Town

According to the calculation, the non-carcinogenic health risk index of 8 heavy metals and risk elements in Gengzhen Town is shown in Table 13.

According to the calculation, the carcinogenic health risk assessment index of four heavy metals and risk elements in Gengzhen Town is shown in Table 14.

A common characteristic of non-carcinogenic health risks for adults and children is $HQ_{ing}>HQ_{derm}>HQ_{inh}$. The three intake methods have the same order of influence, with oral intake being the main factor affecting non-carcinogenic health risks. One difference in the non-carcinogenic health risks between adults and children is that the order of impact of various heavy metals differs between the two groups. Adults have As>Cr>Pb>Ni>Cu>Cd>Zn>Hg, while children have As>Cr>Pb>Ni>Cu>Zn>Cd>Hg. The order of the impact of Zn and Cd on adults and children has changed, which is the latest finding of this assessment, indicating that the differences in various evaluation indicators between adults and children can affect the degree of non-carcinogenic impact of heavy metals; the proportion of the impact of 8 heavy metals on adults and children is shown in Fig. 3. The average risk index of heavy metals on adults and children is less than 1, with values of 0.113 and 0.766, respectively, indicating that there is no overall health risk of heavy metals on adults and children. In particular, the maximum value of the health index for adults is also less than 1, with a maximum value of 0.232, indicating that heavy metals do not pose a health risk to adults. Still, for children, the maximum value of the health risk index is 1.57, which

Table 11. Non-carcinogenic daily exposure dose table in Gengzhen Town [mg/(kg/d)].

Heavy metal		Adult				Children			
		ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD	ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD
Zn	max	1.69E-04	1.80E-08	8.15E-07	1.70E-04	1.21E-03	3.33E-08	1.56E-06	1.21E-03
	avg	1.32E-04	1.41E-08	6.37E-07	1.33E-04	9.42E-04	2.60E-08	1.22E-06	9.44E-04
Cu	max	4.64E-05	4.95E-09	2.24E-07	4.67E-05	3.32E-04	9.15E-09	4.30E-07	3.32E-04
	avg	3.73E-05	3.98E-09	1.80E-07	3.75E-05	2.66E-04	7.35E-09	3.45E-07	2.67E-04
Hg	max	3.55E-07	3.78E-11	1.71E-09	3.56E-07	2.53E-06	6.98E-11	3.28E-09	2.54E-06
	avg	9.71E-08	1.04E-11	4.69E-10	9.76E-08	6.94E-07	1.91E-11	8.99E-10	6.95E-07
Pb	max	5.50E-05	5.87E-09	2.66E-07	5.53E-05	3.93E-04	1.08E-08	5.09E-07	3.94E-04
	avg	3.04E-05	3.24E-09	1.47E-07	3.05E-05	2.17E-04	5.99E-09	2.81E-07	2.17E-04
Cr	max	2.01E-04	2.14E-08	9.70E-07	2.02E-04	1.44E-03	3.96E-08	1.86E-06	1.44E-03
	avg	1.04E-04	1.11E-08	5.04E-07	1.05E-04	7.45E-04	2.05E-08	9.65E-07	7.46E-04
Ni	max	8.63E-05	9.20E-09	4.17E-07	8.67E-05	6.16E-04	1.70E-08	7.98E-07	6.17E-04
	avg	5.37E-05	5.72E-09	2.59E-07	5.39E-05	3.84E-04	1.06E-08	4.97E-07	3.84E-04
Cd	max	5.57E-07	5.94E-11	2.69E-09	5.60E-07	3.98E-06	1.10E-10	5.15E-09	3.99E-06
	avg	3.72E-07	3.96E-11	1.80E-09	3.74E-07	2.66E-06	7.33E-11	3.44E-09	2.66E-06
As	max	3.75E-05	4.00E-09	1.81E-07	3.77E-05	2.68E-04	7.38E-09	3.47E-07	2.68E-04
	avg	1.70E-05	1.81E-09	8.22E-08	1.71E-05	1.22E-04	3.35E-09	1.57E-07	1.22E-04
ADD	max	5.96E-04	6.35E-08	2.88E-06	5.99E-04	4.26E-03	1.17E-07	5.51E-06	4.26E-03
	avg	3.75E-04	4.00E-08	1.81E-06	3.77E-04	2.68E-03	7.39E-08	3.47E-06	2.68E-03

Note: max -maximum, avg -average value.

Table 12. Carcinogenic daily exposure dose table in Gengzhen Town [mg/(kg/d)].

Heavy metal		Adult				Children			
		ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD	ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD
Cr	max	6.98E-05	7.44E-09	3.37E-07	7.01E-05	1.89E-04	1.07E-08	4.92E-07	1.90E-04
	avg	3.62E-05	3.86E-09	1.75E-07	3.64E-05	9.83E-05	5.57E-09	2.55E-07	9.85E-05
Ni	max	3.00E-05	3.19E-09	1.45E-07	3.01E-05	8.13E-05	4.61E-09	2.11E-07	8.15E-05
	avg	1.86E-05	1.99E-09	9.00E-08	1.87E-05	5.06E-05	2.87E-09	1.31E-07	5.07E-05
Cd	max	1.93E-07	2.06E-11	9.34E-10	1.94E-07	5.25E-07	2.98E-11	1.36E-09	5.27E-07
	avg	1.29E-07	1.38E-11	6.24E-10	1.30E-07	3.51E-07	1.99E-11	9.10E-10	3.51E-07
As	max	1.30E-05	1.39E-09	6.29E-08	1.31E-05	3.53E-05	2.00E-09	9.18E-08	3.54E-05
	avg	5.91E-06	6.30E-10	2.85E-08	5.94E-06	1.60E-05	9.09E-10	4.17E-08	1.61E-05
ADD	max	1.13E-04	1.20E-08	5.45E-07	1.13E-04	3.07E-04	1.74E-08	7.96E-07	3.07E-04
	avg	6.09E-05	6.49E-09	2.94E-07	6.12E-05	1.65E-04	9.37E-09	4.29E-07	1.66E-04

is higher than 1, indicating that heavy metals pose a health risk to children. A number exceeding 1 is relatively low, indicating that the risk is small. Considering the impact of different heavy metals, As, Cr, and Pb are the main factors causing health risks to adults and children.

From the results of the cancer risk assessment, there are two commonalities: firstly, the order of risk impact of different pathways is the same: $CR_{ing}>CR_{derm}>CR_{inh}$. The second is that the degree of influence of different heavy metals exists as As>Cd>Cr>Ni. As is the factor with the greatest impact on cancer risk. The proportion

Table 13. Gengzhen Town non-carcinogenic health risk index.

Heavy metal		Adult				Children			
		HQ	HQ_{ing}	HQ_{inh}	HQ_{derm}	HQ	HQ_{ing}	HQ_{inh}	HQ_{derm}
Zn	max	5.65E-04	5.63E-04		2.72E-06	4.03E-03	4.02E-03		5.21E-06
	avg	4.42E-04	4.40E-04		2.12E-06	3.15E-03	3.14E-03		4.07E-06
Cu	max	1.17E-03	1.16E-03		5.61E-06	8.30E-03	8.29E-03		1.07E-05
	avg	9.37E-04	9.32E-04		4.50E-06	6.67E-03	6.66E-03		8.62E-06
Hg	max	1.26E-03	1.18E-03	1.26E-07	8.15E-05	8.60E-03	8.44E-03	2.33E-07	1.56E-04
	avg	3.46E-04	3.24E-04	3.45E-08	2.23E-05	2.36E-03	2.31E-03	6.38E-08	4.28E-05
Pb	max	1.62E-02	1.57E-02	1.68E-06	5.02E-04	1.13E-01	1.12E-01	3.10E-06	9.61E-04
	avg	8.96E-03	8.68E-03	9.26E-07	2.77E-04	6.26E-02	6.20E-02	1.71E-06	5.31E-04
Cr	max	8.07E-02	6.70E-02	8.40E-04	1.29E-02	5.05E-01	4.78E-01	1.55E-03	2.48E-02
	avg	4.19E-02	3.48E-02	4.36E-04	6.71E-03	2.62E-01	2.48E-01	8.06E-04	1.29E-02
Ni	max	5.23E-03	4.31E-03	4.00E-04	5.21E-04	3.26E-02	3.08E-02	7.39E-04	9.98E-04
	avg	3.26E-03	2.68E-03	2.49E-04	3.24E-04	2.03E-02	1.92E-02	4.60E-04	6.21E-04
Cd	max	6.71E-04	5.57E-04	5.94E-06	1.08E-04	4.20E-03	3.98E-03	1.10E-05	2.06E-04
	avg	4.48E-04	3.72E-04	3.96E-06	7.18E-05	2.80E-03	2.66E-03	7.33E-06	1.38E-04
As	max	1.26E-01	1.25E-01	2.66E-04	6.03E-04	8.94E-01	8.93E-01	4.92E-04	1.16E-03
	avg	5.71E-02	5.67E-02	1.21E-04	2.74E-04	4.06E-01	4.05E-01	2.23E-04	5.25E-04
HQ	max	2.32E-01	2.15E-01	1.51E-03	1.48E-02	1.57E+00	1.54E+00	2.80E-03	2.83E-02
	avg	1.13E-01	1.05E-01	8.11E-04	7.69E-03	7.66E-01	7.50E-01	1.50E-03	1.47E-02

Table 14. Gengzhen Town carcinogenic health risk index.

Heavy metal		Adult				Children			
		CR	CR_{ing}	CR_{inh}	CR_{derm}	CR	CR_{ing}	CR_{inh}	CR_{derm}
Cr	max	3.12E-07		3.12E-07		4.51E-07		4.51E-07	
	avg	1.62E-07		1.62E-07		2.34E-07		2.34E-07	
Ni	max	2.68E-09		2.68E-09		3.87E-09		3.87E-09	
	avg	1.67E-09		1.67E-09		2.41E-09		2.41E-09	
Cd	max	1.19E-06	1.18E-06	1.30E-10	5.70E-09	3.21E-06	3.20E-06	1.88E-10	8.32E-09
	avg	7.91E-07	7.88E-07	8.67E-11	3.80E-09	2.14E-06	2.14E-06	1.25E-10	5.55E-09
As	max	1.96E-05	1.95E-05	5.97E-12	9.43E-08	5.31E-05	5.30E-05	8.61E-12	1.38E-07
	avg	8.91E-06	8.86E-06	2.71E-12	4.28E-08	2.41E-05	2.41E-05	3.91E-12	6.25E-08
CR	max	2.11E-05	2.07E-05	3.15E-07	1.00E-07	5.68E-05	5.62E-05	4.55E-07	1.46E-07
	avg	9.86E-06	9.65E-06	1.64E-07	4.66E-08	2.65E-05	2.62E-05	2.37E-07	6.80E-08

of each heavy metal's impact on adults and children is shown in Fig. 4. The difference in the impact of various heavy metals on adults and children is that the impact on children is greater than that on adults. The average health risk impact index for adults and children is 9.86×10^{-6} and 2.65×10^{-5}, respectively, with maximum values of 2.11×10^{-5} and 5.68×10^{-5}, respectively. These values are all less than 10^{-4}, indicating that heavy metals in Gengzhen Town do not pose a health risk to humans. However, both the average and maximum values are greater than 10^{-6}, indicating that the health risk of heavy metals exceeds the warning line and requires high attention to strengthen the prevention of heavy metal pollution.

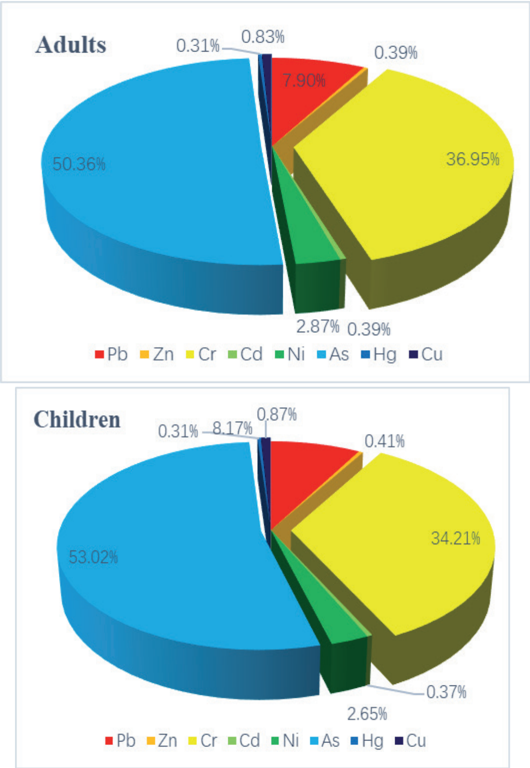

Fig. 3. Adults' and children's HQ contribution rate of 8 heavy metals in the soil.

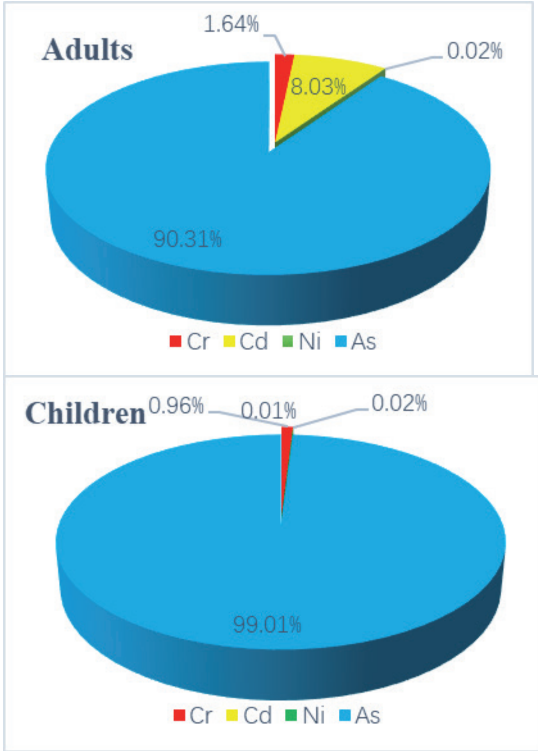

Fig. 4. Adults' and children's CR contribution rate of 4 heavy metals in the soil.

Discussion

The study found that the level of heavy metal pollution in the soil of the research area is very low, and there are light pollution points for Cd, Cr, As, Ni, and Pb; Ling et al. (2024) found that the level of soil heavy metal pollution in Wutai County was very low, with light pollution points for Cd, Cr, As, Ni, and Pb [25]; Sun et al. (2022) also found pollution from Cd, Cr, As, Ni, and Pb in the study of heavy metals and risk elements in farmland soil in Shanxi Province [26]. From this perspective, heavy metal pollution is not only present in Gengzhen Town but also in other parts of Shanxi Province.

The study found that the distribution range of the ecological risk index (RI) for Cd in the research area is 69.56~120.49, which is less than 150, indicating a slight ecological risk. Ling et al. (2024) found that the distribution range of the soil heavy metal ecological risk index (RI) in Wutai County was 40.99~75.58, which was less than 150, indicating a slight ecological risk [26]. Sun et al. (2022) found that the total potential ecological index (RI) of heavy metals and risk elements in farmland soils in Shanxi Province ranges from 28.00 to 1851.01, with slight, moderate, strong, very strong, and extremely strong ecological risks accounting for 97.57%, 1.21%, 0.4%, 0.4%, and 0.4%, respectively, with slight and moderate risks being the main ones. The influencing factors are Cd, Pb, Cu, Hg, and As [27]. This is consistent with the results of this study in that there are ecological risks in the study area, with Cd being a common contaminant. The difference is that Shanxi Province has slight, moderate, strong, very strong, and extremely strong ecological risks, whereas the study area only has slight ecological risks. The main reason is that the original heavy metal content in the study area is low, it is less affected by human factors, and there is no heavy industry pollution.

Research has found that As, Cr, and Pb are the main non-carcinogenic factors in the soil of the study area. As, Cr, and Pb pose a significant non-carcinogenic health threat to children, and risk prevention and control of these elements should be strengthened; Ling et al. (2024) found that the non-carcinogenic factors affecting soil heavy metals in Wutai County were As, Pb, and Cr, which were the main non-carcinogenic factors in the soil of the study area. As and Pb had the greatest impact on adults, while As, Cr, and Pb posed a significant non-carcinogenic health threat to children, consistent with the results of this study, except that the non-carcinogenic risk in the study area was slightly higher [26]; Sun et al. (2022) found that 8 heavy metals and risk elements in farmland soil in Shanxi Province pose non-carcinogenic health risks to adults and children [27]. The comparison results indicate a non-carcinogenic risk from heavy metals in the study area, with a risk value lower than that of Wutai County and even lower than that of Shanxi Province. This indicates that the study area is less impacted by human factors, while other areas are more affected by them.

The average total cancer risk index for adults and children is 9.86×10^{-6} and 2.65×10^{-5}, respectively, with maximum values of 2.11×10^{-5} and 5.68×10^{-5}, both ranging from 10^{-6} to 10^{-4}; this result is consistent with the research findings of Ling et al. (2024), Han et al. (2020), Zhao et al. (2020), Yang et al. (2016) in different regions of Shanxi Province in recent years [28-30].

Overall, the heavy metal pollution in the study area has a low health risk and falls within a controllable range, consistent with the research results of Wutai County and Shanxi Province. The degree of ecological risk varies across different regions and is related to the level of pollution in each area. Heavy metal pollution is mainly caused by human factors. Due to the hidden nature of soil pollution, it is known as "invisible pollution", and the remediation process is challenging, lengthy, and costly. Research on the current status of soil heavy metal pollution, as well as the ecological and health risks associated with soil heavy metals, provides a basis for preventing and controlling soil heavy metal pollution. The research is necessary, and the results are of great significance in guiding the research on heavy metal pollution, ecological risks, and health risks.

Conclusions

Through research, the pollution status of heavy metals in the study area has been determined, providing basic data for subsequent treatment. Determine the degree of harm to the structure and function of soil ecosystems through ecological risk assessment. Through health risk assessment, determine the likelihood and degree of harm in order to take corresponding measures to protect both the ecological environment and human health. It plays a supporting scientific role in environmental protection, sustainable resource utilization, human health protection, policy formulation support, and regional sustainable development.

Given the harmfulness of heavy metals, it is recommended to strengthen the source control of industrial pollution and agricultural inputs, enhance the process prevention and control of farmland irrigation management and soil environment monitoring, strengthen the terminal treatment of excessive soil remediation, and control heavy metals in farmland soil within a healthy and reasonable range.

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Conflicts of Interest

There is no conflict of interest in the article.

Availability of Data and Materials

The data and materials provided by the laboratory of the Harbin Natural Resources Comprehensive Survey Center are reliable.

Author Contributions

Sun Qifa (1966-), male, doctor, and professor-level senior engineer, is mainly engaged in hydrogeology, engineering geology, environmental geology, and geochemical investigation and research.

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