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Development of monitoring and early warning model for harmful trace elements in the environment of grain crop planting in Jilin Province

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Abstract. Accompanied by urbanization and industrial development, the introduction of fertilizers, pesticides, and waste materials into the soil and water has resulted in heavy metal pollution of arable land and water sources, posing a serious threat to food and agricultural product safety, and bringing significant potential harm to human health. This paper focuses on central Jilin (Changchun, Siping, and Songyuan) as the study area, with primary research on the total-effective-plant seed content of heavy metals and their transformation and accumulation, in conjunction with land use data. It explores the constraints of heavy metal pollution in arable soil and the efficiency of its transformation and accumulation in relation to arable land use in the black soil region, aiming to provide a theoretical basis for the sustainable use of arable resources in the context of rapid urbanization in black soil areas.

1.Introduction

As the primary carriers of human agricultural activities, soil and water resources are not only directly affected by the agricultural practices they support, but changes in the external environment due to human utilization also promote alterations in the internal properties of soil and water. For instance, inappropriate types of land and water use, as well as improper production methods, can lead to direct consequences such as soil erosion, degradation of arable land fertility, water pollution, and fragmentation of farmlan[1].With the development of industry and agriculture, heavy metals in soil enter into soil and water through irrigation (especially sewage irrigation), sludge, garbage and other wastes, fertilizers, pesticides and atmospheric deposition, which changes the internal properties of soil and water quality. Heavy metal pollution in farmland and water sources, as an important negative effect of ecological environment, has become an important factor threatening the quality and safety of agricultural products worldwide.Compared to other types of pollution, heavy metal contamination is more concealed, difficult to control, irreversible, and can accumulate through the food chain, posing a serious threat to the safety of grain and agricultural products and bringing significant potential risks to human health.[2]. According to the safety sampling inspection results of rice in the whole Chinese market conducted by the rice quality inspection center of the Ministry of agriculture in 2002, it was found that the Cd content of 10.3% of rice in the market exceeded the legal upper limit; According to the "national soil pollution survey bulletin" issued by the Ministry of environmental protection and the Ministry of land and resources in 2014, the most prominent heavy metal pollution in China's arable land is Cr, Ni, Cu, As, Cd and Pb. The over standard rate of farmland soil points is 19.4%, and the area of farmland polluted by heavy metals is as high as 20million hectares, with 12million tons of contaminated grain per year, which seriously threatens the safety of food and agricultural products and limits the sustainable development of agriculture and ecology. In order to ensure the quality and safety of agricultural products and prevent the occurrence of public hazards, China has taken a series of measures to prevent and control soil and water pollution: on August 28, 2009, the executive meeting of the Ministry of environmental protection discussed and approved in principle the implementation plan for the comprehensive treatment of heavy metal pollution, placing the prevention and control of heavy metal pollution in a more urgent and important position, vigorously preventing and controlling heavy metal pollution and effectively solving prominent environmental problems endangering people's health; The theme of the 2015 International Year of soil conference was "healthy soil for healthy life"; In May 2016, the State Council issued the action plan for the prevention and control of soil pollution (Article 10 of the State Council), which clarified the ideas for the prevention and control of heavy metal pollution in cultivated land soil and water quality from the aspects of promoting legislation,

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strengthening supervision, effective protection and scientific treatment; The 2017 national land planning outline (2016-2030) points out a clear direction for the development, protection and renovation of land space. Therefore, before the occurrence of heavy metal pollution in soil and water quality, how to avoid the massive accumulation of heavy metal elements in cultivated soil, curb their transformation to effective state and prevent their enrichment to the edible part of crops through reasonable land resource planning and regulation is also an important scientific problem that must be solved in the process of realizing the sustainable utilization of regional land resources[1-5].

The assessment of heavy metal pollution in soil and water sources is the basis for the protection and treatment of heavy metal pollution in soil and water sources, and also an important link for ensuring the quality and safety of regional soil and water sources and reasonably regulating the use of land resources. At present, there have been a large number of reports on the evaluation of heavy metal pollution in soil and water sources, the analysis of influencing factors and the spatial distribution characteristics. Changshu City is taken as the research area, and the local soil background value upper limit and the secondary standard of soil and water quality environmental quality standard are taken as the double evaluation standards to evaluate the local heavy metal pollution in soil and water sources in all aspects. The evaluation results under the two evaluation standards are that the content of a variety of heavy metals seriously exceeds the standard; Taking the farmland around the 104 National Road in Shangyu section of Zhejiang Province, China as the research area, the content of heavy metals in the farmland soil around the road was determined. It was found that the heavy metal pollution in the farmland soil around the road was in a strip radiation distribution, and the content of heavy metals in the farmland soil around the road was significantly higher than the background value. With the higher content of heavy metals in the adjacent soil away from the road, the mero comprehensive pollution index of the farmland nearest to the road reached 2.02, which was moderate pollution. However, it can be seen that most studies are based on the total amount or effective amount of soil, which ignores the heavy metal pollution of cultivated land. It is not only reflected in whether each form of heavy metal in soil and water quality exceeds the environmental critical standard, but also whether the quality of agricultural products produced by it is safe? What is the degree of transformation and enrichment of heavy metals in soil crop system? These are the most intuitive indicators to characterize the safety of food and agricultural products, and also important indicators and feedback factors to comprehensively consider whether there is a risk of heavy metal pollution in cultivated land use and guide the rational use of cultivated land. However, at present, the relevant research and reports are not rich [3-14].The black soil area in the middle of Jilin Province is an important part of the typical black soil distribution in the northeast, and it is also the core area of economic development and growth in Jilin Province. The contradiction between urbanization, industrialization and cultivated land resource protection is particularly prominent. Therefore, the protection of the quantity and quality of cultivated land is a focus of land use in the black soil area in the middle of Jilin Province [15]. Taking the central part of Jilin Province (Changchun, Siping and Songyuan) as the research area, focusing on the total and bioavailable amounts of heavy metals, their content in crop seeds, and their transformation and accumulation, combined with land use data, discusses the constraints of heavy metal pollution and transformation and enrichment efficiency of cultivated land on cultivated land use in black soil area, aiming to provide a theoretical basis for the sustainable utilization of cultivated land resources in the context of rapid urbanization in black soil area.

Heavy metal pollution assessment is an important means to master the regional cultivated land soil environmental quality, ensure the safety of crop production and human health. The analysis of the total amount, effective amount and crop enrichment of heavy metals is the basis for evaluating whether heavy metals exceed the environmental critical standard and the quality and safety of agricultural products, and is also the premise for exploring the sustainable utilization of cultivated land resources in black soil area. However, the existing environmental impact assessment results mainly based on the content of heavy metals in soil are relatively single, and the comprehensive assessment system for the risk degree of cultivated land use is not complete, so it is unable to scientifically and comprehensively understand the risk of heavy metals on cultivated land use. Therefore, the construction of a heavy metal pollution assessment system integrating total amount of heavy metals, effective amount of heavy metals and crop enrichment is conducive to the comprehensive assessment of soil water health risk and the safety of material flow and energy exchange in the ecosystem [12-18]. The potential risk of heavy metal pollution in the region was screened by using the relative indicators representing the efficiency of heavy metal transformation and enrichment, such as the effective coefficient and absorption coefficient, which provided a theoretical basis for determining the spatial distribution of warning information in the study area and monitoring it. At the same time, combining the transformation and enrichment of heavy metals with the use of cultivated land and the structural function of cultivated land in the black soil area will help to provide reasonable suggestions for the risk control of heavy metal pollution and the effective utilization of cultivated land resources [19-26].

2. Materials and methods

Sample collection and storage shall be conducted according to HJ/T 166.

Refer to HJ/T 166 and GB 17378.3 for sample preparation.

Electrothermal digestion treatment:

Weigh 0.2 g-0.3 g (accurate to 0.1 mg) of the sample in a 50 ml PTFE crucible, wet with water, add 10 ml of hydrochloric acid, heat it on the electric heating plate in the fume hood at 90 ℃ -100 ℃, make the sample decompose initially, and when the digestion solution evaporates to about 3 ml, add 9 ml nitric acid, cover and heat it until there are no obvious particles, add 5 ml-8 ml hydrofluoric acid, open the cover, heat the silica fume at 120 ℃ for 30 min, cool it slightly, add 1 ml of perchloric acid, and heat it at 150 ℃ -170 ℃ until it emits white smoke. Shake and collapse frequently during heating. If there are black carbides on the wall, add 1 ml perchloric acid to cover and continue heating until the black carbides disappear, then open the cover and heat the acid until the contents are in the shape of liquid beads (observe while hot). Add 3ml nitric acid solution, pyrolysis soluble residue, transfer the whole amount to a 25ml volumetric flask, dilute with nitric acid solution, shake well, store in a polyethylene bottle, stand still, and take the supernatant to be determined. The analysis was completed within 30 days. The experimental reagents and instruments are shown in Table 1 and 2.

The instrument parameters are set as follows:

Light source - sharp line light source

Lamp current -5 mA

Passband width -0.2-1

Flame type - neutral

Calculation method:

The element mass fraction Wi mg/kg is calculated according to formula (1):

$$w_i = \frac{(\rho_i - \rho_{0i}) \times V}{m \times w_{dm}} \quad (1)$$

W_i -- mass fraction of background elements, mg/kg

ρ_i -- mass fraction of sample elements, mg/L

ρ_{0i} -- mass fraction of blank test element, mg/L

V -- constant volume of sample after digestion, ml

m -- sample weight of sample g

W_{dm} -- dry matter content of sample%

Table 1. Experimental reagents

reagent	purity	Manufacturer
HCl	1.19 g/mL	Shanghai Aladdin Biochemical Technology Co., Ltd
HNO_3	1.42 g/mL	Shanghai Aladdin Biochemical Technology Co., Ltd
HF	1.49 g/mL	Shanghai Aladdin Biochemical Technology Co., Ltd
$HClO_4$	1.68 g/mL	Shanghai Aladdin Biochemical Technology Co., Ltd
Cr	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
Ni	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
Cu	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
AS	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
Cd	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
Pb	Spectral orders	Shanghai Aladdin Biochemical Technology Co., Ltd
Reagent bottle	Polyethylene grade	Shanghai Aladdin Biochemical Technology Co., Ltd
C2H2	≥99.5	Shanghai Aladdin Biochemical Technology Co., Ltd
air	Anhydrous	Shanghai Aladdin Biochemical Technology Co., Ltd

Note: the experimental water is Wahaha Purified Water

Table 2. Experimental instruments

instrument	model	Manufacturer
Inductively coupled plasma spectrometer	Agilent 725	Agilent Technologies (China) Co., Ltd
Analytical balance	BSA2238	Sartorius Science Instruments (Beijing) Co., Ltd
General laboratory utensils and equipment		

3. Results

3.1. Study on transfer, migration and diffusion of harmful trace elements

In addition to directly threatening the quality and safety of agricultural products, heavy metal pollution will also cause serious public harm to humans through the accumulation of complex biological chains (Fig.1). Heavy metals such as Cd, Ni, Pb and Hg are abnormally enriched in the human body through the food chain, skin contact and air inhalation, and most of the heavy metals cannot be eliminated by the normal physiological metabolism of the human body, which will continue to accumulate in the human body and directly damage health or bring long-term potential risks. Cr, Zn, Cu and other trace elements are necessary for human body, but when these elements are enriched too much in the human body, they will affect the redox effect in the body, causing gastrointestinal discomfort, liver pox and other diseases, and even cause cancer in severe cases.

Metals may enter the soil through a variety of ways. Several studies have revealed the effects of various physical, chemical and biological processes on the bioavailability of metals in the soil and the spatial distribution of harmful trace elements in landmark dust[17,27-28] (Fig. 2). Peralta video et al. Discussed the mobility of Cd, Cr, Hg, As and Pb in soil and their absorption potential by plants, which was also mediated by rhizosphere microbial activities. At low pH, some metals, such As Cd, Cu, Hg and Pb, are more easily absorbed by plants [29]. Many studies have emphasized the importance of metal bioavailability measurement when assessing the risk of metal accumulation and transfer in the terrestrial food web, but the effectiveness of these bioavailability measurement methods is controversial [30,31]. In a word, the study of the enrichment, transfer and diffusion process of harmful trace elements is of great significance for environmental protection, ecosystem health, soil and water resources management, human health risk assessment and the development of pollution control and remediation technology.

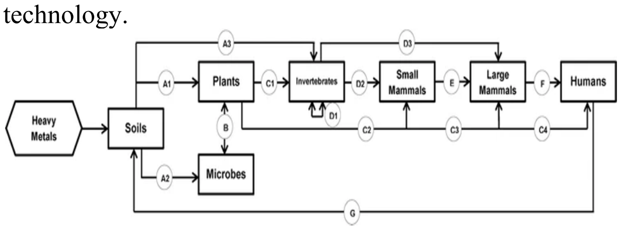

Fig .1. Transfer pathways of harmful trace elements in terrestrial food chains

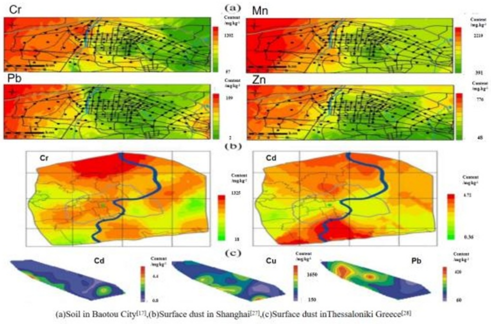

Fig.2. Spatial Distribution of harmful Trace Elements in Soil and Surface Dust of Baotou, Shanghai, and Thessaloniki, Greece

3.1.1 Analysis of harmful trace elements in the environment of grain crop planting areas in Jilin Province

A. Spatial distribution of harmful trace elements in the environment of grain crop planting areas in Jilin Province

The contents of harmful trace elements (Cr, Ni, Cu, As, Cd and Pb) in soil and water samples from the regional environment of grain crops (corn Zea mays, rice Oryza sativa, soybean Glycine max, sorghum Sorghum bicolor, wheat Triticum aestivum) in Jilin Province were determined After the soil and sediment are digested by acid, the metal elements in the sample are atomized in air-b fast flame, and their ground state atoms selectively absorb the characteristic spectral lines of each element, and their absorption intensity is proportional to the concentration of each element within a certain range. The data of harmful trace elements in soil and water were collected and processed to establish the spatial distribution map of harmful trace elements in the regional environment of grain crops in Jilin Province(Fig.3).

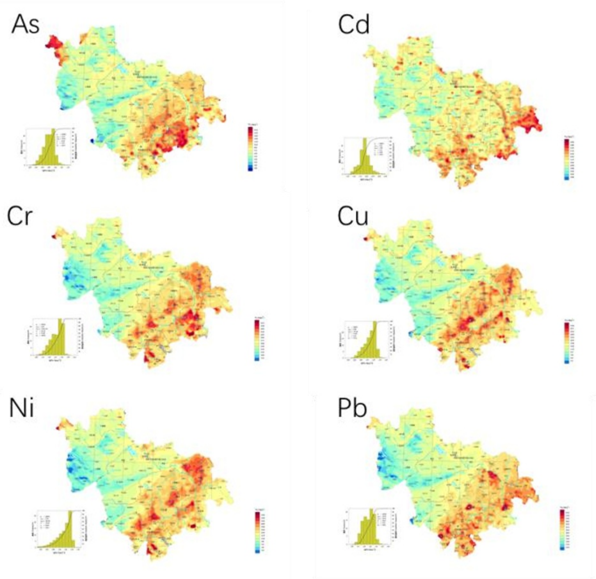

Fig.3. Spatial Distribution of Harmful Trace Elements in the Environment of Grain Crop Planting Area in Jilin Province

B. Distribution of Harmful Trace Elements in the Tissues and Organs of Grain Crops in Jilin Province

Pretreatment steps of plant samples: take samples during the plant harvest (with the consent of local farmers), and the plant sampling point is near the soil sampling point. Plant samples were rinsed with running tap water and deionized water for three times, and baked at 75 ℃ to constant weight. The samples were crushed by a pulverizer and then sampled for elemental analysis. By detecting the contents of harmful trace elements in the samples of crops (corn, rice, soybean, sorghum, wheat) and various parts of crops (roots, stems, leaves, fruits) in the regional environment of grain crops in Jilin Province, the distribution map of harmful trace elements in plant organs and tissues of grain crops in Jilin Province was established(Fig.4-8).The following conclusions can be drawn: the roots are the primary site for the absorption of these harmful elements, followed by the leaves, with the stems in an intermediate position, and the fruits containing the lowest levels. Different crops exhibit varying abilities to absorb, transport, and accumulate harmful elements, which are related to their genetic characteristics, growth environment, and physiological traits. To reduce the risk of harmful elements spreading through the food chain, attention should be focused on the levels of these elements in crop roots and leaves, and appropriate measures—such as soil improvement and the selection of low-accumulation crop varieties—should be taken to mitigate the risk of contamination.

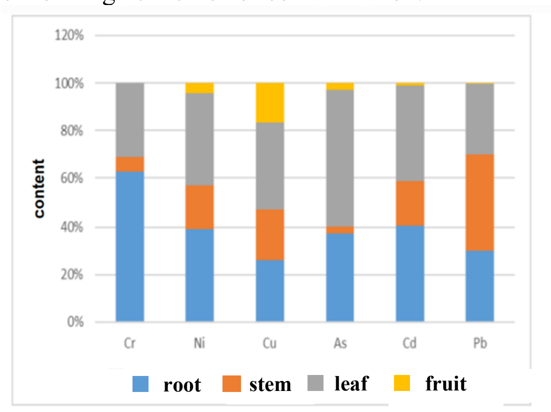

Fig.4. Plant organ and tissue distribution of harmful trace elements in corn

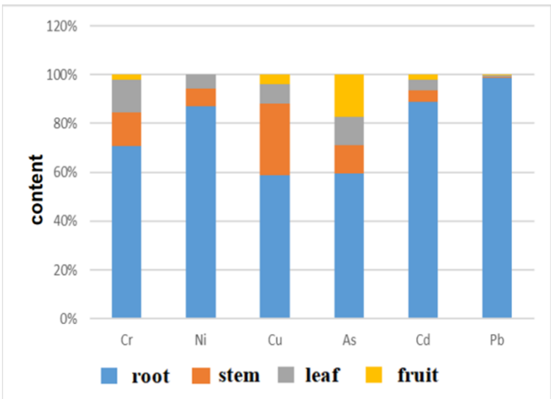

Fig.5. Distribution of harmful trace elements in rice plant organs and tissues

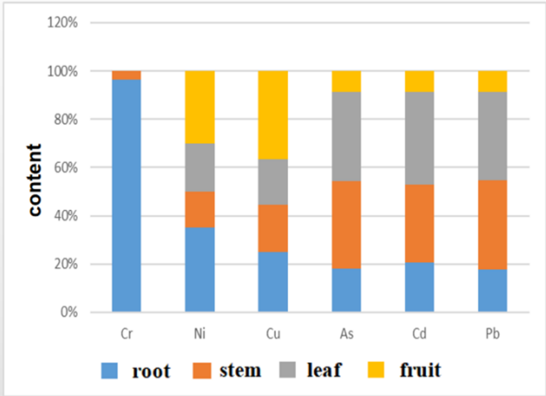

Fig.6. Distribution of harmful trace elements in soybean plant organs and tissues

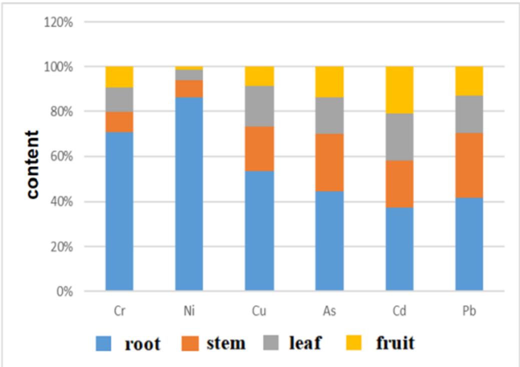

Fig.7. Distribution of harmful trace elements in sorghum plant organs and tissues

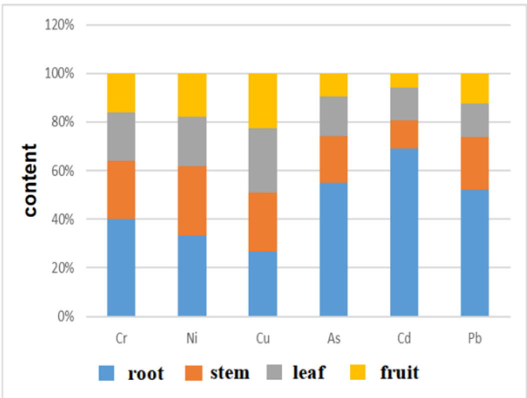

Fig.8. Plant organ and tissue distribution of harmful trace elements in Wheat

3.2. Migration and diffusion model of harmful trace elements in grain crop planting areas in Jilin Province

In this study, the migration and diffusion model of harmful trace elements in the grain crop planting area of Jilin Province was used to study the migration and diffusion law of harmful trace elements in soil, water and plants. The migration and diffusion model of harmful trace elements in the grain crop planting area in Jilin Province was compared with the relevant models reported in the literature, and the simulation experiment was carried out to verify the effectiveness of the migration and diffusion model for the prediction of the migration and diffusion of harmful trace elements, and to optimize the model.

3.2.1 Migration and diffusion of harmful trace elements in grain crop planting areas in Jilin Province

The migration and diffusion model of harmful trace elements is a mathematical model used to describe the transport, migration and diffusion process of harmful trace elements in the environment. The common migration and diffusion models of harmful trace elements include convection diffusion model, equilibrium model, groundwater flow model, multiphase flow model, numerical simulation model, etc. these models can be selected and combined according to specific application scenarios and research purposes, so as to more accurately describe the migration and diffusion behavior of harmful trace elements, and provide a scientific basis for environmental protection and risk assessment.

In this study, the migration and diffusion model of harmful trace elements in the grain crop planting area of Jilin Province is described by the bioconcentration index (BCF-Mi), which is the transfer coefficient of harmful trace elements from the environment to crops, as shown in formula (2), (Table 3).

$$M_i = \frac{C_1}{C_0} \quad (2)$$

Where C_1 is the content of harmful trace elements in crops and C_0 is the content of harmful trace elements in the environment.

Table 3. Summary of Mi values of harmful trace elements in crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
corn	0.016	0.699	2.917	0.067	0.333	1.975
rice	1.420	0.540	1.120	4.460	1.713	0.500
soybean	1.085	0.100	0.160	1.845	0.680	3.010
Sorghum	0.530	0.660	1.900	0.170	1.247	0.145
wheat	0.250	0.620	1.790	0.330	1.450	0.250

The Mi values of Cu, Pb, As, and Cd in various crops are significantly higher than 1, indicating that the accumulation of these elements in crops is relatively severe and may pose a considerable threat to human health. In particular, the Mi value of As in rice is much higher than that of other elements, warranting focused attention.The Mi values of Cr, As, and Ni in crops such as corn, sorghum, and wheat are relatively low, making them relatively safe, but regular testing is still necessary to ensure safety. For crops and elements with higher Mi values, measures should be taken to reduce the heavy metal content in the soil, such as improving the soil and selecting crop varieties with low accumulation. Strengthening the testing and supervision of agricultural products is essential to ensure food safety. Public awareness of heavy metal pollution should be raised, and green agriculture and sustainable development should be promoted.

3.2.2 Model of harmful trace elements in plant enrichment and transportation environment

In this study, a model of harmful trace elements (Cr, Ni, Cu, As, Cd and Pb) in plant enrichment and transportation environment was constructed to study the enrichment and transportation of harmful trace elements (Cr, Ni, Cu, As, Cd and Pb) in maize, rice, soybean, sorghum, wheat and other crops. The difference between the model of harmful trace elements in the plant enrichment and transportation environment constructed in this project and the relevant models reported in the literature was compared, and the plant culture labeling experiment was carried out to verify the effectiveness of the model of harmful trace elements in plant enrichment and transportation in predicting the time and concentration of plant enrichment and transportation, and to optimize the model;

The transfer coefficient (BTF Di) of the transfer ability of harmful trace elements from the environment to various tissues and organs of plants is described.

The enrichment and transport law (Di) of harmful trace elements (Cr, Ni, Cu, As, Cd and Pb) in corn, rice, soybean, sorghum, wheat and other crops is as follows (3):

$$D_i = \frac{D_1}{D_0} \quad (3)$$

Where D_1 is the content of harmful trace elements in crop organs and D_0 is the content of harmful trace elements in the environment.

The determination method of harmful trace elements is the same as above.

The enrichment and transport laws (Di) of harmful trace elements (Cr, Ni, Cu, As, Cd and Pb) in maize, rice, soybean, sorghum, wheat and other crops are summarized as follows (Table 4-8):

Table 4. Summary of Di values of harmful trace elements in corn crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
root	0.625	0.393	0.259	0.373	0.405	0.301
stem	0.100	0.447	0.800	0.080	0.444	1.323
leaf	0.500	0.992	1.421	1.520	0.993	0.987
fruit	0.000	0.107	0.638	0.080	0.030	0.010

Table 5. Summary of Di values of harmful trace elements in rice crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
root	0.709	0.870	0.589	0.595	0.890	0.986
stem	0.135	0.074	0.292	0.116	0.045	0.006
leaf	0.135	0.056	0.079	0.115	0.045	0.005
fruit	0.021	0.000	0.040	0.173	0.020	0.003

Table 6. Summary of Di values of harmful trace elements in soybean crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
root	0.964	0.350	0.251	0.182	0.206	0.176
stem	0.036	0.150	0.194	0.363	0.324	0.372
leaf	0.000	0.200	0.190	0.369	0.382	0.365
fruit	0.000	0.300	0.365	0.087	0.088	0.086

Table 7. Summary of Di values of harmful trace elements in sorghum crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
root	0.708	0.864	0.533	0.446	0.374	0.419
stem	0.091	0.076	0.201	0.255	0.206	0.286
leaf	0.106	0.045	0.180	0.163	0.212	0.166
fruit	0.095	0.015	0.086	0.136	0.209	0.130

Table 8. Summary of Di values of harmful trace elements in wheat crops (n=10)

	Cr	Ni	Cu	As	Cd	Pb
root	0.400	0.332	0.267	0.548	0.692	0.519
stem	0.240	0.285	0.242	0.194	0.115	0.218
leaf	0.200	0.203	0.267	0.161	0.135	0.138
fruit	0.160	0.180	0.224	0.097	0.058	0.125

The enrichment of Cu in the stems of rice and maize is significantly higher than that of other elements and requires particular attention. The enrichment of As is relatively high in maize, soybeans, and rice, especially in the leaves, and further monitoring is needed. Cd shows higher enrichment in the stems of soybeans and the grains of sorghum, which requires focused attention. Ni exhibits higher enrichment in soybeans and sorghum, particularly in the roots, and should be monitored. Cr has higher enrichment in soybeans and maize, especially in the roots, and needs to be observed. The enrichment of Pb in the grains of maize and rice is relatively low and considered safer, but regular testing is still necessary to ensure safety.For crops and elements with high Di values, measures should be taken to reduce the heavy metal content in the soil, strengthen the monitoring and regulation of agricultural products, ensure food safety, and promote green agriculture and sustainable development.

3.3. Risk assessment model and monitoring and early warning model of harmful trace elements

3.3.1 Risk assessment model of harmful trace elements in the environment of grain crop planting areas in Jilin Province

Based on “3.2.1 migration and diffusion of harmful trace elements in grain crop planting areas in Jilin Province”, the risk assessment model of harmful trace elements in the environment of grain crop planting area in Jilin Province was established (Table 9-10).

Hazardous trace element risk assessment model - Environmental diffusion model:

$$P_i = \frac{C_i}{S_i} \tag{4}$$

In the formula, Pi is the element risk index, Ci is the detection value, and Si is the risk screening value.

Table 9. Summary of SI risk screening values

	Corn mg/kg	rice mg/kg	Soybean mg/kg	Sorghum mg/kg	wheat mg/kg
Cr	1	1	1	1	1
Ni	1	1	1	1	1
Cu	1	1	1	1	1
As	0.5	0.2	0.5	0.5	0.5
Cd	0.1	0.2	0.2	0.5	0.2
Pb	0.2	0.2	0.2	0.2	0.5

Table 10. PI risk level table

risk level	Pi	Pollution risk
I	<1	Pollution-free
II	1-2	Minor pollution
III	2-3	Mild pollution
IV	3-5	Moderate pollution
V	>5	Severe pollution

3.4. Monitoring and early warning model workstation of harmful trace element content in the environment of grain crop planting areas in Jilin Province

The significance of the hazardous trace element content monitoring and early warning model workstation is to provide an effective means to monitor and early warning the content of hazardous trace elements. By establishing the model and using the workstation, the concentration and distribution of harmful trace elements in the environment can be monitored in real time, and the abnormal conditions can be found and warned in time The monitoring and early warning model workstation for the content of harmful trace elements in the environment of grain crop planting areas in Jilin Province was constructed based on '3.2 migration and diffusion model of harmful trace elements in grain crop planting areas in Jilin Province' and '3.3 risk assessment model and monitoring and early warning model for harmful trace elements'. In this study, ECharts was selected to build the monitoring and early warning model workstation of harmful trace element content in the environment of grain crop planting area in Jilin Province.

3.4.1 Technical route of workstation

The technical scheme of the workstation is designed as follows(Fig. 9):

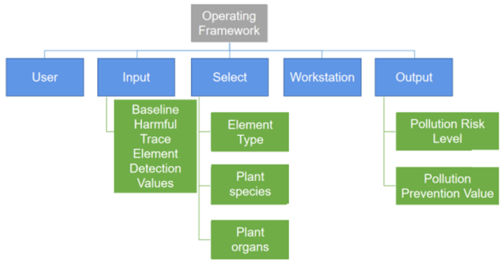

Fig.9. Workstation Framework Diagram

The design contents of the workstation are as follows (Fig. 10):

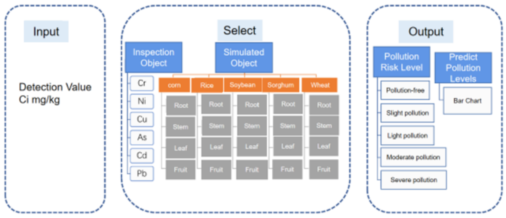

Fig.10. Workstation content diagram

3.4.2 Workstation conceptual model display

The workstation interface consists of three parts: user input page, user selection interface and information output interface. Display address: http://47.106.150.157/text/

The user input page is as follows (Fig. 11):

Fig.11. Workstation-Book Input Page

The user selection interface is as follows (Fig. 12):

Fig.12. Workstation-User Selection Interface

The information output interface is as follows (Fig. 13):

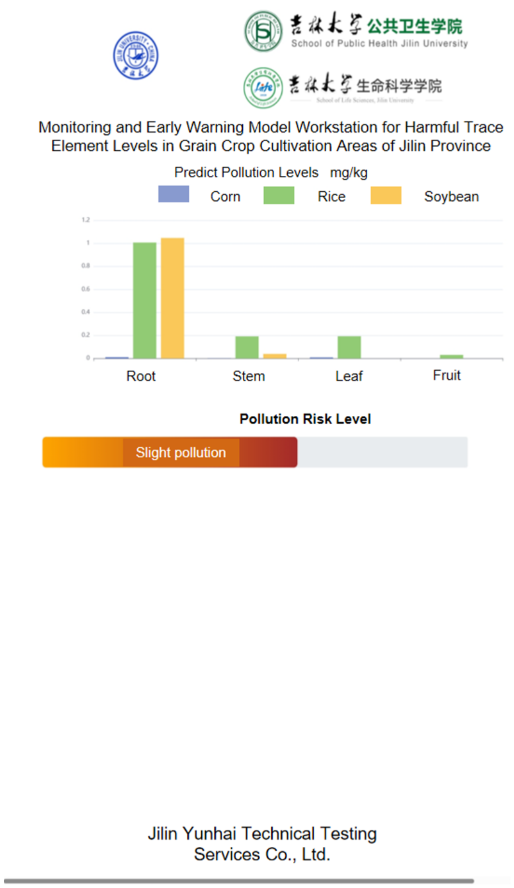

Fig.13. Workstation-Information Output Interface

3.4.3 Workstation operation feedback

After the feedback correction, the prediction accuracy of the simulation operation of the workstation is 75%, and it can run normally on both PC and mobile terminals. However, this workstation has great limitations due to the limitations of research depth and funding. The optimization direction for subsequent research is as follows: integrate sensor technology, add data acquisition and transmission module, supplement data processing and analysis content, optimize early warning system, add data storage and management. To sum up, the design technical route of hazardous trace element content monitoring and early warning model workstation includes sensor technology, data acquisition and transmission, data processing and analysis, early warning system and data storage and management. According to the specific needs and resources, the appropriate technical direction can be selected for design and implementation.

4. Discussion

Heavy metal contamination in farmland triggers a chain reaction of "biotoxicity – food chain enrichment – ecosystem imbalance," fundamentally undermining the core function of farmland as a safe food production base. The complexity and irreversibility of its impacts are particularly severe. Specifically, heavy metals such as Cd, Pb, and As are absorbed by crop roots, where they disrupt chlorophyll synthesis, inhibit the activity of key enzymes like catalase, and consequently impede photosynthesis and cause metabolic dysfunction. This leads to reduced yield or even plant death. Even at low concentrations where acute toxicity symptoms are absent, these metals can insidiously diminish the content of proteins and vitamins in crops, thereby compromising product quality. More critically, due to their bioaccumulation and biomagnification potential, heavy metals accumulate in human organs such as the liver and kidneys through the food chain, inducing chronic poisoning. Sensitive groups, including children and pregnant women, are especially vulnerable; low-dose exposure can cause irreversible harm, such as impaired intellectual development. This underpins why heavy metal contamination is a central issue in source control for food safety.

At the ecosystem level, heavy metals significantly reduce the diversity of soil bacteria and fungi, suppress the activity of functional microorganisms like nitrogen-fixing bacteria, and hinder nutrient cycling. Moreover, they readily form stable complexes with soil colloids, permanently altering critical physicochemical properties such as soil pH and cation exchange capacity (CEC). Even after remediation, it is challenging to restore the soil's original ecological functions, often trapping the system in a vicious cycle of "contamination – degradation – re-contamination."Faced with this formidable challenge, the most direct and common response to contaminated farmland has been restricting or prohibiting its use for agricultural production, aiming to block risks at the source.

This study has developed a comprehensive technical framework encompassing environmental surveys, process modeling, and risk early warning systems. The research first elucidated the distribution and migration patterns of harmful trace elements in Jilin Province's agricultural regions and crop tissues. Subsequently, it established migration-diffusion models for these elements in the environment and quantitative models for their plant accumulation and transport, revealing key process mechanisms. Finally, these findings were integrated into a risk assessment and monitoring early warning workstation, enabling the transition from research to operational management to safeguard the environmental conditions of grain-producing areas and the safety of agricultural products.

Future integration of variables such as crop growth stages and farming management practices, combined with machine learning algorithms, holds promise for further enhancing predictive accuracy. Furthermore, the developed visualization workstation provides an intuitive and practical management tool for local agricultural agencies, farmers, and policymakers, facilitating the translation of research into practice. From a long-term perspective, the framework established here can be expanded from "risk prevention and control" to "green utilization of contaminated farmland under safe production capacity." It possesses significant potential for upscaling—from Jilin Province to the broader Black Soil Region of Northeast China and other major grain-producing areas—thereby contributing to the development of a national-scale monitoring, assessment, and decision-support network for heavy metal pollution and ultimately supporting national food security strategy.

In summary, the prevention and control of heavy metal pollution in farmland is a complex systematic engineering challenge. By integrating spatial informatics, process-based modeling, and risk assessment, this study proposes a preliminary solution spanning from monitoring and early warning to decision support. The future path of remediation necessitates deeper interdisciplinary collaboration across environmental science, agronomy, and information science. This collaborative effort is essential to fundamentally transform the governance paradigm from "passive response" to "proactive prevention and control," and from "experience-based judgment" to "precision management," with the ultimate goal of ensuring both the health of farmland ecosystems and the sustainable safeguarding of food security.

5. Conclusion

This study systematically mapped the spatial distribution of harmful trace elements in Jilin Province's grain crops and their distribution across crop organs and tissues. A migration and diffusion model was developed to analyze the movement of these elements from the environment to different crop tissues, revealing their transfer coefficients. Based on this, a risk assessment model for harmful trace elements was established. Simulation validation showed that the model achieved 75% accuracy when excluding weather and geological factors. The visualization platform ultimately serves as a decision-support tool, transforming data into actionable insights to provide scientific basis for environmental safety and agricultural product risk management in production areas.

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