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# Analysis of the Impact of Rural Households' Behaviors on Heavy Metal Pollution of Arable Soil: Taking Lankao County as an Example

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**Abstract:** As heavy metal pollution of arable soil is a significant issue concerning the quality of agricultural products and human health, the rural households' behaviors have a direct impact on heavy metal content in arable soil and its pollution level, but only a few researches have been done at such microscopic scale. Based on 101 field questionnaires of rural households in Lankao County and the monitoring data on heavy metal of arable soil of each rural household, the kind of rural households' behaviors which impose obvious influence on heavy metal content of arable soil are investigated via single-factor pollution index, Nemerow pollution index and econometric model in this study. The results show that, rural households' land utilization mode affects heavy metal content in soil, e.g., the degree of heavy metal pollution of soil for intensive planting is higher than that of traditional planting, viz. vegetable greenhouse > garlic land > traditional crop farmland. The management of cultivated land with due scale is beneficial to reducing heavy metal content in soil, that is, the land fragmentation degree is in direct proportion to heavy metal content in soil, so rural households are encouraged to carry out land circulation and combine the patch into a large one. Excess application of fertilizer, pesticide and organic fertilizer will lead to heavy metal pollution of soil, while agricultural technical training organized by government department and the foundation of agricultural cooperative can promote the technical level and degree of organization of rural households and enable them to be more scientific and rational in agrochemicals selection and application, hence reducing or avoiding heavy metal pollution of soil. Single factor pollution level of heavy metal in the soil for planting various crops is different, so it is recommended to prepare various pollution reduction programs for different land types and pollution levels for the harmony and unity of human-nature system.

**Keywords:** rural households' behaviors; arable soil; heavy metal pollution assessment; Lankao county

## 1. Introduction

Under the background of acceleration of regional industrialization, urbanization, and agricultural modernization, environmental issues attributed to human activities become increasingly obvious, and heavy metal pollution also becomes one of the major factors affecting the quality of arable soil [1]. According to Analysis of the Report on the National General Survey of Soil Contamination released by China in 2014 for the first time, the over-limit ratio of arable soil in China reaches 19.4% mainly due to such pollutants as heavy metal elements including Ni, Cu, Cd, Pb, As, and Hg, as well as DDT and PAHs [2], so heavy metal pollution of arable soil is an extremely urgent problem. Heavy metal content of arable soil is mainly affected by such natural factors as soil parent material (internal factor) and human activities (external factor), and the latter has been the major factor affecting heavy metal pollution of arable soil along with social and economic development. As the subject of agricultural production and management, rural households impose a direct impact on heavy metal content of soil by applying fertilizer and pesticide or other production activities [3,4]. Therefore, in the context of serious heavy metal pollution of arable soil and the increasing importance of the safety of agricultural products and human health, exploring the influencing mechanism of rural households' behaviors on heavy metal pollution of arable soil is of great significance to the government's preparation of corresponding policies for standardizing rural households' behaviors, improving scientific cognition and technical level of rural households, and pushing forward agro-ecological civilization construction and environment-friendly development of China.

Heavy metal pollution issue of arable soil receives wide concern from scholars at home and abroad due to its universality, management difficulty, and harmfulness, therefore a number of researches focus on the heavy metal content of arable soil [5,6], source analysis [7], pollution assessment [8–10], ecology [1,11], and health risk [12,13] evaluation, etc., mainly by applying the following approaches: single factor pollution index [4], geo-accumulation index [14], Nemerow pollution index [15], pollution load index [16], potential ecological risk index [17], and health risk assessment model [18], etc. In terms of selecting studied area, some scholars also carried out studies on the heavy metal content of arable soil around the functional area in addition to farmland of common areas [19]. For example, cultivated land around the mining area is susceptible to mining, smelting, and dump slag, which will aggravate heavy metal pollution of soil [20]; heavy metal content of arable soil in suburban areas increases obviously due to influences of urban construction, industrial and domestic pollution discharge [21]. As a key factor affecting the heavy metal content in arable soil, it is widely proved that agricultural production promotes the heavy metal accumulation in arable land [22,23]. Relevant researches on heavy metal pollution remediation of arable soil indicates that the adoption of appropriate treatment measures can reduce the heavy metal content of arable soil to some extent, such as the adjustment of planting patterns, deep ploughing for soil amelioration, formula fertilization, and adoption of phytoremediation, etc. [24].

With the transformation of traditional agriculture to modern intensive agriculture speeding up, agricultural production has been one of the major factors affecting heavy metal pollution of arable soil, and it is widely proved that agricultural production promotes the heavy metal accumulation in arable land [22,23]. As the basic economic unit of agricultural production [25], rural households play a crucial role in the process. In earlier research, many scholars incorporate rural households' behaviors into their research system from various aspects [26–29]. Along with increasingly outstanding agricultural pollution issues, the impact of rural households' behaviors on the agricultural environment also becomes a focus of this academic circle [30]. Related researches show that rural households' behaviors impose important impacts on the heavy metal content of arable soil. Such behaviors include rural households' resource utilization, operation, technology application, planting selection, and cognition. Among them, the number of rural households' available resources and the utilization pattern affect heavy metal content in soil. Rural households' operation behaviors such as input into fertilizer, pesticide, and organic fertilizer directly affect the heavy metal content of arable soil. Different scales of cultivated land operation may lead to the differentiation of agricultural environment, for example, small-scale cultivated land operation and high fragmentation will go against the adoption of new farming technology and may lead to increasing dose of agricultural chemicals in unit area [31]. The promotion of agricultural technology level can assist rural households to master or adopt environment-friendly field management technology and improve the utilization rate of fertilizer and pesticide [32]. Rural households' environmental cognitive level is an important factor affecting their behavior [33,34], so the emergence and aggravating of heavy metal pollution of arable soil is largely related to their low environmental cognitive level and weak environmental awareness. Rural households' planting [35] selection may change agricultural landscape structure and production element input, thus affecting the heavy metal content of arable soil to varying degrees, so comparative study by classification will be done in this paper. Besides, the basic attribute of household head and livelihood features of the family are the main motivation of different rural households' behaviors. For example, the higher the education level of the household head is, the higher the environmental awareness will be. Age will affect the rural households' receptivity toward new technology. The household income will affect the input of agricultural means of production, etc. [31,36]. As a result, the attributes of rural households are also included into the analysis variables.

To sum up, existing literatures show in-depth research on heavy metal pollution of arable soil, but most focus on macroscopic scale and a few combine rural households' behaviors with heavy metal content of soil at microscopic scale [37], and even fewer researches combine outdoor questionnaire data of rural households with indoor soil sample monitoring data for quantitative analysis. Therefore, on account of man–land coupling idea and following the research direction of increasing integration of physical geography and human geography, this paper takes rural households' behaviors theory as the basis and Lankao County of Henan as the example based on field investigation and laboratory experiment via such approaches as single factor pollution index, Nemerow Pollution Index and stepwise regression analysis. In this paper, the scientific issue "what kind and how much of the impact imposed by rural households' behaviors on heavy metal content of arable soil" is discussed, so as to provide reference for different regions to prepare scientific pollution reduction programs.

## 2. Materials and Methods

### 2.1. Study Area and Sample Selection

Lying between 114°40′~115°16′ E and 34°44′~35°01′ N and northeast of Henan Province at the middle and lower reaches of the Yellow River, Lankao County is a typical plain rural area and its present agricultural development has certain representativeness for it covers the common features of agricultural development in the middle area of China. In recent years, under the support of industrial poverty shake-off policy, featured agriculture like greenhouse vegetable planting is developed in Lankao County and the planting mode becomes more professional and distinctive in a short period of time, which provides comparable sample for accumulation of heavy metal content in soil, showing certain representativeness.

Sample villages and sample rural households are randomly selected in Lankao County. In order to focus on the impact of rural households' behaviors on heavy metal content of soil, land parcels far from factory, company, highway and construction land are chosen during sampling. Moreover, Lankao County is dominated by subregion climate which generates minor difference in natural factors like climate and parent material, so this can maximally lower the impact of surroundings and natural factors on heavy metal content of soil. By following these principles, we selected 20 sample villages (Figure 1) and 105 sample rural households in total. We handed out designed semi-structured questionnaire to each rural household and carried out "face-to-face" in-depth interviews and collected soil sample from the parcel of each rural household to monitor the heavy metal content of soil. Finally, we acquired 101 valid questionnaires and 101 soil samples accordingly, with effective rate of 96.19%. According to investigation on the types of crops planted in the parcels, farmland of the studied area was classified into traditional crop farmland (for traditional crops: wheat, corn, peanut and cotton), garlic land (for garlic and traditional crops) and vegetable greenhouse (parcels with greenhouse or arched shed for vegetable planting) in a sample size of 64:11:26 in this paper, so as to analyze the influence of rural households' behaviors on heavy metal content of soil under various land utilization modes. This investigation was done by the author and 14 members in July 2017. Questionnaire survey covers the attribute features of household head, status of land resource, agricultural production and operation, rural households' technological utilization and environmental cognitive level.

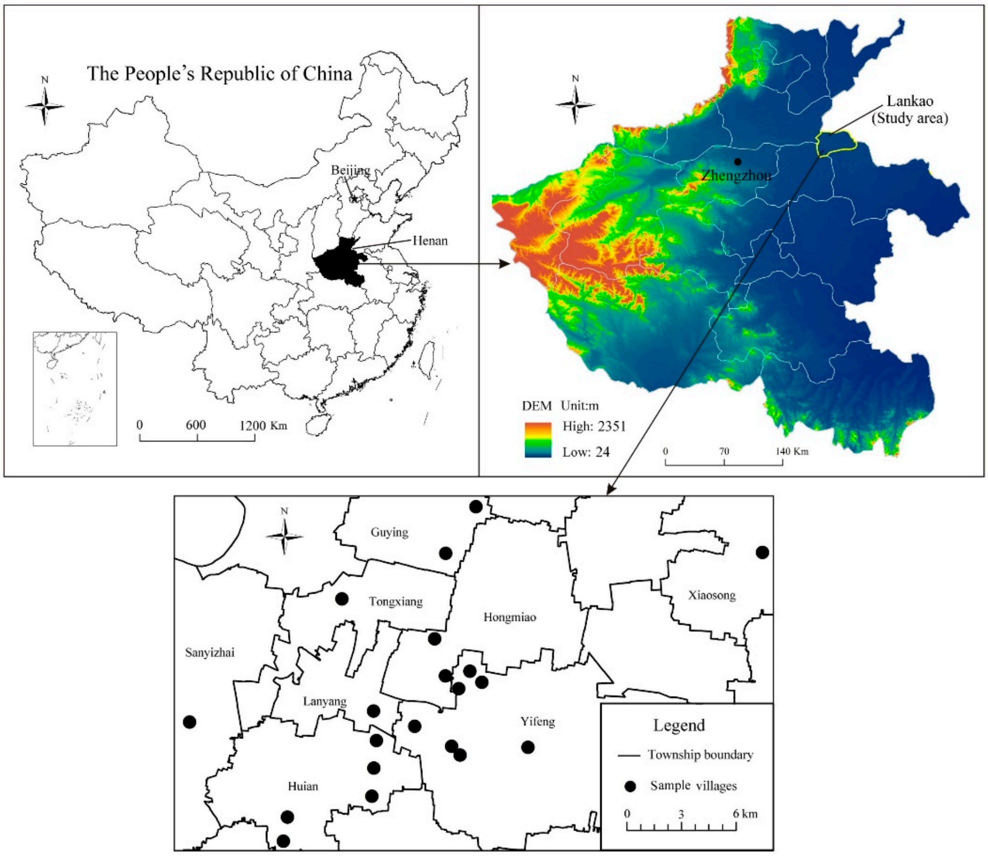


**Figure 1.** Diagram of study area and sample villages.

## 2.2. Soil Sample Collection and Sample Analysis

Taking and processing of 101 soil samples: according to "S" distribution and sampling depth of 0–20 cm, the samples were processed by quartering after removal of impurities like burr, plant & vegetable body and uniform mixing, with the rest 500 g soil analysis sample stored in a clean ziplock bag marked with corresponding No. of rural households' questionnaire and then carried it back to the laboratory. After natural air-drying, the collected samples were crushed and screened by a 2 mm nylon sieve, and then distributed evenly on plastic cloth after thorough mixing. After that, about 50 g was taken by multi-point sampling and further ground by agate mortar after remixing to make the samples all pass 0.15 mm nylon sieve, which was stored in ziplock bag for use.

"$HNO_3$-HF-$HClO_4$" digestion system was adopted for samples, with X-Series inductively coupled plasma source mass spectrometer (ICP-MS, Thermofisher) applied for measuring the content of Cr, Ni, Cu, Zn, Cd and Pb in soil. During the experiment, parallel test and national standard soil sample (GSS-5) recovery test are adopted for quality control. Relative deviation of secondary parallel test is within 5% and recovery rate of standard sample is 92.1%~106.3%.

## 2.3. Approaches for Evaluating Heavy Metal Pollution of Soil

In this paper, single factor pollution index and Nemerow Pollution Index are adopted to evaluate the heavy metal pollution of soil in the studied area.

#### 2.3.1. Single Factor Pollution Index Approach

Single factor pollution index is one of the common approaches to evaluate the pollution level of a certain pollutant in soil [7]. The calculation equation (Equation (1)) is:

$$P_i = C_i/S_i \tag{1}$$

where $P_i$ refers to the single factor pollution index of heavy metal $i$ in soil; Ci refers to the measured value of $i$ in soil (mg·kg$^{-1}$); Si refers to the evaluation criterion of $i$ (mg·kg$^{-1}$), with class II standard in Environmental Quality Standard for Soils (GB 15618—1995) [38] adopted. This standard is the soil limit for guaranteeing agricultural production and maintaining human health [39]. Pollution classification standard of $P_i$ is: soil is clean when $P_i \leq 0.7$, relatively clean but reaches safety warning state when $0.7 < P_i \leq 1$; slight pollution when $1 < P_i \leq 2$, moderate pollution when $2 < P_i \leq 3$ and severe pollution when $P_i > 3$. In the last case, heavy metal pollution of soil is quite serious [15,39].

#### 2.3.2. Nemerow Pollution Index Approach

Heavy metal pollution is usually a kind of combined pollution in soil environment. Therefore, it is necessary to synthesize the pollution index of different pollutants in the same sampling point and different samples of the same pollutant on the basis of single factor pollution index, so as to make a comprehensive evaluation of the result. Nemerow Pollution Index [14,15] approach is widely applied in evaluating soil pollution level, and can comprehensively reflect the level of various pollutants in regional soil [40] and highlight the action of pollutants with heavy pollution [41]. The calculation equation (Equation (2)) is given below:

$$P_N = \sqrt{\frac{(C_i/S_i)^2{}_{max} + (C_i/S_i)^2{}_{ave}}{2}} \tag{2}$$

where $P_N$ is Nemerow Pollution Index of heavy metal element in soil; $(C_i/S_i)_{max}$ is the maximum value of single factor pollution index in heavy metal element participating in soil evaluated; $(C_i/S_i)_{ave}$ is the average of single factor pollution index of various heavy metal elements. Pollution classification standard of $P_N$ is: soil is clean when $P_N \leq 0.7$, reaches safety warning state when $0.7 < P_N \leq 1$; slightly polluted when $1 < P_N \leq 2$, moderately polluted when $2 < P_N \leq 3$ and severely polluted when $P_N > 3$ [15,39].

### *2.4. Setup of Econometric Model*

#### 2.4.1. Model Construction

The following econometric model is set up to analyze the impact of rural households' behaviors on heavy metal pollution of arable soil (Equation (3)):

$$y = \alpha + \sum_i \gamma_i X_i + \varepsilon \tag{3}$$

where $y$ is the heavy metal pollution level of arable soil; α is a constant; $\gamma_i$ refers to regression coefficient, representing the contribution rate of various factors to y; $X_i$ refers to factors affecting heavy metal pollution level of soil; $\varepsilon$ is a random disturbance term.

#### 2.4.2. Variable Selection and Assignment

Based on the above literature analysis, the analysis framework for influence of rural households' behaviors on heavy metal content of arable soil (Figure 2) is established in this paper with the following main idea: under the influence of attributes of different individuals and families, rural households directly or indirectly affect the heavy metal content of arable soil through resource utilization, operation input, technology application, planting selection and cognition, and certain accumulation of heavy metal content will give rise to heavy metal pollution. It is necessary to divide the above behaviors into specific influencing factors, so as to select the corresponding analysis variables based on detailed factors and design the questionnaire for final field investigation.

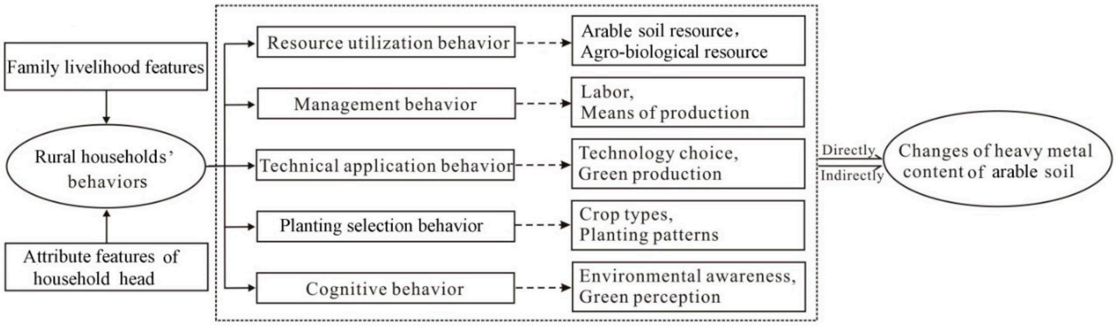


**Figure 2.** Framework for analysis on the impact of rural households' behaviors on heavy metal content of arable soil.

Dependent variable(y) stands for the heavy metal pollution level of arable soil and is represented by Nemerow Pollution Index ($P_N$). Based on theoretical analysis mentioned above, such indicators as attribute features of household head ($X_1$~$X_4$), family livelihood features ($X_5$~$X_8$), land resource endowment ($X_9$, $X_{10}$), input of agricultural means of production ($X_{11}$~$X_{13}$), environment cognition ($X_{14}$, $X_{15}$) and agricultural technology level ($X_{16}$) are selected as the independent variables (Table 1) in this paper. According to investigation result, planting selection of rural household is embodied in classification of vegetable greenhouse, garlic land and traditional crop farmland. Econometric analysis is shown below for the above three types of land.

**Table 1.** Variable selection and assignment of rural households' behaviors.

| Variable | Name | Assignment |
|---|---|---|
| Attribute features of household head | Age ($X_1$) | 1 stands for household head bellow 30 years old, 2 stands for those aged from 30 to 40, 3 stands for those aged from 40 to 50, 4 stands for those aged from 50 to 60, 5 stands for those above 60 years old |
| | Village cadres or not ($X_2$) | 1—Yes, 0—No |
| | Education level ($X_3$) | 1—Illiteracy or semiliterate, 2—Primary school level, 3—Junior high school, 4—Senior high school, 5—Junior college and above |
| | Years of agricultural production ($X_4$) | 1—Under 10 years, 2—10–20 years, 3—20–30 years, 4—Above 30 years. |
| Family livelihood features | Member of agricultural cooperative or not ($X_5$) | 1—Yes, 0—No |
| | Number of family members engaged in agriculture ($X_6$) | Actual labor force |
| | Proportion of agricultural income in family income ($X_7$) | Actual proportion |
| | Annual household income per capita ($X_8$) | Annual household income per capita |
| Land resource endowment | Arable area of the family ($X_9$) | Actual arable area |
| | Land fragmentation degree ($X_{10}$) | Land fragmentation distribution |
| Input of agricultural means of production | Fertilizer input intensity ($X_{11}$) | Fertilizer input of unit area |
| | Intensity of pesticide application ($X_{12}$) | Amount of pesticide input in unit area |
| | Applying organic fertilizer or not ($X_{13}$) | 1—Yes, 0—No |
| Environment cognition | Impact of pesticide and fertilizer on environment ($X_{14}$) | 1—Negative impact, 0—No impact |
| | Environmental awareness ($X_{15}$) | 1—Never concern, 2—Occasional concern, 3—Frequently concern |
| Agricultural technology level | Attending agricultural technical training or not ($X_{16}$) | 1—Yes, 0—No |

2.4.3. Determination of Data Processing and Regression Approach

It is necessary to first take the logarithm of continuous variable to eliminate the impact of variable heteroscedasticity [42]. In order to eliminate the multicollinearity among variables [43], stepwise regression approach is adopted for model estimation.

## 3. Assessment on Heavy Metal Pollution of Arable Soil

### 3.1. Characteristic Analysis on Heavy Metal Content of Arable Soil

Descriptive statistical analysis is performed on heavy metal content of 101 soil samples taken from the studied area, and the results are given in Table 2. The average element content of heavy metal Cr, Ni, Cu, Zn, Cd, and Pb is 53.802 mg·kg$^{-1}$, 28.560 mg·kg$^{-1}$, 44.376 mg·kg$^{-1}$, 125.395 mg·kg$^{-1}$, 0.350 mg·kg$^{-1}$ and 50.360 mg·kg$^{-1}$ respectively. Compared with class II standard (pH > 7.5) in Environmental Quality Standard for Soils (GB15618 -1995), in the studied area, the content of Ni, Cu, Zn, Cd, and Pb, except Cr, in agricultural soil samples exceeds the standard by 1.98%, 1.98%, 4.95%, 6.93% and 2.97% respectively, indicating varying degrees of Ni, Cu, Zn, Cd, and Pb pollution in the studied area. The average content of Ni, Cu, Zn, Cd, and Pb, except Cr, is higher than background value of soil in Henan, showing that heavy metal in arable soil of the studied area presents obvious accumulation trend due to great influence of agricultural production and other human activities. The standard deviation of Zn and Pb are significantly higher than other heavy metal elements, which shows that the sample data are discrete and have major variability. Variable coefficient can reflect the average variation degree of heavy metal element content and that of six heavy metals is: Pb > Zn > Cd > Cu > Ni > Cr. According to classification of variation degree [44], Cr, Ni, and Cu (0.243, 0.268 and 0.345) show moderate variation (0.15 < Cv < 0.36), while Zn, Cd, and Pb (1.034, 0.783 and 1.416) show high variation (Cv > 0.36), especially the variable coefficient of Zn and Pb are all above 1. This indicates that allogenic material enters into some sampling points, which is strongly influenced by human activities.

**Table 2.** Statistics on Heavy Metal Content of Arable Soil in the Studied Area ($n$ = 101).

| Element | Content/ mg·kg$^{-1}$ | Mean/ mg·kg$^{-1}$ | Standard Deviation/ mg·kg$^{-1}$ | Variable Coefficient | Background Value of Soil in Henan/ mg·kg$^{-1}$ | National Soil Environment Quality Standard (Class II )/ mg·kg$^{-1}$ |
|---|---|---|---|---|---|---|
| Cr | 17.598~123.977 | 53.802 | 13.077 | 0.243 | 63.800 | 250 |
| Ni | 17.462~67.362 | 28.560 | 7.640 | 0.268 | 26.700 | 60 |
| Cu | 23.795~118.839 | 44.376 | 15.300 | 0.345 | 19.700 | 100 |
| Zn | 55.142~795.170 | 125.395 | 129.677 | 1.034 | 60.100 | 300 |
| Cd | 0.133~2.321 | 0.350 | 0.274 | 0.783 | 0.074 | 0.6 |
| Pb | 18.338~386.778 | 50.360 | 71.331 | 1.416 | 19.600 | 350 |

By comparing the average heavy metal content in soil in various types of farmland (Figure 3), we can see that the average content of Cr, Ni, Cu, and Cd is the highest in vegetable greenhouse. The sequence of Cr content from high to low is vegetable greenhouse > traditional crop farmland > garlic land, while the average content of Ni, Cu, and Cd is vegetable greenhouse > garlic land > traditional crop farmland. In garlic land, the content of Zn and Pb is higher than that in vegetable greenhouse and traditional crop farmland, in the following sequence: garlic land > vegetable greenhouse > traditional crop farmland (in terms of Zn); garlic land > traditional crop farmland > vegetable greenhouse (in terms of Pb). From a whole view, the content of heavy metal in vegetable greenhouse and garlic land is higher than that in traditional crop farmland.

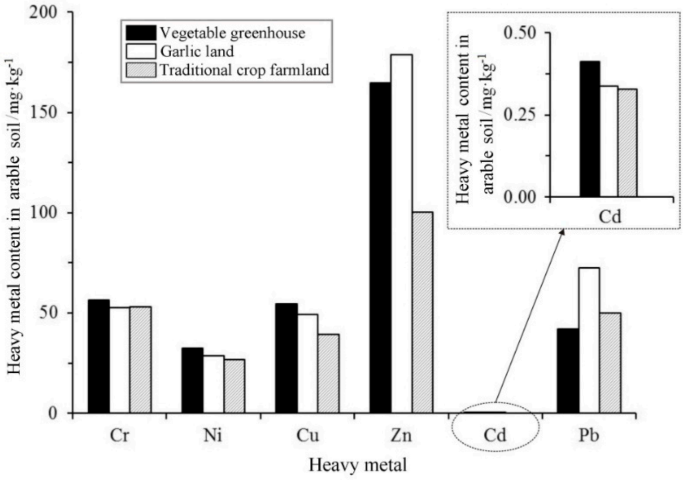


**Figure 3.** Average content of soil heavy metal in different types of farmland.

### 3.2. Analysis on Characteristics of Heavy Metal Pollution of Arable Soil

Single factor pollution index ($P_i$) and Nemerow Pollution Index ($P_N$) of heavy metal elements are calculated by formulas (1) and (2). Range of single factor pollution index of Cr, Ni, Cu, Zn, Cd, and Pb is 0.070~0.496, 0.291~1.123, 0.238~1.188, 0.184~2.651, 0.222~3.869 and 0.052~1.105, with the average sequence of Cd (0.584) > Ni (0.476) > Cu (0.444) > Zn (0.418) > Cr (0.215) > Pb (0.144). It can thus be seen that the average pollution index of all six heavy metal elements is smaller than 0.7, i.e. within the warning limit. Nemerow Pollution Index is 0.256~2.829 with an averaging of 0.578, which shows heavy metal pollution of some sampling points in the studied area, but unpolluted state on the whole.

Frequency distribution of pollution index can further show the pollution of heavy metal elements in the studied area (Table 3). Seen from frequency distribution of single factor pollution index ($P_i$), the frequency of Cr in unpolluted state among the six heavy metal elements is 100%. But Ni, Cu, and Pb show a certain degree of slight pollution and the frequency is 1.98%, 1.98% and 2.97% respectively, with 1.98%, 2.97%, and 1.98% sampling points reaching the warning state; Zn shows moderate and slight pollution in 2.97% and 1.98% sampling points with 3.96% reaching the warning state. Through comparison, we can learn that the pollution frequency and degree of Cd are the highest, that is, severe pollution occurs in 0.99% arable soil, moderate and slight pollution occurs in 0.99% and 4.95% soil, and 13.86% sampling points reach the warning state. Seen from frequency distribution of Nemerow Pollution Index ($P_N$), the frequency of moderate and slight pollution in sampling points is 0.99% and 5.94%, with 7.92% reaching the warning state, while other sampling points are in unpolluted state.

**Table 3.** Frequency distribution of soil heavy metal element pollution index.

| Pollution Degree | Frequency Distribution of Single Factor Pollution Index ($P_i$)/% | | | | | | Frequency Distribution of Nemerow Pollution Index ($P_N$)/% |
|---|---|---|---|---|---|---|---|
| | Cr | Ni | Cu | Pb | Zn | Cd | |
| Unpolluted ($P \leq 0.7$) | 100.00 | 96.04 | 95.05 | 95.05 | 91.09 | 79.21 | 85.15 |
| Warning state ($0.7 < P \leq 1$) | 0.00 | 1.98 | 2.97 | 1.98 | 3.96 | 13.86 | 7.92 |
| Slight pollution ($1 < P \leq 2$) | 0.00 | 1.98 | 1.98 | 2.97 | 1.98 | 4.95 | 5.94 |
| Moderate pollution ($2 < P \leq 3$) | 0.00 | 0.00 | 0.00 | 0.00 | 2.97 | 0.99 | 0.99 |
| Heavy pollution ($P > 3$) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.99 | 0.00 |

Note: $P$ stands for single factor pollution index ($P_i$) or Nemerow Pollution Index ($P_N$).

In order to analyze the average pollution level of various arable soils, the average values of single factor pollution index and Nemerow pollution index are calculated. According to the calculation results of the average values of single factor pollution index (Figure 4), we can learn that the average value of single factor pollution index of heavy metals in three types of arable soil is smaller than 1, indicating no heavy metal pollution of each type on the whole. Pollution index of Pb is the lowest, and that in vegetable greenhouse, garlic and traditional crop farmland is 0.120, 0.207, and 0.143 respectively, while that of Cd, Cu, Ni, and Zn is relatively high. The average value of Nemerow pollution index of heavy metal in three types of arable soil is: vegetable greenhouse (0.703) > garlic land (0.624) > traditional crop farmland (0.519), with no heavy metal pollution on the whole. However, it is worth noting that, the heavy metal pollution index of vegetable greenhouse with high land use intensity has reached the warning state and is higher than that of garlic land and traditional crop farmland, so it is necessary to properly adjust the management and planting strategy of agricultural production in future. It is discovered in investigation that organic fertilizer such as chicken manure, pig manure and excrements of other livestock is widely applied as base fertilizer in vegetable cultivation and some rural households also apply it in garlic land and traditional crop farmland, but excrements of livestock generally contain excess heavy metals like Cd, Cu, Zn, Pb, Cr, and Ni [45,46]. In addition, it is found from questionnaire that the application of fertilizers and pesticides in vegetable greenhouse is also higher than that in garlic land and traditional crop farmland, thus the heavy metal content of various arable soils is closely related to the input of fertilizer, pesticide, farmyard manure, etc.

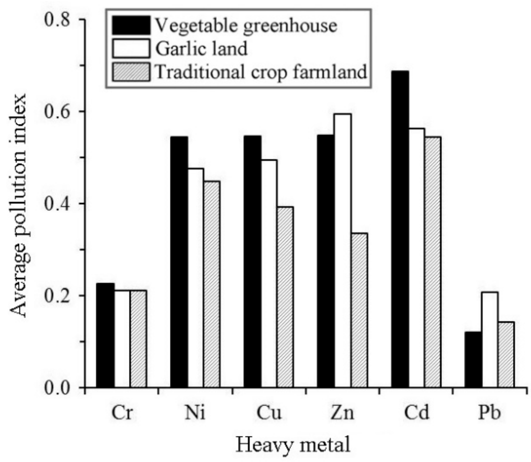


**Figure 4.** Average pollution index of soil heavy metal in different types of farmland.

## 4. Impact Degree of Rural Households' Behaviors on Heavy Metal Pollution of Arable Soil

The stepwise regression model is set up by taking Nemerow Pollution Index as the dependent variable and the rural households' behaviors indicator as the independent variable. In order to better distinguish the impact of rural households' behaviors on heavy metal pollution of soil in different types of arable land, model estimation is first conducted on all samples in this study, and then regression is performed on samples of vegetable greenhouse, garlic land and traditional crop farmland respectively, with the results given in Table 4 (in the table, models I, II, III, and IV respectively show the regression results of all samples from vegetable greenhouse, garlic land and traditional crop farmland).

(1) Overall sample (model I). The stepwise regression result shows that variables included into the model are: applying organic fertilizer or not ($X_{13}$), agricultural technology level ($X_{16}$), fertilizer input intensity ($X_{11}$) and member of agricultural cooperative or not ($X_5$). The following equation (Equation (4)) is established:

$$y = -1.781 + 0.21X_{13} - 0.163X_{16} + 0.241X_{11} - 0.179X_5 \tag{4}$$

Among them, $X_{13}$ and $X_{11}$ impose obvious positive effect on heavy metal pollution level of arable soil, while $X_{16}$ and $X_5$ impose negative effect on it. However, the overall goodness of fit of the equation is relatively low, and the regression results of different types of land are analyzed below.

**Table 4.** Results of the regression analysis on the impact of rural households' behaviors on heavy metal pollution of arable soil.

| Model | Independent Variable | Regression Coefficient | Std. Error | t-Statistic | Adjusted R-squared | Prob. (F-statistic) |
|---|---|---|---|---|---|---|
| I | Constant | −1.781 | 0.393 | −4.532 *** | 0.159 | 0.000 |
| | $X_{13}$ | 0.210 | 0.087 | 2.406 ** | | |
| | $X_{16}$ | −0.163 | 0.080 | −2.027 ** | | |
| | $X_{11}$ | 0.241 | 0.092 | 2.628 ** | | |
| | $X_5$ | −0.179 | 0.099 | −1.808 * | | |
| II | Constant | −2.083 | 1.043 | −1.998 * | 0.339 | 0.007 |
| | $X_{16}$ | −0.341 | 0.171 | −1.988 * | | |
| | $X_5$ | −0.469 | 0.184 | −2.552 ** | | |
| | $X_{12}$ | 0.315 | 0.163 | 1.927 * | | |
| III | Constant | −0.258 | 0.403 | −0.640 | 0.396 | 0.054 |
| | $X_{13}$ | 0.680 | 0.283 | 2.403 ** | | |
| | $X_{15}$ | −0.348 | 0.178 | −1.958 * | | |
| IV | Constant | −1.673 | 0.517 | −3.236 *** | 0.231 | 0.000 |
| | $X_8$ | 0.239 | 0.061 | 3.898 *** | | |
| | $X_{10}$ | 0.166 | 0.071 | 2.330 ** | | |
| | $X_{11}$ | 0.275 | 0.122 | 2.265 ** | | |

Note: ***, ** and * respectively represent that it is significant at 1%, 5% and 10% level.

(2) Vegetable greenhouse (model II). The regression result shows that the key factors affecting heavy metal pollution level of vegetable greenhouse are: agricultural technology level, member of agricultural cooperative or not, and pesticide input intensity. The following equation (Equation (5)) is established:

$$y = -2.083 - 0.341X_{16} - 0.469X_5 + 0.315X_{12} \quad (5)$$

Agricultural technology level ($X_{16}$) of rural households imposes negative effect on heavy metal pollution level of vegetable greenhouse, that is, rural households' participation in agricultural technical training is conductive to lowering the pollution level. Rural households having participated in agricultural technical training will acquire more knowledge and information on agricultural inputs and agricultural production, so that they can "just shoot the problem" in deciding the type and dosage of agricultural inputs [32], which can help to avoid excess input of agricultural chemicals containing heavy metal element. Among the investigated samples, some rural households have rich experiences in planting with arched shed or other simple shed but lack knowledge in planting and management of greenhouse vegetable emerging in recent years, so the training and guidance of related technologies (e.g.: control of greenhouse temperature and humidity, base fertilizer, top application, pesticide application rate and cycle, irrigation cycle, etc.) is of vital importance to guarantee the sustainability of vegetable cultivation.

Member of agricultural cooperative or not ($X_5$) imposes obvious negative effect on heavy metal pollution level of farmland soil, indicating that agricultural cooperative and other effective agricultural organization mode can lower the heavy metal pollution level of soil in greenhouse agriculture. The emergence of agricultural cooperative relieves or eliminates the difficulty of rural households participating in large market [47] to a certain extent, hence beneficial for rural households' acquiring large-scale returns, enhancing market competitiveness and avoiding risks. In the investigated area, some vegetable cooperatives play an important role in vegetable cultivation and selling, which improves the technological level and quality of rural households by providing technical support and consultation services to enable more scientific fertilizer (pesticide) selection and application, thus reducing or avoiding irrational agricultural input and lowering the risk of heavy metal pollution in soil.

Heavy metal pollution level of vegetable greenhouse is in direct proportion to pesticide input intensity ($X_{12}$). Repeated application of pesticide for insect and disease prevention is required in the growth cycle of vegetable, but the catalyst used in synthetic raw material of pesticide contains heavy metals like Cu, Pb, and Cr [4,48]. During pesticide spraying, there will be a part left on the ground or entering into the soil together with crop leaves, resulting in heavy metal accumulation in soil. Therefore, pesticide application rate bears a positive correlation with heavy metal pollution level of soil.

(3) Garlic land (model III). The regression result shows that application of organic fertilizer and rural households' environmental awareness are the key factors affecting heavy metal pollution level of soil in garlic land and the two factors impose positive and negative effect on the variable respectively. However, seen from the overall fitting effect of the model, observed value of F-statistics fails to pass the significance test ($p = 0.054 > 0.05$), which presents low reliability of statistical results. This may be attributed to insufficient samples of garlic land, so this model will not be analyzed.

(4) Traditional crop farmland (model IV). The key factors affecting the heavy metal pollution level of traditional crop farmland are: annual per capital income of family, land fragmentation degree and fertilizer input intensity successively. Its regression equation (Equation (6)) is:

$$y = -1.673 + 0.239X_8 + 0.166X_{10} + 0.275X_{11} \tag{6}$$

Annual household income per capita ($X_8$) imposes obvious positive effect on heavy metal pollution level of traditional crop farmland, viz. the higher the annual per capital income of family is, the higher the pollution level will be. Families with high-income level mostly acquire income by being engaged in industry or project or other part-time jobs, and relatively pay less attention to agricultural production, thus leading to irrational selection and input of agricultural means of production.

Land fragmentation degree ($X_{10}$) bears significant positive correlation with heavy metal pollution level of farmland soil, viz. in direct proportion to pollution level. As a prominent feature in traditional agricultural production of China [49], the land fragmentation may increase the production cost (labor cost, fertilizer cost, etc.) of farmers [50], which increases the dosage of heavy metal source to a certain degree and highlights the necessity of large-scale operation of land in a sense.

Fertilizer input intensity ($X_{11}$) imposes positive effect on heavy metal pollution level of traditional crop farmland, that is, the higher the fertilizer input intensity is, the higher the heavy metal pollution level will be. The commonly sold fertilizers in market of China, such as urea, superphosphate and compound fertilizer contain different levels of heavy metal element [51], and these elements may accumulate in soil along with long-term application of fertilizers. Moreover, some studies point out that fertilizer application rate in China at present is over the optimal rate in economic sense [52], and excess fertilizer application leads to heavy metal element over the standard, which aggravates the pollution.

## 5. Discussion

The existing related studies on rural households' behavior mainly analyzed the laws and problems in social and economic development of rural area at a microscopic scale, for example, rational peasant school [27] regarded peasant as the "economic man" and stressed discussing peasants' economic behavior; Shi Qinghua [28] concerned peasants' sociality and emphasizes that peasant would give equal consideration to social or collective interests while pursuing personal interests; Li Xiaojian [29] thought that peasants' behaviors were in close relation to the environment from a geographic view, etc. It can thus be seen that the existing peasants' behavior theory lacks organic connection of the production, consumption, technical application, cognition and labor supply of peasants with the environmental effect [26]. However, this study found that different planting types and planting modes had different effects on soil heavy metal pollution.

In terms of the heavy metal pollution degree of various arable soils, the pollution degree of vegetable greenhouse under intensive planting mode is relatively high due to more application of agro-chemicals and organic fertilizer—one of the reasons. Related researches indicate that some commonly used chemical fertilizer, pesticide and organic fertilizer contain different amounts of heavy metal element, and the unreasonable application of them is one of the main reasons for the increase of heavy metal content in arable soil. As a result, implementing strict control over the production standards of associated industries including livestock feed and fertilizer and promoting environment-friendly transformation of all links in the whole industry is an effective means to lower heavy metal pollution of soil.

Moreover, the regression results show that land fragmentation degree bears positive correlation with heavy metal pollution level of arable soil, which highlights the necessity of moderate scale management of arable soil. Thus, rural households are encouraged to carry out various land circulations and combine the patch into a large one. In "three powers separation" (separate setting of property, contracting right, and management right of agricultural land) proposed in the new-round land reform at the end of 2014, and "land contracting period extended for 30 years more" proposed in "The 19th National Congress of the Communist Party of China", land circulation of rural households is encouraged and important measures for moderate scale management of soil are promoted, which will further improve the environmental effect of agricultural planting. At the same time, we also find that agricultural technical training and the guidance provided by the agricultural cooperative can help rural households acquire knowledge about agricultural production and planting management. This will help rural households avoid excessive use of agro-chemicals, thus reducing the probability of heavy metal pollution in arable soil. By providing agricultural means of production, agricultural products selling, processing, transportation and storage as well as technology and information relating to agricultural production for its members, agricultural cooperative effectively realizes the merging of dispersed rural households and large market, thus improving the overall large-scale agricultural and environmental benefits. Therefore, agricultural departments at county and town levels shall strengthen the technical training on rural households, perfect the operation and management mechanism of agricultural cooperative and encourage the rural households to join in the cooperative, so as to enhance their scientific cognition and realize the modern agricultural development with equal consideration to environmental protection and quality of agricultural products.

## 6. Conclusions

Empirical analysis is performed on the impact of rural households' behaviors on heavy metal pollution of arable soil based on investigation and experiment data to obtain the following conclusions.

Rural households' land utilization mode affects soil heavy metal content, for example, heavy metal pollution degree of soil for intensive planting is higher than that of traditional planting, viz. vegetable greenhouse > garlic land > traditional crop farmland. This means that the risk of heavy metal pollution of soil is also enlarged during transformation from traditional agriculture to modern agriculture.

The higher the land fragmentation degree is, the higher the heavy metal content of soil will be. This indicates that moderate scale management of land is conductive to lowering the heavy metal content of arable soil. Under proper environmental and economic conditions, moderate scale management of land can lower the land dispersity and enable the optimal combination and effective operation of land, fund, equipment, operation management and information, hence achieving maximum economic benefit and environmental effect.

Excess application of fertilizer, pesticide and organic fertilizer by rural households may result in heavy metal pollution of soil, while agricultural technical training organized by government department can promote the technical level of rural households and enable them to be more scientific and rational in fertilizer (pesticide) selection and application, thus reducing or avoiding heavy metal pollution of soil. Meanwhile, the foundation of agricultural cooperative changes the organization mode of agricultural production.

For soils under different cropping patterns, the pollution level of heavy metal varies. Under the influences of agricultural production and other human activities, heavy metal elements Cr, Ni, Cu, Zn, Cd, and Pb in soil of the studied area accumulate to a certain extent, causing different pollution. The average $P_i$ of six heavy metals is Cd > Ni > Cu > Zn > Cr > Pb. Among them, Cd pollution frequently appears and even reaches severe level in some sampling points. As a result, various pollution reduction programs shall be developed for different crop types and heavy metal pollution levels, and measures such as formulated fertilization and adjustment to local conditions shall be adopted to achieve harmony and sustainable development of human-nature system.

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