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Heavy Metal Pollution Characteristics and Potential Ecological Risk Assessment of Surface Soil in Dawen River Basin

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Abstract. In this paper, 21 surface soil samples on both banks of Dawen River were selected for heavy metal testing and analysis. The average contents of heavy metals in soil samples in Dawen River Basin were as follows: Cr (72.3 mg/kg) > Pb (19.7 mg/kg) > As (8.80 mg/kg) > Cd (0.23 mg/kg) > Hg (0.05 mg/kg). Compared with the regional background value, the content of most heavy metals in the soil of the study area is higher. The single factor index method and Nimero comprehensive index method were used to evaluate the characteristics of heavy metal pollution in soil. The results show that the soil environment is in good condition. Potential ecological hazards of heavy metals in soil were calculated by Hakanson's potential ecological hazard index method. The results showed that 80.95% of the studied areas were slightly ecological hazards, 14.29% were moderately ecological hazards, and 4.76% were very strong ecological hazards.

1.Introduction

With the development of industry and agriculture, heavy metal pollution in the soil environment has become an important killer that restricts the sustainable use of soil, endangers the ecological environment and human health. Soil heavy metal pollution assessment and potential ecological risk assessment have become important research fields of environmental science [1-4]. In recent years, scholars at home and abroad have studied the pollution of heavy metals in soils in some areas [5-9]. Hakanson index method has also been used by many domestic workers to evaluate the potential ecological hazards of heavy metals [10-14]. However, there are few reports on the environmental quality and potential ecological hazard assessment of heavy metals in the topsoil of Dawen River basin. Fertile farmland has formed on the two banks of the Dawen River due to the siltation of river sand, commonly known as Wenyang field. Wenyang field is a famous grain high-yield land in Shandong Province, which is flat, rich in water, convenient to irrigate and fertile in soil. As the saying goes, "It is famous for its high silt in ancient, Qi and Lu will compete for Wenyang field". In recent years, with the development of economy, environmental problems have become more and more serious, and the study of heavy metal pollution in soil has become increasingly urgent. Therefore, we intend to carry out the content test and pollution assessment of heavy metals in the surface soil of the Dawen River basin, which is not only conducive to the accurate assessment of soil pollution, but also helpful for the study of soil pollution sources and ecological restoration.

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2.Materials and experimental methods

2.1 The study area and sampling

The study area is located at the southwest of Tai'an City, Shandong Province of china. It is temperate semi-humid continental monsoon climate, with four distinctive seasons, light and heat synchronous, rain and heat in the same season, so, it is suitable for crop growth. The sampling sites of this study are located on the northern and southern banks of Dawen River, including Hechakou Village, Sanjiakou New Village, Donggaoyu Village, Madongshi Village, Tianjiashi Village, Beidian Village, Xiama Village, Yuejiazhuang Village, Xinghua Village, Qijiazhuang and other 21 locations. In July 2018, mixed samples were collected by 5-point sampling method after field investigation. Sampling depth is less than 20 cm. A mixed sample is collected in one place, which is mixed into one sample by five samples evenly arranged in one sample plot. A total of 21 mixed samples are collected, named after WYT1, WYT2……WYT21. Samples collected are stored in plastic bags and brought back to the laboratory for testing after air drying.

2.2 Experimental Method

Five heavy metal elements, Cr, Pb, Cd, Hg and As, were determined by inductively coupled plasma mass spectrometry (ICP-MS). During the experiment, the sensitivity, oxide and double charge of the instrument are tuned by the tuning solution of mass spectrometer. Under the condition that the sensitivity, oxide and double charge of the instrument meet the requirements, the relative standard deviation of the signal intensity of the elements in the tuning solution given by mass spectrometer is less than 5%. Quality correction and resolution verification are carried out in the range of mass numbers covering the elements to be measured. The concentration range of internal standard is 10 ug/L.

3.The results

The five heavy metals content are shown in Table 1. The average contents of five heavy metals in soil samples in Dawen River Basin were as follows: Cr (72.3 mg/kg) 、 Pb (19.7 mg/kg) 、 As (8.80 mg/kg) 、 Cd (0.23 mg/kg) and Hg (0.05 mg/kg), the regional background value of five heavy metals are in turn: 56.20 mg/kg、25.40 mg/kg、6.30 mg/kg、0.11 mg/kg and0.03 mg/kg, so, the content of most heavy metals except Pb in the soil of the study area is higher, which indicates that the soil of the study area has been affected by human activities to a certain extent. The coefficient of variation of Hg, Pb and As are all greater than 0.3, which indicates that they are significantly affected by external interference.

Table 1. The results of heavy metals in soil of Dawen River Basin.

heavy metal （n=21）	Range （mg/kg）	average （mg/kg）	standard deviation	Coefficient of variation （%）	Soil background [22]
Cd	0.17-0.36	0.23	0.05	0.21	0.11
Pb	15.7-48.5	19.70	6.79	0.33	25.40
Cr	47-87.3	72.30	9.60	0.13	56.20
Hg	0.01-0.40	0.05	0.08	1.60	0.03
As	3.92-9.10	8.81	3.42	0.37	6.30

At present, there are many methods to evaluate the pollution of heavy metals in soil, including single factor index method and Nimero comprehensive index method (multi-factor comprehensive index method), pollution load index method, potential ecological hazard index method, environmental risk index method, and different evaluation methods. The emphasis is different. In this study, single factor index method and Nimero comprehensive index method were used to evaluate the soil environmental quality in the study area, and potential ecological hazard index method was used to evaluate the ecological hazards of heavy metals in the study area.

4.Assessment of Heavy Metal Pollution in Soil and Ecological Risk Assessment

Single factor pollution index method and comprehensive pollution index method are commonly used in soil environmental quality assessment [15-19].

4.1 Style and spacing Heavy Metal Pollution Assessment

4.1.1 Evaluation Method and Criteria. For the single factor pollution index method, the small value of the pollution index indicates that the pollution degree is lighter, and vice versa, it is heavier. The formula of single factor pollution index evaluation method is as follows：

$$P_i=C_i/S_i$$

Among this Formula：P_i is the single pollution index of pollutants; C_i is the measured data of pollutants; Si is the evaluation standard of pollutants. If $P_i \leqq 0.7$, the soil environment is in a clean and safe state; $0.7 < P_i < 1.0$, soil environmental quality is basically clean； $1.0 < P_i < 2.0$; soil pollution is slight； $2.0 < P_i < 3.0$， Soil Pollution is moderate； $P_i \geq 3.0$, soil pollution is heavy.

The Nimero pollution index method was used to evaluate the comprehensive pollution. The Nimerow pollution index method (N.C. Nemerow) reflected the comprehensive pollution degree of various pollutants on the soil environment, highlighted the impact of high concentration pollutants on the soil environmental quality. The calculation formula was as follows:

$$P_N=[(P^2_i+P^2_{i(max)})/2]^{1/2}$$

Among them, P_N is the comprehensive pollution index of soil, P_i is the average value of each pollutant in soil, and P_i (max) is the maximum pollution index of single pollutant in soil. The classification standard is the same as that of single factor index method.

To ensure agricultural production and maintain human health, the limit value of heavy metals in soil is set. Soil quality basically does not cause harm and pollution to plants and the environment in the limit. Now, two Standards of "Standard for Risk Control of Soil Pollution in Agricultural Land of Soil Environmental Quality (Trial Implementation) (GB15618-2018)" and "Standard for Risk Control of Soil Pollution in Construction Land of Soil Environmental Quality (Trial Implementation) (GB36600-2018)" began to be implemented in 2018, we chose "Standard for Risk Control of Soil Pollution in Construction Land of Soil Environmental Quality (trial implementation) (GB15618-2018) " [20] as the evaluation standard. In this document, the evaluation criteria for paddy fields and other sites are different. Because the main soil vegetation in this study area is arid land, we chose the standard of no-paddy fields to use. and the content of heavy metals in soil is obviously affected by the PH. The measured values of soil PH in this study area are all greater than 7.5, so the soil quality standard of PH > 7.5 is chosen. In short, Standard values that meet the conditions of the study area from GB15618-2018 are Cr (250 mg/kg) 、 Pb (170 mg/kg) 、 As (25 mg/kg) 、 Cd (0.6 mg/kg) and Hg (3.4 mg/kg).

4.1.2 Results of Heavy Metal Pollution Assessment. The results of soil heavy metal pollution assessment in Dawen River Basin are shown in Table 2. The results of single factor pollution index method show that except for Zhengjiazhuang (WYT-21) with As pollution (P_N=0.76), environment of all the other places is clean and safe. The comprehensive pollution index evaluation results showed that the soil pollution index in the study area was all within the range of $P_N<0.7$($0.23<P_N<0.59$), which means the soil environment clean and safe. In short, farmland in the Dawen River basin is largely free from heavy metal pollution.

4.2 Potential ecological risk assessment

Table.2 Assessment of heavy metal pollution in soil of Dawen River Basin

Sampling point	Individual pollution index					Evaluation result	Comprehensive Pollution Index	Evaluation resul
	Cr	Pb	Cd	Hg	As			
WYT-1	0.34	0.11	0.32	0.01	0.42	Clean and safe	0.34	Clean and safe
WYT-2	0.35	0.11	0.37	0.02	0.49	Clean and safe	0.39	Clean and safe
WYT-3	0.33	0.11	0.35	0.01	0.37	Clean and safe	0.31	Clean and safe
WYT-4	0.31	0.10	0.30	0.01	0.48	Clean and safe	0.38	Clean and safe
WYT-5	0.30	0.10	0.33	0.01	0.32	Clean and safe	0.28	Clean and safe
WYT-6	0.30	0.11	0.30	0.01	0.40	Clean and safe	0.32	Clean and safe
WYT-7	0.28	0.09	0.35	0.01	0.57	Clean and safe	0.44	Clean and safe
WYT-8	0.31	0.10	0.50	0.01	0.27	Clean and safe	0.39	Clean and safe
WYT-9	0.29	0.12	0.60	0.01	0.33	Clean and safe	0.47	Clean and safe
WYT-10	0.29	0.13	0.60	0.12	0.40	Clean and safe	0.48	Clean and safe
WYT-11	0.29	0.11	0.40	0.01	0.27	Clean and safe	0.32	Clean and safe
WYT-12	0.24	0.10	0.40	0.01	0.27	Clean and safe	0.32	Clean and safe
WYT-13	0.29	0.10	0.28	0.00	0.16	Clean and safe	0.23	Clean and safe
WYT-14	0.31	0.10	0.43	0.01	0.25	Clean and safe	0.34	Clean and safe
WYT-15	0.30	0.10	0.43	0.01	0.30	Clean and safe	0.35	Clean and safe
WYT-16	0.33	0.11	0.32	0.01	0.28	Clean and safe	0.28	Clean and safe
WYT-17	0.25	0.10	0.32	0.01	0.25	Clean and safe	0.26	Clean and safe
WYT-18	0.27	0.11	0.37	0.01	0.30	Clean and safe	0.30	Clean and safe
WYT-19	0.19	0.11	0.37	0.01	0.26	Clean and safe	0.29	Clean and safe
WYT-20	0.25	0.12	0.37	0.01	0.25	Clean and safe	0.29	Clean and safe
WYT-21	0.26	0.29	0.40	0.04	0.76	basically clean	0.59	Clean and safe
average	0.39	0.12	0.29	0.02	0.35			

4.2.1 Evaluation Method and Criteria of Potential Ecological Hazard Index. In 1980, Swedish scholar Hakanson established a set of methods to evaluate heavy metal pollution and ecological hazards by applying sedimentological principles, namely, potential ecological hazard index method. Compared with other evaluation methods, this method is mainly based on the characteristics of heavy metals and environmental behavior. From the sedimentological point of view, it proposes a method to evaluate heavy metals pollution in soil or sediment. This method not only considers the content of heavy metals in soil, but also links the ecological and environmental effects of heavy metals with toxicology. It is evaluated by comparable and equivalent attribute index classification method. Therefore, the potential ecological hazard index method proposed by Swedish scholar Hakanson [21] is used to evaluate the ecological risk, which is based on the toxicity level of various heavy metals and the sensitivity of organisms to their pollution. The toxicity level of heavy metals was Hg > Cd > As > Pb > Cr. The range of toxicity response coefficient was Hg = 40, Cd = 30, As = 10, Pb = 5, Cr = 2. The formula for calculating the ecological risk index is as follows:

$$C^i_f = C_d^i / C^i_r$$

$$E^i_r = T^i_r C^i_f$$

$$RI = \Sigma E^i_r$$

In the formula, C^i_f is the single metal pollution coefficient; C_d^i is the measured value of Dawen River Basin; C^i_r is the background reference value of heavy metals in Shandong Province; T^i_r is the

response factor of different metals' biological toxicity; E^i_r is the single metal potential ecological risk factor; RI is the potential ecological risk index of poly metals. In order to reflect the regional characteristics, the background value of heavy metals in Shandong Province (Table 1) was selected as the comparative object [22]. Potential ecological hazard index method is used to classify pollution degree as shown in Table 3. The evaluation results are shown in table 4.

Table.3 Pollution degree classification standard of potential ecological hazard index method

E^i_r	Pollution level	RI	Hazard level
＜40	Slight ecological hazard	＜150	Minor ecological damage
40~80	Moderate ecological hazard	150~300	Moderate ecological damage
80~160	Strong ecological hazard	300~600	Strong ecological damage
160~320	Very strong ecological hazard	≥600	Very Strong ecological hazards
≥320	Extremely strong ecological hazard		

*4.2.2 Potential Ecological Risk Assessment of Soil.*As can be seen from Table 4, the potential ecological hazard index(E^i_r) of heavy metals Hg > Cd > As > Pb > Cr is less than 80 in most locations, which belongs to slight and medium ecological hazards. *The average of RI is* 157.17, Which means that the soil environment in most places is slight ecological hazard. few locations (three locations) belong to strong ecological hazards and only one place belong to very strong ecological hazards. Among the potential ecological hazards index of polymetallic, 80.95% of the areas are slight ecological hazards, 14.29% are moderate ecological hazards, 4.76% are serious ecological hazards, and the whole is slight potential ecological hazards. Comparing the results with the early environmental investigation around the sampling sites, it is found that the areas with moderate and serious ecological hazards are surrounded by factories and industrial waste outlets or near rural residential areas. Through field investigation and speculation, it is considered that the dust and sewage discharged from factories in this area are one of the important sources of heavy metal pollution in Wenyang field. At the same time, poor infrastructure of rural life, imperfect disposal of household garbage and human activities such as fertilization and irrigation are also the reasons why heavy metal pollutants enter farmland [23-24]. Heavy metal potential ecological hazard index and polymetallic potential ecological risk index are generally small, but some areas have higher ecological hazards, which should be paid attention to and strengthened management.

5. Conclusion

(1) The average contents of heavy metals in soil samples in Dawen River Basin were as follows: Cr (72.3 mg/kg) > Pb (19.7 mg/kg) > As (8.80 mg/kg) > Cd (0.23 mg/kg) > Hg (0.05 mg/kg). Compared with the regional background value, the content of most heavy metals in the soil of the study area is higher, which indicates that the soil of the study area has been affected by human activities to a certain extent. The coefficients of variation of Hg, Pb and As are all greater than 0.3, which is a strong variation, indicating that their contents are quite different.

(2) The results of single factor index evaluation of heavy metals showed that the pollution degree was Cr > As > Cd > Pb > Hg in turn. The Cr, Cd, Pb and Hg in soil samples were not polluted. Most of As samples were clean and safe, and only 0.05% were on alert. The evaluation results of Nimero comprehensive index show that the soil environment is in good condition.

(3) The potential ecological hazard of soil heavy metals in the study area was calculated by the potential ecological hazard index method. The overall performance of the area was considered as a slight potential ecological hazard. The percentage of minor ecological hazards, moderate ecological hazards and serious ecological hazards were 80.95%, 14.29%, 4.76%. The construction of ecological restoration projects should be strengthened to reduce environmental damage and pollution caused by industrial production and human activities.

Table.4 Evaluation results of potential ecological hazards of heavy metals in soil of Dawen River Basin

Sampling site	E^i_r					RI	Evaluation result
	Cr	Pb	Cd	Hg	As		
WYT-1	3.07	3.70	52.78	40.00	16.51	116.05	Slight ecological hazard
WYT-2	3.11	3.78	61.11	89.66	19.37	177.02	Moderate ecological hazards
WYT-3	2.94	3.66	58.33	27.59	14.86	107.38	Slight ecological hazard
WYT-4	2.76	3.35	50.00	49.66	19.21	124.97	Slight ecological hazard
WYT-5	2.65	3.43	55.56	49.66	12.62	123.90	Slight ecological hazard
WYT-6	2.65	3.56	50.00	48.28	15.87	120.36	Slight ecological hazard
WYT-7	2.48	3.09	58.33	37.24	22.70	123.84	Slight ecological hazard
WYT-8	2.77	3.39	83.33	45.52	10.81	145.82	Slight ecological hazard
WYT-9	2.59	4.17	100.00	37.24	12.97	156.97	Moderate ecological hazards
WYT-10	2.59	4.39	100.00	550.34	15.87	673.20	Very strong ecological hazards
WYT-11	2.59	3.62	66.67	44.14	10.71	127.73	Slight ecological hazard
WYT-12	2.14	3.25	66.67	26.21	10.76	109.02	Slight ecological hazard
WYT-13	2.54	3.29	47.22	15.17	6.22	74.45	Slight ecological hazard
WYT-14	2.75	3.46	72.22	35.86	9.95	124.26	Slight ecological hazard
WYT-15	2.68	3.35	72.22	38.62	11.86	128.72	Slight ecological hazard
WYT-16	2.96	3.74	52.78	60.69	11.13	131.29	Slight ecological hazard
WYT-17	2.22	3.27	52.78	33.10	9.81	101.18	Slight ecological hazard
WYT-18	2.38	3.84	61.11	49.66	11.97	128.96	Slight ecological hazard
WYT-19	1.67	3.60	61.11	24.83	10.13	101.34	Slight ecological hazard
WYT-20	2.20	3.96	61.11	38.62	10.02	115.91	Slight ecological hazard
WYT-21	2.28	9.55	66.67	179.31	30.32	288.12	Moderate ecological hazards
average	2.57	3.88	64.29	72.45	13.98	157.17	

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