ORIGINAL ARTICLE

The longitudinal translocation characters and the influencing factors of Hg, Cd in the soil

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Abstract

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Combining the methods of simulation test and field survey, the longitudinal distribution and the influencing factors of Hg and Cd in the profile in the typical sewage irrigation area were studied in this paper and the result shows: (1) the content distribution of Hg, Cd in the superficial soil profile was higher than that in the bottom and the content decreased with the increase of the depth, the translocation ability of the Hg, Cd in the garden mould and cinnamon soil were lower than that in the paddy soil and fluve-aquic soil, the longitudinal translocation ability of the Cd in the soil profile was stronger than that of Hg; (2) Hg was accumulated in the different soil and has the highest accumulation rate in the paddy soil and the lowest in the cinnamon soil; the translocation order of the Cd in the different was: garden mould > paddy soil > cinnamon soil > fluve-aquic soil; (3) the concentration of Hg, Cd in the soil leacheate increased with the concentration increase of Hg, Cd in the sewage, the migration rate increased with the roughness of the soil quality and decreased with the increase of pH and soil organic matter.

Key words : heavy metal, soil contamination, translocation

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บทคัดย่อ

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ลักษณะการเคลื่อนที่ในแนวดิ่งและปัจจัยที่มีผลต่อ Hg และ Cd ในดิน

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จากผลการศึกษาลักษณะการกระจายในแนวดิ่งและปัจจัยที่มีผลต่อสารปรอทและแคดเมียมในชั้นดินของพื้นที่ที่ใช้น้ำเสียในการชลประทาน โดยวิธีการทดสอบการจำลองสภาพความเป็นจริง (simulation test) และการสำรวจทดลองในแปลงร่วมกัน พบว่า (1) ปริมาณการกระจายของสารปรอทและแคดเมียมในชั้นดินบนจะสูงกว่าในชั้นดินล่าง และปริมาณจะลดลงตามความลึก ความสามารถในการเคลื่อนที่ของสารปรอทและแคดเมียมในดิน garden mould และดิน cinnamon จะต่ำกว่าในดิน paddy และดิน fluve-aquic โดยที่สารแคดเมียมจะมีความสามารถในการเคลื่อนที่ตามแนวดิ่งในชั้นดินได้ดีกว่าสารปรอท (2) สารปรอทจะสะสมในดินต่างชนิดกัน โดยมีอัตราการสะสมสูงที่สุดในดิน paddy และต่ำที่สุดในดิน cinnamon ส่วนสารแคดเมียมจะมีการเคลื่อนที่ในดินแตกต่างกันโดยเรียงตามลำดับ ดังนี้คือ ดิน garden mould > ดิน paddy > ดิน cinnamon > ดิน fluve-aquic (3) ความเข้มข้นของสารละลายปรอทและแคดเมียมจะเพิ่มขึ้นตามปริมาณความเข้มข้นที่เพิ่มขึ้นของสารปรอทและแคดเมียมในน้ำเสีย และอัตราการเคลื่อนย้ายจะเพิ่มขึ้นตามคุณภาพของความหยาบความละเอียดของเนื้อดิน และลดลงเมื่อความเป็นกรดเป็นด่างและปริมาณอินทรียวัตถุที่เพิ่มขึ้น

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Hg and Cd are the common exist contaminated heavy metals elements in the environment. They are occupied high proportion in the soil of the sewage irrigation area. In the sewage irrigation condition because of the kinetic action of waters, it always lead to the longitudinal translocation of the contaminants in the soil profile and the sewage can pass through the different qualities of the moisture content and infiltrated into the ground, thus they bring contamination to the sewage irrigation area as well as the source of drinking water of the cities. There are some researchers reported that 60 percent of the soil and almost the shallow ground water in every sewage irrigation area in Huabei are suffered from different levels of water pollution. (Zhaochang, 1990).

Several researches indicated that (Senzhao, 1995) the groundwater of the areas that irrigated with sewage long term may be contaminated with SO_4^{2-}, Cl^- and NO_3^-. For the heavy metals, it still had disputed that if they can contaminate to ground water or not. According to the different characteristics of the movement and translocation of the contaminations and transported contaminants. The second one are easily contaminate to soil biosphere and ground water. Zenglu (1992) considered that the intensity of the contamination entering the ground water decided on the soil water composition, the contaminating way of the contamination and the area hydrographic geology condition. From the soil environment capacity aspect, he analysed the influences of heavy metals to ground water in five soils: terra near (black soil), sie rozem, yellow brown earth, red brown soil and purple soil. He concluded that the heavy metals can contaminate ground water and the effects of heavy metals of different soil types on ground water is different. Shangping and Taoshu (1999) researched the longitudinal translocation pattern of the 13 micro-elements of Tianjin District soil. Most researchers (Piccolo, 1992 and Robert, 1985) considered that the heavy metals accumulated in the 0-20 cm plough layer of the soil and with decrease in longitudinal downward, but there were reported that the ground water of the sewage irrigation areas are suffered from heavy metals contaminations (Zhaochang, 1990 and Jingwen, 1992).

It was known that it is very difficult to bring the contaminated ground water under control. Therefore, it is necessary to research the longitudinal translocation characteristics of the heavy metals in the soil ground water in the sewage irrigation conditions in order to control the sewage irrigation and protect the water-soil environment. Although several learners considered that after the heavy metals got into the soil because of the stationary and the adsorption of the organic matter, it caused the heavy metals concentrated at the plough layer 0-20 cm which were difficult to move downward. However, it is different in sewage irrigation area with different sewage water quality, hydrographical geology condition and different soil physics and chemical quality. It is the way to control the sewage irrigation to arouse ground water contamination that master the possibility of the heavy metals to pollute ground water. This paper concentrated that the distribution characteristics of Hg and Cd content in the soil profile in the sewage irrigation area of Taiyuan, China by the filed survey and the method of simulation soil column test, hence to study the factors effecting the longitudinal translocation of Hg and Cd in the soil profile.

Matetials and Methods

Background of the sewage irrigation area

The Taiyuan's sewage irrigation area is located on the north of Taiyuan Basin in the middle of Shanxi province, north .latitude 37º32'-38º01' and east longitude 112º25'-112º39'.This territory is surrounded by mountains on three sides. The land altitude decreased from north to south, ranging between 760-820 m above the sea level. The geomorphic features of the studied zone are of three types: diluvial slanted plain in the west.; fluvial plain on both shores of the Fen River in the middle; diluvial fluvial plain in the east. It generally is very vast and even and the degree of slope is 0.4º-1º.

The sewage irrigation area is located at Taiyuan Basin, which is a typical cenozoic clevage basin, the watering rock group must be divided into three levers: the upper-level, the middle-level and the lower-level of the quaternary Rejuvenation sandy lay and sandy-gravel lay. There are four types of the ground water : karst water of carbonatite fissure, crevice water of carbonatite clastic rock fissure, crevice water of clastic rock and void water of loose rock . The replenishing sources of ground water included atmospheric precipitation infiltration ,country rock water lateral inflow the surface water and the irrigation water infiltration.

Simulation Test

1. Sampling and Analytical Method

The experimental soil and water were collected in Taiyuan's sewage irrigation area.

Soil physical and chemical properties including pH, O.M, CEC, Capacity and Mechanical Composition were determined with the routine methods described by State Environmental Protection Administration of China (2002). The obtained data are shown in Table 1.

Water properties including Hg: 0.006 mg/kg; Cd: 0.0034mg/kg; pH 7.4; COD_{cr}:176.2 mg/kg were determined with the routine methods described by State Environmental Protection Administration of China (2002).

Table 1. The physical and chemical properties of the experimental soil

Soil type	< 0.01mm particle seize (%)	capacity (g/cm^3)	O.M (g/kg)	pH	CEC (cmol/kg)	Hg (mg/kg)	Cd (mg/kg)
Fluve-aquic	35.0	1.31	24.1	8.3	11.0	0.102	0.22
Cinnamon	41.6	1.40	13.7	8.5	12.8	0.083	0.18

2. Simulation test Details

1) The simulation test of different irrigation water, different concentration of Hg,Cd and different pH, to study the influences of Hg, Cd content and pH of the sewage on the longitudinal translocation.

2) The simulation test of the soil pH, soil properties and the organic matter content, to study the influences of soil specific properties on the translocation of Hg, Cd in the soil profile.

The soil samples were air-dried, ground to pass though 2 mm, added the soil to the plastic column and then used the water to pack soil and the height of the soil was 80 cm. The length of soil column is 100 cm, the diameter is 15 cm, added the height of soil is 80 cm. The details of soil column test as follow:

1. Take out the sewage from the sewage irrigation water, then added the clean water to make the different concentration of the irrigation water, used dilute-acid or dilute-alkali to adjust the pH of the wastewater.

2. Take out the soil which the content of clay is higher, then added the sand grain to imitate the different soil texture.

3. Take out the soil with the different contents of organic matter to get the different organic matter concentration to make the soil column test.

Analytical Method

Soil: - Total Hg of the soil samples was extracted by digestion with concentrated HNO, HSO(1:1) and KMnO. A sequential extraction procedure (Rukun, 2002) was used to determine the distribution of different Hg fractions in the soil. Extracted Hg was determined by a Hg-meter with cold atom fluoroscopic spectrum (CVAFS) methods.

- Total Cd of the soil samples was extracted by digestion with concentrated HCl, HNO and HClO. Extracted Cd was determined by a Cd-meter with cold atom fluoroscopic spectrum methods.

Water: -Total Hg of the water samples was extracted by digestion with concentrated HNO, HSO(1:1) and KMnO. A sequential extraction procedure (State Environmental Protection Administration of China, 2002) was used to determine the distribution of different Hg fractions in the water. Extracted Hg was determined by a Hg-meter with cold atom fluoroscopic spectrum (CVAFS) methods.

-Total Cd of the water samples was extracted by digestion with concentrated HCl, HNO and HClO. Extracted Cd was determined by a Cd-meter with cold atom fluoroscopic spectrum methods. (State Environmental Protection Administration of China, 2002)

Analysis Results

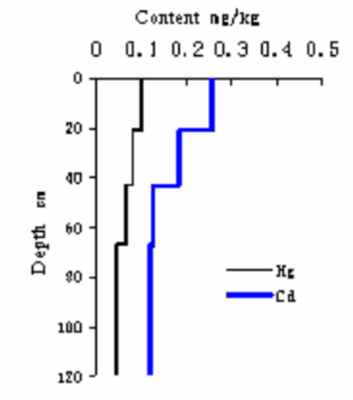
The longitudinal distribution of Hg, Cd in the soil

1. The distribution of Hg, Cd in the soil profile

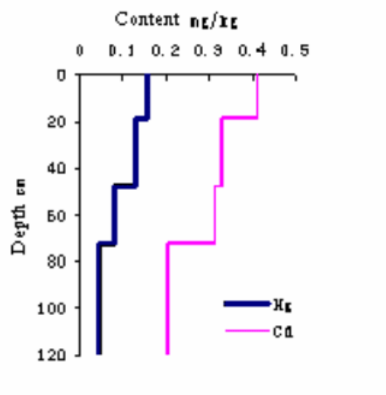
In Figure 1 is the trend of typical distribution characteristics of heavy metals Hg,Cd in the soil profile of Taiyuan sewage irrigation area are basically identical. The content distribution of Hg,Cd in the top soil profile was higher than that in the bottom and the content decreased with the increase of the depth. The rate of decrease of Cinnamon soil was quicker than Fluve-aquic soil. The contamination of the same element was very high at the upper soil layer and increase with depth when it moved downward at about 60 cm. Below 60 cm, the change of Hg,Cd content in the soil profile of sewage irrigation area is small.

2. The different longitudinal translocation characteristics of Hg, Cd in different soils

The absolute content of heavy metals in soil is determined by the content of soil-forming parent material and the amount of external input (sewage irrigation, fertilization, atmosphere dust etc.) As to Taiyuan sewage irrigation area, the type of soil-forming parent material is alluvial parent material and loessial parent material. The content of heavy metals in the type of soil-forming parent material was little. So, the effect of parent material on soil heavy metals content is little and the distribution of longitudinal translocation of heavy



a. cinnamon soil
(the soil belong to Alfisols in ST,1999)



b. fluve-aquic soil
(the soil belong to Entisols in ST,1999)

Figure 1. The content distribution of Hg,Cd in two typical soil profile

Table 2. The longitudinal translocation characteristics of heavy metals Hg ,Cd in different soils

Soil types	Soil layers	Hg	Cd
Fluve-aquie	A /C	1.29	1.01
	B /C	1.07	0.73
Cinnamon	A /C	2.52	1.20
	B /C	1.53	0.95
Paddy	A/ C	1.24	0.82
	B /C	1.36	0.87
Garden mould	A /C	2.14	1.10
	B /C	2.32	0.91

A: leached horizon, eluvial horizon (the depth of the soil is 0-20 cm from the surface soil)
B: illuvial horizon (the depth of soil is 20-40 cm)
C: parent material horizon (the depth of soil is 40-60 cm)

metal elements in the soil can reflect the process of the heavy metals that imported by external sources and sewage infiltrated into the soil. Because the content of heavy metals in soil-forming parent material and the amount of external inputs (sewage irrigation, fertilization, atmospheric dust etc.) determine the absolute content of heavy metals in the soil.

Table 2 shows the ratio of the average content of heavy metals Hg, Cd in A and B layers of different soils and the corresponding content of C layer of Taiyuan sewage irrigation area. These ratios were reflecting the different longitudinal translocation characteristics. Except the ratio of Cd content in A and C layers of paddy soil was less than 1, the ratios of Hg, Cd content in A/C layer of the rest were more than 1. It was shown that the heavy metal elements were easier to enrich in the A layer (top soil layer). The ratio of Hg, Cd elements in A/C layer of soils were cinnamon soil > garden mould > fluve-aquic soil > paddy soil. This illustrated that the longitudinal translocation ability of the heavy metals Hg, Cd elements in the paddy soil was higher than the rest of the three soils. The ratios of Hg, Cd content in B/C layer of soils were Hg: garden mould > cinnamon soil > paddy soil > fluve-aquic soil; Cd: cinnamon soil > garden mould > paddy soil > fluve-aquic soil. It indicated that the longitudinal translocation ability of Hg,Cd in garden mould and cinnamon soil were lower than that in the paddy soil and fluve-aquic soil; especially the ratios of Cd content in B/C layer of fluve-aquic soil, paddy soil, cinnamon soil and garden mould were less than 1. It showed that the longitudinal translocation ability of Cd in the soil profile was stronger than that of Hg.

The translocation and accumulation of Hg, Cd in different soils

The intensity of translocation of the soil elements was marked by the translocation rate of the soil elements. To study further about the intensity of translocation of two heavy metals: Hg and Cd in different soils of sewage irrigation area by using the following equation to calculate the rate of translocation of elements in the soil profile, the calculated results as shown in Table 3.

$$y_x = \left[\left(\frac{a_x}{D_x} - 1\right) + \left(\frac{b_x}{D_x} - 1\right)\right] \times 100 \qquad (1.1)$$

$$\bar{y}_x = \frac{1}{n}\sum_{i=1}^{n} y_{xi}$$

a_x the content of x element in A layer
b_x the content of x element in B layer
D_x the abundance of x element in parent rock
y_x the translocation rate or accumulation rate of x element in the soil profile
$\bar{y}_x$ the average translocation rate or accumulation rate of x element in each soil
n the numbers of the soil profile

In the equation (1.1) positive yx indicated the accumulation rate, negative yx indicated the translation rate. (Shuiquan, 1990)

From Table 3 shows that Hg was accumulated in different soils of the swage irrigation area and has the highest accumulation rate in paddy soil and the lowest in the cinnamon soil; Cd was translocated in different soils of the swage irrigation area and has the translocation order was garden mould > paddy soil > cinnamon soil. It showed that expect the influence of the nature heavy metal itself, the specific property of soil was the important influence of the translocation of the heavy metals.

The influencing factor of the translocation and leaching of Hg Cd in soil

1. The affection of irrigated water quality

With the concentration of Hg, Cd in the irrigated water increasing of the concentration of dissolved Hg, Cd in the soil column (Table 4). The concentration of Hg, Cd in the the irrigated water was extened the same multiple, the absolute increasing of dissolved Cd concentration is much higher than Hg. This illustrated that the downward translocation of Cd in soil was easier than Hg.

Except the concentration of Hg, Cd in irrigated water, pH of the irrigated water is also the factor that effecting the translocation of Hg, Cd in the soil leaching and translocation. From Figure 2 was clearly shown that the trend of the irrigation rate of Hg, Cd was decreased pH from

Table 3. The rate of translocation and accumulation of Hg, Cd in different soils (%)

Element \ Soil	Fluve-aquic	cinnamon	Paddy soil	Garden mould	Average
Hg	132	128	1040	596	474
Cd	-33	-27.4	-86	-111.2	64.5

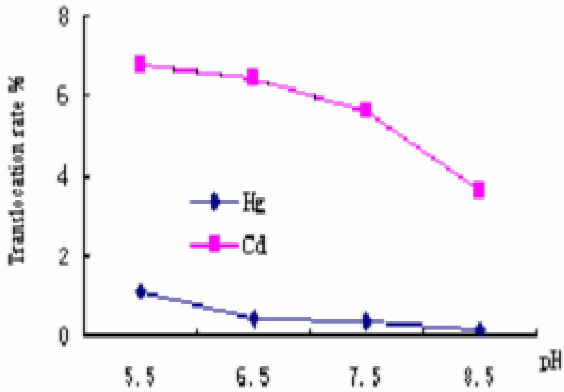


Figure 2. The effect of pH of irrigated rates on the translocation of Hg and Cd

Table 4. The different content of dissolved Hg, Cd in the different concentration of irrigated water

Cdconcentration in irrigated water (mg/L)	0.0005	0.005	0.05	0.5
Dissolved Cdcontent (mg/L)	0.008	0.014	0.015	0.022
Hgconcentration in irrigated water (mg/L)	0.0001	0.001	0.01	0.1
Dissolved Hgcontent (µg/L)	0.182	0.191	0.370	0.98

Table 5. The migration rate(%) of Hg, Cd in different soil texture of the soil columns

Texture	Loam	Sandy loam	Fine sand	Sand
Hg concentration (µg/L)	0.754	0.978	1.043	1.230
Hg migration ratio (%)	1.29	1.67	1.78	2.11
Cd concentration (mg/L)	0.032	0.031	0.0283	0.0286
Cd migration ratio (%)	6.4	6.2	5.66	5.67

5.5 to 8.5 of irrigation water. As the same, the decreased rate of translocation of Cd was higher than Hg.

2. The affection of soil texture

Soil texture is another important factor that influences the translocation of the elements in the soil. The results of simulation test of different soil texture of the soil columns as shown in Table 5. It indicated that the concentration of dissolved Hg, Cd of the soil columns was increased with the roughness of the soil. The trend of migration rate of Hg, Cd was quite the same. The concentration of dissolved Hg of the soil columns was increased with the decreased of the content of soil clay. It was shown that the soil clay has adsorption and retention to Hg. The migration order of four different soil columns was: sand > fine sand > sandy loam>loam. The irrigation rate of Hg in the sand soil is the highest and the vary trend of Cd is not obviously because the difference of soil clay in different soil columns was small. The soil texture is much claier than others that can prevent the heavy metals contamination from contaminating ground water.

3. The affection of the soil organic matter

The concentration of dissolved heavy

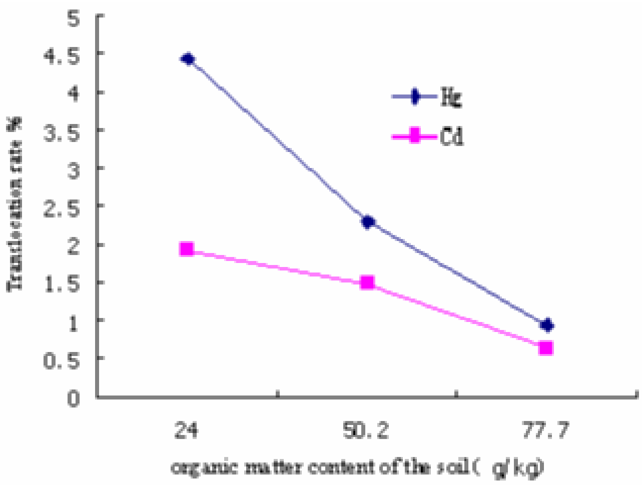


Figure 3. The effect of soil organic matter on the translocation of Hg and Cd

metals Hg, Cd from the soil column was decreased with the higher soil organic matter (Figure 3). The concentration of dissolved Hg, Cd of the different organic matter content of the soil columns was obviously different. It showed that organic matter has the stronger capacity of adsorption and chelation to Hg, Cd. There are hydroxyl radical, amino etc. in the organic matter which can form stable complexation or chelation with Hg, Cd, it leads to that the higher organic matter of the soil has the lower of dissolved Hg, Cd in the soil. The migration rate of Hg, Cd of the three soil columns was higher with the decrease of soil organic matter of the soil columns.

Conclusion

1. The content distribution of Hg and Cd of different soil profile was higher in the top than that in the bottom. It was clearly shown that the accumulation of Hg and Cd was at the top soil layer. The translocation ability of Hg and Cd was different in different soils and the translocation order was: paddy soil > fluve-aquic soil > garden mould > cinnamon soil.

2. The translocation and accumulation characteristics of Hg and Cd was different in different soils. The content of Hg in the four different soils indicated that the accumulation phenomenon and the accumulation order was: paddy soil > garden mould > fluve-aguic soil > cinnamon soil.

3. The influence of the translocation of Hg and Cd in the soil of sewage irrigation area are pH, heavy metal content, soil texture and soil organic matter. The migration rate of Hg and Cd increased with the concentration increase of Hg and Cd in the sewage and increased with the roughness of soil texture and decreased with the increase of pH and soil organic matter.

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