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Characteristics analysis of the heavy metal content in wheat irrigation water systems in Xiaoxian county, China

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ABSTRACT

An integrated approach of pollution evaluation indices, correlation cofficient analysis and box plot analysis was employed to evaluate the intensity and sources of pollution in wheat irrigation water of Xiaoxian county in China. Lead(Pb), cadmium(Cd), chromium(Cr), arsenic(As),mercury(Hg) levels in most of the samples do not exceed the national standards that only Hg level of 3 samples which is Qinglong town,Jiudian town and Dulou town exceed. The average content of Pb, Cd, Cr, As, Hg is respectively 16.33μg/L, 7.29μg/L, 6.69μg/L, 4.45μg/L, 0.41μg/L. Using the method of single factor index and the Nemero index, the quantitative proportion of good level is 65.22% that shows the quality of wheat irrigation water in Xiaoxian county has no harm to agricultural production. The Nemero index (I) shows strong correlations with Hg that the correlation coefficient is 0.946,and gives a better assessment of pollution levels. The key metal contributing to the computed indices is Hg. There are regional differences in the content of heavy metals, especially Hg. The box plot analysis suggest that the wheat irrigation water in Qinglong town,Jiudian town and Dulou town is contaminated by anthropogenic such as mineral activity. The pollution status of wheat irrigation systems in the study area are of great environmental and health concerns.

Key words: Irrigation water; Wheat; Heavy metal; Xiaoxian county; Nemero index.

KEYWORDS

Irrigation water; Wheat; Heavy metal; Xiaoxian county; Nemero index.

INTRODUCTION

Heavy metals such as lead(Pb), cadmium(Cd), chromium(Cr), mercury (Hg) and arsenic(As) and so on, have significant biological toxicity. Heavy metals also have the characteristics of high stability, difficult degradation and accumulation. Heavy metals of irrigation water not only affect the safety of agricultural products quality, but also seriously affect people's health which enter human body through the food chain[1,2]. Heavy metals pollution in irrigation water have become a serious water environmental problem which seriously affect the development of the agricultural economy and ecological security[3].

Xiaoxian county is located at between 33°56'~34°29' north latitude and 116°31'~ 117°12' east longitude, with a total area of 1885 km^2. There are 23 towns under the Xiaoxian county. They are Longchen town (T1), Huangkou town (T2), Yanglou town (T3), Liutao town(T4), Xinzhuang town (T5), Yanji town (T6), Dulou town (T7), Wangzhai town (T8), Zulou town (T9), Dingli town(T10), Baitu town (T11), Majing town(T12), Zhangzhuangzhai town (T13), Zhaozhuang town (T14), Yonggu town (T15), Qinglong Town (T16), Datun town(T17), Guanqiao town (T18), Quanxiang town(T19), Jiudian town (T20), Shilin town(T21), Sunweizi town (T22) and Zhuangli town (T23). The main food crops is wheat in Xiaoxian county that is the national important planting base of high quality wheat. Xiaoxian county has been designated as a special high-quality strong gluten wheat area by the Ministry of agriculture. The total area of wheat is about 786.7km^2, the average single yield can reach 604500kg/km^2 and the total yield is up to 475.54 million kg. The production base of high-quality wheat which is 200km^2 has been identified as the national standardization of green food production base by the Ministry of agriculture. Xiaoxian county is a typical temperate continental climate and has distinctive seasonal characteristics. The average annual temperature is 14.4ºC and the average annual rainfall is 811.2 mm. Irrigation water source in Xiaoxian county is mainly shallow groundwater.

The present study assesses the heavy metal concent in wheat irrigation water in Xiaoxian county,China. Pollution indices and different multivariate approaches are used to identify the pollution status and probable sources of pollutants in the study area.

MATERIALS AND METHODS

Sample collection and elemental analyses

In a typical sampling points in each towns, samples of irrigation water were collected in the depth of 20cm-50cm below water, with adding HNO_3 to keep stability, and then filtered with 0.45μm membrane, sealed and stored at 4ºC. With samples digestion using HCl-HNO_3-HF-$HClO_4$, the method of ICP-AES was accepted to determine the content of heavy metals. The accuracy and precision of the ICP-AES method were verified by triplicate analyses of standard reference material. All experimental data measured three times and averaged to ensure the accuracy were processed with Origin software and SPSS software.

Evaluation methods and standards

In this study, the method of single factor index(I_i) and the Nemero index(I) is selected to evaluate the characteristics of heavy metal content. The single factor index method can determine the main heavy metal pollutants and hazard degree by the evaluation of each single heavy metal. The Nemero index method is a prominent maximum weighted multi-factor environmental quality index, it can have a comprehensive evaluation of the heavy metal content and highlight the serious pollution of heavy metal pollutants.

The method of single factor index is calculated as follow:

$$I_i = \frac{C_i}{S_i} \quad (1)$$

Where I_i is the single factor index of the i pollutant, C_i(mg/L) is the heavy metal content in the i, S_i(mg/L) is standard limits of the i pollutant. When $I_i \leq 1$,it indicates the irrigation water is not contaminated by heavy metals. When $I_i > 1$, it indicates irrigation water has been polluted. The value of I_i is larger, the pollution is more serious.

Because the source of wheat irrigation water is shallow groundwater in Xiaoxian county, groundwater quality standard (GB/T 14848,China) is selected. The class III water which mainly is to consider whether it is harmful to human health and safety as a benchmark, is usually applied to the more concentrated residential areas for drinking water and industrial and agricultural water. This study selects class III water as evaluation standard. The specific standard values is in TABLE 1.

TABLE 1 : The groundwater quality standard of heavy metals content(μg/L)

Elements Class	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Pb	≤5	≤10	≤50	≤100	>100
Cd	≤0.1	≤1	≤10	≤10	>10
Cr	≤5	≤10	≤50	≤100	>100
As	≤5	≤10	≤50	≤50	>50
Hg	≤0.05	≤0.5	≤1	≤1	>1

The method of Nemero index is calculated using the expression below:

$$I = \sqrt{\frac{(MaxI_i)^2 + (AveI_i)^2}{2}} \quad (2)$$

Where I is the comprehensive pollution index, $MaxI_i$ is the maximum value of I_i, $AveI_i$ is the average value of I_i. The evaluation standard of I is in TABLE2.

TABLE 2 : The classification of I

I	I≤0.5	I≤0.5	1.0<I≤2.0	2.0<I≤3.0	2.0<I≤3.0
The class level	excellent	good	medium	bad	worse

RESULT AND DISCUSS

General characteristics of five kinds of heavy metal contents

Heavy metals content of wheat irrigation water in Xiaoxian county is shown in Figure 1. The content of Pb is between 4.02-31.24μg/L, the maximum content is in Longchen town and the minimum content is in Hungkou town. The content of Cd is between 5.14-10.54 μg/L, the maximum content is in Jiudian town and the minimum content is in Yanglou town. The content of Cr is between 2.08-25.66μg/L, the maximum content is in Majing town and the minimum content is in Huangkou town. The content of As is between 1.92-9.54μg/L, the maximum content is in Huangkou town and the minimum content is in Majing town. The content of Hg is between 0.09-1.69μg/L, the maximum content is in Qinglong town and the minimum content is in Huangkou town.

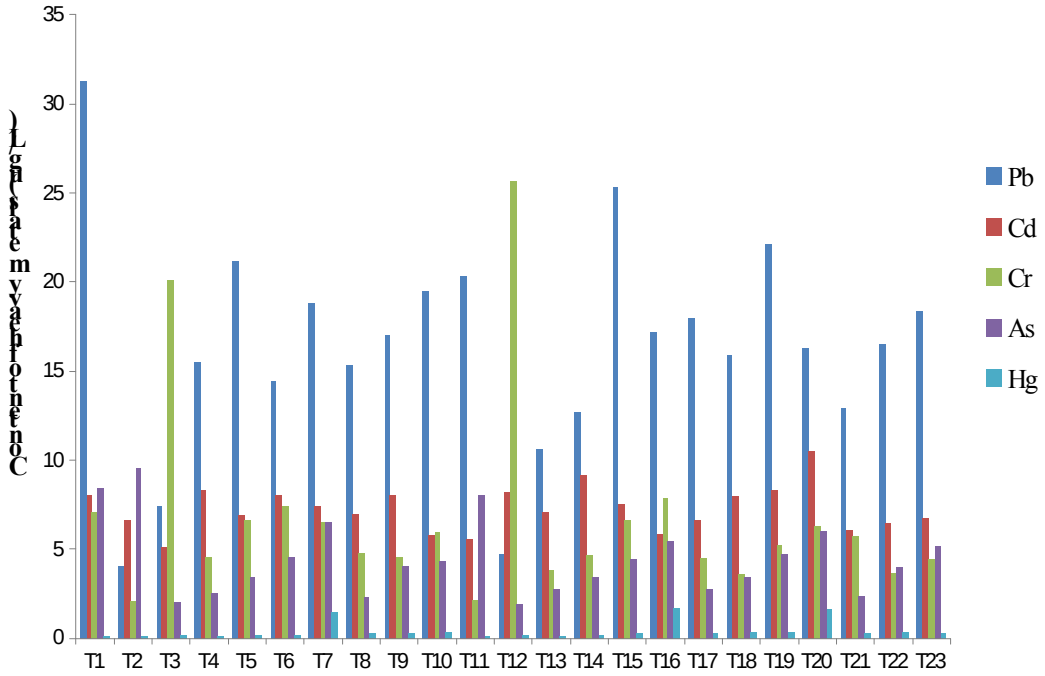

Figure 1 : Heavy metals content of wheat irrigation water in Xiaoxian county

Evaluation of heavy metals pollution

Analysis results of heavy metals content with single factor index and Nemero index are shown in TABLE 4. The single factor index(I_i) of Pb, Cd, Cr and As in 23 sampling points is less than 1,it shows that these four kinds of heavy metals contents is in the normal range and not excessive in accordance with the groundwater quality standard. However,there are three groups of Hg that the single factor index(I_i) is greater than 1 which is outside the normal range. It accounts for 2.6% of all single factor indices and its arrangement is Qinglong town>Jiudian town>Dulou town. The wheat irrigation water of these three towns in Xiaoxian county which account for 13.04% of 23 sampling points may be subject to different degrees of pollution.

The high data of the Nemero index(I) of Qinglong town, Jiudian town and Dulou town is respectively 1.2629, 1.2411, 1.1503 and the pollution class is in the medium level. The pollution class of these 5 towns of Huangkou town,Yanglou town,Dinli town, Baitu town and Shilin town is in excellent level and the proportion of all samples is 21.74%.And the pollution class of remaining 15 towns is in good level and the proportion is 65.22% of all samples.On the basis of proportion, the rank of pollution class is good, excellent, medium and the proportion of good level is the largest. So wheat irrigation water in Xiaoxian county has no harm to agricultural production.

TABLE 4 : Pollution indices of heavy metals

Samples	The single factor index (I_i)							The Nemero index(I)	Pollution class
	Pb	Cd	Cr	As	Hg	average	maximum		
T1	0.6248	0.801	0.141	0.1682	0.11	0.369	0.801	0.6236	good
T2	0.0804	0.661	0.0416	0.1908	0.09	0.2128	0.661	0.491	excellent
T3	0.149	0.514	0.4024	0.0402	0.18	0.2571	0.514	0.4064	excellent
T4	0.3106	0.832	0.0922	0.0502	0.11	0.279	0.832	0.6205	good
T5	0.424	0.693	0.132	0.0688	0.21	0.3056	0.693	0.5356	good
T6	0.2892	0.805	0.1494	0.0914	0.22	0.311	0.805	0.6102	good
T7	0.3764	0.741	0.1304	0.131	1.52	0.5798	1.52	1.1503	medium
T8	0.3078	0.7	0.0968	0.0464	0.28	0.2862	0.7	0.5347	good
T9	0.3408	0.805	0.0912	0.0808	0.31	0.3256	0.805	0.614	good
T10	0.3902	0.581	0.1188	0.0866	0.37	0.3093	0.581	0.4654	excellent
T11	0.4062	0.558	0.043	0.1608	0.1	0.2536	0.558	0.4334	excellent
T12	0.0938	0.822	0.5132	0.0384	0.17	0.3275	0.822	0.6257	good
T13	0.212	0.703	0.077	0.056	0.11	0.2316	0.703	0.5234	good
T14	0.2538	0.917	0.0922	0.0696	0.24	0.3145	0.917	0.6855	good
T15	0.5068	0.751	0.132	0.0878	0.25	0.3455	0.751	0.5845	good
T16	0.343	0.588	0.1582	0.11	1.69	0.5778	1.69	1.2629	medium
T17	0.3592	0.661	0.0892	0.0554	0.25	0.2830	0.661	0.5084	good
T18	0.3174	0.8	0.072	0.0696	0.35	0.3218	0.8	0.6097	good
T19	0.4434	0.838	0.1052	0.0946	0.36	0.3682	0.838	0.6472	good
T20	0.3248	1.054	0.1258	0.1204	1.63	0.651	1.63	1.2411	medium
T21	0.2592	0.606	0.1142	0.048	0.24	0.2535	0.606	0.4645	excellent
T22	0.3292	0.647	0.0732	0.0794	0.32	0.2898	0.647	0.5013	good
T23	0.3676	0.679	0.0884	0.1036	0.29	0.3057	0.679	0.5265	good

The correlation characteristic of heavy metals in wheat irrigation water

TABLE 5 : Correlation coefficients for heavy metal content and the Nemero index(I)

	Pb	Cd	Cr	As	Hg	I
Pb	1					
Cd	0.095	1				
Cr	-0.394	-0.035	1			
As	0.302	0.015	-0.381	1		
Hg	0.108	0.208	-0.007	0.233	1	
I	0.123	0.433*	0.018	0.256	0.946**	1

*** Correlation is significant at the 0.05 level.**

**** Correlation is significant at the 0.01 level.**

In order to investigate the key metals contributing to the computed indices, correlation was performed between the Nemero index(I) and heavy metals content and the correlation analysis results are shown in TABLE 5.Only two elements, Cd and Hg show significant correlations with all the indices, suggesting that these metals are the major contributory parameters[4-6].The correlation coefficient is 0.946 between Hg and Nemero index(I) that is much higher than the other. The Nemero method and single factor method show comparable results, samples T7, T16 and T20 are considered as contaminated by the Hg and the pollution class of these samples is medium level corresponding.

The contribution of each town in the heavy metals content is represented by box plot(seen Figure 2 and Figure 3). Each box plot contains 25%, median, 75% and the maximum amount of contribution.The content of heavy metal in wheat irrigation water has a distinctive regional characteristics[7,8]. Longchen town has a biggest contribution on the content of Pb. Jiudian town has a biggest contribution on the content of Cd. Majing town has a biggest contribution on the content of Cr. Huangkou town has a biggest contribution on the content of As. And all the maximum content of Pb,Cd,Cr,As is in the standard limits.For the content of Hg,there are 3 towns that their content is beyond the standard limits.The contribution of Hg content which their contributions don't have much difference is in the order of Qinglong town, Jiudian town and Dulou town, they make contribute to excessive levels together.It shows that wheat irrigation water in these 3 towns may be polluted by Hg and it needs to be monitored to prevent the deterioration of water quality.

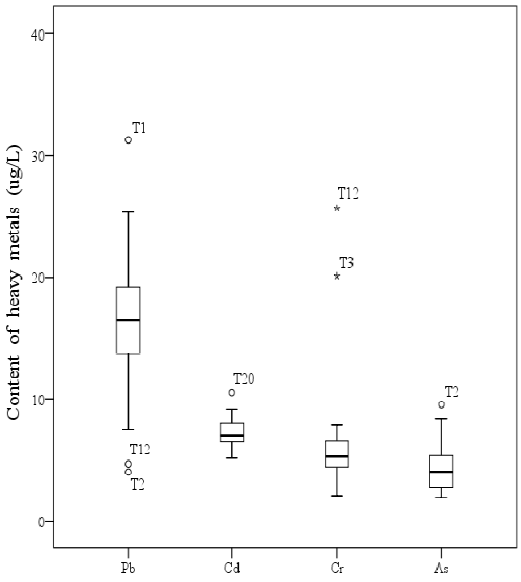

Figure 2 : The contribution of Pb,Cd,Cr,As

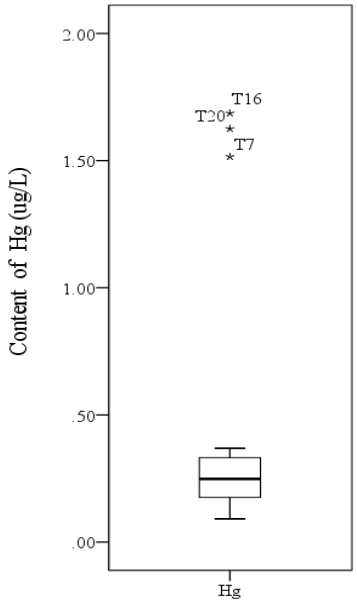

Figure 3 :The contribution of Hg

CONCLUSION

At present, there is a few papers about the heavy metal content of irrigation water and the papers related to the heavy metal content of wheat irrigation water is less. Because the water source of wheat irrigation water is shallow groundwater in Xiaoxian county, this paper is the first to analyze the characteristics of heavy metal content of the wheat irrigation water.

On the basis of sample collection and analysis, the contents of Pb, Cd, Cr, As, Hg of wheat irrigation water in Xiaoxian county are respectively 4.02-31.24 μg/L, 5.14-10.54 μg/L, 2.08-25.66 μg/L, 1.92-9.54 μg/L, 0.09-1.69 μg/L. In general, the heavy metal contents of wheat irrigation water is in the allowable standard range. On the other hand, the regional differences of heavy metal contents is big. With the method of the single factor index and Nemero index, the heavy metal contents of wheat irrigation water in Xiaoxian county have no harm to the agricultural production. There are only 3 samples where the content of Hg is a little beyond the standard limits value.

This paper provides the basic data of heavy metal contents in wheat irrigation water in Xiaoxian county, it can provide data support and technical guidance for the use of agricultural water in Xiaoxian county.

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