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Study on the proposed environmental guidelines for Cd, Hg, Pb and As in soil of China

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Abstract — This paper deals with the soil-environmental standard. According to the current situation of researching on the soil-environmental quality guideline at home and abroad, and on the basis of the foundations and principles of enacting the soil-environmental standard, the soil environment quality guideline values of Hg, Cd, Pb and As were suggested.

Keywords: soil-environmental standard; soil guideline; heavy metal; functional land use; soil background content.

RELEVANT CONCEPTS

The enactment of the soil-environmental quality standard which is an important part of environmental standards, laws and regulations aims at preserving the soil-environmental quality, maintaining the soil-ecosystem balance and protecting human health, and can provide scientific bases for making full use of the environmental self-purificatory and tolerant ability of a land treatment system and for laying plans including protection of soil resources and impact assessments of soil-environments.

There are some differences between the soil environmental standard and the guideline. The guideline which is summarization of scientific researches based on the dose effect of an element to the consumers is not subjectively tendentious and means that contents of pollutants in soils will amount to or exceed the limit value of biological damage (Niu, 1989). The standard is the sum total of technological indexes and norms with lawful coercivenesses and reflects the social-technological-economic and administrative demands of a country. The guideline has not a legal effect and the standard embody the policy of a country (Lu, 1989). A guideline value should be a range with the highest and lowest level. Usually a standard should be equal to or lower than a guideline (Xiong, 1984).

The enactment of the soil-environmental quality standard is extremely difficult. So far more than eighty countries in the world have their own air-environmental standard system and water-environmental standard systems, but there is not a country with a perfect soil-environmental standard system.

In view of soil-environment problems which are increasingly severe, a lot of countries have paid great attention to research on the soil-environmental standard in the recent decade in order to protect soil which is a kind of irregenerative resources for mankind existence. Now a lot of countries have some temporary or trial stipulations for heavy metals and toxical organic matters to avoid deterioration of soil environments and carry out soil-environmental protection policies.

In China, the departments of environmental protection, scientific research and hygiene have amply paid attention to human health affected by high contents of harmful matters in soils. In the past years soil-environmental pollution has been spreading from urban areas to rural areas with the development of rural enterprises. Therefore, to protect soil environments is important increasingly. Environmental scientists and pedologist have a profound understanding of the importance and essentiality of stipulating the soil-environmental standard in our country and have had some good assumptions. To enact the soil-environmental standard of China as soon as possible and to control soil pollution macroscopically is a pressing task.

METHODOLOGY

According to the available data, research methods for establishing the soil-environmental guideline at home and abroad can be integrated into two types.

The eco-toxicological methodology

This includes: (1) the soil hygiene and enzymology index method; (2) the food health standard method; (3) the plant and animal ecological effect index method; (4) the environmental effect index method; (5) the epidemiologically index method; (6) the human health effect index method; (7) the synthetic ecological method; soil-plant systems, soil microorganisms systems and soil-water systems are considered synthetically, the critical content of an element in soil for these systems are obtained, the minimum limit factor is selected, the system with the lowest value is regarded as the limit factor.

The geochemical methodology

This method means that the soil-environmental guideline can be obtained from environmental background values and high-background values of elements in soils. This is includes: (1) $x+s$ system; x is an arithmetic mean of background values, s is a standard deviation. (2) *GM* system; *GM* is a geometric mean of background values. (3) kx system; k is a coefficient of multiple. (4) "the average concentration of an element in soil of a high-background region" system; it suggests that the average content of an element in soil of a high-background region be taken as the maximum allowable concentration of the element in soil. (5) other systems; the environmental quality guideline for Cd in soil of Holland (Page, 1988) and some environmental quality guidelines of E. E. C. and Britain (Mininni, 1987) were suggested according to types of land use.

As early as 1970s Chinese pedologists and environmental researchers calculated soil pollution trigger concentrations according to the method of a soil background value added to two multiples of a standard deviation during the soil assessment in the southeast suburbs of Beijing and this method has still been used by provinces, municipalities and regions of our country in their soil assessments till today. During the period of the Sixth Five-Year Plan the soil-capacity research group of Chinese Academy of Sciences suggested that the environmental quality guidelines for some soils of China on the basis of the eco-toxicological methodology (Xia, 1988).

FOUNDATIONS AND PRINCIPLES

In this paper, the guiding ideology of stipulating the soil environmental guideline is to consider the eco-toxicblogical methodology and the geochemical methodology comprehensively.

Therefore, the principal foundations of our studying on the soil-environmental guideline should include as follows:

1. Functionality of the soil eco-system in question

According to the actual situation of the soil-environmental quality in China, the functional land use includes:

Division I

It represents natural areas and drinking-water resource areas. There are characteristics that the soil in the region is not yet polluted by mankind and the long-term natural geochemical movement of an element can be reflected.

Division II

It represents agricultural and pastoral areas which include dry farmland, paddy field, grassland, grass-mountain and grass-hillside field. It involves food chain which is significant for human health.

Division III

It includes different kinds of forest lands, not relating directly to food chain.

Division IV

It represents waste and sewage disposal areas, urban areas, playing fields, work areas and mineral areas. Contents of poisonous metals in this region should be controlled in order to inhibit the strengthening pollution.

The soil-environmental guideline, not being a single limit value stipulated, should be a multiple-level hierarchical system corresponding to its functional land use, according to available information at home and abroad, and the research experiences of air and water environmental quality standards. Therefore, we suggests, the hierarchical system of the soil-environmental quality guideline includes four levels. Meanings corresponding to the four levels and application of them to administration can see Table 1.

Table 1 The soil-environmental guideline hierarchy in China

Level	state	Nomenclature	Ecological effect	Management required	Functionality
1	Ideal	Background value	Normal	Very strict	I
2	Acceptable	Threshold value	Little	Strict	II
3	Tolerable	Warning value	Mild	Relaxed	III
4	Doubtful	Critical value	Severe	Very relaxed	IV

2. Data of soil-environmental background values

More than 28900 analytical data on concentrations of Hg, Cd, Pb and As in soils were obtained in the soil-background value investigation of the country during the period of the Seventh Five-Year Plan. These data were calculated statistically on the basis of 97 statistical units and overall distributive characteristics, ranges of background values of Hg, Cd, Pb and As were obtained. According to the data, soil-environmental quality guideline values were calculated roughly and regarded as a mark of judging soil pollution.

The investigation showed that the maximum frequency distributive range of Hg, Cd, Pb and As is 0.01 – 0.0103, 0.001 – 0.165, 11.6 – 36.9 and 2.9 – 17.6 mg/kg, respectively; while the accumulative frequency is equal to 95%, the background value of Hg, Cd, Pb and As amounts to 0.27, 0.31, 55.6 and 27.0 mg/kg, respectively. This research also indicated that the average background value (ABV) of Hg, Cd, Pb and As in soil of the country is 0.038, 0.079, 23.9 and 9.6 mg/kg, respectively. 95% of the fiducial range of Hg, Cd, Pb and As is 0.006 – 0.272, 0.017 – 0.332, 10.0 – 56.1 and 2.5 – 33.5 mg/kg, respectively (Table 2). These data are thought as one of the bases of stipulating the soil-environmental guideline.

Table 2 The soil-background values and ranges of Hg, Cd, Pb and As in China (in unit: mg/kg)

Element	No. of samples	Median	*AM**	*GM**	95%*PV**	95% fiducial limit
As	4093	9.6	11.2	9.2	27.0	2.5 – 33.5
Cd	4095	0.079	0.097	0.074	0.264	0.017 – 0.333
Hg	4092	0.038	0.065	0.040	0.221	0.006 – 0.272
Pb	4095	23.6	26.0	23.9	55.6	10.0 – 56.1

**AM* = arithmetic mean, *GM* = geometric mean, *PV* = place value

3. The dose-effect of an element to consumers

Hg and Cd have strong biological transmission and low phytotoxicity. The remnant toxicities of Hg, Cd, As and Pb in seeds may harm human health. However, the rate of wheat absorbing Cd in dry land is three times than that rice in paddy field, Hg in paddy field is more poisonous than that in dry land (Xia, 1988). Soybean and leaf vegetables are sensitive to the accumulation of Pb (Zhou, 1986). Rice is most sensitive to the toxicity of As (Xia, 1988). Obviously, leaching and migrating phenomena of As are likely to result in the pollution of environments and deterioration of water quality (Horvath, 1983). The dose-effect of the element mentioned above should be considered in the course of enactment of the soil-environmental guideline.

RECOMMENDATORY SCHEMES

The guidelines for Hg, Cd, As and Pb can be grouped into the following four levels.

Level 1 is the "ideal" level which corresponds to the median of a background content of an element in soil of the country or can be represented by the formula of GM·GD (GD = geometric standard deviation) according to the above-mentioned principles. The calculation showed that the soil-environmental guideline value for level 1 amounts to 0.10 (Hg), 0.15 (Cd), 15 (As) and 30 (Pb) mg/kg.

Level 2 is the "acceptable" level or "threshold" value which is a dividing line of judging polluted and clean soil which may relate closely to human health because it should be suitable for agricultural and pastoral uses and used to control soil pollution macroscopically. Therefore, the soil-environmental guideline value for level 2 is calculated according to the formula of $GM \cdot GD^2$ or $x + 2s$. Because of the high toxicity of As, the soil guideline value of As for level 2 is calculated exceptionally according to $GM \cdot GD$. The result shows that soil-environmental quality guideline value for level 2 amounts to 0.20 (Hg), 0.30 (Cd), 20 (As) and 60 (Pb) mg/kg.

Level 3 refers to the "endurable" level which is a "warning" value. Some influences on soil ecosystems appear when contents of these heavy metals reach the level, so their lowest affection contents are selected as the "warning" values. The research (Xia, 1988) showed that the critical concentration of Hg inhibiting bacteria and actinomyces is 0.5 mg/kg, which is also the critical content of soil enzymology. The field investigation in the Zhangshi Sewage Irrigation Area of Shenyang indicated that the content of Cd in rice will exceed 0.2 mg/kg while the content of Cd in soil is up to 0.49–0.8 mg/kg (Wu, 1980). The research indicated that soybean shoots growing on soil may be inhibited while the content of Pb in soil is up to 100 mg/kg (Zhou, 1986). While the content of Pb in soil is more than 100 mg/kg, the content of Pb in child blood is up to 15 μg/100ml, which amounts to the allowable level of Pb in child blood of China (Tian, 1990). The critical concentration of As for microorganism in meadow drab soil which was planted rice is 27 mg/kg (Xia, 1988). Therefore, we suggest that the soil-environmental quality guideline value for level 3 amount to 0.5 (Hg), 0.5 (Cd), 27 (As) and

100 (Pb) mg/kg.

Level 4 is the "critical" level which corresponds to a upper limit of environmental quality guidelines and the proposed maximum allowable concentrations or limit values in other countries. It has serious influences on ecosystems while the content of Hg, Cd, As and Pb in soil reaches, respectively. The soil guideline value of level 4 should be equal to the high-background value of an element in soil of mineralized areas or geochemical anomalous areas or the upper limit of concentrated contents of an element in original environments, because it means that manmade chemical pollution will appear when concentration of an element in soil exceed the value. In addition, the soil-ecological research data were considered. The geochemical background values of Hg or Cd in soils of two Hg mineralized areas and two Pb-Zn mineralized areas were obtained (Table 3). Another research indicated that the high background value of Cd in calcareous paddy soil of the Siding Pb-Zn Mineralized Areas in Guangxi is 1.13 mg/kg (Wu, 1986). The research (Xia, 1988) indicated that the content of Hg in soil is 1.50 mg/kg when the yield of potted wheat decrease 10%. When the content of Cd in rice is up to 0.4 mg/kg, the concentration of Cd in red-loam paddy soil is 1.1 mg/kg. While the content of Pb in child blood is up to 25 μg/100ml, the content of Pb in the corresponding soil is 300–500mg/kg (Chaney, 1986). The experiment in tidal-soil and alkaline-soil areas of the North China showed that the critical value of As in soil is 26.7–39.4 mg/kg (Xiong, 1986; Tian, 1990). The research indicated that shallow ground water is likely to be polluted when the concentration of As in sand soil is more than 20 mg/kg; however, while the content of As in soil of a normal area is lower than 30 mg/kg the quality of ground water can not be harmed (Tian, 1990). To sum up, we propose that the soil-environmental guideline values for level 4 be 1.0 (Hg), 1.0 (Cd), 30 (As; except sand soil) and 300 (Pb) mg/kg.

Table 3 The background data (mg/kg) for Hg, Cd, Pb and As in soils from four mineralized areas in China

Functional zone	Wanshan	Danzhai	Chaihe		Qingchenzi		
	Hg	Hg	Cd	Pb	Cd	Pb	As
Control	0.107	0.295	0.129	26–35	0.145	24–33	15.0–18.0
Transition	0.409	0.480	0.333	60–81	0.522	60–70	57.8
Anomalous	1.10	1.09	0.546	126	1.03	150	73.6–105
Pollution	7.00	10.6	1.32	548–1500	2.40	500–2000	190–576

APPLICABILITY TESTS

1. Comparisons with other countries

Now we list the proposed maximum allowable concentrations of Hg, Cd, As and Pb in soil of other countries (Table 4). It is obvious that the guideline values for level 1 and 2 are stricter than those of other countries, the guideline values for level 4 approach those of France, U.S.A. and E.E.C. countries, but the guideline value of As for level 4 is more relaxed in China. However, different countries have varied developing degrees, natural conditions, hygienic levels and limit factors when the guideline was enacted; thereupon, the limit values of the same contaminator in soil of several countries differ from each other especially the soil guideline for Pb.

Table 4 Proposed maximum allowable contents (mg/kg) for four metals in soils of some countries

Country	Hg	Cd	As	Pb
E.E.C. countries	1−1.5	1−3	−	50−300
U.S.A.	5.34	3.56	36.6	1821
France	1	2	−	100
Germany	2	3	20	100
Italy	2	3	−	100
Scotland	0.4	1.6	12	90
England	1	3.5	4.5(pH6.5)*	550
Canada	0.5	1.6	14	60
USSR	2.1	5	15	*BV*** + 20

* Sewage sludge has been applied long-termly;

** *BV*, background value

2. Applicability in China

A vast amount of soil samples from widespread areas were collected and analyzed, these data of soil background values can be used to judge the feasibility of applying the soil-environmental guideline. By making a comparison between the mentioned above guideline values and the soil background value data of 26 provinces and regions, the result shows that the contents of these heavy metals in soil of most provinces and regions are lower than the soil-environmental guideline value for level 1 and belong to the "ideal" level of clean areas, except that the average content of Cd in soil of Yunnan, Guangxi and Guizhou, Hg in soil of Guangxi, Guizhou, Hunan and Jiangsu, Pb in soil of Guizhou, Yunnan, Fujian and Shanxi is slightly higher than the soil-environmental guideline values for level 1, because most areas in Yunnan, Guangxi and Guizhou are covered with limestone, soil in Hunan is affected by mineral resources and intensive agricultural utilization, and long-term applying pesticide which contain Hg increased the content of Hg in soil of Jiangsu (ABV-Hg $=0.18$ mg/kg, $n=237$). The background value research on soils in 8 coastal cities indicated that the content of Hg in topsoil of Ningbo City is on the high side, that of Hg is layer B and C is under the normal content range; the content of Pb in topsoil of Shenzhen, Wenzhou and Xiamen cities is also on the high side. The investigation showed that the area of farmlands polluted by Hg, Cd, As and Pb has reached more than 10000 ha, but the contaminating degree of these polluted farmlands differ greatly. To sum up, the materials mentioned above show that the contaminating degree of soil in China can be judged by the soil-environmental guideline value.

CONCLUSIONS

In this paper, the soil-background-value data which are obtained during the period of the Seventh Five-Year Plan of China and the high-background-value data(involving Hg, Cd, As and Pb) which were obtained from 4 mineralized areas of Liaoning and Guizhou were applied. At the same time, some results obtained by soil-ecological experiments in China were cited. The research showed that the soil-environmental guideline in China should be a four-level hierarchical system, the functional land use in China includes: (1) natural areas and drinking-water resource areas; (2) agricultural and pastoral areas; (3) forested lands; (4) waste material and sewage disposal areas, urban areas, work areas and mineralized areas. On the basis of these four parts, the soil-environmental guideline values of 4 levels were suggested (Table 5).

Table 5 Proposed soil-environmental quality guidelines for four heavy metals in China (in unit: mg/ kg)

Grade	Hg	Cd	Pb	As
1	0.1	0.15	30	15
2	0.2	0.3	60	20
3	0.5	0.5	100	27
4	1.0	1.0	300	30*

* except sandy soil

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