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Statistical Analysis and Evaluation of Heavy Metal Ions in Soil Environment

Min Tang, Jianping Hou

Environmental Monitoring Station, Chongqing, China
Email: tengzi12280741@163.com

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Abstract

The paper comprehensively analyzes and evaluates the urban grid soil and rural soil quality and pollution characteristics through methods of single factor index and Nemero comprehensive pollution index on the physical and chemical nature of soil, the element pollutants, organic pollutants and other pollutants. The contents of soil pollutants in rural and urban areas showed that the overall soil quality is good and advice on how to improve soil quality in the region is put forward.

Keywords

Soil Environment, Heavy Metals, Statistical Analysis, Single Factor Index Method and Nemerow Comprehensive Pollution Index Method

Subject Areas: **Environmental Sciences**

1. Introduction

With the rapid development of industry and agriculture, the unreasonable use of pesticides and fertilizers, long-term sewage irrigation, as well as urban and industrial pollution and other factors since 1930s, through different ways, a great number of pollutants entered into the soil environment, did damage to the soil structure, destroyed the soil function [1], and caused quality deterioration of soil ecological environment, making soil pollution a great threat to agricultural product quality safety across China and even the global [2]. The composition, structure, function, characteristics and the special status and role played in the environment ecosystem in environmental ecosystem of soil make the soil pollution more complicated than the air and water pollution.

Soil pollutants can be roughly divided into two kinds: inorganic pollutants and organic pollutants [3]. Inorganic pollutants mainly include acid, alkali, heavy metals, salts, compound of radioactive elements Cs and Sr, compound of As, Se and F etc. Organic pollutants mainly include organic pesticides, phenols, cyanide, petroleum, synthetic detergent, benzopyrene and harmful micro-creature produced by the city sewage, sludge and manure etc. In order to know about the current situation of soil environmental quality in X area of China, improve the

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ability to monitor soil pollution, evaluate the risk of soil pollution, confirm the soil environmental safety level, and establish the supervision and management system for soil environmental quality, an investigation on soil environmental quality was carried out in 2014. The investigation and monitoring protect and reasonably utilize land resources, as well as offer scientific and effective basic data to improve the quality of soil environment.

2. Survey Method

Grid distribution is used in urban soil, which means that 1 km × 1 km size square grid is drawn in administrative map with corresponding proportion, 1 monitoring point lying in each grid. According to the landscape, distribution of land use types, soil types and other factors in Northern Yangtze River area, the number of points is obtained by the formula that land use area/grid size = number of sample points. After optimization, points number of urban soil survey is ultimately determined as 62. The rural scope of the soil investigation involves the 7 villages of Wubao town and each village has 1 monitoring point, 7 monitoring points in total.

3. Evaluation Index

The evaluation on soil quality is mainly based on Soil environmental quality standard (GB15618-1995) [4], which is divided into three major categories. Class I is mainly applicable to natural reserves approved by the state (except reserves with the original background of high heavy metal concentrations), the centralized drinking water source, tea garden, and pasture and soil in other protected areas; soil quality maintains the natural background level. Class II is mainly suitable for general farmland, vegetable lands, tea gardens, orchards, pasture and other soil; soil quality basically does not do harm to the plant and the environment nor causes pollution. Class III is mainly used in forest land and farmland such as soil with high background value and mineral those have large deal of pollutants (except the vegetable land) ; soil quality basically does not do harm to the plant and the environment nor causes pollution. The detection of soil generally focuses on detecting their physicochemical properties: pH, full Nitrogen, full Phosphorus and full Kalium and the organics; elements: Arsenic, Cadmium, Cobalt, Chromium, Copper, Fluoride, Mercury, Manganese, Nickel, Lead, Selenium, Vanadium, Zinc; organic pollutants: organochlorine pesticides (Six Six Six, DDT) and other major categories. Soil is often contaminated by a variety of heavy metals. Therefore methods of single factor index [5] and Nemero comprehensive pollution index [6] [7] are often used for comprehensive evaluation on soil pollution.

3.1. Single Factor Pollutant Index

P_i reflects the extent of pollution. Its values less than 1 means no pollution while that greater than 1 means pollution. It can be expressed as follows.

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

where P_i is the single pollution index of pollutant i in the soil; C_i is the measured concentration of pollutant i in the soil of surveyed locations; S_i is standard referential value for the evaluation of pollutant i.

3.2. Nemero Comprehensive Pollution Index

Nemero comprehensive pollution index are often used for comprehensive evaluation on soil pollution and the formulation is as below:

$$P_N = \left\{ \left[\left(P_{\text{mean}} \right) + \left(P_{\max}^2 \right) \right] / 2 \right\}^{1/2} \tag{2}$$

$$P_N = \left\{ \left[\left(P_{\text{mean}} \right) + \left(P_{\max}^2 \right) \right] / 2 \right\}^{1/2} \tag{3}$$

where P_N is the Nemero comprehensive pollution index; P_{mean} is the average single pollution index; P_{mean}^2 is the maximum single pollution index.

Nemero index reflects the effect of the pollutants on the soil [6] [7], while highlighting the impact of high-concentration pollutants on the soil environment quality. Pollution levels can be divided according to the Nemero pollution index. Soil pollution evaluation criteria for Nemero index see **Table 1**.

Table 1. Nemero pollution index soil evaluation criteria.

Grade division	Single pollution index	Class of pollution
I	$PN \le 0.7$	Clean (SAFE)
II	$0.7 < PN \le 1$	Relatively clean (alert limit)
III	$1 < PN \le 2$	mild concentration
IV	$2 < PN \le 3$	middle level pollution
V	$PN > 3$	heavy pollution

4. Results and Discussions

There are 7 sampling rural fields for the survey, and the monitoring projects include 20 items: pH, full Nitrogen, full Phosphorus and full Kalium and the organics; elements: Arsenic, Cadmium, Cobalt, Chromium, Copper, Fluoride, Mercury, Manganese, Nickel, Lead, Selenium, Vanadium, and Zinc. The monitoring results of physicochemical properties, elemental pollutants and organics are shown in **Tables 2-4**, respectively.

Basic situation of soil fertility: the material composition, structure status and the natural conditions determine the level of soil fertility, which affects growth of plant and is the material basis for the crop yields [8]. From the results of the physicochemical property in **Table 7**, the pH of rural sampling points varies from 6.9 to 8.0 while the appropriate growth pH environment for general crops is nearly neutral. Thus, the rural soil pH is moderate.

According to the dry soil fertility grading standard (see **Table 5**) of Environmental quality standard of national green food places of origin (NY/T391-2000) [9], among seven surveyed villages, whose soil organic contents vary from 9.2 to 14.2 g/kg, the highest is village C, and the lowest is village F. The content of organics reaching class II of accounts for 71.4%, class III 28.6%, which shows that the majority of soil organics in the seven villages reaches class II (good level). The monitoring results of soil full Nitrogen, full Potassium and full Phosphorus show that the soil fertility levels of the seven villages are all proved to be class III (relatively bad level), indicating the insufficient contents of N, P and K in soil.

The content and distribution of pollutants : The monitoring result of element pollutants in **Table 3** shows that there is no Arsenic, Mercury and Cadmium, Selenium in the seven villages; the content of Fluoride is 189 - 452 mg/kg, the average value is 318 mg/kg, and village A has the highest content of it; the content of Chromium is 58 - 198 mg/kg, the average value is 107 mg/kg, and village G has the highest content of it; the content of Copper is 15 - 43 mg/kg, the average value is 32 mg/kg, and village A has the highest content of it; the content of Manganese is 505 - 7306 mg/kg, the average value is 1988 mg/kg, and village F has the highest content of it; the content of Zinc is 24 - 99 mg/kg, the average value is 58 mg/kg, and village B has the highest content of it; the content of Nickel is 33 mg/kg, it's sampled in village B and none of it were detected in the other six villages; the content of Cobalt is 0 - 1195 mg/kg, and village F has the highest content of it; the content of Lead is 0 - 24 mg/kg, and village A has the highest content of it. From the organochlorine pesticide monitoring result in **Table 4**, organochlorine pesticides of Six Six Six and DDT were not detected in any of the seven villages. In all of the monitoring results, Cadmium, Mercury, Arsenic, Copper, Lead, Chromium, Zinc, Nickel and organochlorine pesticides all meet class II. Five elements of Fluoride, Manganese, Cobalt, Selenium and Vanadium are not required in class II. And those that are detected high content of elemental monitoring factors are village F, A and B.

Urban grid soil sampling points are distributed across the whole are, a total of 62 points, and the monitoring projects include 14 items: pH, Arsenic, Cadmium, Cobalt, Chromium, Copper, Fluoride, Mercury, Manganese, Nickel, Lead, Selenium, Vanadium, and Zinc. The detailed monitoring result is shown in **Tables 5-7**.

Statistics of pH monitoring: Among 62 urban grid soil point locations, pH monitoring result is in the range of 4.72 - 8.40, the lowest is in the entry into 412 Park, the highest point is 708. There are 9 points with value of pH less than 6.5 accounting for 14.5% of the total grid number. The number of pH value ranging from the 6.5 - 7.5 is 14 accounting for 22.6% of the total grid number. The number of pH value greater than 7.5 is 39 accounting for 62.9% of the total grid number. The result shows that the pH in this area of soil is alkalescent (**Figure 1**).

Pollution index evaluation [10]: according to the monitoring results of heavy metal pollutants in soil, single factor index and comprehensive pollution index are calculated respectively and the detailed results are shown in **Table 8**.

Table 2. List of results of physical and chemical properties of rural areas.

Sampling point	Projects and results				
	pH	Total nitrogen (%)	Total phosphorus (mg/Kg)	Total potassium (mg/Kg)	organic matter (g/Kg)
A	7.62	0.004	ND	25764	13.4
B	7.83	0.002	ND	27702	9.9
C	7.68	0.006	ND	19854	14.2
D	7.25	0.005	ND	29687	13.5
E	7.84	0.009	ND	25103	12.9
F	8.02	ND	ND	20530	9.2
G	6.93	0.003	ND	30605	11.5

Remarks: ND: Not detected.

Table 3. List of monitoring results of soil elements in rural areas (unit mg/Kg).

Sampling point	**Projects and results**											
	Fluoride	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Hg**	**Mn**	**Ni**	**Pb**	**Se**	**Zn**
A	452	ND	ND	ND	58	43	ND	572	ND	24	ND	83
B	361	ND	ND	ND	84	29	ND	560	33	20	ND	99
C	204	ND	ND	ND	74	15	ND	505	ND	20	ND	46
D	344	ND	ND	195	88	33	ND	880	ND	ND	ND	69
E	382	ND	ND	460	104	35	ND	1551	ND	ND	ND	56
F	189	ND	ND	521	140	27	ND	2544	ND	ND	ND	24
G	293	ND	ND	1195	198	42	ND	7306	ND	ND	ND	26

Remarks: ND: Not detected.

Table 4. A list of results of the monitoring results of soil organic chlorine pesticides in rural areas (unit: mg/Kg).

Sampling point	A list of results of the monitoring results of soil organic chlorine pesticides in rural areas (unit: mg/Kg).Projects and results							
	α-benzene hexachloride	β-benzene hexachloride	γ-benzene hexachloride	δ-benzene hexachloride	p,p'-DDD	p,p'-DDE	p,p'-DDT	o,p'-DDT
A	ND	ND	ND	ND	ND	ND	ND	ND
B	ND	ND	ND	ND	ND	ND	ND	ND
C	ND	ND	ND	ND	ND	ND	ND	ND
D	ND	ND	ND	ND	ND	ND	ND	ND
E	ND	ND	ND	ND	ND	ND	ND	ND
F	ND	ND	ND	ND	ND	ND	ND	ND
G	ND	ND	ND	ND	ND	ND	ND	ND

Remarks: ND: Not detected.

Table 5. List of monitoring results of soil elements in urban areas (pH < 6.5) (unit: mg/Kg).

Grid name	pH	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
005	5.27	227	199	32,229	1866	ND	95	22	ND	ND	ND	ND	165
509	6.07	98	76	257	ND	ND	27	55	17	ND	ND	ND	14
306	6.33	370	77	6580	ND	67	37	68	23	ND	ND	ND	36
004	5.98	102	81	682	ND	30	42	104	17	ND	ND	ND	21
511	5.18	81	64	383	ND	ND	28	52	ND	ND	ND	ND	26
003	5.82	77	72	430	ND	51	29	68	11	ND	ND	ND	18
105	6.32	91	108	601	198	ND	39	77	ND	ND	ND	ND	25
412	4.72	73	72	459	110	ND	18	38	9	ND	ND	ND	13
304	6.26	97	69	528	ND	ND	31	78	ND	ND	ND	ND	31
Standard limit (≤)	/	/	150	/	/	40	50	200	40	/	0.30	0.30	250

Remarks: ND: Not detected.

Table 6. List of monitoring results of soil elements in urban areas (pH > 7.5) (unit: mg/Kg).

Grid name	pH	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
708	8.40	114	77	673	ND	29	21	82	ND	ND	ND	ND	24
708	8.40	133	83	742	ND	29	45	107	ND	ND	ND	ND	35
601	7.72	98	53	551	ND	35	37	70	16	ND	ND	ND	18
707	8.01	76	77	569	ND	ND	41	86	ND	ND	ND	ND	24
801	8.12	99	87	539	ND	31	39	83	12	ND	ND	ND	ND
701	7.55	94	127	668	ND	32	54	169	15	ND	ND	ND	47
603	7.72	105	77	846	ND	43	32	110	ND	ND	ND	ND	23
706	7.85	87	72	613	ND	35	45	86	15	ND	ND	ND	26
805	7.68	108	74	555	ND	ND	33	93	10	ND	ND	ND	18
308	8.06	101	69	614	ND	32	29	79	12	ND	ND	ND	16
211	7.93	89	54	448	ND	ND	22	61	9	ND	ND	ND	13
107	7.82	113	104	758	ND	ND	42	98	16	ND	ND	ND	21
712	7.94	91	86	665	ND	36	67	88	ND	ND	ND	ND	26
413	8.04	106	76	740	ND	33	22	74	11	ND	ND	ND	23
605	7.77	99	43	578	ND	36	ND	73	ND	ND	ND	ND	22
803	8.33	102	77	589	ND	40	55	89	ND	ND	ND	ND	31
607	7.86	131	65	541	ND	ND	82	321	23	ND	ND	ND	40
709	7.88	113	58	570	ND	42	32	90	14	5.5	ND	ND	31
406	7.78	100	60	570	ND	52	37	84	ND	ND	ND	ND	19
508	7.82	74	51	87	ND	ND	ND	37	17	ND	ND	ND	16
309	8.12	91	64	581	ND	28	41	84	ND	ND	ND	ND	24
408	7.68	97	79	881	ND	42	98	182	ND	ND	ND	ND	83
606	7.60	104	73	557	ND	36	23	87	14	ND	ND	ND	22

Continued

502	7.63	86	85	547	ND	48	34	69	ND	ND	ND	ND	24
612	7.56	108	41	395	ND	34	27	64	ND	ND	ND	ND	17
409	7.74	90	102	594	ND	ND	24	97	12	ND	ND	ND	20
705	7.78	88	67	478	ND	ND	24	82	ND	ND	ND	ND	30
802	7.67	87	70	722	ND	45	36	77	ND	ND	ND	ND	30
202	7.84	115	52	510	ND	ND	39	76	ND	ND	ND	ND	22
204	8.25	111	73	650	ND	32	31	81	10	ND	ND	ND	13
106	7.90	87	52	639	ND	ND	35	68	14	ND	ND	ND	18
804	8.08	108	81	677	ND	38	44	85	ND	ND	ND	ND	27
307	8.18	95	60	623	ND	31	17	65	ND	ND	ND	ND	15
510	7.83	110	98	1150	373	ND	32	67	ND	ND	ND	ND	ND
103	8.32	128	114	1549	571	ND	32	60	ND	ND	ND	ND	ND
104	7.79	193	216	2887	1050	ND	54	62	ND	ND	ND	ND	ND
109	7.70	154	243	5659	1201	ND	65	42	ND	ND	ND	ND	ND
108	7.81	128	217	5221	1182	ND	52	25	ND	ND	ND	ND	ND
506	7.84	229	309	7554	1638	ND	223	216	19	ND	ND	ND	ND
110	7.66	169	258	13,001	1558	ND	56	22	ND	ND	ND	ND	ND
Standard limit (≤)	/	/	250	/	/	60	100	300	25	/	0.60	1.0	350

Remarks: ND: Not detected.

Table 7. List of monitoring results of soil elements in urban areas (pH = 6.5 - 7.5) (unit: mg/Kg).

Grid name	pH	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
609	7.02	285	492	31,354	2676	ND	81	27	ND	ND	ND	ND	86
410	7.44	161	224	6435	1977	ND	93	95	ND	ND	ND	ND	ND
703	7.41	78	152	579	ND	37	84	286	ND	ND	ND	ND	86
310	6.86	84	64	133	ND	41	18	33	11	ND	ND	ND	20
402	7.20	110	89	580	ND	ND	33	85	ND	ND	ND	ND	17
702	7.46	114	77	554	ND	50	45	85	ND	ND	ND	ND	21
711	7.32	100	88	682	ND	ND	50	76	12	ND	ND	ND	25
312	6.95	101	59	520	ND	31	40	74	ND	ND	ND	ND	22
203	7.20	75	46	519	ND	ND	ND	72	ND	ND	ND	ND	55
710	7.29	100	72	551	ND	39	44	93	ND	ND	ND	ND	24
206	7.12	117	82	574	ND	31	39	94	ND	ND	ND	ND	30
208	7.26	102	75	452	ND	ND	29	78	10	ND	ND	ND	26
313	7.15	89	50	400	ND	ND	30	55	16	ND	ND	ND	22
207	7.22	93	89	536	ND	ND	28	99	15	ND	ND	ND	21
Standard limit (≤)	/	/	200	/	/	50	100	250	30	/	0.30	0.50	300

Remarks: ND: Not detected.

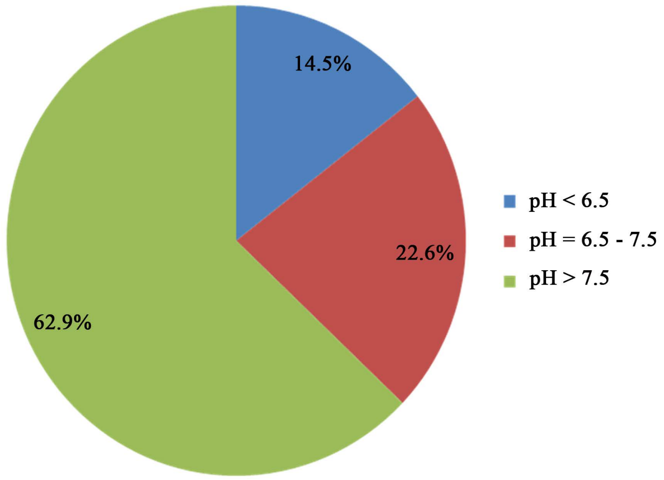

Figure 1. The pH range distribution of the grid soil.

Table 8. Heavy metal pollution index of soil.

Area	Sample number	Pi						Comprehensive pollution index
		Cr	Zn	Ni	As	Pb	Cu	
City Proper	62	0.50	0.34	0.38	0.20	0.09	0.21	0.41
Countryside	7	0.43	0.19	0.08	/	0.03	0.32	0.24

From **Table 8**, it can be seen that the comprehensive pollution index of the rural soil and urban grid soil is less than 0.7, which means safe and clean. The single factor pollution index indicates the greatest single factor pollution index of Cr in Northern Yangtze River area, which shows that the main pollution factor in this area is Cr.

5. Conclusions

From the above investigations, the followings are concluded:

1) The contains of heavy metals and organ chlorine pesticides in the soil of the Northern Yangtze River area are low, abundant in the organics, N, P, K are obviously insufficient but in some areas the organic content is low and organic fertilizers should be added.

2) The total content of heavy metals in urban soils of Northern Yangtze River area is not very high, and the soil environment quality is good. In terms of the average pollutant index level of heavy metals, there is no pollution, but the heavy metal content in some regions is high, which leads to relatively high potential hazard.

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