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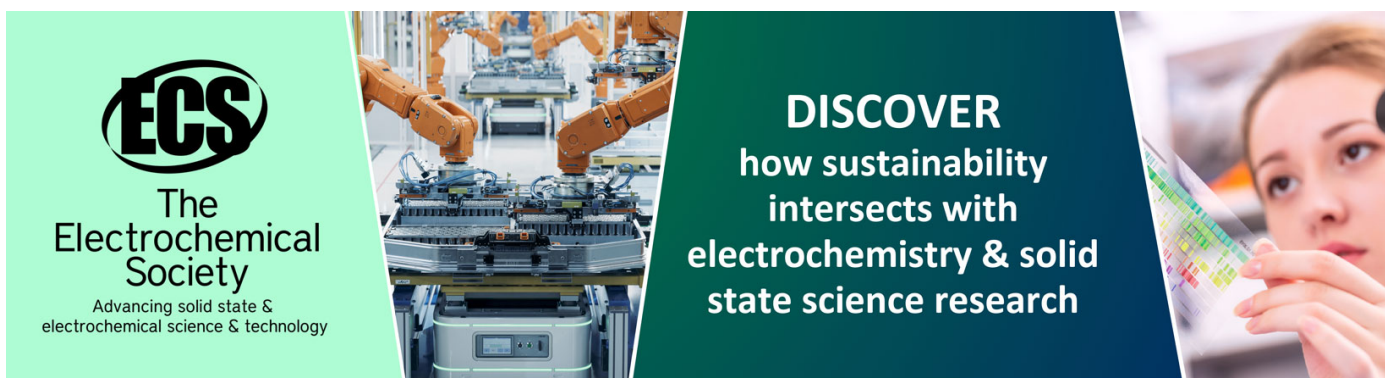
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To cite this article: Q Sheng *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **186** 012070

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Pollution and potential ecological risk assessment of heavy metal of the sludge in treatment plants in Beijing

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Abstract. In 2016, it had been monitored for one year that the heavy metals of sludge in six treatment plants in Beijing. In this paper, several indexes were applied to assess the heavy metals of sludge in treatment plants, including the single factor index, the Nemerow composite index and the potential ecological risk index. The results showed that the concentration of Zn was the highest among the six heavy metals in the treatment plants. The treatment plants with different water intake, the transnormal items of heavy metals of the sludge in these plants are also different. The comprehensive pollution levels of sludge of five treatment plants are all warning line. The other one is better, its comprehensive pollution level is clean. The comprehensive risk indexes of sludge of five treatment plants are belonging to medium contamination. The other one is worse, belonging to the high ecological risk.

1. Introduction

In the treatment of wastewater, a large quantity of sludge is produced. These sludge enriched most of the pollutants in wastewater, including a lot of organic matter and nutrient elements. For disposing sludge, the agricultural disposal is an extensive approach ^[1,2]. However, the poisonous and harmful material enriched in the sludge from wastewater, such as heavy metal, will migrate along with sludge disposal. The heavy metal, as a kind of persistent and potentially toxic pollutants ^[3], accumulates in the environment, rather than being biodegraded as organic matters. This situation is a kind of threat to the environment^[4], and also the limit to the reuse of sludge.

In this study, it was applied the potential risk method to assess the heavy metals in sludge. The method provided the better assessment in the situation of heavy metal pollution and the theory basis for the sludge agricultural disposal technology.

2. Materials and Methods

2.1 Collection and pretreatment of sludge samples

Sludge samples from six treatment plants with different drainage basins in Beijing, marked as No. 1~6, were collected for monitoring the concentration of heavy metals, such as Pb, Zn, Cu and Cr. Among the six treatment plants, the main water source of five was sewage, and that of the other one was industrial waste water. For reflecting the situation of heavy metal pollution as true as possible, 500 g sludge samples from the mud outlet of sludge dewatering were collected in polyethylene collection vessels once a month for one year. Before testing, the samples were pretreated after natural air drying and fine grinding. After digestion, the concentration of Pb, Zn, Cu and Cr was monitored. And the average concentration of each kind of heavy metal was achieved as the evaluation value.



2.2 Analysis methods

2.2.1 Assessment of heavy metal concentration in sludge

According to the Quality of Sludge from Municipal Wastewater Treatment Plant (GB 24188-2009), Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB 18918-2002) and National Standard of Pollutants Control of Agricultural Sludge (GB4284 84), the average concentration of four kinds of heavy metal of the sludge in the six treatment plants was evaluated.

2.2.2 Assessment of heavy metal pollution in sludge

There were two methods applied to evaluate the heavy metal pollution in sludge, as single factor index method and Nemerow composite index method.

Firstly, single factor index method was one of the generally adopted methods to evaluate the pollution of the sludge. The method was applied to evaluate the pollution degree of one certain pollutant in sludge^[5], and the calculation formula was as follows:

$$P_i = C_i / S_i \quad (1)$$

In the formula, P_i was the environmental quality index of pollutant i in soil; C_i was the measured concentration of pollutant i (mg/kg); and S_i was the environmental quality standard for pollutant i (mg/kg).

Differently, Nemerow composite index method could comprehensively reflect the average pollution level of various pollutants in the soil, and also highlighted the environmental harm caused by the most serious pollution. The calculation formula was as follows:

$$P = \sqrt{\frac{P_{i, \text{ave}}^2 + P_{i, \text{max}}^2}{2}} \quad (2)$$

In the formula, P was the comprehensive pollution index; $P_{i, \text{ave}}$ was the average of single pollution index of all pollutants; and $P_{i, \text{max}}$ was the maximum of single pollution index of all pollutants.

According to the single factor index method and the Nemerow composite index method, the heavy metal pollution level of soil can be divided into five grades, as shown in table 1.

Table 1 Pollution level of heavy metal pollution in soil divided with the single factor index method and the Nemerow composite index method

Grade	Single factor index	Pollution level	Grade	Comprehensive factor index	Pollution level
1	$P_j \leq 1$	Slight concentration	1	$P \leq 0.7$	clean
2	$1 < P_j \leq 3$	Moderate	2	$0.7 < P \leq 1$	Still clean
3	$3 < P_j \leq 6$	Serious contamination plcontamination	3	$1 < P \leq 2$	Slight concentration
4	$P_j > 6$	Severe contamination	4	$2 < P \leq 3$	Moderate concentration
			5	$P > 3$	Serious contamination plcontamination

2.2.3 Potential ecological risk assessment of heavy metals in sludge

The potential ecological risk assessment of heavy metals was also applied here. The method involved the coordinated action of multielement, toxicity level, pollution concentration and environmental sensitivity to the pollution of heavy metal, and so on. Without considering the influence of the different regions and pollution sources, the formula was as follows:

$$C_f^i = C_s^i / C_n^i \quad (3)$$

$$E_r^i = T_r^i \times C_f^i \quad (4)$$

$$RI = \sum_{i=1}^n E_r^i = \sum_{i=1}^n T_r^i \times C_f^i \quad (5)$$

C_f^i was the pollution coefficient of relative reference ratio of heavy metal I; C_s^i was the measured concentration of heavy metal i; C_n^i was the evaluation parameter ratio of heavy metal I; E_r^i was the environmental risk index of heavy metal I; T_r^i was the toxic response factor of heavy metal I; and RI was environmental risk composite index. The detail was shown in Table 2.

Table 2 Potential ecological risk levels

E_r^i	RI	Potential ecological risk
$E_r^i < 10$	$RI < 30$	Low ecological risk
$10 \leq E_r^i < 20$	$30 \leq RI < 60$	Medium ecological risk
$20 \leq E_r^i < 40$	$60 \leq RI < 120$	High ecological risk
$40 \leq E_r^i < 80$	$RI \geq 120$	Higher ecological risk
$E_r^i \geq 80$		Extremely high ecological risk

3. Results and Discussion

3.1 Assessment of heavy metal pollution in sludge

The heavy metal concentration and pollution analysis of sludge of six treatment plants were shown from Table 3 to Table 4

Table 3 The heavy metal concentration of sludge in the No.1 treatment plant

No.1 treatment plant	Pb	Zn	Cu	Cr
	mg/kg	mg/kg	mg/kg	mg/kg
Average concentration	15.8	527	126	74.8
GB 24188-2009	<1000	<4000	<1500	<1000
GB 18918-2002	pH<6.5	<300	<2000	<800
	pH≥6.5	<1000	<3000	<1500
GB 4284-1984	pH<6.5	<300	<500	<250
	pH≥6.5	<1000	<1000	<500

As shown in Table 3, the Zn concentration was 527mg/kg, exceeding the standard limit value (500mg/kg) stipulated in the National standard of pollutants control of agricultural sludge (GB4284-1984).

Table 4 The comprehensive pollution index of heavy metal of sludge

Heavy metal	measured concentration	Standard	Single factor index	Pollution level
	mg/kg	mg/kg		
Pb	15.8	500	0.032	Slight concentration
Zn	527	500	1.05	Moderate concentration
Cu	126	400	0.315	Slight concentration
Cr	74.8	300	0.249	Slight concentration
comprehensive pollution index		0.798		Still clean

As shown in Table 4, the single factor index of Zn was 1.05, which belonged to moderate concentration in pollution level. Except that, the pollution level of the other metals was all slight concentration. The comprehensive pollution index of heavy metals was 0.798, which belonged to the still clean in pollution level.

Table 5 Zn concentration of sludge in different treatment plants

Table 5 Zn concentration of sludge in different treatment plants								
Project Plant		Heavy metal mg/kg		Standard pH<6.5	Single factor index	Pollution level	comprehensive pollution index	comprehensive pollution level
No.2	Zn	525		<500	1.05	Moderate concentration	0.803	Still clean
No.3	Zn	555		<500	1.11	Moderate concentration	0.840	Still clean
No.4	Zn	508		<500	1.02	Moderate concentration	0.777	Still clean

No.5	Zn	454	<500	0.908	Slight concentration	0.383	clean
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As shown in Table 5, the heavy metal concentration and pollution situation of sludge in No.2, No.3 and No.4 treatment plants were similar to that in No.1 treatment plant, the pollution level of Zn of the sludge in three treatment plants were moderate concentration. The comprehensive pollution index of heavy metals of the sludge in three treatment plants were more than 0.7, which belonged to still clean. While the sludge pollution situation in No.5 treatment plant was better than others, the comprehensive pollution index of heavy metals of the sludge was 0.383, which belonged to clean.

Table 6 The heavy metal concentration of sludge in the No.6 treatment plant

No.6 treatment plant		Pb	Zn	Cu	Cr
		mg/kg	mg/kg	mg/kg	mg/kg
The average of plant		23.3	1250	732	79.7
GB 24188-2009		<1000	<4000	<1500	<1000
GB 18918-2002	pH<6.5	<300	<2000	<800	<600
	pH≥6.5	<1000	<3000	<1500	<1000
GB 4284-1984	pH<6.5	<300	<500	<250	<600
	pH≥6.5	<1000	<1000	<500	<1000

As shown in Table 6, the concentration of Zn and Cu was 1250 mg/kg and 732 mg/kg, respectively. Both of them exceeded the standard limit values stipulated in the National standard of pollutants control of agricultural sludge (GB4284-1984).

Table 7 The comprehensive pollution index of heavy metal of sludge

Heavy metal	measured concentration	Standard	Single factor index	Pollution level
	mg/kg	mg/kg		
Pb	23.3	500	0.047	Slight concentration
Zn	1250	500	2.50	Moderate concentration
Cu	732	400	1.83	Moderate concentration
Cr	79.7	300	0.266	Slight concentration
comprehensive pollution index		1.95		Slight concentration

As shown in Table 7, the single factor index of Zn and Cu were 2.50 and 1.83, respectively, which belonged to moderate concentration. The pollution levels of the other metals were all slight concentration. The comprehensive pollution index of heavy metals was 1.95, which belonged to the slight concentration.

From Table 3 to Table 7, the pollution evaluation index of heavy metals in different sludge was different. This may have some relationship with the sewage source. In this study, the comprehensive pollution index of heavy metals of sludge in five treatment plants were between 0.7 to 1, which reached the level of still clean. It should be paid attention that these pollution may lead to the risk of heavy metals in the process of recycling use.

3.2 Potential ecological risk assessment of heavy metals in sludge

The environmental risk index and composite index in sludge were shown in Table 8 to Table 10.

Table 8 Potential ecological risk index of No.1 treatment plant

Heavy metal	measured concentration	environmental risk index		composite index RI
	mg/kg	C^i_f	E^i_r	
Cu	126	4.20	21.0	33.3
Zn	527	6.59	6.59	
Pb	15.8	0.632	3.16	
Cr	74.8	1.25	2.49	

As can be seen from Table 8, the environmental risk index of Cu in No.1 treatment plant was 21.0, which belonged to the high ecological risk. The comprehensive risk index was 33.3, which belonged to the medium ecological risk.

Table 9 Potential ecological risk index of Cu

Project Plant	Cu measured concentration	environmental risk index		Environmental risk assessment	composite index RI	composite index assessment
	mg/kg	C^i_f	E^i_r			
No.2	140	4.66	23.3	High ecological risk	37.9	Medium ecological risk
No.3	123	4.10	20.5	High ecological risk	34.7	Medium ecological risk
No.4	153	4.10	20.5	High ecological risk	34.7	Medium ecological risk
No.5	131	4.39	21.9	High ecological risk	32.7	Medium ecological risk

It can be seen from Table 9 that the environmental risk index of Cu of the sludge in No.2, No.3, No.4 and No.5 were all between 20 and 40, which belonged to the high ecological risk. The comprehensive risk index of the four treatment plants were between 30 and 60, which belonged to the medium ecological risk.

Table 10 Potential ecological risk index of No.6 treatment plant

Heavy metal	measured concentration	environmental risk index		composite index RI
	mg/kg	C^i_f	E^i_r	
Cu	732	24.4	122	145
Zn	1.25E+03	15.6	15.6	
Pb	23.3	0.931	4.65	
Cr	79.7	1.33	2.66	

As can be seen from Table 10, the environmental risk index of Cu in No.6 treatment plant was 122, which belonged to the extremely high ecological risk. The environmental risk index of Zn in No.6 treatment plant was 15.6, which belonged to the Medium ecological risk. The comprehensive risk index was 145, which belonged to the higher ecological risk.

4. Conclusions

1) The pollution of metal Zn and Cu of sludge in the treatment plant was serious.

2) According to the assessment of heavy metal pollution in sludge, the pollution index of heavy metals of sludge in five treatment plants were between 0.7 to 1, which reached the level of still clean. The main sewage source of No.1 to No.5 treatment plants was domestic sewage, Zn concentration exceeded the standard limit value seriously. The comprehensive pollution level of the sludge from No.1 to No.4 treatment plant was still clean, the comprehensive pollution level of No.5 treatment plant was clean. The main sewage source of No.6 treatment plant was industrial wastewater. The concentration of Zn and Cu in the treatment plant exceeded the standard limit value seriously. And the comprehensive pollution level of sludge in the treatment plant belonged to slight concentration.

3) According to the Potential ecological risk assessment of heavy metals in sludge, the main sewage source of No.1 to No.5 treatment plants was domestic sewage. The environmental risk index of Cu was higher. The comprehensive risk level of sludge in five treatment plants was Medium ecological risk. The main sewage source of No.6 treatment plants was industrial wastewater. The environmental risk index of Cu and Zn were higher. The comprehensive risk level of sludge was higher ecological risk.

Acknowledgements

This work was supported by the Beijing Nature and Science Foundation (No. 8162020).

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