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Assessment of Abandoned Unsanitary Landfills in Rural Areas of Ningbo, China

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This paper reports the characteristics and the pollution status of the abandoned unsanitary landfill which were widespread in the southeast countryside of China. The results show there were at least 100 unsanitary landfills in Ningbo and the waste accumulated was estimated to be equal to the landfill capacity of one large sanitary landfill that had been running for 40 years with an input of 1,000 tons of waste each day. The organic components and Cd content of the rural waste were high, 69.8 g organic matter (OM) kg^{-1} DW^{-1} (dry weight) and 17.6 mg Cd kg^{-1} DW^{-1} (dry weight) respectively. nitrogen and chemical oxygen demand (COD) were the primary products in the leachate in the unsanitary landfills and its concentrations of macronutrients were much lower than that from the sanitary landfill. The macronutrients (chemical oxygen demand, nitrogen and phosphorus) were the prevalent contaminant in the surface water around the unsanitary landfills. Compared with the reference values, the total nitrogen, total phosphorus and cadmium contents of the soil surrounding the unsanitary landfills had the trend of accumulation. Geoaccumulation index results show the Cd and Zn contamination of the soil were moderately and unpolluted-moderately polluted, respectively.

Key Words: Rural waste, Unsanitary landfills, Soil contamination, Leachate, Ningbo.

INTRODUCTION

Rural waste is combined solid waste in rural residents' daily life. In China, the environment impact of rural waste was low until 1980s, because the components of the waste were sole, almost all of them belonged to natural organic waste that can be decomposed naturally and used predominantly as the livestock feed and the compost of the farmland in the agricultural production. The rapid development of China's east coastal areas and the accompanying population hike in the 1990s spurred rising rural waste management issues. Not only the amount of rural waste increase dramatically, but its components changed greatly as well (including coal cinder, food waste and dirt soil, plastic refuse, abandoned battery and packaging materials). Rural waste is no longer to be one favourable agricultural fertilizer. The giant imbalance between the less utilization of the rural waste with the increasingly high waste production has led to increasingly serious environmental problems.

Given the awful circumstances, almost each village constructed one (or even two) dumping site to dispose the solid waste in countryside. After 2000s, with the incremental awareness of the environmental protection, standardized municipal landfills were constructed to replace the unsanitary landfills. Hence, these sites were gradually shuttered and abandoned since 2000s. Almost all the unsanitary landfills were covered with the soil and some of them were planted. In general, the odor and the fly were absent and the offensive appearance of the sites was alleviated to some extent.

Majority of rural villagers and government officials in the region believed that pollution was eliminated following the closure of unsanitary landfills. However, field investigations revealed that these sites continued to discharge pollutants (especially leachate) into the adjacent area. Nevertheless, there were little data available and few research reports about the abandoned unsanitary landfill in China and the remediation report on these unsanitary landfills lacked. East China is one of the chief economic drivers of the country, with 6 % population and accounting for 22 % of the gross domestic product (GDP). Its healthy and stable development depends significantly on effective decontamination control. As one of the classical and highly developed metropolis in east China, the investigation results in Ningbo would be a beneficial reference to understand the contamination condition of the unsanitary landfill in this region.

The objectives of the study are to (1) investigate the characteristics of the unsanitary landfills (including their dimensions, number and the physical parts of the rural waste); (2) determine the environmental pollution condition within the unsanitary landfills, including the main pollutants and the contamination degree of the surface water and sediment; (3) provide cost-effective remediation suggestions for the unsanitary landfills.

EXPERIMENTAL

Description of study area: Ningbo is located in the middle part of the coastline in southeast China (latitude of 28º51' E-30º33' N), east of the NingShao Plain in Zhejiang province and is a classical subtropical monsoon climate region with an average annual precipitation of 1500 mm. The city has a population of 6.9 million in 2007 and the rural land accounts for 74.9% of the total area in the region. The economy in the region is primarily supported by the garment, textile, mechanical, petrochemical, steel, paper and bio-pharmaceutical industries. Ningbo, China.

Sampling: Ten representative unsanitary landfills were chosen for field investigation and sample collection (Fig. 1). By visiting the surrounding farmers, local township officials, other insiders and investigating the unsanitary landfill, a great deal of first-hand information about the unsanitary landfills was obtained. Questionnaires pertaining to the unsanitary landfills were also issued. All the investigation activities were recorded with camera.

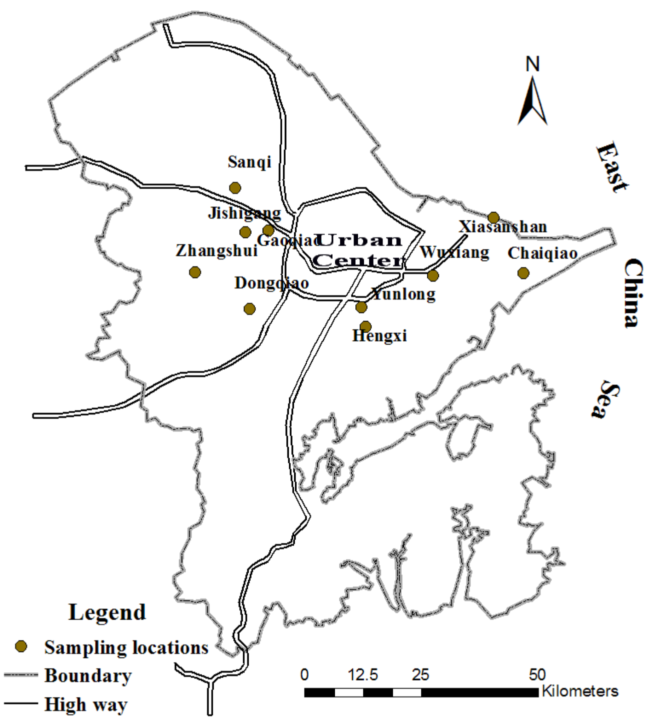

Fig. 1. Sampling locations of the rural unsanitary landfills in Ningbo, China

The investigation lasted from March to October 2008. All of the samples were collected within a distance of 0-100 m inside the unsanitary landfills after it was confirmed that the sampling locations were contaminated visibly and/or informed from the local residents. The sampling area was barren farmland or woodlands, where no industrial activities existed. Leachate and water samples were collected, capped airtight and immediately stored at 4-5 ºC. Soil samples, from 0 to 20-cm in depth, were collected at each sampling point and mixed thoroughly to get a representative sample of 1.5 kg to 2.0 kg. Each solid waste sample weighed about 5-10 kg and the final sample was about 2-3 kg by using quartering method. The prepared soil and solid waste samples were then sealed in polyethylene bags and stored at 4 ºC for further analyses.

Analysis: The pH of the water and the soil were measured using glass electrodes (Sartorius, PB-10) and the electrical conductivity (EC) of the water was analyzed using the probe method (Lida DDS-11AW). The total nitrogen (TN), ammonia nitrogen (NH_4-N), total phosphorus (TP), potassium permanganate (COD_{Mn}) and chemical oxygen demand (COD_{Cr}) were measured according to the standard method[1]. Heavy metals of leachate and surface water were measured using ICP-MS (Agilent 7500a).

The soil and solid waste samples were air dried in shady and cool conditions until a constant weight was reached. Then the soils were sieved with a 1 mm mesh sieve to remove large debris, stones and pebbles. By quartering each soil sample, about 50-100 g samples were ground with a wood bar and sieved with 0.15 mm mesh to collect fine particles (< 0.15 mm). The total nitrogen, NH_4-N, total phosphorus and organic matter (OM) of the soil were measured using standard procedures[2]. For heavy metal analysis of soil, 0.25 g soil was digested with 4 mL HNO_3, 1 mL HF and 1 mL $HClO_4$ under sealed Teflon tank for 10 h (120 ºC for 2 h and then 175 ºC for 8 h). Heavy metals of soil were measured using ICP-MS (Agilent 7500a).

Assessment of environmental quality: Using integrated pollution index (IPI)[3,4] the water quality index to evaluate the water surrounding the unsanitary landfills (the criteria value is the grade III of surface water (EPA of China and CAQSIQC (Central Administration of Quality Supervision-Inspection and Quarantine of China)[1]. The integrated pollution index for each sample was defined as the arithmetic mean of the pollution index. The pollution index was classified as the ratio of the concentration of i^{th} pollutants to the corresponding concentration of i^{th} pollutants of criteria value. The integrated pollution index was classified as clean (IPI = 0.2), warning (0.2< IPI = 0.4), slight pollution (0.4< P = 0.7), moderate pollution (0.7< IPI = 1.0), heavy pollution (1.0< IPI = 2.0), serious pollution (IPI >2.0). The exceeding ratio of samples is defined as: for the ith pollutant, the ratio of number of the samples exceeding the standard concentration to the sample numbers.

Geoaccumulation index (I_{geo}) was calculated to assess the degree of heavy metal pollution in soil surrounding the unsanitary landfills. I_{geo} was calculated by the following equation: $I_{geo} = \log_2[C_n/1.5B_n]$, where C_n represents the measured concentration of the metal n and B_n is the background values of the soils[5,6]. The following classification is given for I_{geo}: <0 = practically unpolluted, 0-1 = unpolluted to moderately polluted, 1-2 = moderately polluted, 2-3 = moderately to strongly polluted, 3-4 = strongly polluted, 4-5 = strongly to extremely polluted and >5 = extremely polluted. The background values of nature soil in Ningbo, China is used as the reference values[7].

Data analysis: Data collected from the interviews, investigations, surveys and field-work were processed, reviewed, edited and analyzed using SPSS 14 and Origin 6.

RESULTS AND DISCUSSION

Characteristics of the unsanitary landfills: The average dump volume, daily input of waste and site area of the abandoned unsanitary landfill were 80509 m^3, 41 tons per day and 9961 m^2 (Table-1). Fig. 1 shows that the unsanitary landfills originally situated in the countryside was in outskirts or even embedded in the urban areas already owing to the fast urbanization process. The results indicate the notable characteristics of these sites: daily input was small, but the waste retained was large and the sites scattered throughout the region.

TABLE-1
BASIC PROPERTY OF RURAL WASTE UNSANITARY LANDFILLS IN NINGBO

	Daily input of waste, ton day^{-1}	Site area (m^2)	Dump volume (m^3)
Average	41 ± 12	9956 ± 7368	80508 ± 102976
Range	18 – 50	2000 – 26680	4060 – 360200

Analyzing result of the physical components of the rural waste is shown in Table-2. The major parts was inorganic, 78.7 % DW (dry weight) and the ratio of the plastic, glass and textile was 11.5, 5.2 and 3.0 % respectively. The portion of the yard waste, metals and hazardous materials (including plastic, syringes, batteries, rubber polymers and grease, *etc.*) was all not more than 0.6 % and the ratio of the paper and food scraps was zero.

TABLE-2
COMPOSITION OF RURAL WASTE IN UNSANITARY LANDFILLS (n = 5)

Component	% (w/w, dry weight)
Wood	0.6
Metals	0.6
Shell & bone	1.1
Plastic	11.5
Textile	3.0
Glass	5.2
Earth material	58.8
Brick & gravel	18.8
Hazardous waste	0.3

The variations of chemical components of rural waste were great except pH (Table-3). About the macronutrients, the loss on ignition, organic material and total nitrogen contents were high, 20.3 %, 69.8 g kg^{-1} DW^{-1} and 2217.6 mg kg^{-1} DW^{-1}, respectively, while the NH_4-N and total phosphorus content were much lower, 356.0 and 693.9 mg kg^{-1} DW^{-1}, respectively. Considering the metal contents, of most concern was Cd (17.6 mg kg^{-1} DW^{-1}) and Zn (1795.6 mg kg^{-1} DW^{-1}).

Characteristics of the leachate: The characteristics of the leachate from unsanitary landfills are listed in Table-4. The elements of great variation included COD_{cr}, NH_4-N, total nitrogen, total phosphorus and heavy metal contents (Cr, Zn, Cd and Pb). In organic contaminants, the concentration of COD_{cr} and total nitrogen were the highest (181.6 and 149.9 mg L^{-1}, respectively), while the total phosphorus concentration was quite low, 5.5 mg L^{-1}. Similar with the leachate from the municipal landfill[8,9] the heavy metal contents in leachate from the unsanitary landfills were low, except Cu and Zn (106.3 and 475.1 mg L^{-1}, respectively).

TABLE-3
CHEMICAL COMPONENTS OF RURAL WASTE IN UNSANITARY LANDFILLS AND SANITARY LANDFILLS (n = 5)

		Average	Range
pH	–	7.5 ± 0.6	6.9-7.9
LOI	%	20.3 ± 22.0	1.0-68.0
OM	g kg^{-1}	69.8 ± 71.9	8.0-227.4
TN	mg kg^{-1}	2217.6 ± 1347.8	695.4-3259.4
NH_4-N	mg kg^{-1}	319.1 ± 356	94.5-729.5
TP	mg kg^{-1}	693.9 ± 410.7	70.4-1296.2
Cr	mg kg^{-1}	501.3 ± 791.1	96.5-2112.6
Cu	mg kg^{-1}	707.4 ± 912	127-2547.9
Zn	mg kg^{-1}	1795.6 ± 1141.1	703.5-3744.3
Cd	mg kg^{-1}	17.6 ± 21.9	1.9-57
Pb	mg kg^{-1}	499.6 ± 659.1	86.5-1764.7

TABLE-4
CHARACTERISTICS OF THE LEACHATE FROM UNSANITARY LANDFILLS IN NINGBO (n = 28)

		Unsanitary landfills in Ningbo		SL*
		Mean	Range	
pH	–	7.7 ± 0.9	3.9-8.7	7.9
EC	µS cm^{-1}	2105.2 ± 3515.8	308.5-13700.0	21000
COD	mg L^{-1}	167.4 ± 702.7	7.3-3465.6	3633.3
NH_4–N	mg L^{-1}	76.1 ± 171.2	0.8-680.8	1055.2
TN	mg L^{-1}	162.0 ± 418.0	2.9-2266.8	1219
TP	mg L^{-1}	3.3 ± 11.8	0-65.3	8.1
Cr	µg L^{-1}	81.1 ± 285.4	2.5-1472.2	49.0
Cu	µg L^{-1}	106.3±118.6	2.1-392.4	53.7
Zn	µg L^{-1}	475.1±2088.1	12.8-10700	22.1
Cd	µg L^{-1}	3.4±15.2	0.1-78.1	119.8
Pb	µg L^{-1}	49.2±198.1	0.5-1015.3	241.5
Ni	µg L^{-1}	40.9±50.0	3.6-139.6	NA

SL*, Tianziling sanitary landfill was operated for more than 18 years in Hangzhou, China

Assessment of surface water and soil pollution surrounding the landfills: Compared with the background values, the nutrients in the surface water were higher than the former (especially the total nitrogen and NH_4-N, Table-5) and the nutrient levels (N and P) were also much higher than that of the surface water standard (grade III), indicating the prevalent contamination of macronutrients. According to integrated pollution index (Table-6), about 55 % of samples were classified as moderate-serious pollution. The maximum levels of Cr, Cd and Pb in the surface water were higher than the surface water criteria value in China (EPA of China) and CAQSIQC (Central Administration of Quality Supervision-Inspection and Quarantine of China)[4]. According to the criteria value, the surface water could be used as the irrigation water (only one water sample's maximum Cr concentration beyond the threshold). However, the more frequent and long-term monitoring is needed to secure the safety of the agricultural products, since heavy metals could reach problematic levels despite depressed concentrations through the bio-accumulation mechanism[10,11].

Table-6 reveals the characteristic of the soil. The variation of total nitrogen, total phosphorus, Zn and Cd was high, while

TABLE-5
CHARACTERISTICS OF SURFACE WATER SURROUNDING THE UNSANITARY LANDFILLS (n = 20)

		Mean	Range	Reference[A]	Standard[B]
pH	–	7.4 ± 0.8	6-9.5	7.5 ± 0.1	6-9
EC	µs cm^{-1}	361 ± 283	119.3-1124.0	233 ± 102	NA
CODMn	mg L^{-1}	6.1 ± 3.9	2.0-18.9	3.5 ± 1.8	6
NH_4-N	mg L^{-1}	3.0 ± 4.8	ND-17.4	0.5 ± 0.2	1
TN	mg L^{-1}	6.5 ± 8.2	0.4-34.1	4.8 ± 0.7	1
TP	mg L^{-1}	0.3 ± 0.5	0-1.7	0.1 ± 0.0	0.2
Cr	µg L^{-1}	22.1 ± 32.6	0.5-139.2	1.6 ± 0.8	50
Cu	µg L^{-1}	14.6 ± 23.4	0.7-72.8	15.4 ± 12.4	1000
Zn	µg L^{-1}	56.1 ± 103.6	0.5-450.6	89.1 ± 67.7	1000
Cd	µg L^{-1}	0.9 ± 1.8	0-6.7	0.5 ± 0.6	5
Pb	µg L^{-1}	5.0 ± 12.2	0.1-53.3	2.9 ± 0.7	50
Ni	µg L^{-1}	3.9 ± 4.2	0-14.5	2.4 ± 2.7	20

[A]The reference is the water quality of two wells inside two unsanitary landfills; [B]The surface water standard is grade III criteria of the national surface water quality standard GB 3838-2002 [18]

TABLE-6
CHARACTERISTICS OF THE SOIL SURROUNDING THE UNSANITARY LANDFILLS (n = 21)

		Mean	Range	Reference [21]	Std. [26]
pH	–	5.6 ± 1.4	3.7-7.9	5.3 ± 0.36	None
OM	g kg^{-1}	20.0 ± 9.4	8.7-40.1	22 ± 6.9	None
TN	mg kg^{-1}	1671.1 ± 2027.3	358.2-9916.1	1201 ± 247	None
TP	mg kg^{-1}	684.4 ± 658.2	163.8-3311.8	528 ± 126	None
Cr	mg kg^{-1}	48.2 ± 27.5	15.4-126.8	38 ± 15.2	250
Cu	mg kg^{-1}	26.5 ± 15.6	9.0-74.9	17 ± 4.9	50
Zn	mg kg^{-1}	192.7 ± 269.7	72.5-1221.3	68 ± 10.9	200
Cd	mg kg^{-1}	0.9 ± 1.2	0.2-4.7	0.18 ± 0.03	0.3
Pb	mg kg^{-1}	34.7 ± 9.4	21.1-65.7	32 ± 3.4	250

Note: Std., standard value of the surface water

TABLE-7
GEOACCUMULATION INDEX (I_{geo}) OF HEAVY METALS OF THE SOIL SURROUNDING THE UNSANITARY LANDFILLS (n = 21)

	I_{geo}		Class	Pollution level	Ratio of samples, %		
	Mean ± SD	Range			< 0	0-1	≥1
Cr	-0.5 ± 0.9	-3.2-1.2	0	Unpolluted	71.4	24.4	4.8
Cu	-0.2 ± 1.0	-3.1-1.6	0	Unpolluted	54.8	36.6	9.5
Zn	0.2 ± 1.1	-1.9-4.5	1	Unpolluted-moderate	52.4	36.6	11.9
Cd	1.0 ± 1.3	-1.5-4.2	2	Moderate	19.0	53.7	28.6
Pb	-0.6 ± 0.6	-4.0-1.0	0	Unpolluted	95.2	4.9	0.0

that of organic matter and Pb was low. Compared with the background value, the total nitrogen, total phosphorus, Zn and Cd contents were much higher and the Cr, Cu and Pb levels were slightly higher. Although the average organic matter content of the soil in the landfill was not higher than that of the reference, there was an evident trend of the soil souring. Compared with the regulatory limits (Table-6 and Fig. 2), the average Cd content was more than 3-folds higher and maximum levels of Cu and Zn were also higher than that of the standard level. Therefore, according to the legislative limit[1] the land of the landfills were just suitable to be used as wood land, rather than as the agricultural land (food, tea, vegetable and fruit production) to protect the health of human being.

As shown in Table-7, the results of the calculated I_{geo} values of the soil are -3.2-1.2 for Cr, -3.1-1.6 for Cu, -1.9-4.5 for Zn, -1.5-4.2 for Cd, -4.0-1.0 for Pb. Based on th classification of geoaccumulation index (I_{geo}), the average geoaccumulation indexes of Zn (0.2 ± 1.1) and Cd (1.0 ± 1.3) suggest that the soils are unpolluted-moderately and moderately

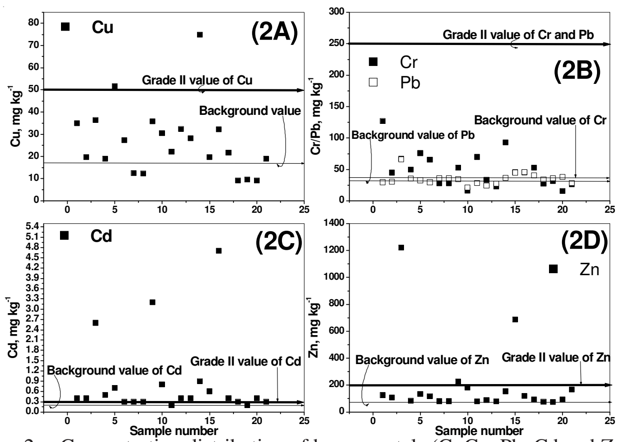

Fig. 2. Concentration distribution of heavy metals (Cr,Cu, Pb, Cd and Zn) in soils surrounding the abandoned rural unsanitary landfills in Ningbo

Note: Maximum acceptable soil limits of Cr, Cu, Zn, Cd and Pb for the protection of agricultural production, safeguarding human health health (Grade II threshold limits): 250, 50, 200, 0.3 and 250 mg kg^{-1}, respectively polluted by with Zn and Cd, respectively. In contrast, the average geoaccumulation indexes of Cr (-0.5 ± 0.9), Cu (-0.2 ± 1.0) as well as Pb (-0.6 ± 0.6) are less than zero ($I_{geo} < 0$) (Table-7), suggesting that the soils have not been polluted overall by these metals.

Pollution of the abandoned unsanitary landfills: Tables 2 and 3 illustrate the high organic matter and total nitrogen contents of (Grade II threshold limits): 250, 50, 200, 0.3 and 250 mg kg^{-1},respectively the rural waste (major parts of the earth material should be the food waste) since usually the kitten food scraps accounted for more than 50 % (w/w) of the municipal solid waste in east China[12]. Moreover, the high metal contents in the waste (especially Cd and Zn) reveal the pollution risk of the rural waste. Chen *et al.*[13] and He *et al.*[12] pointed out that the processing capacity of the sanitary landfills were over 1000 tons each day in east China, which were far higher than that of these sites (41 tons per day). However, the results of field survey indicate that there were more than 100 abandoned unsanitary landfills in the rural areas of Ningbo, China (a conservative estimate of the average landfilling life of the rural waste was 10 years). While the numbers of the sites multilplied the waste amassed, the waste accumulated was equal to the landfill capacity of one large sanitary landfill that had been running for 40 years with an input of 1,000 tons of waste each day. The potential contamination from such a huge mass of accumulated waste in the landfills should be paid sufficient attention. Field survey also found pollution accidents associated with the unsanitary landfills (including body collapse, seashore pollution, self-ignition and fish deaths, *etc*., which were probably originated from the unstable geographical conditions of the sites or the harmful chemicals commingled in the rural waste) were one of the characteristics to be noticed. In summary, such a huge accumulated waste and the high contents of the macronutrients and metal in the waste revealed that the rural waste in the unsanitary landfills posed great pollution potential on the outside environment.

The serious macronutrients contamination on the surface water (Table-5 and supplementary Table-1) and moderate heavy metal contamination on the soil (Tables 6 and 7) surrounding the unsanitary landfills imply that the most possible pollution source was from the discharge of overflowed leachate run-off. Under the continuous leaching of the rural waste (broken and exposed section of the clay cover layer of the unsanitary landfills), the organic matter, N and P content of the surface water and soil would increase gradually under the fertilizing effect of the leachate. In this process, the trace heavy metals in the leachate will inevitably enter the soil accompanying the organic contaminants (organic matter, N and P).

To sum up, the leachate production was greatly magnified[14] by the large amounts of waste (equal to 1000 tons per day roughly) and the heavy precipitation (annual average precipitation 1500 mm. The much lower concentrations of the contaminants in the leachate from the unsanitary landfills than that of the sanitary landfill show the more intensive dilution by the precipitation. This process enhanced the leachate migration capacity on the surrounding environment and thus expanded the scope of the contaminated area. Since the rich river systems (74 large-scale rivers or lakes and numerous small streams or ponds in Ningbo, China[15] the overloaded nutrient input from the leachate aggravated the eutrophication of the downstream water body. Therefore, it is time to initialize the decontamination research on the unsanitary landfills located in the rural areas.

Decontamination recommendation for the abandoned unsanitary landfill: As one of the remediation options, the rural waste from several unsanitary landfills had been excavated and moved it into the new sanitary landfill. Although this method can prevent new pollution, it was not feasible for the large number of unsanitary landfills. Since those sites were dispersed throughout the whole area of Ningbo, China the costs of the removal, transportation and disposal these wastes were expensive. More importantly, sanitary landfill itself is a kind of non-renewable resources currently and it is much harder to find a suitable area to build a sanitary landfill than ever because of the stronger public opposition and the more expensive land expenditure.

Here, we proposed a decentralized *in situ* restoration approach for the unsanitary landfills, a combination of the leachate drainage controlling with the leachate treatment using land application. Because of the leachate is the overwhelming contamination source and the continued rainfall in Ningbo, China surface water and drainage control would be an indispensable prerequisite in reducing the contamination from the leachate. Rebuilding the surface water control systems, especially the flood drainage ditch, would effectively restrict the amount of water (mainly rainfall) entering into the landfill body[16]. Furthermore, the planted vegetation and the enclosure would also hamper the leachate flow. About the leachate treatment, present results prove that the constructed wetland (CW) and multi-soil-layering system (MSL) were viable options to purify the organic matter and nutrients in the leachate through the media adsorption, aquatic plant absorption, the microorganism decomposition and utilization and their interactional processes[17-19].

Conclusion

This research found there were at least 100 unsanitary landfills in Ningbo and the waste accumulated was estimated to be equal to the landfill capacity of one large sanitary landfill that had been running for 40 years with an input of 1,000 tons of waste each day. A lack of environmental protection measures resulted in a series of problems, including serious pollution accidents, cadmium pollution to soil and prevalent nutrient contamination to the surface water. Finally, we proposed a decentralized *in-situ* restoration approach for the unsanitary landfills, a combination of the leachate drainage controlling with the leachate treatment using land application.

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