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Impact of Electronic Wastes Recycling on Environmental Quality

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Objective To evaluate the environmental quality of Guiyu, Guangdong impacted by the electronic waste recycling industry. **Methods** The surface water, ground water and sediment samples taken separately from two sites that recycle E-wastes and other rubbish relevant to the E-waste recycling, and an agricultural area, were analyzed, and the data were used to evaluate the impact of E-waste recycling on the environmental quality of Guiyu based on environmental quality standards in China. **Results** The concentrations of lead and iron in the surface water samples significantly different in the three locations. The maximum value of lead in the first site was 8 times higher than the threshold of environmental quality standards for surface water. The concentration of iron in polluted sample was 22 times that of the background sample. Manganese and iron also showed a significant difference in ground water samples between the three sites. The amount of iron was 22 times that of the threshold of the quality standard for ground water, and 120 times that of the background sample. Moreover, the results of all the eight heavy metals showed significant differences among the sediment samples. The concentrations of copper, cadmium, nickel, and lead in the polluted samples were above the median benchmarks of National Oceanic and Atmospheric Administration (NOAA). The copper concentration of 2670 mg/kg was 10 times that of the median benchmark. **Conclusion** E-waste recycling has led to the severe pollution Guiyu.

Key words: Electronic waste recycling; Environmental quality impact evaluation

INTRODUCTION

At present, electronic waste has increases rapidly in the world. The developed countries export E-wastes to Asia by different ways, which inevitably cause severe pollution of the environment in the victim countries. Such an irresponsible action now attracts the attention of some international environmental protection organizations and Chinese government[1]. Investigation and an abundance of news about the E-waste recycling in China have shown the very serious situation in the eastern coast of Guangdong Province[2]. The report by the Basel Action Network and Silicon Valley Toxics Coalition pointed out that, the lead concentration in samples taken in an E-waste recycling location was 2400 times that prescribed in World Health Organization (WHO) Drinking Water Guidelines. In December 2001, the levels at the same site were found to be 190 times the threshold WHO level. Furthermore, the results of sediment samples were especially surprising. A sediment sample taken under the river showed lead content 212 times higher than that in the hazardous waste from the Rhine River bottom in the Netherlands[2]. Contents of other heavy metals were hundred times higher than those of the EPA threshold for environmental risk in soil; especially the copper accounted for 13.6% of the total. Although some of these samples were taken directly from the E-waste residues, some were taken from the surface water and sediment adjacent to the E-waste recycling site; therefore the results were certainly very high and could not be used to evaluate the whole environmental quality of Guiyu. Nevertheless, the results of the former report and another report about the impact of the E-waste recycling on the health of residents in Guiyu by the International Green Peace Organization and Sun Yat-Sen University showed[3] that E-waste import and the outdated recycling methods have resulted in the serious harm to the environment and the residents' health. For the purpose of investigating the real environmental quality of Guiyu thoroughly, samples of surface water, ground water, and sediment were taken from the three sites, and the results were analyzed to evaluate the impact of E-waste recycling on the environmental quality of Guiyu.

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METHODS

Sampled Locations

Since no background values for such samples of Gui Yu were available before E-waste import, only one site was chosen as the contrast locality for taking the background samples. Another site with a number of workshops for gathering and processing E-wastes was chosen for taking the polluted samples, whereas an other site for gathering other rubbish relevant to the E-waste recycling was also chosen as the contrast locality. Samples of surface water, ground water, and sediment were taken from the three localities. The samples in detail are shown in Table 1.

TABLE 1

Sampled Locations and Samples Taken

Remark	Site Number	Locations
Samples of Surface Water, Ground Water, and Sediment Were Taken From the Three Locations	1	One Site With Workshops for Gathering and Processing E-wastes
	2	One Site for Gathering Other Rubbish Relevant to E-waste Recycling
	3	One Site for Taking Background Samples

Note. The samples taken from sites 1, 2, and 3 are here in after referred to as samples No.1, 2, and 3.

Sample Collection

In order to find the relationship between samples and time or season, the samples were taken in December of the first year (low-water season), April (intermediate-water season) and August (high-water season) of the second year. The sample size was sufficient for the determination.

Sample Preparation

Water samples were treated with acid or stored in refrigerator. After being air-dried, the sediment samples were crushed and ground to 100-mesh size. The preparation of sediment samples for each heavy metal was in accordance with the standard determination methods.

Determination Items

According to the environmental quality standard of China and with regard to the possible pollution caused by the E-waste recycling[2,4-5], the following items were determined (Table 2).

Determination Methods

All items of the samples were determined according to the Chinese national standard methods or the standard analytical methods established by the Chinese Environmental Protection Agency[6-7]. Quality control included parallel sample determination, recovery experiment, and unknown standard sample[8].

TABLE 2

Samples and Determination Items

Samples	Determination Items
Surface Water	pH, Dissolved Oxygen, Permanganate Index, Ammonium, Oil, Fluoride, Arsenic, Mercury, Copper, Zinc, Cadmium, Lead, Nickel, Chromium, Manganese, Iron
Ground Water	pH, Turbidity, Fluoride, Arsenic, Mercury, Copper, Zinc, Cadmium, Lead, Nickel, Chromium, Manganese, Iron
Sediment	Arsenic, Mercury, Copper, Zinc, Cadmium, Lead, Nickel, Chromium

RESULTS AND DISCUSSION

Results of Surface Water and Evaluation

The determined values of selected items of surface water and the reference values of Chinese environmental quality standards for surface water are shown in Table 3.

Evaluation of Results

As shown in Table 3, the ranges of pH, arsenic, mercury, copper, zinc, cadmium, and nickel in the three samples were 6.71-7.58, <0.008-0.011 mg/L, $<5.0\times10^{-5}$ mg/L, <0.05-0.67 mg/L, 0.03-0.45 mg/L, <0.0008-0.0038 mg/L, and <0.05 mg/L, respectively, below the threshold values of the Chinese

environmental quality standards for surface water. The range of dissolved oxygen was 0.85-10.4 mg/L. All the results of sample No.1 were above the threshold. Samples No.2 and No.3 in August were also above the threshold probably due to the hot weather or high temperature. The range of permanganate index was 6.89-40.0 mg/L; its maximum value was in sample No.1 in April. The range of ammonium was 0.450-12.5 mg/L, with the maximum value also in sample No.1 in April. It is shown that the quality of surface water in location 1 reaches the worst peak in April. The maximum value of lead in sample No.1 in December was 8 times the standard threshold. The maximum concentration of manganese in sample No.2 in August was 4 times the threshold. The maximum value of iron in sample No.1 in December was 3 times the threshold. Since heavy metals are the most serious threat to surface water from the E-waste, the results of lead, manganese, and iron were compared between the samples and evaluated (Table 4).

TABLE 3

Determined Results of Surface Water (mg/L)

Items	Reference Values of Standards	Sample No. 1			Sample No. 2			Sample No. 3		
		Dec.	Apr.	Aug.	Dec.	Apr.	Aug.	Dec.	Apr.	Aug.
pH	6.5-8.5	6.71	7.21	7.07	6.78	7.43	7.27	6.95	7.58	7.20
Dissolved Oxygen	⩾5	3.66	0.85	4.79	10.4	7.31	3.56	9.51	9.99	3.75
Permangnate Index	⩽8	11.8	40.0	10.7	8.30	20.0	8.16	6.89	12.6	8.69
Fluoride	⩽1.0	1.11	1.84	1.18	1.53	1.26	1.32	2.10	1.10	1.48
Ammonium	⩽0.5	5.04	12.5	0.874	0.667	11.3	0.594	0.150	2.70	0.68
Oil	⩽0.05	0.235	0.268	<0.050	0.312	0.347	<0.050	<0.050	0.184	<0.050
Arsenic	⩽0.05	0.011	0.010	0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Mercury	$\leqslant 1.0\times 10^{-4}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$	$<5.0\times 10^{-5}$
Copper	⩽1.0	0.67	0.55	0.35	0.13	0.38	0.09	0.08	<0.05	0.08
Lead	⩽0.05	0.40	0.19	0.18	0.034	0.040	0.026	0.034	0.038	0.017
Zinc	⩽1.0	0.45	0.39	0.33	0.19	0.11	0.08	0.03	0.13	0.09
Cadmium	⩽0.005	0.0038	0.0033	0.0030	<0.0008	0.0010	<0.0008	<0.0008	0.0015	<0.0008
Manganese	⩽0.1	0.18	0.24	0.12	0.16	0.37	0.43	0.08	0.11	0.13
Iron	⩽0.5	1.7	0.85	0.75	0.20	0.12	0.40	<0.05	<0.05	<0.05
Nickel		0.04	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

TABLE 4

Comparison of Lead, Manganese, and Iron Concentrations Between Three Samples

Metals	Concentration Sample No. 1 (C_1)	Concentrations Sample No. 2 (C_2)	Concentration Sample No. 3 (C_3)	C_1/C_2	C_1/C_3	C_2/C_3
Lead	0.257	0.033	0.030	7.8	8.6	1.1
Manganese	0.180	0.320	0.107	0.56	1.7	3.0
Iron	1.10	0.240	0.05	4.6	22	4.8

As shown in Table 4, the concentration of iron in sample No.1 was 22 times that of sample No.3. The concentration of lead in sample No.1 was 9 times that of sample No. 3. The results of manganese were the same level in the three samples. The significant difference in iron and lead between sample No.1 and No.3 reflected the severe pollution existing in sample No.1, which probably was due to the input of E-waste recycling. Although sample No.2 was not located beside the E-waste recycling site, its environmental quality was deteriorated to a polluted extent due to the gathering of the rubbish relevant to E-waste. As discussed above, lead and iron are the main polluting factors in surface water.

Quality Control

The relative deviation of parallel samples was 0%-4%, and that of unknown standard samples was 0%-4% except for 11% of arsenic. The recovery varied between 87.2% and 105%.

Results of Ground Water

The results of ground water and the third class threshold of Chinese quality standard for ground water (GB/T14848-1993) are given in Table 5.

Evaluation of Results

As shown in Table 5, the concentrations of all items in sample No.3 were below the threshold value except for fluoride. The concentrations of fluoride, manganese, and iron in the ground water near the E-waste recycling site were above the threshold. Manganese was about 5 times the threshold value, and iron even up to 20 times. Evidently the ground water was polluted by the E-waste recycling and not suitable for drinking. The high fluoride concentration of the three samples proves that the locality is a high-fluoride zone. The comparison of manganese and iron concentrations between the three samples are listed in Table 6.

As shown in Table 6, the concentration of manganese in sample No.1 was 7.2 times that in sample No.3; the difference in iron concentration between the two samples even reached 120 times. Such a significant difference suggests that the ground water at site 1 is seriously polluted by the metals

TABLE 5

Results of Ground Water (mg/L)

Item	GB/T14848-1993 Threshold	Sample No. 1			Sample No. 2			Sample No. 3		
		Dec.	Apr.	Aug.	Dec.	Apr.	Aug.	Dec.	Apr.	Aug.
pH	6.5-8.5	6.59	6.73	6.75	6.68	6.89	6.91	6.83	7.06	6.84
Turbidity	⩽3	5	<3	<3	<3	<3	<3	<3	<3	<3
Fluoride	⩽1.0	2.46	2.06	2.68	3.14	2.96	3.44	5.44	4.06	3.14
Arsenic	⩽0.05	<0.008	0.013	0.012	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Mercury	⩽0.001	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$	$<5.0\times10^{-5}$
Copper	⩽1.0	0.067	<0.05	<0.05	<0.05	<0.05	<0.05	0.067	<0.05	<0.05
Lead	⩽0.05	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.005	0.004
Zinc	⩽1.0	0.03	0.08	0.07	0.04	0.07	0.06	0.02	0.10	<0.05
Cadmium	⩽0.01	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Manganese	⩽0.1	0.48	0.59	0.66	0.13	0.17	0.10	<0.05	<0.05	0.14
Iron	⩽0.3	6.67	5.90	5.40	0.65	0.50	0.33	<0.05	<0.05	<0.05
Nickel	⩽0.05	0.10	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05

TABLE 6

Comparison of Manganese and Jron Concentration Between the Three Samples

Metal	Sample No.1 (C_1)	Average Concentrations Sample No. 2 (C_2)	Sample No. 3 (C_3)	C_1/C_2	C_1/C_3	C_2/C_3
Manganese	0.577	0.133	0.08	4.3	7.2	1.7
Iron	5.99	0.493	0.05	12.2	120	9.9

Quality Control

The relative deviation of parallel samples was 0%-0.9%, while that of unknown standard samples was 0%-3% except for 14% of fluoride. The recovery ranged from 86.2% to 106%.

Results of Sediment

The results of sediment are shown in Table 7. Owing to no quality evaluation standard for sediment available in China and EPA, a non-regulatory quality guideline for interpreting chemical data for sediment

analysis generated by National Oceanic and Atmospheric Administration (NOAA) is also shown in Table 7.

Evaluation of Results

As shown in Table 7, concentrations of all the metals in sample No.1 were above the NOAA sediment benchmark. The concentrations of copper, cadmium, nickel, and lead were above the median benchmark. The highest copper level was 10 times the median benchmark. The highest nickel and lead levels were 6 and 3 times the median benchmark, respectively. Most metals in sample No.2 were also above the NOAA sediment benchmarks, and some were above the median benchmarks. Copper was the main pollutant. The concentrations of metals in sample No.3 were below the low benchmarks. The highest value appeared in December and the lowest

TABLE 7

Results of Sediment and NOAA Sediment Benchmarks (mg/kg)

Metals	NOAA Sediment Benchmarks		Sample No. 1			Sample No. 2			Sample No. 3		
	Low	Median	Dec.	Apr.	Aug.	Dec.	Apr.	Aug.	Dec.	Apr.	Aug.
Arsenic	8.2	70	9.35	8.67	9.73	4.38	5.82	5.75	2.37	2.80	2.44
Mercury	0.15	0.71	0.385	0.252	0.297	0.272	0.124	0.133	0.079	0.036	0.030
Copper	34	270	2.67×10^3	1.35×10^3	734	854	82	56.6	44	73	42
Lead	47	220	762	575	504	114	74.0	68.0	22.0	29.0	14.7
Zinc	150	410	293	265	224	143	155	116	46	68	72
Cadmium	1.2	9.6	19.2	17.6	11.9	10.6	6.2	5.0	0. 17	0.15	0.19
Nickel	21	52	344	312	325	107	72	143	13	24	11
Chromium	81	370	55.6	50.1	43.4	8.9	16	15.2	5.9	6.2	4.7

value appeared in August. The reason was that the government halted the E-waste recycling and the environmental quality was restored to some extent by its ecological self-remediation. Because the sediment is the final accumulating carrier of most pollutants, especially metals, the concentrations of heavy metals in sediment are usually above 3-5 orders of magnitude higher than those in the surface water. The high levels of heavy metals in sediment in Gui Yu demonstrate that the E-waste recycling has lasted for a long time and the environment is severely polluted.

Quality Control

The relative deviation of parallel samples was 0%-16%, and the recovery was 72.9%-101%.

Summary

In surface water, lead and iron are the main pollutant factors. The maximum concentration of lead in sample No.1 in December is 8 times the threshold value of the environmental quality standards for surface water. The dissolved oxygen, permanganate index, and ammonium in sample No. 1 have shown the deterioration in quality. All items do not show any evident relationship with time. The significant difference between samples No. 1 and No. 3 demonstrates the impact of E-waste recycling on the environmental quality in different locations, the nearer the E-waste processing location, the more severe the pollution. The harvest area is almost not impacted by the E-waste recycling.

In ground water, iron and manganese are the main pollutants. The difference between samples is very significant. The concentration of manganese in sample No.1 is 7.2 times that in sample No. 3, the difference in iron content between the two samples even reaches 120 times. Such a significant difference suggests that the ground water at site 1 was seriously polluted by the metals.

In sediment sample, copper, lead, and nickel are the three main pollutants. The concentrations of copper, cadmium, nickel, and lead in sample No.1 are above the NOAA median benchmarks. The concentrations of most metals in sample No.2 are above the low benchmarks and some exceed the median benchmarks. The metal concentrations in sample No. 3 are below the low benchmarks. The relationship between time and the concentration shows a decreasing tendency. The high level of heavy metals in sediment in Gui Yu demonstrates that E-waste recycling has severely polluted the environment.

The above results show that the impact of E-waste recycling on environmental quality of Gui Yu is very severe. It is urgent for the government to prohibit the E-waste import and its processing by

outdated ways.

REFERENCES

1. The bulletin about the environmental management of electronic products waste. State environmental protection administration of China, 2002-05-30, 1-4. (In Chinese)
2. Jim P, Leslie B, Sarah W, *et al.* (2002). Exporting Harm: The high-tech trashing of Asia. The Basel Action Network and Silicon Valley Toxics Coalition. 24.
3. The anthropology investigation report about the electronic waste recycling industry of Guiyu in Shantou. (2003). The anthropology department of Sun Yat-Sen university and the international green and peace organization. 1-23.
4. Environmental quality standard for surface water. (2002). State environmental protection administration of China. (In Chinese)
5. Quality standard for ground water. (1993). State environmental protection administration of China. (In Chinese)
6. The determination methods for water and waste water. (2002). State environmental protection administration of China. 345-346. (In Chinese)
7. Standard measurement for drinking water. (1986). Ministry of health people's republic of China. (In Chinese)
8. Zhang Y L (1994). The manual of quality assurance in Environmental water quality monitoring. 2nd Ed. Chemical Industry Press. Beijing, 326-328. (In Chinese)

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