Study on the impact of the soil and shallow groundwater quality by a hazardous waste incinerator in Shanghai

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Abstract. Hazardous wastes are often corrosive, toxic, reactive or infective, the feasible treatments for which include landfill, incineration, solidification, and chemical methods. In this research, an environmental investigation of a hazardous waste incinerator (operated by A Co. Ltd.) in Shanghai has been made into the soil and shallow groundwater quality inside and outside the factory, which uses incineration technology. The results are analysed and the conclusions reached are that the incineration technology in A Co. Ltd. has had no effect yet on the soil in and near the factory, and on the surrounding agricultural soil. However, the shallow groundwater below the production warehouse No.2 has been contaminated by Cd, Cu, and Ni which originate from the disposal process.

1. Introduction

Hazardous wastes generated from the industrial development usually have one or more of the characteristics, corrosiveness, toxicity, reactivity or infectivity, which can not only harm human beings but also damage the local environment. Therefore, it is important to prevent and control the hazardous waste contamination.

Hazardous waste is a serious worldwide concern and hazardous waste treatments may significantly intensify the issue. At present, the treatments by landfill, incineration, solidification, and chemical methods are all the feasible solutions for hazardous wastes. Numerous studies have been conducted concerning hazardous waste treatments, but few have been conducted related to the impact of soil or shallow groundwater quality by hazardous waste disposal and recycling, especially incineration. The substances generated from industrial hazardous waste incineration have been monitored, i.e., bottom ash from residues [1], emitted particulates [2], and dioxin [3]. Human health safety for the exposure to metals and organic substances at hazardous waste incinerators has been assessed [4-6]. Hazardous waste incineration process has been analyzed [7-8]. In addition, Huang H predicted the impact on soil environment with incineration gas in an industrial zone in Shanghai [9]. Zhao X et al set up the evaluation system of the pollution control level, using Delphi combined with the Analytic Hierarchy Process and Five score to assess the control level and facilitate risk management of the hazardous waste incinerator [10].

Nowadays, human survival and social economic development have been affected by the severe environmental contamination so it’s urgent that there is the further control of soil pollution. During the hazardous waste disposal process, it’s easy for the local soil and shallow groundwater to be influenced. In this paper, the soil and shallow groundwater quality in a hazardous waste incinerator (operated by A Co. Ltd.) and its surroundings in Shanghai has been subjected to environmental investigation.
2. Study area

2.1. A hazardous waste incinerator

Founded in 1993, A Co. Ltd. is the high-tech enterprise for the waste recycling and reuse, the disposal for the cupferous materials, the nickelic materials, acids, solvents and their drums. It’s about 0.03 km² area with the annual disposal of 2.6 x 10⁴ tonnes waste and 1.5 x 10⁵ waste-solvent drums.

Figure 1 shows the plane layout of A Co. Ltd. There are six hazardous waste storages, four workshops for waste solvent recycling, solvent drums sorting, copper salts production, and nickel salts production, two office buildings, two production warehouses and one sewage treatment station in it. A Co. Ltd. produces CuSO₄ (Cu ≥ 25 %), CuCl₂ (98 %), NiCl₂ (Ni ≥ 24 %), FeCl₃, Cl₃FeH₁₂O₆, Xylenes, CH₃OH, C₃H₆O, C₇H₈, HCl (8 %), NH·H₂O (20 %), and NaCl₂. Therefore, Copper, Methylbenzene, Total Petroleum Hydrocarbon (TPH), Xylene Mixed Isomers, Methanol, Acetone, Cupric Chloride, Copper Chloride, and Ferric Chloride are analyzed as the contaminants of concern.

![Figure 1. Layout of A Co. Ltd.](image)

2.2. Local environment

The site area, located in the Yangtze River Delta, has the flat terrain that is 4.20 m above the Wusong Elevation [11]. It is in the north subtropical oceanic monsoon climate zone, warm and rainy but with four distinctly different seasons with the local annual rainfall of about 1950 mm, annual frost-free period of 247 days, average temperature of about 15.5 °C [11]. It has a strategic location, with land and river transport facilities, rich fresh water resources (1.2 x 10⁸ m³) [11]. The maximum water level achieves to 2.71 m, while the minimum is 2.58 m [11].

The local shallow groundwater, which is mainly recharged by the meteoric water and the seepage from production and living, is composed by the perched water and the pore water. The groundwater depth is in the range of 0.5 – 0.9 m, the elevation of 3.35 ~ 3.25 m correspondingly [11].

3. Data and methods

3.1. Samples

According to the potential pollution sources, a number of samples were collected, i.e., 6 soil samples and 3 shallow groundwater monitoring wells in A Co. Ltd., 8 samples for the soil and shallow groundwater at the boundaries (see Figure 2). Furthermore, considering the impact on the surrounding surface soil by air-incineration plants, the maximum distance for the maximum ground concentration of air pollutants with the South-East wind prevailing was predicted to be about 1.0 km. Thereby, 12 surface soil samples were taken in the agriculture land from 1.5 km around A Co. Ltd. (see Figure 3).

![Figure 2. Locations of the soil and shallow groundwater samples in A Co. Ltd. and its boundaries.](image)
3.2. Sampling and testing
The soil and shallow groundwater sampling satisfies National Technical Guidelines for Investigation on Soil Contamination of Land for Construction (HJ 25.1-2019) of the People's Republic of China (PRC) [12]. The surface, aeration zone and saturated soils were collected at each monitored site in A Co. Ltd. and its boundaries. Surface soils in the surrounding agriculture land were also sampled. According to HJ 25.1-2019 of the PRC [12] and National Soil Environmental Quality Risk Control Standard for Soil Contamination of Development Land (GB 36600-2018) of the PRC [13], pH, 7 heavy metals, 31 volatile organic compounds (VOCs), 8 semi-volatile organic compounds (SVOCs), and Petroleum Hydrocarbon (C_{10}-C_{40}) in the soil or shallow groundwater samples were tested.

3.3. Evaluation methods
The Single Pollution Index Method is applied for the soil and shallow groundwater quality by \( P_{ip} = \frac{C_i}{S_ip} \), where \( P_{ip} \) is the Single Pollution Index; \( C_i \) is the \( i^{th} \) measured concentration of soil or groundwater pollutant; \( S_ip \) is the standard value for the \( i^{th} \) soil or groundwater pollutant. For soil, \( P_{ip} \leq 1.0 \), soil uncontaminated; 1.0 < \( P_{ip} \leq 2.0 \), slight pollution; 2.0 < \( P_{ip} \leq 3.0 \), light pollution; 3.0 < \( P_{ip} \leq 5.0 \), moderate pollution; \( P_{ip} > 5.0 \), heavy pollution. Meanwhile, for groundwater, \( P_{ip} \leq 1.0 \), water unpolluted; \( P_{ip} > 1.0 \), water contaminated.

In this research, GB 36600-2018 of the PRC with II risk screening values [13], and National Standard for Groundwater quality (GB/T 14848-2017) of the PRC with IV limit [14] are adopted to evaluate the soil and shallow groundwater quality in A Co. Ltd. and its boundaries. National Soil Environmental Quality Risk Control Standard for Soil Contamination of Agricultural Land (GB 15618-2018) of the PRC [15] and GB 36600-2018 of the PRC with I risk screening values [13] are evaluated the surrounding agricultural soil.

4. Results and discussions
4.1. Soil environment quality
Table 1 is summarized the soil samples collected in and near A Co. Ltd., and 1.5 m around it. Cluster analysis (\( CV \)) is adopted to distinguish the different groups. \( CV \) values for the detected heavy metals (As, Cd, Cu, Pb, Hg, Ni) in and near A Co. Ltd. and 1.5 m ambient area range 21.4 ~ 209.6, 15.4 ~ 71.4, 19.0 ~ 62.5 respectively (see Table 1). Referring to the study by Guo et al who investigated that the heavy metals with \( CV < 20 \% \) were dominated by natural sources while those with \( CV > 50 \% \) were mainly affected by anthropogenic sources [16], in this research, \( CV \) for Cd or Cu in the factory is above 50 \%; near it, \( CV \) for Pb is less than 20 \%, \( CV \) for Hg exceeds 50 \%; in the surrounding agricultural land, \( CV \) for Ni is lower than 20 \%, \( CV \) for Hg is higher than 50 \% (see Table 1).

In A Co. Ltd., As, Cd, Cu, Pb, Hg, Ni, C_{2}H_{4}Cl; are detected with \( pH \) of 6.7 ~ 7.9 and \( P_{ip} < 1.0 \) (see Figure 4). Near the factory, As, Cd, Cu, Pb, Hg, Ni, C_{10}H_{12}, C_{20}H_{12}, C_{22}H_{12}, Petroleum Hydrocarbon (C_{10}-C_{40}) are detected with \( pH \) of 7.5 ~ 9.0 and \( P_{ip} < 1.0 \) (see Figure 5). In the farm 1.5 km around, As, Cd, Cu, Pb, Hg, Ni, C_{10}H_{12}, C_{20}H_{12}, C_{22}H_{12}, Petroleum Hydrocarbon (C_{10}-C_{40}) are detected and \( P_{ip} < 1.0 \) (see Figure 6). It’s indicated that the soils in and near A Co. Ltd have been uncontaminated yet and its incineration technology has no effect on the surrounding agricultural soil now.
Table 1. Summary of the detected contents in the soil samples.

| Location          | Items | Detection limit (mg/kg) | Min (mg/kg) | Max (mg/kg) | Mean (mg/kg) | SD<sup>a</sup> | CV<sup>b</sup> |
|-------------------|-------|-------------------------|-------------|-------------|--------------|--------------|---------------|
| In A Co. Ltd.     | pH    | -                       | 6.70        | 7.90        | 7.07         | 0.95         | 13.4          |
|                   | As    | 0.01                    | 4.84        | 10.5        | 7.32         | 1.71         | 23.4          |
|                   | Cd    | 0.01                    | 0.08        | 0.51        | 0.15         | 0.10         | 66.7          |
|                   | Cu    | 1.0                     | 23.0        | 981.0       | 126.24       | 264.56       | 209.6         |
|                   | Pb    | 0.10                    | 27.80       | 99.90       | 39.74        | 18.27        | 46.0          |
|                   | Hg    | 0.002                   | 0.10        | 0.20        | 0.14         | 0.03         | 21.4          |
|                   | Ni    | 5.0                     | 27.0        | 108.0       | 41.0         | 19.12        | 46.6          |
|                   | C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub> | 0.05 | ND<sup>d</sup> | 0.06 | - | - | - |
| Near A Co. Ltd.   | pH    | -                       | 7.50        | 9.0         | 8.38         | 0.34         | 4.1           |
|                   | As    | 0.01                    | 5.12        | 15.0        | 8.17         | 2.95         | 36.1          |
|                   | Cd    | 0.01                    | 0.04        | 0.17        | 0.09         | 0.03         | 33.3          |
|                   | Cu    | 1.0                     | 10.0        | 53.0        | 24.84        | 9.58         | 38.6          |
|                   | Pb    | 0.10                    | 19.30       | 38.90       | 24.70        | 3.80         | 15.4          |
|                   | Hg    | 0.0002                  | 0.024       | 0.202       | 0.07         | 0.05         | 71.4          |
|                   | Ni    | 3.0                     | 22.0        | 52.0        | 37.15        | 7.86         | 21.2          |
|                   | C<sub>18</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.20 | - | - | - |
|                   | C<sub>20</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.30 | - | - | - |
|                   | C<sub>22</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.30 | - | - | - |
|                   | C<sub>10</sub>-C<sub>40</sub> | 6.0  | 14.60       | 144.0       | 41.58        | 29.21        | 70.3          |
| 1.5 km around A Co. Ltd. | pH    | -                       | 6.70        | 8.70        | 7.95         | 0.76         | 9.6           |
|                   | As    | 0.01                    | 5.35        | 10.60       | 7.52         | 1.99         | 26.5          |
|                   | Cd    | 0.01                    | 0.06        | 0.13        | 0.10         | 0.04         | 40.0          |
|                   | Cu    | 1.0                     | 11.0        | 35.0        | 21.17        | 6.45         | 30.5          |
|                   | Pb    | 0.10                    | 16.20       | 29.20       | 22.70        | 5.67         | 25.0          |
|                   | Hg    | 0.0002                  | 0.03        | 0.17        | 0.08         | 0.05         | 62.5          |
|                   | Ni    | 3.0                     | 27.0        | 54.0        | 36.33        | 6.89         | 19.0          |
|                   | C<sub>18</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.20 | - | - | - |
|                   | C<sub>20</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.20 | - | - | - |
|                   | C<sub>22</sub>H<sub>12</sub> | 0.10 | ND<sup>d</sup> | 0.30 | - | - | - |
|                   | C<sub>10</sub>-C<sub>40</sub> | 6.0  | 25.90       | 175.0       | 56.73        | 40.13        | 70.7          |

<sup>a</sup> SD is the standard deviation.

<sup>b</sup> CV is the coefficient of variation.

<sup>c</sup> ns is the number of soil samples.

<sup>d</sup> ND denotes that the detected value is below the corresponding detection limit.
4.2. Shallow groundwater environment quality
The shallow groundwater samples collected in and near A Co. Ltd. are monitored and the results are shown that the groundwater quality in the factory is worse than that at the boundaries (see Table 2).

In A Co. Ltd., \( \text{As}, \text{Cd}, \text{Cu}, \text{Pb}, \text{Ni}, \text{CHCl}_3, \text{C}_2\text{H}_4\text{Cl}_2, \text{C}_7\text{H}_8, \text{C}_8\text{H}_{10}, \text{Xylenes}, \text{CHBr}_2\text{Cl}, \text{C}_8\text{H}_{14}, \text{C}_3\text{H}_6\text{O}, \text{Petroleum Hydrocarbon} (\text{C}_{10-40}) \) are detected with \( \text{pH} \) of 7.0 ~ 7.3 and the maximum Pip for \( \text{Cd}, \text{Cu}, \text{or} \text{Ni} \) is higher than 1.0 (see Figure 7). Near the boundaries, \( \text{As}, \text{Cd}, \text{Cu}, \text{Hg}, \text{Ni}, \text{Petroleum Hydrocarbon} (\text{C}_{10-40}) \) are detected with \( \text{pH} \) of 6.8 ~ 7.4 and \( P_{ip} < 1.0 \) (see Figure 8). It’s shown that the shallow groundwater below the monitored site No. F-6 where is closed to the production warehouse No.2 has been polluted by \( \text{Cd}, \text{Cu}, \text{and} \text{Ni} \) originated from the disposal process, but the shallow groundwater below the boundaries hasn’t been contaminated.

5. Conclusions
With the rapid industrial development, great quantities of the hazardous wastes are generated. They present dangers for both the people and the environment, so that the prevention and control of hazardous waste contamination has received much attention. Landfill, incineration, solidification, and chemical methods are the feasible treatments. In this research, the environmental investigation of a hazardous waste incinerator (operated by A Co. Ltd.) in Shanghai assessed the impact on the soil and shallow groundwater quality inside and outside the factory that could be caused by the incineration. The results are analyzed and the conclusions obtained are: (1) the incineration technology in A Co. Ltd. has no effect on the inner-factory soil, the outer-factory soil, and the surrounding agricultural soil, all of which show \( P_{ip} < 1.0 \). (2) the shallow groundwater below the production warehouse No.2 has been contaminated by \( \text{Cd}, \text{Cu}, \text{and} \text{Ni} \) with \( P_{ip} > 1.0 \), originating from the disposal process, while the
groundwater near the boundaries is unpolluted. The results show where more attention is needed and available measures need be taken to achieve superior environment management through regular monitoring of the soil and shallow groundwater.

Table 2. Summary of the detected contents in the shallow groundwater samples.

| Location         | Items | Detection limit (mg/L) | Min (mg/L) | Max (mg/L) | Mean (mg/L) | SDa | CVb |
|------------------|-------|------------------------|------------|------------|-------------|-----|-----|
| In A Co. Ltd.    | pH    | -                      | 7.0        | 7.30       | 7.21        | 0.19| 2.6 |
| (nw = 3)         | As    | 0.0003                 | 0.0071     | 0.0008     | 0.01        | 0.00086 | 8.6 |
|                  | Cd    | 0.00005                | NDb        | 0.023      | -           | -   | -   |
|                  | Cu    | 0.00008                | 0.009      | 68.60      | 22.87       | 39.60| 173.2|
|                  | Pb    | 0.00009                | 0.003      | 0.017      | 0.0079      | 0.008 | 100.5|
|                  | Ni    | 0.00006                | 0.004      | 9.28       | 3.10        | 5.36 | 172.9|
|                  | CHCl₃ | 0.0005                 | 0.0006     | 0.0056     | 0.0023      | 0.0028 | 121.5|
|                  | C₂H₄Cl₂| 0.0005                | NDd        | 0.009      | -           | -   | -   |
|                  | C₃H₆ | 0.0005                 | NDd        | 0.0011     | -           | -   | -   |
|                  | C₄H₁₀ | 0.0005                 | NDd        | 0.0088     | -           | -   | -   |
|                  | Xylenes | 0.0005               | NDd        | 0.022      | -           | -   | -   |
|                  | CHBr₂Cl | 0.0005            | 0.0067     | 0.0091     | 0.0075      | 0.0014 | 18.1|
|                  | C₆H₁₄ | 0.0005                 | 0.0094     | 0.0096     | 0.0095      | 0.00012 | 1.3 |
|                  | C₇H₈O | 0.0005                 | 0.018      | 0.309      | 0.115       | 0.17 | 146.1|
|                  | C₁₀-C₄₀ | 0.01           | 0.03       | 0.10       | 0.06        | 0.03 | 50.8 |
| Near A Co. Ltd.  | pH    | -                      | 6.75       | 7.36       | 7.09        | 0.20 | 2.8 |
| (nw = 8)         | As    | 0.0003                 | NDd        | 0.0008     | -           | -   | -   |
|                  | Cd    | 0.00005                | NDd        | 0.00006    | -           | -   | -   |
|                  | Cu    | 0.00008                | 0.00075    | 0.00758    | 0.0041      | 0.0021 | 51.7|
|                  | Hg    | 0.00009                | 0.00002    | 0.00048    | 0.00009     | 0.0002 | 166.7|
|                  | Ni    | 0.00006                | 0.00178    | 0.0697     | 0.0215      | 0.028 | 130.0|
|                  | C₁₀-C₄₀ | 0.01        | 0.03       | 0.10       | 0.06        | 0.03 | 50.8 |

a SD is the standard deviation.
b CV is the coefficient of variation.
c nw is the number of shallow groundwater samples.
d ND denotes that the detected value is below the corresponding detection limit.

Figure 7. The evaluation results of the shallow groundwater quality in A Co. Ltd.
Figure 8. The evaluation results of the shallow groundwater quality near A Co. Ltd.

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