

Research Article

Survey and Risk Assessment of Contaminants in Soil from a Nitrogenous Fertilizer Plant Located in North China

Xizhao Tian ¹, Cunliang Fan,¹ Zhiqiang Gong,¹ Ziting Yuan,¹ Zhiyuan Ma,¹ Xiaosen Xing,² Wei He,¹ and Pengfei Jin ¹

¹Hebei Key Laboratory of Environment Monitoring and Protection of Geological Resources, Hebei Geological Environment Monitoring Institute, Shijiazhuang 050000, China

²Land Resources Exploration Center, Bureau of Geology and Mineral Exploration and Development of Hebei Province, Wuhan, China

Correspondence should be addressed to Pengfei Jin; 676704360@qq.com

Received 11 March 2021; Accepted 21 June 2021; Published 2 August 2021

Academic Editor: Xubo Gao

Copyright © 2021 Xizhao Tian et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

China is the world's largest consumer of fertilizer, with fertilizer plants widely distributed throughout the country. With the removal and closing of fertilizer factories in recent years, pollutant surveys and risk assessments (human health risks) for these sites have become increasingly necessary. However, there has been little research on contaminated fertilizer factory sites. This study aimed to characterize the distribution of pollutants, assess the health risk of the site, and calculate the remediation area and volume in a typical fertilizer plant site in North China. A total of 443 samples were collected in 2019; they indicated that the study site had high concentrations of copper (Cu), ammonia-nitrogen (NH₃-N), total petroleum hydrocarbons (TPH), and fluoride at maximum ratios (the ratio of the highest value of all test data for a particular pollutant to the standard value of the pollutant) of 3.30, 2.55, 19.69, and 1.10, respectively. The health risk assessment results suggested that some hazard quotients exceeded the threshold safe level (>1 established by environmental regulations). The risk control values of soil were 2000 mg/g (Cu), 826 mg/g (TPH), and 1549 mg/g (NH₃-N), and the total remediation soil volume was 72860.71 m³. The results provided basic information on soil pollution control and environmental management in a contaminated fertilizer plant site.

1. Introduction

Nitrogen is the first element in soil for plant growth. The nitrogenous fertilizer has been intensively used in agricultural systems to achieve higher yields in China. China is the largest consumer of fertilizer and has the biggest nitrogen production in the world [1–3]. Fertilizer plants are widely distributed throughout China. A large amount of chemicals have been released from these plants into soil and groundwater during their production. In recent years, with the change of fertilizer demand from chemical fertilizer to organic fertilizer, lots of nitrogen fertilizer plants have been closed. The land of these plants had been planned to be used for residential or recreational purposes [4]. Investigation and assessment of contaminants left in these sites is necessary for their safe redevelopment. A large number of studies have

focused on the investigation and assessment of contaminants on petroleum [5], coking [6], and chemical-contaminated sites [7]. However, there has been little concern about the fertilizer-contaminated sites, but in fact, this kind of site could have serious environmental impacts and human health risks.

Ammonia-nitrogen (NH₃-N) is the most typical pollutant found at fertilizer-contaminated sites [8]. As a major element determining plant growth and productivity, inorganic and organic forms of NH₃-N in the soil can be absorbed by plants through their roots [9, 10]. However, high levels of NH₃-N have become an increasingly significant environmental problem [11], along with the acidification and eutrophication of ecosystems and climate change [12]. Although NH₃-N is not considered a carcinogenic pollutant when assessing human health risks, the exposure

to $\text{NH}_3\text{-N}$ at high concentrations could be harmful to the respiratory tract, eyes, and skin [13, 14]. Compared with $\text{NH}_3\text{-N}$, other typical pollutants, such as copper (Cu), total petroleum hydrocarbons (TPH), and fluoride, are at relatively low concentrations in fertilizer-contaminated sites. Even so, they cannot be neglected because of potential bioaccumulation and carcinogenicity.

Understanding the fate and transport of the contaminants present on fertilizer plant sites and identifying their environmental exposure risks are not only the preconditions for soil pollution prevention and control but also to provide important information for making decisions on polluted site remediation. The specific objectives of this study were to (1) characterize the distribution of pollutants in the fertilizer-contaminated site, (2) assess the health risk of pollutants in the study site and identify health risk exposure pathways, and (3) calculate the remediation soil area and volume.

2. Materials and Methods

2.1. Contaminated Site Characterization. The fertilizer plant in this study is located in Linzhang County in the southern part of Hebei Province, belonging to Taihang Mountain's foreland and flood plain. Construction waste and miscellaneous fill (0.1–2.8 m) are distributed on the surface of the study area, and below them are silt (8.8–11.4 m), silty clay (0.6–2.3 m), and silt (0.4–7.0 m) formed in alluvial and diluvial sediments of quaternary. The site began operating in 1975 and shut down completely in 1999; it covers an area of $53 \times 10^3 \text{ m}^2$ (Figure 1). The plant received anthracite, water, electrolytic copper, and catalyst as the raw material. The main product of the plant was ammonia ($30 \times 10^3 \text{ t/a}$), and the byproduct was ammonium bicarbonate ($100 \times 10^3 \text{ t/a}$). However, poor pollution controls and production technology during the operational period caused serious environmental pollution. Many hazardous substances were released into the soil, resulting in potential damage to the surrounding environment and the plant site. A detailed survey of the contaminants present along with a risk assessment is essential if the site is to be redeveloped, in particular as residential land.

2.2. Soil Sampling. A total of 55 soil sampling sites were planned in the plant (Figure 2). The depths of soil sampling from a soil-drilling core were decided by soil lithology and the transport character of contaminants. The soil cores were collected by a drilling rig (SH-30, drilling rig manufacturer). The sampling standard is that one sample is taken from 0.5 m on the surface, and the vertical sampling interval is less than 2 m between 0.5 m and 6 m; if the sampling distance is less than 6 m, one sample is taken every 3 m until no obvious pollution odor is found on the spot. The specific locations of the sampling points this time are 0–0.5 m, 1–1.5 m, 3–3.5 m, 5–5.5 m, 8–8.5 m, 11–11.5 m, 14–14.5 m, 17–17.5 m, and 20–20.5 m. The vertical sampling interval was less than 2 m in 0.5–6 m, and the sampling interval was 3 m at most when the depth exceeded 6 m. To avoid cross-contamination, the sampling personnel replaced their disposable gloves after

retrieving each sample. The samples to be analyzed for TPH and $\text{NH}_3\text{-N}$ were transferred to 250 mL brown glass bottles as soon as possible, and the samples to be analyzed for copper and fluoride were transferred to valve bags. All the samples were stored at 4°C and transported to the laboratory for analysis immediately. In total, 443 samples were collected in April and August of 2019.

2.3. Sample Analyses. All analyses were completed by the Pony Testing International Group. Table 1 provides the selected analytical methods employed to measure copper, TPH, fluoride, and $\text{NH}_3\text{-N}$. To corroborate the results and determine the accuracy of each method, 82 duplicate samples were analyzed by Hebei Shipu Testing Technology Service Co., Ltd. The relative deviation and relative standard deviation can meet the national standard (technical code for soil environmental monitoring HJ/T 166-2004).

2.4. Assessment Standard. TPH and copper concentrations were converted using the risk screening and risk intervention values in accordance with the soil environmental quality risk control standard for soil contamination of development land (GB36600-2018) [18]. However, fluoride and $\text{NH}_3\text{-N}$, which could not be found in GB36600-2018, were calculated using the technical guidelines for the assessment of contaminated sites (HJ25.3-2014) [19].

The risk assessment of soil contaminants was carried out according to HJ 25.3-2014 [19]. To simplify calculations, the soil was divided into 6 layers as given in Table 2. It is worth mentioning that because the pollutants did not exceed the standard in the 20–25 m depth layer, the layer was ignored.

According to the plan for land utilization of Linzhang County, the future land use pattern of the fertilizer site was residential. Therefore, both adults and children were considered the sensitive human receptors under the residential scenario. The soil exposure of the local population was estimated by considering six different routes: oral ingestion, dermal contact, inhalation of soil particles by mouth, inhalation of gaseous pollutants from the surface soil in the outdoor air, and inhalation of gaseous pollutants from the underlying soil in outdoor and indoor air. The hazard quotient (HQ) of exposure pathways was estimated using the equations given in Table 3.

2.5. Contaminated Soil Remediation. According to the health risk assessment guidelines, human health might be harmed when the hazard quotient exceeds 1, and soil remediation is necessary. The risk control values of soil (RCVS) were calculated using the equations given in Tables 4 and 5. Furthermore, to avoid excessive remediation, RCVS was compared with the screening value of GB36600-2018 [18].

3. Results and Discussion

3.1. Contaminant Characteristics and Sources. The soil sample results are given in Table 6. Cu concentrations

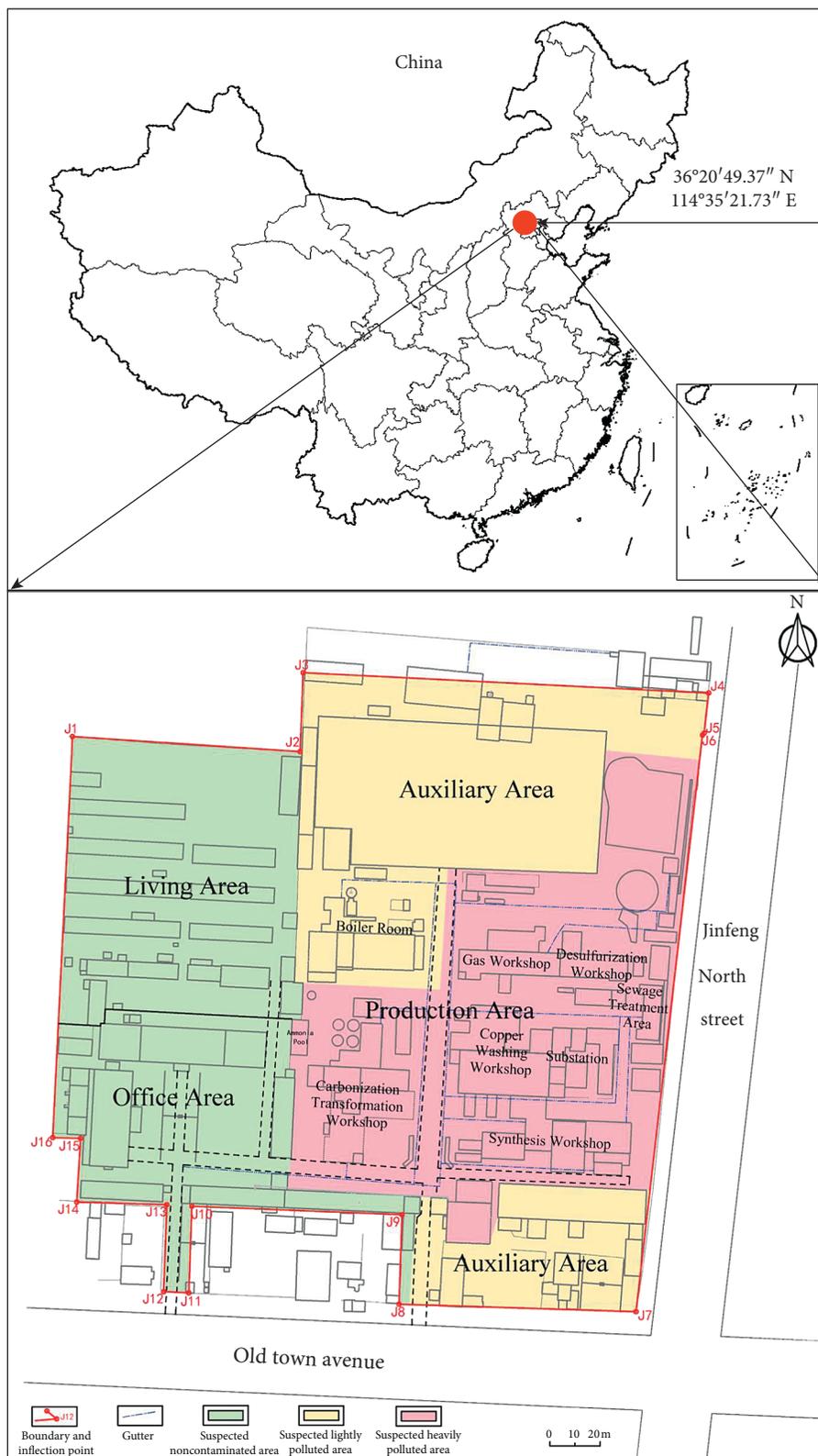


FIGURE 1: Overview of the study area.

ranged from 5.94 mg/kg to 6590 mg/kg, with an average of 107.82 mg/kg and a maximum ratio of 3.3. As shown in Figures 3(a) and 4, samples with higher concentrations were

mainly distributed among the copper washing workshop and production area entrance, where copper ammonia acetate solution was received as a raw material for the

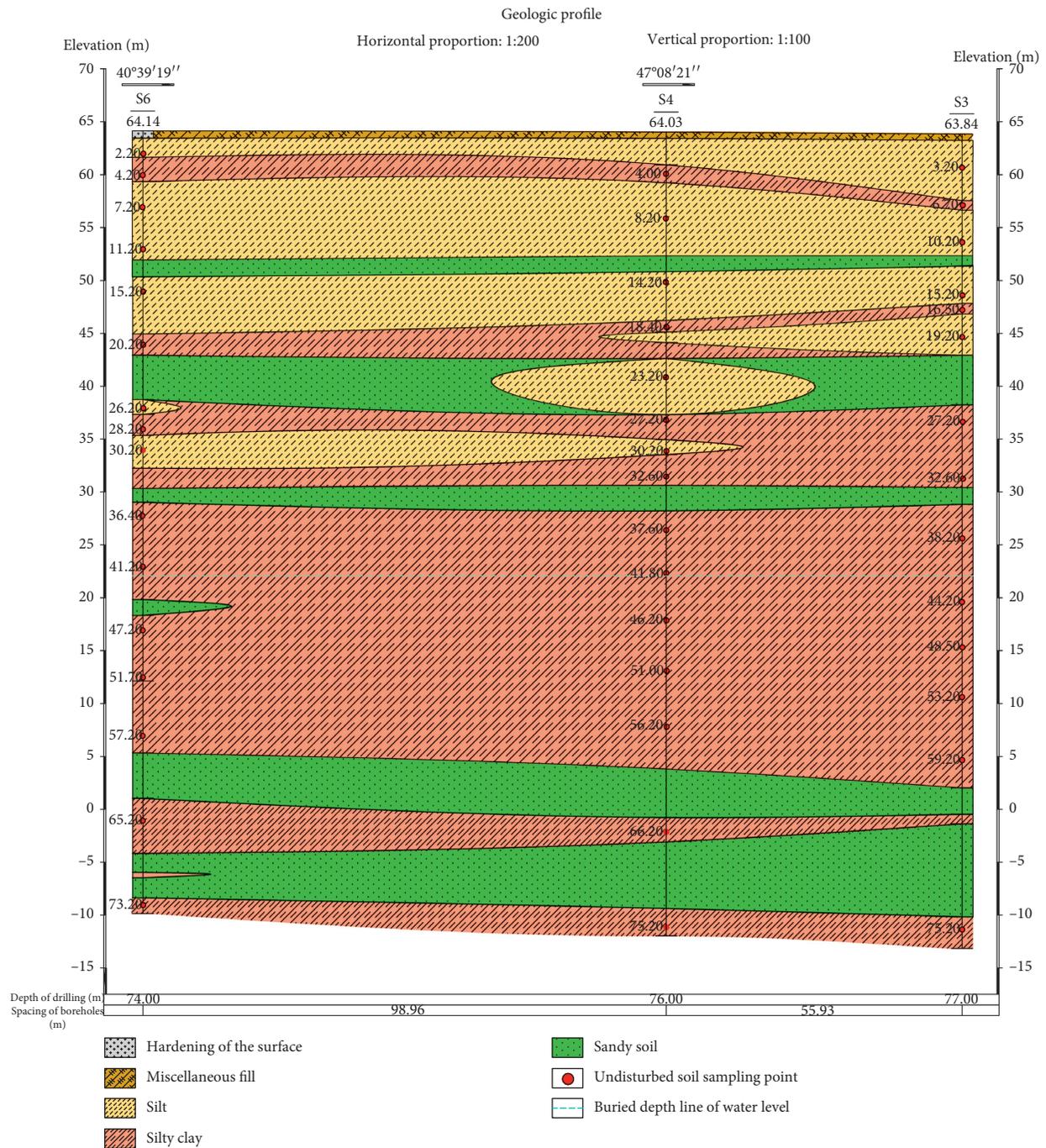


FIGURE 2: Stratigraphic profile of the study area.

TABLE 1: Target pollutants and analytical methods.

Target pollutants	Test method	Reference
Cu	Atomic adsorption spectrometry	[14]
TPH	Gas chromatography	[15]
Fluoride	Ion selective electrode method	[16]
NH ₃ -N	UV-visible scenery photometry	[17]

NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

TABLE 2: Soil layers and depth.

Layer	Soil	Depth (m)
1	Silt	0–4.5
2	Clay	4.5–6.5
3	Silt	6.5–10
4	Silt	10–15
5	Silt	15–20
6	Silt	25–30

TABLE 3: Calculating models of hazard quotient.

Exposure pathway	Explanation	Calculation model	Equation number
Oral ingestion	6 ways receptors are exposed to pollutants	$HQ_{ois} = OISER_{nc} \times C_{sur}/RfD_o \times SAF$	(1)
Dermal contact		$HQ_{dcs} = DCSE_{nc} \times C_{sur}/RfD_d \times SAF$	(2)
Inhalation of soil particles by mouth		$HQ_{pis} = PISER_{nc} \times C_{sur}/RfD_i \times SAF$	(3)
Inhalation of gaseous pollutants from the surface soil in outdoor air		$HQ_{io1} = C_{sur} \times IOVER_{nc1}/RfD_i \times SAF$	(4)
Inhalation of gaseous pollutants from the underlying soil in outdoor air		$HQ_{io2} = C_{sub} \times IOVER_{nc2}/RfD_i \times SAF$	(5)
Inhalation of gaseous pollutants from the underlying soil in indoor air		$HQ_{iiv1} = C_{sub} \times IIVER_{nc1}/RfD_i \times SAF$	(6)

TABLE 4: Major parameters in the calculation models of hazard quotient.

Parameter	Explanation	Value	Unit
SAF	Reference dose distribution ratio for exposure to soil	0.5	/
C_{sur}	Concentration of contaminants in soil	434	mg/kg
C_{sub}	Concentration of contaminants in underlying soil	434	mg/kg
RfD_i	Reference dose for inhalation	$7E-02$	/
$IOVER_{nc1}$	Exposure dose by inhaling gaseous pollutants from the surface soil in outdoor air	$9.88E-06$	/
$IOVER_{nc2}$	Exposure dose by inhaling gaseous pollutants from the underlying soil in outdoor air	$1.14E-06$	/
$IIVER_{nc1}$	Exposure dose by inhaling gaseous pollutants from the underlying soil in indoor air	$1.60E-04$	/

TABLE 5: Calculation models of risk control values of soil (RCVS).

Exposure pathway	Explanation	Calculation model	Equation number
Oral ingestion	Formulas for calculating the amount of contaminants ingested orally	$RCVS_{ois} = ACR/OISER_{ca} \times SF_o$	(7)
Dermal contact	Formula for calculating the amount of contaminants ingested by skin contact	$RCVS_{dcs} = ACR/DCSE_{ca} \times SF_d$	(8)
Inhalation of soil particles	Inhaled soil particle pollutant quantity calculation formula	$RCVS_{pis} = ACR/PISER_{ca} \times SF_i$	(9)

TABLE 6: Sample analysis results.

Variable	Pollutant concentration (mg/kg)			Screening value (mg/kg)	Control value (mg/kg)	Detection rate (%)	Overstandard rate (%)	Maximum ratio
	Max	Mean	Min					
Cu	6590.00	107.82	5.94	2000	8000	100	1.81	3.30
NH ₃ -N	3951.00	445.19	0.14	1549	—	100	10.16	2.55
TPH	16263.00	129.19	<3.00	826	5000	30.70	1.81	19.69
Fluoride	1150	424.94	127.00	1050	—	100	0.23	1.10

NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

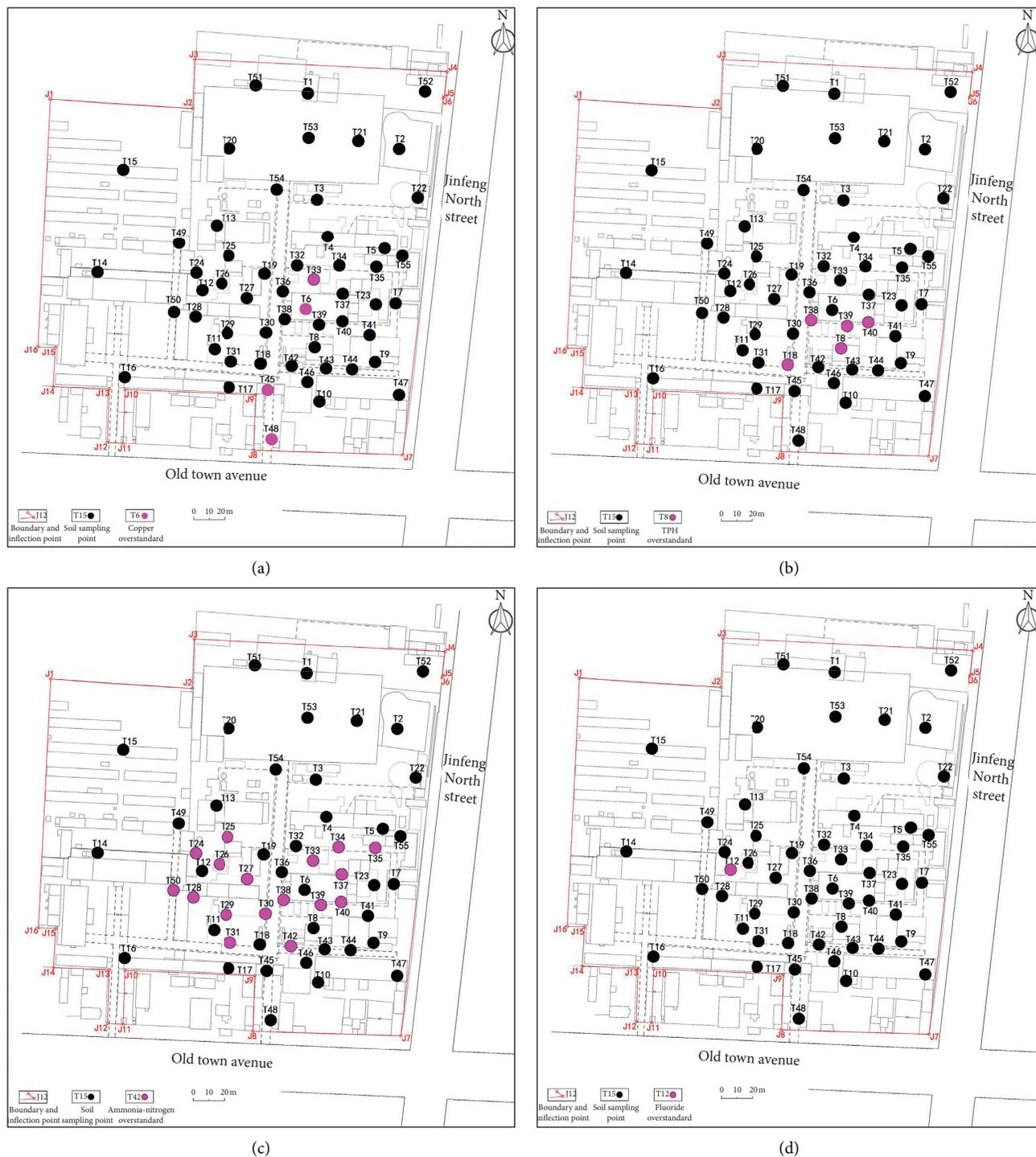


FIGURE 3: Overstandard points of the study area. (a) Cu, (b) TPH, (c) $\text{NH}_3\text{-N}$, (d) fluoride. $\text{NH}_3\text{-N}$, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

adsorption of CO , CO_2 , O_2 , and H_2S . Thus, it can be concluded that the main reason for high Cu concentrations was the corrosion and aging of the machine that accelerated the release of wastewater [20, 21].

TPH ranged from $<3 \text{ mg/kg}$ to 16263 mg/kg with an average concentration of 129.19 mg/g . The maximum ratio

was 19.69, and the distribution of TPH was relatively concentrated (Figure 4). However, TPH was not a raw material used in the fertilizer plant. It could be concluded that TPH was from the lubricating oil leakage of machines in the process of operation or migration (Figure 3(b)). The pollution level decreased with increasing depth due to

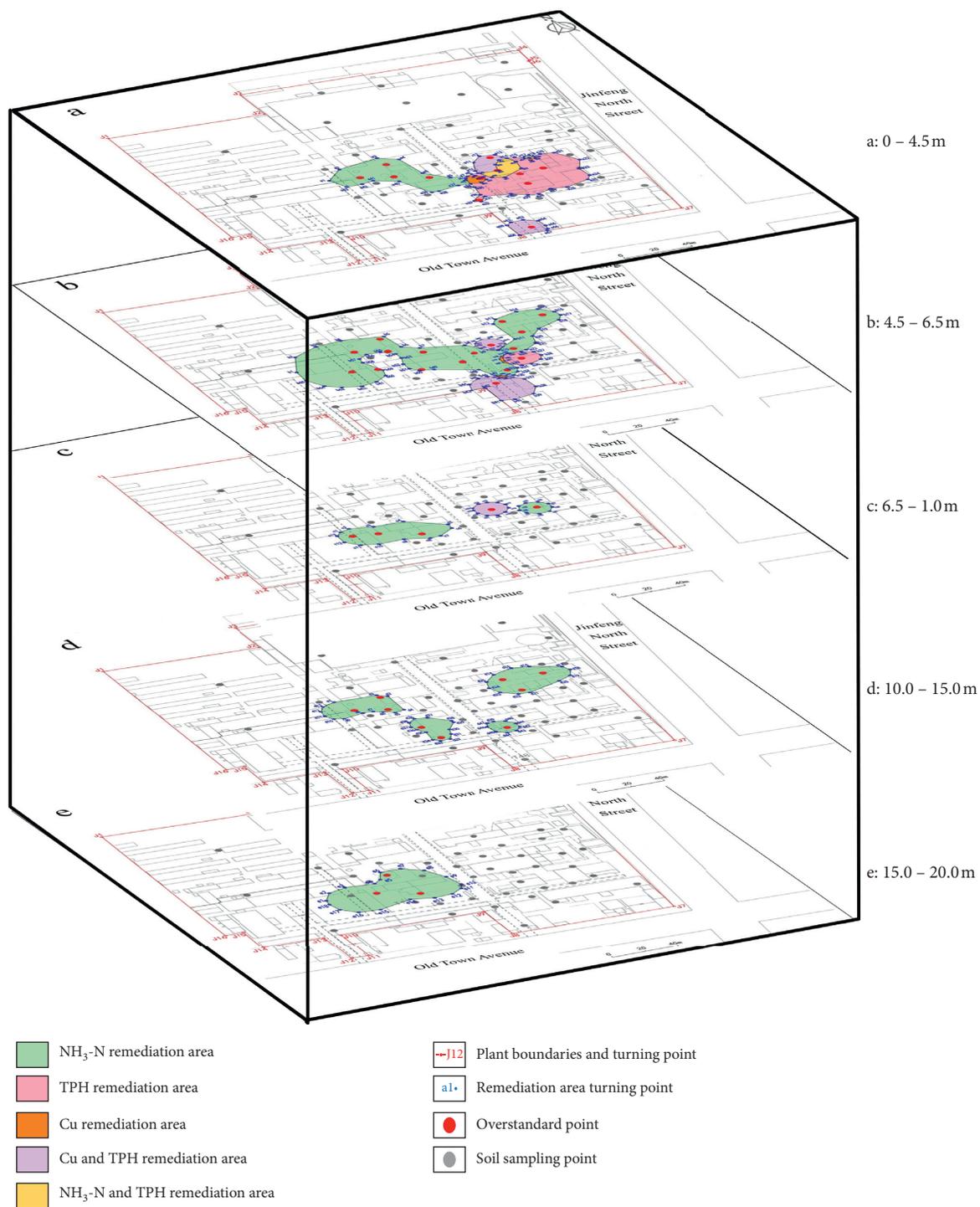


FIGURE 4: Polluted areas from different soil layers. (a) The first layer, (b) the second layer, (c) the third layer, (d) the fourth layer, (e) the fifth layer, (f) the sixth layer.

TABLE 7: Pollutant levels from different layers and locations.

Pollutant	Layer	Polluted area (m ²)	Maximum pollutant concentration (mg/kg)	Maximum ratio	Distribution region
Cu	1	908.09	6590	3.30	Copper washing compression workshop (T6)
	2	1038.06	6162	3.08	Production area entrance (T45)
	3	253.45	5050	2.53	Copper washing compression workshop (T6)
TPH	1	2730.22	16263	19.69	Compression workshop (T40)
	2	318.48	2130	2.58	Compression workshop (T8)
NH ₃ -N	1	1829.33	3951	3.30	Carbonization transformation workshop (T24)
	2	5739.5	3316	2.14	Carbonization transformation workshop (T50)
	3	1516.05	2799	1.81	Copper washing compression workshop (T40)
	4	2844.85	3713	2.40	Copper washing compression workshop (T35)
	5	2484.11	3785	2.44	Carbonization transformation workshop (T28)
	6	150.97	1747	1.13	Copper washing compression workshop (T33)
Fluoride	1	7	1150	1.10	Carbonization transformation workshop (T12)

NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

interception by the soil (Table 7). The low volatility, low solubility, and high hydrophobicity and sorption capacity of TPH made remediation difficult [22, 23].

As the main product of the fertilizer plant, NH₃-N concentrations ranged from 0.14 mg/kg to 3951 mg/kg, with a mean concentration of 445.1 mg/kg and a maximum ratio of 2.55. The main layers of the plant site were silt and silty clay with low water permeability. With the migration of rainfall and wastewater, NH₃-N could permeate down to a high depth. The deepest depth that the sample drill could reach was 27 m, and NH₃-N was present in those samples. As shown in Figures 5(c) and 3, NH₃-N was distributed near the copper washing and carbonization transformation workshops. The pollution level was not typically consistent with the depth, which suggests that the area had been polluted with NH₃-N for many years (Table 7). This could be attributed to the leakage of wastewater and the leaching of solid waste. Furthermore, poor pollution control and environmental protection awareness during the operational period could have been key factors affecting the contamination of the site.

Fluoride ranged from 127 mg/kg to 1150 mg/kg with a mean concentration of 424.94 mg/kg and a maximum ratio of 1.10. The overstandard point was at the ammonia pool of the carbonation transformation workshop. The fluoride-polluted area was relatively small compared with the other contaminants, and fluoride was only present in the surface soil (first layer) (Table 7). The presence of fluoride may be attributed to the atmospheric deposition of coal burn or the high background value [24, 25].

The polluted areas were 2199.6 m², 3048.7 m², 14564.81 m², and 7 m² for Cu, TPH, NH₃-N, and fluoride, respectively. These areas could be potentially harmful for

human health. Therefore, it was necessary to conduct a health risk assessment as per HJ25.3-2014 [26]. It should be mentioned that the total polluted area of the last 4 layers was not consistent with the increasing depth. The reason for this requires further investigation and analysis.

3.2. Health Risk Assessment. The hazard quotients in soils of the study area were calculated from Table 3 and are given in Table 8. Based on the values obtained, the main potential exposure pathway of Cu, fluoride, and TPH could be from oral ingestion. Inhalation of soil particles and dermal contact were the second most likely pathways for fluoride and TPH, respectively. However, the values with different exposure pathways of NH₃-N varied significantly in the following order: inhalation of gaseous pollutants from the surface soil in outdoor air > inhalation of soil particles. The contribution of inhalation of gaseous pollutants from the underlying soil in the outdoor and indoor air for NH₃-N was insignificant and may be ignored.

In general, the contribution rates of oral ingestion, dermal contact, and inhalation of gaseous pollutants from the surface soil in the outdoor air were 43.3%, 30.6%, and 25.9%, respectively. These results suggested that wearing safety masks would be an effective measure to reduce the negative health effects for workers and residents in the study site.

As given in Table 8, as the soil depth increased, the concentration of most of the pollutants tested decreased gradually. In the first two layers (0–6.5 m), the hazard quotients of Cu, NH₃-N, and TPH were greater than 1. In the third layer (6.5 m–10 m), Cu and NH₃-N were higher than the standard HQ. Until the fourth (10 m–15 m) and fifth

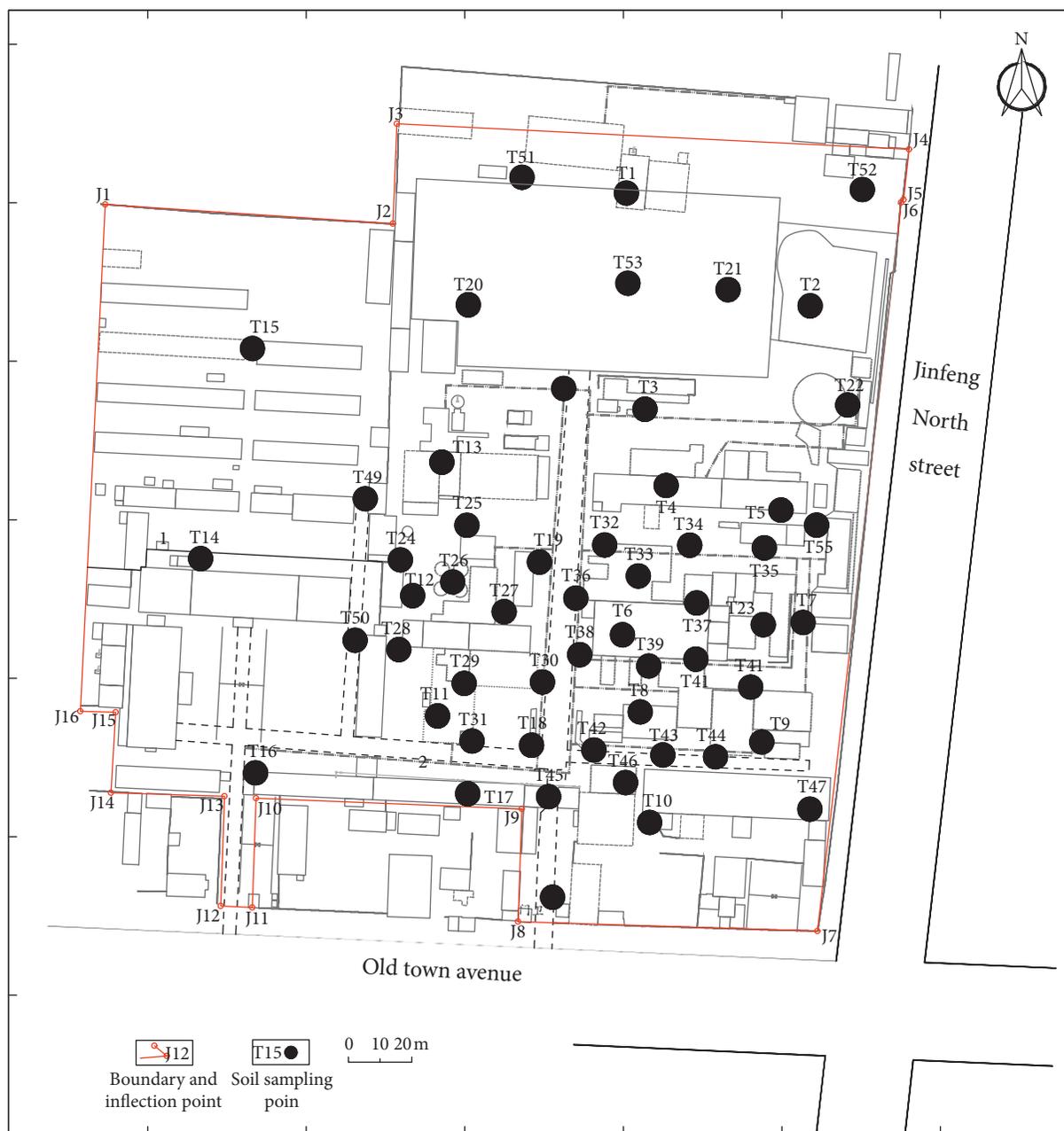


FIGURE 5: Sampling points in the study area.

layer (15 m–20 m), the HQs of $\text{NH}_3\text{-N}$ were 2.32 and 2.34, respectively. Li et al. also found that the surface soil was more vulnerable to contamination by pollutants compared with deeper soil. Those results indicated that the comprehensive HQs of the study site were relatively high and the soil should be remediated [27, 28].

3.3. The Target Value of Contaminated Soil Remediation and the Amount of Pollution. The RSVs of Cu, TPH, and $\text{NH}_3\text{-N}$ were calculated and are presented in Table 9, except for fluoride, which had an $\text{HQ} < 1$. The calculated RSVs of Cu and TPH were lower than GB36600-2018 [22]; thus, the final RSVs was based on GB36600-2018.

TABLE 8: HQs of pollutants in different layers.

Contaminants	Layer	HQ						Total
		HQ _{ois}	HQ _{dcs}	HQ _{pis}	HQ _{iov1}	HQ _{iov2}	HQ _{iiv1}	
Cu	1	3.29E+00						3.29
	2	3.08E+00						3.08E+00
	3	2.52E+00						2.52E+00
Fluoride	1	3.83E-01		1.83E-02				4.04E-01
NH ₃ -N	1			2.10E-02	2.40E+00	1.18E-06	1.63E-08	2.42E+00
	2			1.76E-02	2.01E+00	9.92E-07	1.37E-08	2.02E+00
	3			1.48E-02	1.70E+00	8.37E-07	1.16E-08	1.72E+00
	4			2.01E-02	2.30E+00	1.13E-06	1.57E-08	2.32E+00
	5			2.01E-02	2.32E+00	1.13E-06	1.57E-08	2.34E+00
	6			2.00E-03	3.21E-01	1.23E-06	2.57E-08	3.23E-01
TPH	1	8.12E+00	1.16E+01					1.97E+01
	2	1.06E+00	1.51E+00					2.57E+00
Total		1.85E+01	1.31E+01	1.14E-01	1.11E+01	6.5E-06	9.87E-08	4.27E+01
Total (%)		43.3	30.6	0.2	25.9	0	0	100

HQ, hazard quotient; NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

TABLE 9: RSVS of contaminants of concern.

Contaminant	RSVS (mg/kg)		
	Calculated	GB36600-2018	Final
Cu	1890	2000	2000
TPH	820	826	826
NH ₃ -N	1549	--	1549

NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

TABLE 10: Study site remediation statistics.

Layer	Targeted pollutants	Remediation area (m ²)	Remediation volume (m ³)
1	Cu, TPH, NH ₃ -N	5259.41	23667.35
2	Cu, TPH, NH ₃ -N	7307.12	14614.24
3	Cu, NH ₃ -N	1874.79	6561.77
4	NH ₃ -N	2965.5	14827.5
5	NH ₃ -N	2637.97	13189.85
Total			72860.71

NH₃-N, ammonia-nitrogen; TPH, total petroleum hydrocarbons.

The remediation area and volume for the targeted pollutants for each different layer were determined by interpolation and manual correction; results are given in Table 10. The spatial distribution of the remediation area for Cu, TPH, and NH₃-N is shown in Figure 6. Cu and TPH need to be remediated only in the first three layers. The Cu and TPH remediation areas overlapped almost completely in

the second and third layers. In contrast, the area that requires remediation of NH₃-N comprises almost five layers. The total remediation volume was 72860.71 m³ after superposition. These results show that a risk assessment is necessary where fertilization plants have been operational, and they can be used to compare, develop, and select remediation options.

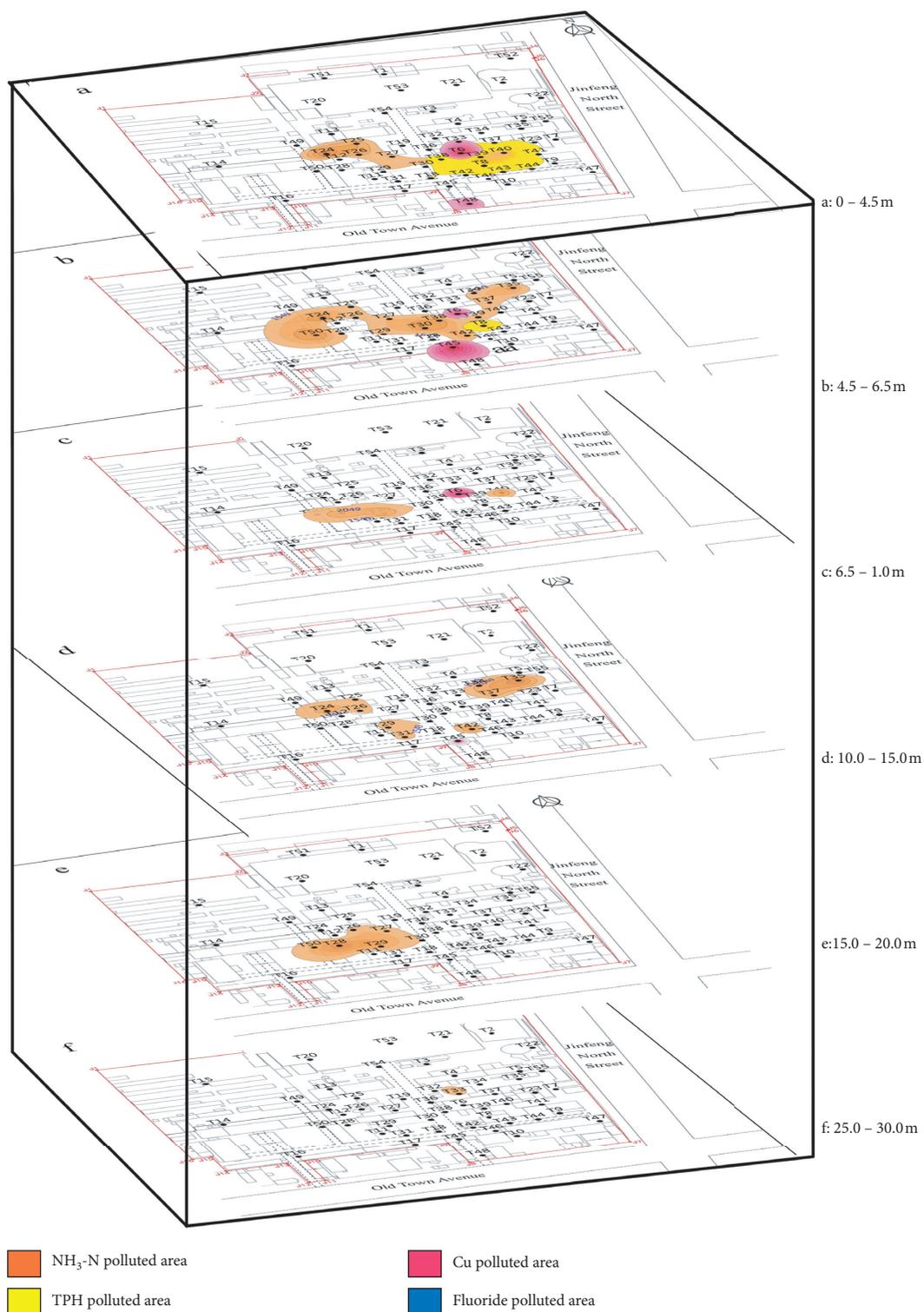


FIGURE 6: Remediation areas from different soil layers: (a) the first layer; (b) the second layer; (c) the third layer; (d) the fourth layer; (e) the fifth layer.

4. Conclusion

In this study, a pollutant survey and risk assessment of soils were carried out in a fertilizer plant in Linzhang County, North China. The results indicated that the site was polluted by four main contaminants: fluoride, copper, TPH, and $\text{NH}_3\text{-N}$. These contaminants were mainly attributed to coal burning, the leakage of wastewater, and lubricating oil. Their presence also reflected the poor pollution controls and environmental protection awareness during the operation period. The total areas polluted by fluoride, Cu, TPH, and $\text{NH}_3\text{-N}$ were 7 m^2 , 2199.6 m^2 , 3048.7 m^2 , and 14564.81 m^2 , respectively. The hazard quotients found were relatively high and indicate that oral ingestion, inhalation of soil particles, and inhalation of gaseous pollutants from the surface soil in the outdoor air could be the main exposure pathways of this site without any remediation steps. RSVS was calculated and compared with GB36600-2018, and the final total remediation soil volume was 72860.71 m^3 after superposition. To solve the problem of soil pollution and protect public health in the study area, the enterprise and local government should make more efforts to remediate the soil pollution. This study provides useful information and reference for environmental management in fertilizer plant sites.

Data Availability

The data used to support the findings of this study are included within the article, and any data in the full-text can be quoted and does not involve the situation of leakage.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors thank LetPub (<http://www.letpub.com>) for its linguistic assistance and scientific consultation during the preparation of this manuscript. The fund of this study mainly comes from the national financial project—the Soil Pollution Status Investigation Project of Key Industry Enterprises in Hebei Province.

References

- [1] W.-F. Zhang, Z.-X. Dou, P. He et al., "New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China," *Proceedings of the National Academy of Sciences*, vol. 110, no. 21, pp. 8375–8380, 2013.
- [2] Y. Du, B. Cui, Q. Zhang et al., "Effects of manure fertilizer on crop yield and soil properties in China: a meta-analysis," *Catena*, vol. 193, Article ID 104617, 2020.
- [3] X. Ju, B. Gu, Y. Wu, and J. N. Galloway, "Reducing China's fertilizer use by increasing farm size," *Global Environmental Change*, vol. 41, pp. 26–32, 2016.
- [4] Y. C. Chien, "Field study of in situ remediation of petroleum hydrocarbon contaminated soil on site using microwave energy," *Journal of Hazardous Materials*, vol. 199–200, pp. 457–461, 2012.
- [5] I. S. Park and J. W. Park, "Determination of a risk management primer at petroleum-contaminated sites: developing new human health risk assessment strategy," *Journal of Hazardous Materials*, vol. 185, no. 2-3, pp. 1374–1380, 2011.
- [6] W. Hou, L. Zhang, Y. Li et al., "Distribution and health risk assessment of polycyclic aromatic hydrocarbons in soil from a typical contaminated urban coking sites in Shenyang city," *Bulletin of Environmental Contamination and Toxicology*, vol. 95, no. 6, pp. 815–821, 2015.
- [7] G. Liu, J. Niu, C. Zhang, and G. Guo, "Characterization and assessment of contaminated soil and groundwater at an organic chemical plant site in Chongqing, Southwest China," *Environmental Geochemistry and Health*, vol. 38, no. 2, pp. 607–618, 2016.
- [8] T. Kiba and A. Krapp, "Plant nitrogen acquisition under low availability: regulation of uptake and root architecture," *Plant and Cell Physiology*, vol. 57, no. 4, pp. 707–714, 2016.
- [9] T. Zakharova, F. Tatàno, and V. Menshikov, "Health cancer risk assessment for arsenic exposure in potentially contaminated areas by fertilizer plants: a possible regulatory approach applied to a case study in Moscow region-Russia," *Regulatory Toxicology and Pharmacology*, vol. 36, no. 1, pp. 22–33, 2002.
- [10] R. Zuo, X. Chen, X. Li et al., "Distribution, genesis, and pollution risk of ammonium nitrogen in groundwater in an arid loess plain, northwestern China," *Environmental Earth Sciences*, vol. 76, no. 17, Article ID 629, 2017.
- [11] M. Van Damme, L. Clarisse, S. Whitburn et al., "Industrial and agricultural ammonia point sources exposed," *Nature*, vol. 564, no. 7734, pp. 99–103, 2018.
- [12] J. Wu and Z. Sun, "Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, mid-west China," *Exposure and Health*, vol. 8, no. 3, pp. 311–329, 2016.
- [13] M. E. Davidson, J. Schaeffer, M. L. Clark et al., "Personal exposure of dairy workers to dust, endotoxin, muramic acid, ergosterol, and ammonia on large-scale dairies in the high plains Western United States," *Journal of Occupational and Environmental Hygiene*, vol. 15, no. 3, pp. 182–193, 2018.
- [14] Ministry of Ecology and Environment of China (MEEC), *Soil and Sediment-Determination of Copper, Zinc, Lead, Nickel and Chromium-Flame Atomic Absorption Spectrophotometry (HJ 491-2019)*, MEEC, Beijing, China, 2019, In Chinese.
- [15] European Committee for Standardization (ECS), *Soil Quality-Determination of Content of Hydrocarbon in the Range C10 to C40 by Gas Chromatography*, ECS, Brussels, Belgium, ISO 16703:2004, 2011.
- [16] General Administration of Quality Supervision, *Inspection and Quarantine of China (GAQSIQC), Soil Quality-Analysis of Fluoride-Iron Selective Electrometry (GB/T 22104-2008)*, GAQSIQC, Beijing, China, 2008, In Chinese.
- [17] Ministry of Environmental Protection of China (MEPC), *Soil-Determination of Ammonium, Nitrite and Nitrate by Extraction with Potassium Chloride Solution-Spectrophotometric Methods (HJ 634-2012)*, MEPC, Beijing, China, 2012, In Chinese.
- [18] Ministry of Ecology and Environment of China (MEEC), *Soil Environment Quality Risk Control Standard for Soil Contamination of Development Land (GB 36600-2018)*, MEEC, Beijing, China, 2018, In Chinese.

- [19] Ministry of Environmental Protection of China (MEPC), *Technical Guidelines for Risk Assessment of Contaminated Sites (HJ 25.3-2014)*, MEPC, Beijing, China, 2014, In Chinese.
- [20] Z. Ma, K. Chen, Z. Li, J. Bi, and L. Huang, "Heavy metals in soils and road dusts in the mining areas of Western Suzhou, China: a preliminary identification of contaminated sites," *Journal of Soils and Sediments*, vol. 16, no. 1, pp. 204–214, 2016.
- [21] E. Wcislo, J. Bronder, A. Bubak, E. Rodriguez-Valdes, and J. L. R. Gallego, "Human health risk assessment in restoring safe and productive use of abandoned contaminated sites," *Environment International*, vol. 94, pp. 436–448, 2016.
- [22] S.-H. Do, J.-H. Jo, Y.-H. Jo, H.-K. Lee, and S.-H. Kong, "Application of a peroxymonosulfate/cobalt (PMS/Co(II)) system to treat diesel-contaminated soil," *Chemosphere*, vol. 77, no. 8, pp. 1127–1131, 2009.
- [23] C. H. Yen, K. F. Chen, C. M. Kao, S. H. Liang, and T. Y. Chen, "Application of persulfate to remediate petroleum hydrocarbon-contaminated soil: feasibility and comparison with common oxidants," *Journal of Hazardous Materials*, vol. 186, no. 2-3, pp. 2097–2102, 2011.
- [24] H. G. Mikkonen, R. van de Graaff, A. T. Mikkonen et al., "Environmental and anthropogenic influences on ambient background concentrations of fluoride in soil," *Environmental Pollution*, vol. 242, pp. 1838–1849, 2018.
- [25] J. Chen, G. Liu, Y. Kang et al., "Atmospheric emissions of F, As, Se, Hg, and Sb from coal-fired power and heat generation in China," *Chemosphere*, vol. 90, no. 6, pp. 1925–1932, 2013.
- [26] J. Li, J. Fan, J. Jiang et al., "Human health risk assessment of soil in an abandoned arsenic plant site: implications for contaminated site remediation," *Environmental Earth Sciences*, vol. 78, no. 24, Article ID 673, 2019.
- [27] Y. Zou, Y. Li, L. Hu et al., "Health risk assessment of arsenic in soils from three thermal power plants in Southwest China," *Human and Ecological Risk Assessment: An International Journal*, vol. 26, no. 5, pp. 1221–1233, 2020.
- [28] L. Hu, L. Bai, J. Kang, and J. Jia, "Contamination level and potential health risk assessment of hexavalent chromium in soils from a coal chemical industrial area in Northwest China," *Human and Ecological Risk Assessment: An International Journal*, vol. 26, no. 5, pp. 1300–1312, 2020.