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ORIGINAL ARTICLE

Assessing pollutions of soil and plant by municipal waste dump

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Abstract Research is few in the literature regarding the investigation and assessment of pollutions of soil and plant by municipal waste dumps. Based upon previous work in seven waste dumping sites (nonsanitary landfills) in Beijing, Shanghai and Shijiazhuang, this study expounds the investigation and assessment method and report major pollutants. Using relative background values, this study assesses soil pollution degree in the seven dumping sites. Preliminary conclusions are: (1) pollution degrees are moderate or heavy; (2) pollution distance by domestic waste that is dumped on a plane ground is 85 m; (3) the horizontal transport distance of pollutants might be up to 120 m if waste leachates are directly connected with water in saturated soils; (4) vertical transport depth is about 3 m in unsaturated silty clayey soils. Furthermore, using relative background values and hygiene standards of food and vegetable this study assesses the pollutions of different parts of reed, sorghum, watermelon and sweet-melon. It is found: (1) in comparison with the relative background values in a large distance to the waste dumping sites, domestic wastes have polluted the roots and stems of reed and sorghum, whereas fine coal ash has polluted the leaves, rattans and fruits of watermelon and sweet-melon; (2) domestic wastes and fine coal ash have heavily polluted the edible parts of sorghum, water melon and sweet-melon. As, Hg, Pb and F have far exceeded standard values, e.g., Hg has exceeded the standard value by up to 650–1,700 times and Cd by 120–275 times, and the comprehensive pollution index is up to 192.9–369.7; (3) the polluted sorghum, watermelon and sweet-melon are inedible.

Keywords Waste dumping site · Soil pollution · Plant pollution · Pollutant transport distance

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Introduction

Many work (e.g. Liu et al. 1999, 2003, 2005; Tchobanoglous et al. 1993; Zhang et al. 1996, 2003; Guleg et al. 2001; Kabata-Pendias 1995; Klein et al. 1975; Romic and Romic 2003) have indicated that unplanned municipal waste dumps could pollute soil, surface water and groundwater, which have attracted considerable attentions from scholars and governmental agencies in the past 20 years. Numerous results on pollutions of surface water, groundwater and air due to improper treatment of municipal waste have been reported in recent years (see Liu et al. 1999, 2003, 2005; Tchobanoglous et al. 1993; Zhang et al. 1996, 2006; Romic and Romic 2003), but work on assessing soil and plant pollutions by municipal waste is few. For examples, Yang (1995) and Wang (2000) reported soil pollution by waste water, fertilizer and solid wastes, Klein et al. (1975), Kabata-Pendias (1995), Zhang et al. (1996), Tchobanoglous et al. (1993), Guleg et al. (2001) and Romic and Romic (2003) all discussed soil contamination by municipal waste but gave no details on the pollution degree of soil, the migrating distance and influence scope of pollutants and their assessment method; Li and Hao (2002), Zhu et al. (2003), Hao et al. (2003), Ke (2005), Wang (2005), Gu et al. (2005) and Hu et al. (2005) reported that heavy metal (As, Hg, Cd, Pb and Cr) were accumulated in plant and absorbed by plant, but did not discuss anything related to municipal waste dump; Tang et al. (2003) reported Hg pollution and migration in soil-plant systems in different units of municipal waste dump site, but did not detail the pollution degree of plant by nearby municipal waste.

As a result, the pollution degree of soil by nearby municipal waste, the migrating distance and influence scope of pollutants and the accumulative pollution of plant (in particular of crops) are not clear. Based upon previous work in Beijing and other cities, this paper intends to explore answers to these questions.

Method to research and assess

Research method

The major research methods include field investigation into municipal waste dumping sites, indoor test of soil and plant samples, and assessment using single-factor index or comprehensive pollution index according to relative background values and food-vegetable hygiene standard.

Field investigation into polluted soil and collecting samples

The present study investigated soil pollutions in four municipal waste dumps in Beijing, i.e., Zhangguozhuang, Wenzhuangzi, Beitiantang and Mentougou, one in Shijiazhuang city, i.e., Taitou municipal waste dump, and Jiangzhen municipal waste dump in Pudong, Shanghai. The topography and soil properties at each dump site are summarized in Table 1.

When investigating the pollution degree of soil by municipal waste dumps the present study consider the dump sites as point-type sources of pollution and then collected soil samples at different depths and in different horizontal distances (Table 2) in accordance with principles and standards outlined as follows.

1. Principles for sampling

(a) Relative-background-value samples: It is hard to collect non-polluted soil sample adjacent to dumping sites. Relative-background-value samples, i.e., soil samples at the same depth as that of polluted soil sample but in a location where the municipal waste dump could not affect, were thus collected.

(b) Where municipal waste could exert influence, samples were collected according to ‘‘distance-waning principle, i.e., pollutant concentration declines with distance’’ and ‘‘depth-waning principle, i.e., pollutant concentration declines with depth’’. Generally, from five to seven samples were collected.

2. Standard for collecting, storing and testing of soil samples

The collection and storage of soil samples were performed according to the technique standard for monitoring soil environment (State Environmental Protection Administration of China, HJ/T166-2004 2004), that is to allocate drilling hole in a certain distance to the dumping sites and collect soil sample at different depth in the same hole using simple tool (i.e., Luoyang shovel) and according to the specific field condition. The drill locations and sampling depths are listed in Table 2. As the volatility of testing elements is low soil samples were packed with Polyethylene and put inside brown-colored glass bottles and directly forwarded to the laboratory.

Test of soil samples was conducted according to the technique standard for monitoring environment of municipal domestic waste dumping site (Ministry of Construction, P.R. China, CJ/T3037-95 1995) and the soil environment quality standard (Quality Standard of Soil Environment GB15618-1995, 1995). The testing method is reported in Table 3.

Field investigation into plant pollution and collecting samples

Sampling arrangement: according to ‘‘distance-waning principle, i.e., pollutant concentration declines with distance due to filtering and attraction of soil layers and physo-biological processes’’, from three to five samples were collected (State Environmental Protection Administration of China, HJ/T166-2004 2004; Liu et al. 1999; Zhang et al. 2006).

A certain number of roots, stems, leaves or fruit of plant were collected and immediately put inside clean plastic bottles and plastic bags. They were then taken to laboratory to test.

Assessment method

Assessment method for soil pollution by municipal waste dumps

Pollution-assessing factor The major pollutants from domestic wastes include COD, BOD, phenol, three N

Table 1 Topography and soil properties at investigated municipal waste dump sites

Municipal waste dump site	Topography	Soil properties	Means by which leachate pollutes soils
Zhangguozhuang	Ground is very gently inclined; domestic wastes have been dumped on the ground for 4 years; soil is unsaturated	Top clayey soil layer is about 0.7-m thick, it is silty clayey soil underlain by gravels	Leachates appear as sheet flows in heavy rains; but pollutants migrate in lateral and vertical directions in most cases
Duqingtang	Ground is flat; domestic wastes have been dumped on the ground for 11 years; soil is unsaturated	Top clayey soil layer is about 7-m thick, it is silty clayey soil underlain by fine sand	Leachates appear as sheet flows in heavy rains; but pollutants migrate in lateral directions in most cases
Beitiantang	Domestic wastes have been dumped in a 7 m deep pit for 7 years	Top clayey soil layer is about 0.6-m thick, sandy clayey soil	Leachates also appear as sheet flows in heavy rains, but pollutants migrate only in sandy soil layer below the top soil layer in lateral and vertical directions
Mentougou	Ground is flat; fine coal ash has been dumped on the ground for 3 years; soil is unsaturated	Top clayey soil layer is about 0.5 m, it is clayey soil underlain by gravels	Leachates appear as sheet flows in heavy rains, but pollutants migrate in lateral and vertical directions to pollute soil and plant in most cases
Shaziying	Ground is flat, domestic wastes have been dumped in a shallow pond that is connected with phreatic water for 5 years; soil is unsaturated; the buried depth of shallow groundwater is bout 1 m	Top clayey soil layer is 1.2-m thick, it is silty clayey soil interbedded with silty soil, below is medium-coarse sand	Leachates appear as sheet flows and pollutants migrate with phreatic water to pollute soil and plant
Jiangzhen in Shanghai	Ground is flat, domestic wastes have been dumped in a shallow pond that is connected with phreatic water for 8 years, soil is saturated	Top clayey soil layer is about 3.5-m thick, silty clayey soil, below is fine sand	In most cases pollutants migrate with phreatic water in lateral and vertical directions
Taitou in Shijiazhuang	Ground is flat; domestic wastes have been dumped on the ground for 6 years; soil is unsaturated	Top clayey soil layer is about 4-m thick, silty clayey soil, below is fine silt	Leachates appear as sheet flows in heavy rains, but pollutants migrate in lateral and vertical directions to pollute soil and plant in most cases

(nitrate, nitrite and ammoniac nitrogen), phosphoric acid roots, alum root and metal ions (Cd, As, Cr, Mn, Cu, Ni, Zn) (Technique Standard for Monitoring Environment of Domestic Waste Landfill CJ/T3037-95 1995; Tchobanoglous et al.1993; Zhang et al. 1996, 2006; Wang et al. 2004). Therefore, these pollutants serve as pollution-assessing factors.

Pollution-assessing method Calculations were executed according to single pollution index or multi-factor pollution indexes. Whether soil is polluted or not is judged on the basis of soil's relative background values. According to the previous work (Liu 1989; Lu 1999; Yang 1995; Wang 2000), the single-factor index and comprehensive index is calculated as follows, respectively:

1. Single-factor index assessment. The formula is:

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

where P_i is the pollution index of the ith pollutant in soil or plant,C_i is the measured value of the ith pollutant (mg/kg), and S_i is the relative background value of the ith pollutant (mg/kg). The pollution degrees are classified according to single-factor pollution index as non-polluted ($P \leq 1$), lightly polluted ($1 < P \leq 2$), moderately polluted ($2 < P \leq 3$) and heavily polluted ($P > 7$).

2. Comprehensive-index assessment. The formula is:

$$P = \sum_{i=1}^{N} P_i, \quad (2)$$

Table 2 Sampling at each municipal waste dumps

Municipal waste dump	Sampling
Beitiantang	Drilling samples at a depth of 0.3 and 3 m in a distance of 1 m to the municipal waste dump site were collected. Samples at a depth of 3 m were taken as relative-background-value samples. Horizontally, samples in a distance of 0.5, 15, 25, 35, 45, 85, and 180 m to the municipal waste dump site were collected, respectively, with the 180 m sample assigned as the relative-background-value sample
Zhangguozhuang	Drilling samples at a depth of 0.5, 1, 1.5, 2.0, and 2.5 m in a distance of 5 m to the municipal waste dump site were collected, respectively. Samples at a depth of 2.5 m were taken as relative-background-value samples
Duqingtang	Drilling samples were collected in a distance of 0, 3, 5, 17, 30, 42, 58, and 85 m to the municipal waste dump site but at the same depth of 15 cm. The 85 m sample was chosen as the relative-background-value sample. In the core nearest to the municipal waste dump site, samples at a depth of 0.25, 1.25, 1.75, 2.25, 2.75, and 3.75 m were collected, respectively. The deepest sample was chosen as the relative-background-value sample
Mentougou	Samples close to the fine coal ash dump site at a depth of 0.1, 0.25, and 0.45 m were collected, respectively. Background-value samples were taken where the municipal waste dump site could not affect. Watermelon and sweet-melon samples were collected in soils adjacent to the municipal waste dump site with sample in a distance of 1,000 m as the relative-background-value sample
Jiangzhen in Shanghai	Samples in a distance of 2.5, 7, 15, 27.5, 45, 80, 120, and 300 m to the municipal waste dump site were collected, respectively. The furthest sample was chosen as the relative-background-value sample In the 2.5-m-distance core, samples at a depth of 0.25, 0.75, 1.5, 2, 3, and 8 m were collected, respectively. The 8 m depth sample was chosen as the relative-background-value sample
Taitou in Shijiazhuang	Samples in a distance of 2, 5, 9, 15, 25, 40, and 80 m to the municipal waste dump site were collected, respectively, and the furthest sample was chosen as relative-background-value sample In the 2-m-distance core, samples at a depth of 0.2, 0.5, 1.25, 2, 3, and 4 m were collected, respectively, and the 4-m-distance sample was chosen as the relative-background-value sample
Shaziying	Samples in a distance of 0, 3, 15, 30, 60, 80, and 200 m were collected, respectively. Reed and sorghum samples were collected in a distance of 0, 60, and 200 m, respectively. The 200-m-distance samples were chosen as the background-value sample

Table 3 Testing method for soil pollutants

Testing	Analyzer	Testing method
Cd	Atomic absorption spectrometer	Graphite oven atomic absorption spectrophotometry (GOAAS)
Hg	Mercury analyzer	Cold atomic absorption method
As	Spectrophotometer	Potassium borohydride–silver nitrate spectrophotometric method
Cu	Atomic absorption spectrometer	Flames atomic absorption spectrophotometry (FAAS)
Pb	Atomic absorption spectrometer	Graphite oven atomic absorption spectrophotometry (GOAAS)
Cr	Atomic absorption spectrometer	Flames atomic absorption spectrophotometry (FAAS)
Zn	Atomic absorption spectrometer	Flames atomic absorption spectrophotometry (FAAS)
Ni	Atomic absorption spectrometer	Flames atomic absorption spectrophotometry (FAAS)
Ca^{2+}	Ion chromatograph	Ion chromatography
COD		Potassium permanganate process
Mn	Atomic absorption spectrometer	Atomic absorption spectrophotometry
F	Ion chromatograph	Ion chromatography
NH_4^+	Ion chromatograph	Ion chromatography
Cl^-	Ion chromatograph	Ion chromatography
SO_4^{2-}	Ion chromatograph	Ion chromatography
NO_2^-	Ultraviolet spectrophotometer Ultraviolet spectrophotometry	
NO_3^-	Ion chromatograph	Ion chromatography
Total N		Kjeldahl determination

where P is the comprehensive index, P_i the pollution index of the ith pollutant, and N the number of pollutants.

3. Grades on comprehensive pollution degree. According to the comprehensive pollution index, grades on pollution degree were classified as non-polluted ($P \leq 1$), lightly polluted ($1 < P \leq 2.5$), moderately polluted ($2.5 < P \leq 7$) and heavily polluted ($P > 7$).

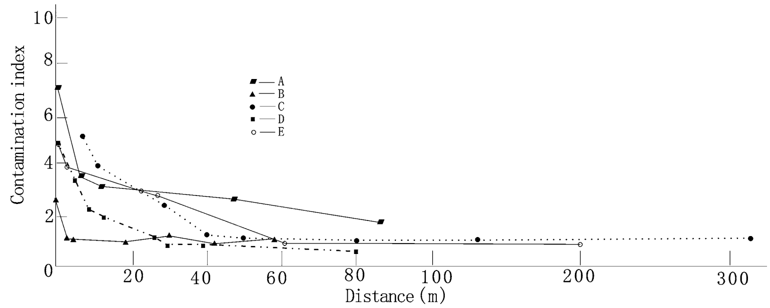

Fig. 1 Variations of soil pollution degrees with distance to the municipal waste dump in Beitiantang (*A*), Duqingtang (*B*),Jianzhen (*C*), Taitou (*D*)and Shaziying (*E*), respectively

Method to assess the pollution of plant by municipal waste dumping sites

Assessment method On the "distance-waning" principle the present study uses the relative background value and the hygiene standard of food and vegetable of the Peoples' Republic of China to assess the relative pollution degree, but use the latter to assess the absolute pollution degree.

Pollution calculation method The assessing index is determined by the above-mentioned single-factor index and multi-factor comprehensive index. Concentration-trend method and relative-background-value method were used to judge whether pollution has occurred.

1. Single-factor assessment

According to previous work (Ke 2005; Wang 2005; Gu et al. 2005; Hu et al. 2005; Zhu 2003; Tang 2003; Li and Hao 2002; Guleg et al. 2001; Liu et al. 2001), As, Hg, Cd, Pb and F (Wang 2000; Yang 1995; Hao et al. 2003) were chosen as pollution-assessing factors. The calculation formula is the same as Eq. 1 (Wang 2000; Yang 1995; Hao et al. 2003). The pollution grades were determined accordingly.

2. Comprehensive-factor evaluation

The calculation formula is the same as Eq. 2 (Wang 2000; Yang 1995; Hao et al. 2003). The corresponding pollution grades were determined accordingly.

Results of soil pollution by municipal waste dump

Soil pollution by municipal waste dump

The soil pollutions by municipal waste dumps (Table 1) were assessed. Results are shown in Figs. 1 and 2.

The major pollutants from Beitiantang waste dump site are Hg, total Ag, COD, but Cl^-, metal ions (Cd, As, Cr, Mn, Cu, Ni, Zn) are minor. Figure 1A shows that pollution degrees decrease and pollution degrees lighten with increasing distance: it is heavy pollution within a distance of 15 m to the municipal waste dump site, moderate pollution within a 15–40 m distance, light pollution within a 40–85 m distance but no pollution outside the 85 m distance.

The major pollutants from Zhangguozhuang waste dump site are NH_4^+, Cl^-, total Hg, Ca^{2+}, Cu^{2+} and Zn^{2+}. Figure 2A shows that it is moderate pollution in shallow-than-1 m soils; pollution degrees rapidly decrease with increasing depth, it is light pollution within a depth of 1–2 m and no pollution below 2 m.

The major pollutants from Mentougou waste dump site are Hg, Cd, As, Pb, F, Ca^{2+}, Cu^{2+} and Zn^{2+}, other element is few. Figure 2B shows that pollution degrees decrease with depth. At 0.1 m depth is moderate pollution, below 0.25 m depth is light pollution; pollution depth of clayey soil is less than 0.5 m.

The major pollutants from Duqingtang waste dump site are Cl^-, SO_4^{2-}, Na^+, total N and COD, other metal iron is few. Figure 2B shows that pollution is apparent within a 5 m distance, but light pollution occurs within a distance of 5–58 m and no pollution outside the 58 m distance. Figure 2C shows that pollutions decrease with depth: <0.25 m is heavy pollution, at 0.25–2.75 m depth is moderate pollution and below 2.75 m depth no pollution.

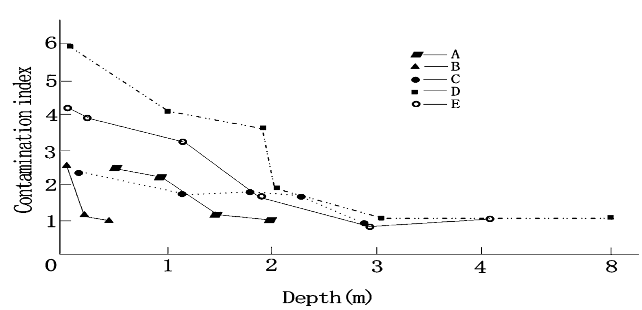

Fig. 2 Variations of soil pollution degrees with depth to the municipal waste dump in Zhangguozhuang (*A*), Mentougou (*B*), Duqingtang (*C*), Jianzhen (*D*) and Taitou (*E*), respectively

The major pollutants from Jiangzhen in Shanghai waste dump site are Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, total N and COD, other metal ion is few. Figure 1C shows that within 10 m distance soil is subjected to heavy pollution, in 10–15 m distance is moderate pollution, in 15–120 m distance is light pollution and outside 120 m distance no pollution occurs. Figure 2D shows that above 1.4 m depth soil is subjected to heavy pollution, at 1.4–2 m depth is moderate pollution, at 2–3 m depth is light pollution and below 3 m depth no pollution.

The major pollutants from Taitou in Shijiazhuang waste dump site are Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, COD, other metal ion is few. Figure 1D shows that heavy pollution occurs within 5 m distance, moderate pollution in 5–15 m distance, light pollution in 15–40 m distance and no pollution outside 40 m distance. Figure 2D shows that soil is subjected to heavy pollution above 1.25 m depth, at 1.25–2 m depth is moderate pollution, at 2–3 m depth is light pollution.

The major pollutants from Shaziying waste dump site are Hg, Cd, As, Pb, F, Ca^{2+}, Cu^{2+}, Zn^{2+}, Cl^-, three N and COD, other pollutant is few. Figure 1E shows that in 0–15 m distance is heavy pollution, in 15–50 m distance is moderate pollution and in 50–80 m distance is light pollution.

Influence depth and distance of pollutants in top soils

The influence depth and distance of pollutants in top soils are important indexes for people to assess soil pollution degree. Previous work (Tchobanoglous et al. 1993; Zhang et al.1996; Wang et al. 2004; Liu et al. 2003) show that pollutant concentrations might drop when municipal waste leachates migrate through soil layers due to physical, chemical and biological processes; soil's capacity to purify pollutants is determined by lithology, mineral composition, microbiological process and groundwater dynamics; the finer the soil grain is, the better the filtering and cleaning by suspended matter and bacteria is; the more the clayey minerals are, the stronger the absorption of pollutants is; the higher the phreatic water head is and the faster groundwater runs, the faster the pollutant concentrations drop.

Pollutants from municipal wastes are generally Cl^-, SO_4^{2-}, NO_2^-, NH_4^+, total N, COD, total Cu, total Zn, total Pb, total Mn, total Cd, total Ni, Cr^{6+}, Zn^{2+}, Kr^+, Cu^{2+}, Mg^{2+}, Ag^+, etc. But the concentrations of Cl^-, SO_4^{2-}, NO_2^-, NH_4^+, total N and COD are comparably higher, causing soil pollution; concentrations of other metal ions are lower, causing minor soil pollution. Therefore, the present study investigates the lateral and vertical migration distance of Cl^-, SO_4^{2-}, NO_2^-, NH_4^+, total N and COD only. Cl^-, SO_4^{2-}, NO_2^-, NH_4^+

Influence depth of pollutants in soils

The pollutant concentrations in the soil profile in the Duqingtang municipal waste dump site were analyzed. The variations of pollutant concentration with depth in the top clayey soil layer are shown in Fig. 3.

Figure 3 indicates that Cl^-, COD, total S, total P, total N, ammoniac nitrogen, nitrate, nitrite are higher within 0–1 m depth at the Duqingtang municipal waste dump site but below 1 m depth are they lower. This indicates that domestic wastes in Beijing have caused obvious pollutions of top clayey soil shallow than 1 m but the influence depth could reaches 3 m.

Lateral distribution of municipal waste pollutants in soil layers

To study the lateral distribution of municipal waste pollutants in top soil layers the present study collected and analyzed soil samples in different distances to the Duqingtang municipal waste dump. Results are shown in Figs. 4 and 5.

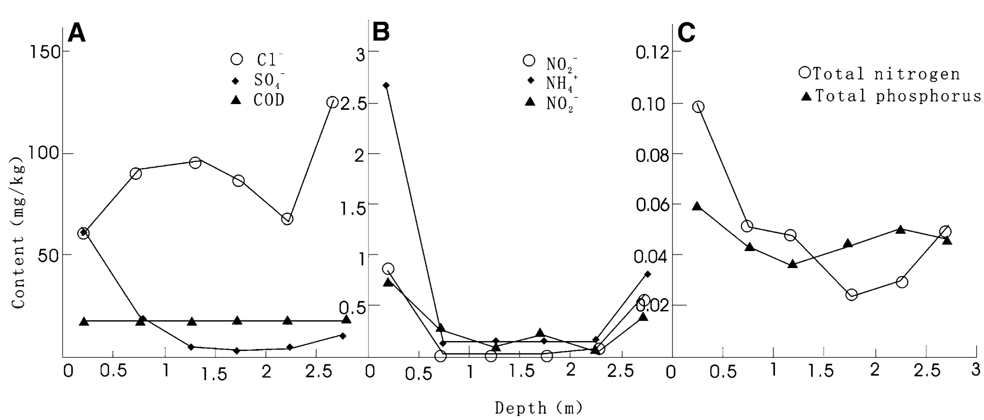

Fig. 3 Vertical variation of pollutant concentration in the top clayey soil layer in the Duqingtang municipal waste dump site, Beijing

Figure 4A shows that as the distance increases from 0 to 58 m, concentration variations of total P, total N and phosphoric acid roots in the 0.25-m-deep clayey soil with the distance are not obvious. Figure 4B shows that concentrations of ammoniac nitrogen and nitrite gradually decrease within a distance of 42 m, suggesting that the influence distance in top clayey soils by the plane Duqingtang municipal waste dump is around 40 m. Figure 4C shows that concentration of nitrate decreases within a distance of 18 m but keeps constant outside this distance.

Figure 5A shows that concentrations of ammonia ions, nitrate and nitrite drops within a distance of 5 m but keep constant outside this distance. Figure 5B, C shows that COD does not change after dropping from 60 to 20 mg/kg within a distance of 0–15 m; Cl^- could migrate a longer distance (about 15 m). This indicates that ammoniac nitrogen, nitrate, nitrite and COD in the leachates from the Beitiantang municipal wastes which are dumped in a sandy pit could travel 5 m distance but Cl^- ion could travel about 15 m.

Results on plant pollution by municipal waste dump

Municipal pollutants that are easily accumulated in plants are mainly heavy metal ions and F, which are most harmful to human's health (Ke 2005; Wang 2005; Gu et al. 2005; Hu et al. 2005;Zhu et al. 2003; Tang et al. 2003; Li et al. 2002; Liu et al. 2001). The present study chooses a domestic waste dump at Shaziying in Beijing and a fine coal ash waste dump at Mentougou as examples to assess plant pollution by municipal waste pollutants.

It is through soil that municipal pollutants pollute plants or vice versa (Wang 2000; Yang 1995; Wang 2005; Hu et al. 2005; Li and Hao 2002). The more the pollutants are in soils, the easier plant absorb them. The further the distance is to the municipal waste dump, the smaller the effects of municipal waste dump upon soils are and consequently the smaller the influences on plants are. So, after collecting plant samples that are furthest from the municipal waste dump as relative-background-value sample the present study assesses the plant pollution.

Influence of domestic waste pollutants upon plants

After testing the leachates from the Shaziying domestic waste dump the present study finds that the concentrations of metal ions are higher too. Reed and sorghum samples in a distance of 0, 60 and 200 m to the dump site were collected for analyzing their leaves,

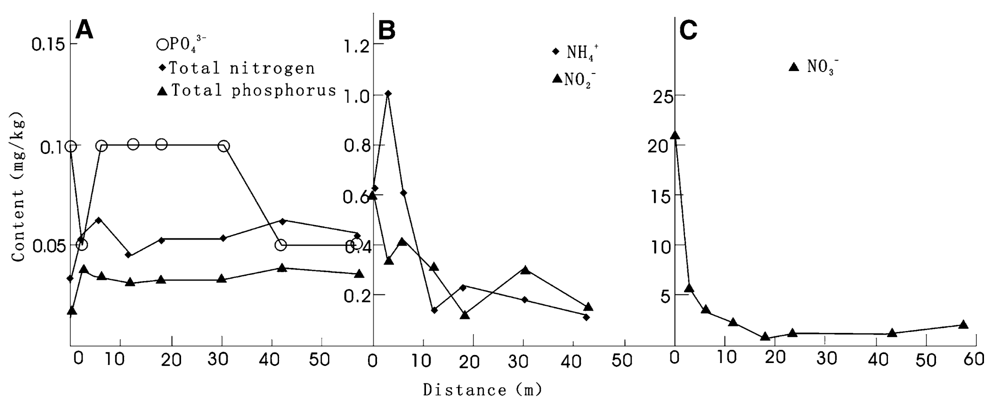

Fig. 4 Lateral distributions of pollutants in top clayey soils from the Duqingtang municipal waste dump, Beijing

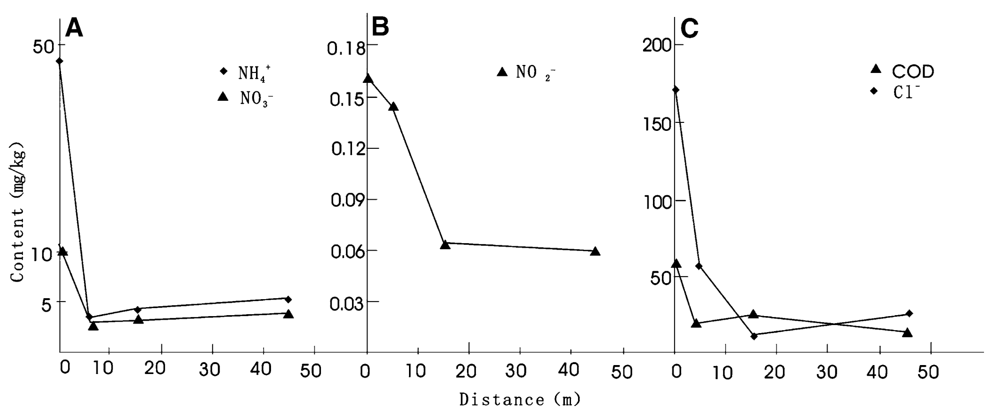

Fig. 5 Lateral distributions of pollutants in top sandy soil from the Beitiantang municipal waste dump, Beijing

stems, roots and fruit with regard to As, Cd, Hg, Pb, F, etc. in specialized laboratories. Results are reported in Table 4.

The present study chooses the plant sample in a distance of 200 m to the waste dump as the relative-background-value sample to assess pollutions using single-factor index and comprehensive index, respectively. Results are shown in Table 5.

As shown in Table 5, the single-factor index and comprehensive index of reed leaves in a distance of 0 and 60 m are all close to 1, suggesting no apparent pollution; but the single-factor indexes of Hg, Cd and Pb in 0 m-distance reed stems are all larger than 1, suggesting light pollution; as to reed roots, the single-factor index of As, Hg and Cd is 1.7, 1.4 and 2.0, respectively, suggesting light pollution. In general, reeds are subjected to heavier pollution in a distance of 0 m than in a distance of 60 m.

As to sorghum grains, light pollution occurs in 0 and 60 m distances; but concentrations of Hg, Cd and Pb are higher in 0-m-distance sorghum stems, the single-factor index is 3.3, 2.5 and 2.5, respectively, suggesting moderate pollution; the pollution index for Hg in 0-m-distance sorghum roots is 5, indicating heavy pollution.

According to the comprehensive pollution index, reeds have not been affected by the waste dump, but sorghums have been subjected to heavier pollution.

As to sorghum grains, the present study uses the hygiene standard of food and vegetable (Vegetable Hygiene Standard- GB4788-1994, P.R. China 1994; Food Hygiene Standard- GB2715-1996, P.R. China 1996) to assess (Table 6). Results are shown in Table 7.

Results show that pollutants in sorghum grains far exceed the hygiene standard of food (Food Hygiene Standard- GB2715-1996, P.R. China 1996), the comprehensive pollution indexes exceed by 238.80 and 192.92 times, respectively (Table 7). Hg exceeds the standard by 1,000 and 650 times, respectively, while Cd exceeds the standard by 170 and 275 times.

Influence of fine coal ash dump on plants

Watermelon and sweet-melon were directly growing near the Mentougou fine-coal-ash dump site where soil has been mixed with coal ash. The leaves, rattans and fruit of watermelon and sweet-melon were collected for analysis by specialized laboratories, and samples in a distance of 1000 m to the dump site were taken as the

Table 4 Pollutant concentrations of plant in the Shaziying domestic waste dump (μg/g)

Plant type and part	As	Hg	Cd	Pb	F	As	Hg	Cd	Pb	F	As	Hg	Cd	Pb	F
Reed															
Leaf	1.5	62	15	7.4	73	2.4	65	147	8.9	98	2.5	69	137	9.0	98
Stem	0.6	33	46	2.0	28	0.7	21	26	2.4	45	1.0	23	29	1.4	55
Root	0.9	18	117	0.7	21	0.5	11	60	0.9	22	0.5	12	61	0.7	23
Sorghum															
Grain	0.5	20	34	1.1	22	0.5	13	55	2.9	37	0.5	17	32	1.2	35
Stem	0.5	13	52	1.4	26	0.5	33	37	0.5	28	0.5	4.2	21	0.5	40
Root	1.8	37	14	4.6	40	0.9	14	136	2.2	35	1.7	8.4	96	2.8	51
Distance (m)	0					60					200				

Table 5 Influences of the Shaziying domestic waste on plant

Plants and their parts	As	Hg	Cd	Pb	F	Comprehensive index	As	Hg	Cd	Pb	F	Comprehensive index
Reed												
Leaf	0.6	0.9	0.1	0.8	0.8	0.6	1.0	0.9	1.1	1.0	1.0	1.0
Stem	0.6	1.4	1.7	1.4	0.5	1.1	0.7	0.9	0.9	1.0	0.8	0.9
Root	1.7	1.4	2	1	0.9	1.2	1.0	0.9	1.0	1.3	1.0	1.0
Sorghum												
Grain	1.0	1.1	1.1	0.9	0.6	0.9	1.0	0.8	1.7	1.7	1.1	1.3
Stem	1.0	3.3	2.5	2.5	0.7	2.0	1.0	10	1.7	1.0	0.7	2.9
Root	1.1	5	0.4	1.7	0.8	1.8	0.5	1.7	1.4	0.6	0.7	1.0
Distance	0 m						60 m					

Table 6 Hygiene standard of food and vegetable (μg/g)

Element	As	Hg	Cd	Pb	F
Vegetable	0.2	0.01	0.2	0.3	1
Food	0.7	0.02	0.2	<1	1

Table 7 Evaluation results on sorghum grains using the hygiene standard of food

Element	As	Hg	Cd	Pb	F	Comprehensive index	Distance (m)
Sorghum	0.71	1,000	170	1.1	22	238.80	0
Sorghum	0.71	650	275	1.9	37	192.92	60

relative-background-value sample. Data are compiled in Table 8 and assessment results in Table 8.

The single-factor indexes for the leaves, rattans and melons of watermelon and sweet-melon all exceed 1, whereas the comprehensive indexes are in 1.6–3.8 (Table 9). This indicates that these plant parts have been all subjected to pollution.

Table 10 reports the results assessed by the hygiene standard of food and vegetable. It shows that pollutants in watermelon and sweet-melon all exceed the standard, especially, Hg and Cd are the most serious; Hg exceeds the standard in watermelon and sweet-melon by 1,700 and 1,300 times, respectively, while Cd exceeds by 120 and 140 times, respectively. The comprehensive pollution index for watermelon and sweet-melon is 369.70 and 292.90, respectively. This indicates that they have been polluted heavily and become inedible.

Remarks and conclusions

The influences of municipal wastes upon soil and plant are closely related to municipal waste type, dumping time, pollutant concentration, topography and soil property of dumping site, buried depth of groundwater, connection of waste leachate with soil solution, and plant species, etc. Some conclusions on pollutions of soil and plant by municipal waste could be drawn.

Soil pollution

1. Pollutants from municipal waste are mainly Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, total N, COD. Whereas concentrations of total Cu, total Zn, total Pb, total Mn, total Cd, total Ni, Cr^{6+}, Zn^{2+}, Kr^+, Cu^{2+}, Mg^{2+}, Ag^+ are lower, causing lighter pollution of soil.
2. Municipal wastes dumped on a plane ground could affect top clayey soil (vadose zone) that is shallow than 3 m.
3. Pollutants from the municipal wastes dumped on a plane ground could migrate horizontally a distance of over 85 m in top clayey soils (vadose zone),

Table 8 Influences of the Mentougou fine-coal-ash dump upon plant (μg/g)

Plant type and part	As	Hg	Cd	Pb	F	As	Hg	Cd	Pb	F
Watermelon										
Leaf	2.1	93	125	11.0	87	1.0	35	51	3.6	51
Rattan	1.7	32	67	4.1	51	1.2	13	26	1.1	22
Melon	0.8	17	24	1.0	21	0.4	10	12	0.5	13
Sweet-melon										
Leaf	2.0	75	151	8.6	69	0.6	25	19	3.4	29
Rattan	0.9	17	189	2.2	32	0.6	10	142	1.2	20
Melon	0.6	13	28	0.5	20	0.2	14	21	0.7	22
Distance (m)	0					1,000 (relative background value)				

Table 9 Influence of the Mentougou fine-coal-ash dump on plant

Single-factor index	As	Hg	Cd	Pb	F	Comprehensive index
Watermelon						
Leaf	2.2	2.7	2.5	3.0	1.7	2.4
Rattan	1.5	2.5	2.6	3.7	2.3	2.5
Melon	2.0	2.7	2.0	2.0	1.6	1.9
Sweet-melon						
Leaf	3.3	3.0	8.0	2.5	2.4	3.8
Rattan	1.5	2.7	1.3	2.8	1.6	1.6
Melon	6.0	0.9	1.3	0.7	0.9	2.0

Table 10 Pollutants in watermelon and sweet-melon

Element	As	Hg	Cd	Pb	F	Comprehensive index
Vegetable						
Watermelon	4	1,700	120	3.3	21	369.7
Sweet-melon	3	1,300	140	1.7	20	292.9

whereas pollutants from municipal waste dumped and buried in a sandy pit could travel a distance of over 15 m in the sandy soil (vadose zone) adjacent to the dumping site. The influence process is mainly lateral migration of leachates.

4. As to municipal waste dumped in a shallow pond, if the pond is hydraulically connected with soil water, pollutants could affect a distance of 120 m.

Plant pollution

1. Compared with relative background value, heavy metal ions As, Hg, Cd, Pb from the Shaziying municipal waste dump has caused no pollution of reed leaf but pollution of reed stems, roots and sorghum grains and stems.
2. Compared with the hygiene standard of food and vegetable, Hg, Cd, Pb and F in the sorghum grains neighboring the municipal waste dump site all exceed the standard, especially, the most toxic ions Hg, Cd in sorghum grains exceed the standard by 650 and 170 times, respectively.
3. Compared with the relative background value, the leaves, stems and rattans of watermelon and sweet-melon in soils near to the Mentougou fine coal ash dump site have been subjected to heavy pollution. As, Hg, Cd, Pb and F in these plant parts all normally exceed the relative background value by 2–3 times or a maximum of 6–8 times.
4. Compared with the hygiene standard of food and vegetable, As, Hg, Cd, Pb and F in the edible parts of watermelon and sweet-melon all far exceed the standard; especially, the most toxic Hg, Cd exceed the standard by 1,700 and 1,300 times in watermelon, and by 120 and 140 times in sweet-melon.
5. The present study suggests that enough attention be paid to the pollutions of plants in soils that have been polluted by domestic waste and fine coal ash.

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