App. Envi. Res. 41(2) (2019): 73-83

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer

Environmental Soil, Water, and Sediment Quality of Dong Thang Landfill in Can Tho City, Vietnam

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Article History

Submitted: 20 March 2019/ Revision received: 2 June 2019/ Accepted: 10 June 2019/ Published online: 30 July 2019

Abstract

This study is a preliminary assessment of water, soil, and bottom sediment quality at and around Dong Thang landfill in Co Do district, Can Tho city, Vietnam. Four canal water samples, one leachate sample, and three soil samples from the surrounding rice fields, two bottom sediment samples from the canals, and one bottom sediment sample from the leachate pond were examined for this purpose. The results revealed that the leachate sample contained six heavy metals (Mn, Fe, Cu, Zn, Cr, and Ni) with high electrical conductivity (EC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia (NH_4^+-N), nitrate (NO_3^--N), and phosphate (PO_4^{3-}-P) (9922.7 µS cm^{-1}, 832.00 mg L^{-1}, 3,729.08 mg L^{-1}, 743.75 mg L^{-1}, 366.27 mg L^{-1}, 6.03 mg L^{-1}, and 0.22 mg L^{-1}, respectively). Further, seven heavy metals (Zn, Cu, Mn, Cr, Ni, Pb, and Fe) were detected in the sediment of the leachate collection pond. COD, TSS, NH_4^+-N, Mn, and Fe concentrations for surface water exceeded the permissible level prescribed by the Vietnam national standard for surface water (QCVN 08-MT:2015/BTNMT). All heavy metals found in the leachate sediments were also detected in canal sediments and rice-field soil, thereby leading to the conclusion that pollutants disperse into the surrounding environment. Further, principal component analysis revealed that 91.3% of the variations in soil and sediment data could be explained by two primary components, PC1 and PC2. These components represent two sources of pollution, agricultural production and landfill activities, besides other pollution sources. The findings of this preliminary study show that water, soil, and bottom sediment in the area surrounding the landfill are contaminated with organic matter, nutrients, and heavy metals. Therefore, monitoring of the environment in the study area should be conducted to detect any pollutants, and alert local authorities and environmental managers.

Keywords: Landfill; Water quality; Dong Thang; Heavy metals; Organic pollution

Introduction

Solid waste management is a significant concern in Vietnam. The amount of solid waste generated increases rapidly with socio-economic development. Total solid waste generated nationwide is estimated to have increased from 17,682 ton d^{-1} (in 2007) to 32,000 ton d^{-1} (in 2014), which is an average annual increase of 12 percent [1]. The rate of solid waste generation varies from 0.3 to 1.2 kg $capita^{-1}$ d^{-1}, with an average value of 0.75 kg $capita^{-1}$ d^{-1} [1]. However, solid waste generation rate in the Vietnamese Mekong Delta (VMD) is only 0.61 kg $capita^{-1}$ d^{-1} and solid waste generated in the VMD is estimated at 10,675 ton d^{-1}, which is lower than values reported by the Ministry of Natural Resources and Environment (Vietnam). Solid waste in the VMD is commonly treated by landfilling. Dong Thang Landfill, in Co Do District, Can Tho City, receives about 180 ton d^{-1} of unclassified solid waste/ from nearby districts. This landfill covers an area of about 0.06 km^2, and is divided into three cells. It has four leachate collection ponds, a spare area (0.009 km^2), and two incinerators. These incinerators can burn 10 ton d^{-1} of waste, and the remaining waste (170 tons) is dumped into the landfill. Currently, solid waste is not classified, the landfill is not covered properly, and leachate is not treated appropriately.

Leachate is water that has passed through a landfill and therefore carries landfill contaminants with it. Due to rainwater and degradation of solid waste, leachate can infiltrate soil, surface water, and groundwater. Leachate contains an abundance of hazardous pollutants, including halogenated aliphatic compounds, aromatic hydrocarbons, and phenolic compounds [2], and can therefore cause complex environmental problems [2-4]. Previous study showed that leachate contains several heavy metals, depending on the composition of landfill waste [2-3]. Heavy metals in the environment around a landfill are a major threat to human and ecosystem health because such metals are stable, non-biodegradable, dispersible, and accumulative. Consequently, heavy metals could come into contact with plants, animals, and ultimately humans, through consumption of contaminated food [4-5]. Currently, little information has been reported on environmental problems at the Dong Thang Landfill, Can Tho, Vietnam. Therefore, this study aims to assess the quality of surface water, soil, and bottom sediment around Dong Thang Landfill. The study findings could provide useful information for local authorities and environmental managers on the state of the environment, especially information about the occurrence of hazardous wastes such as heavy metals, which could have unpredictable effects.

Materials and methods

1) Study site and sampling

The studied landfill is located in Dong Thang Commune, Co Do District, Can Tho City. Water, soil, and bottom sediment sampling stations are illustrated in Figure 1. This landfill primarily receives agricultural wastes and wastes from residential and urban areas.Water samples were collected from the landfill and areas surrounding it. Four water samples were collected from the canals (N1, N2, N3, and N4) surrounding the landfill as indicated in Figure 1. Landfill water sample was collected from the leachate pond (N5). Soil samples (depth of 0-20 cm) were collected from three locations (D1, D2, and D3) on the rice paddies (Figure 1). Bottom sediment samples were collected from three locations, B3 (in the leachate pond) and B1 and B2 (points along the canals where leachate leaked, overflowed or was discharged directly (Figure 1)). Soil and sediment samples were air-dried, pulverized, and sieved through a mesh of 0.5 mm. Samples were then analyzed for organic matter (OM, %), total nitrogen (TN, %), total phosphorus (TP, %), and heavy

metals (mg kg^{-1}). OM, TN, and TP analyses were conducted using the Walkley-Black dichromate wet oxidation method, the Kjeldahl method, and a colorimetric method (after samples were digested with a mixture of H_2SO_4 and $HClO_4$), respectively. For heavy metal analysis, the sieved samples (0.5 g) were digested using a microwave digester (Microwave digester, Milestone, Ethos) following the EPA3051 method, wherein 10 mL of 65% HNO_3 was added and the digester was operated at 1,000 W. Temperature was maintained at 175°C for 15.5 min and at 175°C for 10 min [6]. Heavy metal concentrations (Cd, Cr, Cu, Fe, Ni, Mn, Pb, and Zn) were determined using an atomic absorption spectrometer (AAS, Agilent, AA240). All glasswares used for heavy metal analysis were washed with 0.1 M HNO_3 for 24 h and then rinsed with distilled water. Heavy metal analyses of the samples were carried out in triplicates.

Electrical conductivity (EC, µS cm^{-1}), total suspended solids (TSS, mg L^{-1}), biochemical oxygen demand (BOD, mg L^{-1}) chemical oxygen demand (COD, mg L^{-1}), and nutrient content (NH_4^+-N, NO_3^--N, and PO_4^{3-}-P; mg L^{-1}) of the water samples were determined according to the standard methods for the examination of water and wastewater [7]. Analysis for heavy metals (Cd, Cr, Cu, Fe, Ni, Mn, Pb, and Zn; mg L^{-1}) was conducted using an AAS (Agilent, AA240).

2) Data analysis

Soil and bottom sediment quality data are reported as mean ± standard deviation (SD). The difference between the mean values of the analysis results of soil and bottom sediment samples from different sites were determined by analysis of variance (ANOVA) using IBM SPSS statistics for Windows (Version 20.0; IBM Corp., Armonk, NY, USA) at a 5% significance level.

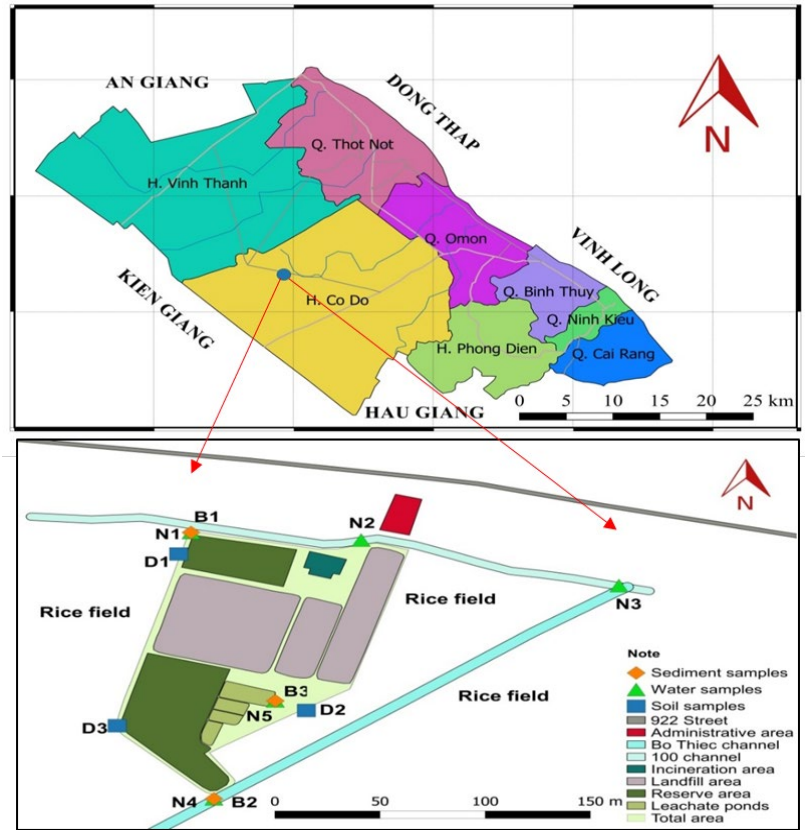

Figure 1 Surface water, bottom sediment, and soil sampling sites at the study landfill.

Principle component analysis (PCA) was extensively used in multivariate analysis to extract important information from the original dataset [8-10]. PCA reduces initial data variables that do not contribute significantly to data variation, while creating a group of new variables called principle components or primary factors (PCs or PFs). These PCs are not interconnected and appear in descending order of importance. The important factor to consider is the eigenvalue coefficient. The larger the coefficient, the greater is its contribution towards explaining variations in the original dataset. Varimax was widely used as a rotation method; each of the original data variable is associated with one component and each component represents only a small set of variables [8]. The correlation between the main components and the initial data variables were indicated by loadings [8]. In this study, PCA were performed using Primer 5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

Results and discussion

1) Characteristics of leachate and surface water

The quality of leachate and surface water samples from the canals around the landfill was assessed using EC, BOD, COD, TSS, NH_4^+-N, NO_3^--N, and PO_4^{3-}-P as parameters (Table 1).

As shown in Table 1, the EC of leachate is high (9,922.7 μS cm^{-1}), indicating the presence of several soluble ions in the leachate. However, the EC of the leachate collected from our study site is much lower than that from Phuoc Thoi Landfill (17,444.4 μS cm^{-1}), which is also located in Can Tho City. This discrepancy in EC values indicates difference in dissolved ion levels of the leachate samples due to variations in factors such as landfill age and solid waste composition. BOD and COD of the leachate were 832.0 mg L^{-1} and 3729.1 mg L^{-1}, respectively. The BOD/COD ratio of the leachate from Dong Thang Landfill was 0.2, indicating that the leachate may contain different persistent organic compounds, such as lignin, humic acid, and fulvic acid, as well as inorganic compounds [11]. A previous study reported that the BOD/COD ratio of leachate from Phuoc Thoi Landfill in Can Tho was 0.18 [12], which is close to the value determined in this study. TSS level in the leachate from Dong Thang Landfill was as high as 743.75 mg L^{-1}. The concentrations of NH_4^+-N, NO_3-N, and PO_4^{3-}-P were 366.27 mg L^{-1}, 6.03 mg L^{-1}, and 0.22 mg L^{-1}, respectively. These findings show that the leachate contains high levels of NH_4^+-N and therefore if discharged directly into the surrounding areas, would be toxic for living organisms [11].

Table 1 Characteristics of leachate from the collection pond and surface water from the canals

Parameter	Unit	N1	N2	N3	N4	N5
EC	μS cm^{-1}	214.7	192.3	148.3	125.3	9922.7
BOD	mg L^{-1}	3.04	3.58	2.51	2.05	832.00
COD	mg L^{-1}	18.1	19.2	14.1	13.6	3729.1
TSS	mg L^{-1}	12.0	26.0	34.0	33.3	743.8
NH_4^+-N	mg L^{-1}	1.72	1.12	0.87	0.44	366.27
NO_3-N	mg L^{-1}	0.139	0.142	0.244	0.506	6.031
PO_4^3-P	mg L^{-1}	0.105	0.097	0.056	0.043	0.224

Surface water quality parameters at four sites (N1, N2, N3, and N4) along the canals surrounding the landfill are presented in Table 1. It shows that EC at these sampling sites ranged from 125.3 to 214.7 μS cm^{-1}, while BOD values ranged from 2.05 mg L^{-1} to 3.58 mg L^{-1}, which are within the Vietnam national standard values (QCVN 08-MT: 2015/ BTNMT, column A1) [13]. However, COD values at the sampling sites ranged from 13.6 to 18.1 mg L^{-1}, which exceed the permissible surface water quality limit (QCVN 08-MT:2015/BTNMT, column A1) [13]. Further, BOD/COD ratios of surface water from the four sampling sites ranged from 0.15 to 0.19, indicating that the surface water samples contain persistent OM. Suspended solid content of surface water from the four sites ranged from 12 to 34 mg L^{-1}, exceeding the permissible limit (20 mg L^{-1}) with the exception of surface water from N1.

Concentrations of NH_4^+-N, ranging from 0.44 mg L^{-1} to 1.72 mg L^{-1}, were higher than the permissible limit at all sites. However, levels of NO_3^--N were within the national limits (2 mg L^{-1}), ranging between 0.14 and 0.51 mg L^{-1}. Further, unlike NH_4^+-N levels, NO_3^--N levels increased from N1 to N3, possibly due to increase in dissolved oxygen concentrations along N1 to N3. Higher levels of NH_4^+-N than NO_3^--N indicate slow oxidation due to hypoxia or absence of microbial activity. As shown in Table 1, PO_4^{3-}-P levels ranged from 0.04 mg L^{-1} (N4) to 0.11 mg L^{-1} (N1) and were within the national regulation (0.1 mg L^{-1}), except for the sample from N1, which exceeded the permissible limit slightly.

2) Heavy metal concentration in landfill leachate and canal surface water

Table 2 presents heavy metal concentrations in the leachate and canal surface water. Six out of the seven heavy metals tested (Mn, Fe, Cu, Zn, Cr, and Ni) were present in the leachate pond (N5). However, Pb was not detected in leachate samples. Among the heavy metals found in leachate, concentrations of Fe, Mn, and Cr were the highest and exceeded the national standard values, indicating risk to the surrounding environment. Zn was detected at low concentrations (0.014 to 0.019 mg L^{-1}) in surface water from both N1 and N4 as these two sites were directly affected by leachate leaching and discharge. Cu, Cr, Ni, and Pb were not present in surface water samples from N1, N2, N3, and N4. The presence of Mn, Fe, and Zn in water samples from N5, N4, and N1 indicates that heavy metals may have migrated from the leachate pond into the canals.

3) Soil quality of paddy fields surrounding the landfill

3.1) OM and nutrients in soil

OM levels in soil samples from D1, D2, and D3 were 3.68±0.04%, 5.52± 0.07%, and 3.28± 0.04%, respectively, and were significantly different ($p<0.05$). OM levels in the soil samples fall in the medium range [14]. TN content was in the range of 0.3±0.007% to 0.46±0.004%. Further, TN concentrations at the different sampling locations were statistically different ($p<0.05$), with highest and lowest concentrations recorded at D2 and D3, respectively. All these sites were classified as nitrogen rich [14]. TP levels ranged from 0.11± 0.03% to 0.14± 0.001% (classified as phosphorus rich) and variations between different sites were not significantly different ($p>0.05$) [14].

3.2) Heavy metals in paddy field soil

Heavy metal concentrations in soil of the paddy field near the landfill are reported in Table 3. Seven different heavy metals were found at the three sampling sites. Average concentrations of these heavy metals were in the order Fe < Pb < Ni < Cu < Cr < Zn < Mn.

Table 2 Heavy metal levels in leachate and canals around the landfill

Sample	Unit	Mn	Fe	Cu	Zn	Cr	Ni	Pb
N1	mg L^{-1}	0.166	0.996	ND	0.019	ND	ND	ND
N2	mg L^{-1}	0.274	1.727	ND	ND	ND	ND	ND
N3	mg L^{-1}	0.266	2.695	ND	ND	ND	ND	ND
N4	mg L^{-1}	0.097	1.414	ND	0.014	ND	ND	ND
N5	mg L^{-1}	0.425	7.238	0.075	0.292	0.365	0.089	ND

ND: Not detected

Table 3 Soil heavy metal concentrations (mg kg^{-1}) in the paddy field around the landfill

Sample	Fe	Cu	Zn	Mn	Ni	Cr	Pb
D1	2.66^{b} ± 0.08	21.57^{b} ± 1.61	72.47^{b} ± 4.95	193.67^{a} ± 12.86	19.2^{b} ± 2.86	80.93^{b} ± 2.04	4.23^{a} ± 0.66
D2	3.17^{a} ± 0.08	26.7^{a} ± 0.89	84.33^{a} ± 1.76	190.33^{a} ± 2.52	27.17^{a} ± 1.66	89.1^{a} ± 1.56	2.31^{b} ± 0
D3	2.54^{b} ± 0.09	18.43^{c} ± 0.61	63.93^{c} ± 2.14	209.33^{a} ± 19.66	13.03^{c} ± 0.76	44.77^{c} ± 1.35	2.31^{b} ± 1.16

Note: Letters a, b, c indicate significant differences at a significance level of 5%.

In this study, Mn concentrations in soil samples ranged from 190.33±2.52 to 209.33± 19.66 mg kg^{-1} (Table 3). However, in a previous study, soil Mn concentrations around the landfill ranged from 82.72 to 536.41 mg kg^{-1} [5]. Mn is the most leachable metal [15] and concentration of this heavy metal was the second highest (0.425 mg L^{-1}) in the leachate sample (Table 2), while Fe levels ranged from 2.54±0.095 to 3.17±0.076 mg kg^{-1}. Currently, Mn and Fe contents are not regulated in agricultural soil. However, presence of heavy metals may have a negative effect on soil micro flora and fauna, thereby leading to soil degradation.

Zn concentrations at the sampling sites ranged from 63.93±2.14 to 84.33±1.76 mg kg^{-1}, and were significantly different ($p<0.05$). These concentrations are within the national standard (QCVN 03-MT: 2015/BTNMT, 200 mg kg^{-1}) and the Canadian Council of Ministers of the Environment (CCME) limits [16-17]. Ni and Cr levels ranged from 13.03±0.76 to 27.17± 1.66 mg kg^{-1} and 44.77±1.35 to 89.1±1.56 mg kg^{-1}, respectively. Further, Ni and Cr levels at different sampling locations were significantly different ($p<0.05$). Ni levels remained within the limits prescribed by CCME (50 mg kg^{-1}) [17], while Cr concentrations at D1 and D2 exceeded CCME limits. Soil Cu concentration at different sampling sites were significantly different ($p<0.05$) and ranged from 18.43±0.61 to 26.70±0.89 mg kg^{-1}. Pb was detected at concentrations of 2.31±0.00 to 4.23±0.66 mg kg^{-1}. Both Cu and Pb levels were in line with relevant national regulations (QCVN 03-MT: 2015/BTNMT; 70 mg kg^{-1}) and CCME guidelines [16-17]. Although Ni, Cr, Cu, and Pb were not detected in any of the canal water samples, all four metals were detected in the soil samples, indicating that heavy metals tend to accumulate in soil.

4) Bottom sediment quality of the leachate pond and canals surrounding the landfill

4.1) OM and nutrients in bottom sediment

OM content of bottom sediments from the different sampling sites ranged from 2.64±0.04 to 16.8±2%, and varied significantly ($p<0.05$). However, TN content did not show much

fluctuations (0.28±0.004 to 1.89±0.028%). Further, the TN level of leachate pond sediment was significant higher ($p<0.05$) than that of canal sediment. TP concentrations in sediments from B1, B2, and B3 were 0.14±0.03%, 0.16± 0.004%, and 4.13±0.100%, respectively, thereby indicating accumulation of phosphorus in bottom sediment.

4.2) Heavy metals in bottom sediment

The concentrations of seven heavy metals in the bottom sediments are presented in Table 4. Mn concentrations at different sampling sites ranged from 334.33±109.92 to 337.33± 94.21 mg kg^{-1}, with statistically insignificant differences ($p>0.05$). This could be due to the high mobility of Mn. Although Mn concentration in bottom sediment is not regulated under the national standard, the presence of Mn in bottom sediment of the sampling sites at concentrations exceeding the natural level (<300 mg kg^{-1}) is indicative of environmental pollution [18].

Fe content in bottom sediment ranged from 2.30±0.08 to 3.26±0.09 mg kg^{-1}. This is in contrast with Fe concentrations in water sample from the same sampling site, indicating that Fe tends to exist in its soluble form and therefore dissolves in water. Ni concentration in the bottom sediment was in the range of 24.3±0.72 to 26.83±1.16 mg kg^{-1}, indicating moderate pollution of the sediment environment [18]. Currently, national regulations do not exist for both Fe and Ni. Zn concentration varied from 77.77±3.76 to 1197.33±41.04 mg kg^{-1}. Further, its concentration in sewage sludge (592 mg kg^{-1}) [19] was higher than that in the canals but significantly lower than that in leachate pond sediment. Concentrations of Cr in bottom sediment from B1, B2, and B3 were 67.4± 1.56, 54.73±2.08, and 82.1±1.8 mg kg^{-1}, respectively. Cr concentrations at B1 and B2 were low, while that at B3 was similar to the national standard limit (QCVN 43: 2012/ BTNMT on the limit of heavy metals concentration in freshwater sediments; 90 mg kg^{-1}) [20]. A previous study also reported Cr pollution of canal sediment [18]. Pb and Cu levels in sediment samples were in the ranges of 1.92±0.67 to 10.77±0.64 mg kg^{-1} and 21.83 ±0.23 to 402.67±8.5 mg kg^{-1}, respectively, and varied significantly ($p < 0.05$). Cu concentration in leachate pond sediment far exceeded the national limit (QCVN 43: 2012/BTNMT). These results show that heavy metals are more abundant in bottom sediment than in water.

Cr and Pb are classified as human carcinogens [5] as human exposure to even low concentrations of these metals could lead to multiple organ damage [21]. Heavy metals have little or no involvement in the process of decomposition, but they are often absorbed onto clay particles, suspended solids in water, soil, and sediment. Aquatic organisms (especially benthic animals) and plants can accumulate large amounts of heavy metals in their tissue. Heavy metals can also accumulate in humans, through the food chain, and cause toxicity. These metals have been reported to accumulate in rice, with bioaccumulation factors (BAFs) in the order: root > straw > grain [5]. Further, heavy metal accumulation in roots is more than in other parts of rice plants [22]. Therefore, the presence of Cr and Pb poses a great threat to the environment, living organisms, and humans around Dong Thang Landfill.

Table 4 Heavy metals in bottom sediment of leachate pond and canals (mg kg^{-1})

Sample	Fe	Cu	Zn	Mn	Ni	Cr	Pb
B1	2.76^{b} ± 0.17	22.7^{b} ± 0.89	79.07^{b} ± 1.33	334.33^{a} ± 109.92	24.3^{b} ± 0.72	67.4^{b} ± 1.56	3.84^{b} ± 0.66
B2	3.26^{a} ± 0.09	21.83^{b} ± 0.23	77.77^{b} ± 3.76	337.33^{a} ± 94.21	25.4^{ab} ± 0.72	54.73^{c} ± 2.08	1.92^{c} ± 0.67
B3	2.3^{c} ± 0.08	402.67^{a} ± 8.5	1157.33^{a} ± 41.04	334.33^{a} ± 112.57	26.83^{a} ± 1.16	82.1^{a} ± 1.8	10.77^{a} ± 0.64

Note: Letters a, b, c indicate significant differences at a significance level of 5%.

5) Correlation between OM, nutrient, and heavy metal contents in soil and sediment

Pearson correlation was applied to examine the relationship between OM, nutrient, and heavy metal contents in soil and sediment samples. A positive correlation means that the two variables increase or decrease simultaneously, while a negative correlation means that when one variable increases, the other variable decreases [23]. The correlation matrix of OM nutrient, and heavy metal contents in soil and sediment is shown in Table 5. If the correlation value is greater than 0.50, correlation between the two variables is significant at 5% ($p<0.05$); all such values are indicated in bold in Table 5. The correlation values clearly show that %OM, %TN, and %TP contents are strongly correlated with each other, and showed good correlation with heavy metals (Cu, Zn, Mn, and Pb). However, OM and nutrient contents were negatively correlated with Fe contents and exhibited poor correlation with Ni and Cr levels. The correlation between Cr and Ni ($r = 0.592$) is indicative of their co-occurrence at the landfill site. Further, strong correlations between heavy metals, Cu, Zn, Mn, and Pb, (Table 4) indicate that their generation sources at the study site are similar.

PCA revealed that five main components could explain all the variations (PC1, PC2, PC3, PC4, and PC5 could explain 74.60%, 16.60%, 7.20%, 1.30%, and 0.20%, respectively) in soil and sediment quality data (Table 6). The two main components PC4 and PC5, with eigenvalue coefficients of 0.13 and 0.02, respectively, could only explain a minor part of the variations in sediment and soil quality. Since the eigenvalue coefficients of PC4 and PC5 are much smaller than 1, these components can be ignored [24].

Table 5 Correlation matrix of OM, nutrient, and heavy metal contents in soil and sediment

Parameter	%TN	%TP	%OM	Fe	Cu	Zn	Mn	Ni	Cr	Pb
%N	1.000									
$\%P_2O_5$	**0.994**	1.000								
%OM	**0.996**	**0.983**	1.000							
Fe	**-0.590**	**-0.611**	**-0.574**	1.000						
Cu	**0.995**	**1.000**	**0.985**	**-0.608**	1.000					
Zn	**0.994**	**0.999**	**0.984**	**-0.606**	**1.000**	1.000				
Mn	**0.882**	**0.920**	**0.849**	-0.455	**0.916**	**0.919**	1.000			
Ni	0.388	0.368	0.405	0.352	0.374	0.377	0.465	1.000		
Cr	0.422	0.347	0.469	-0.034	0.357	0.353	0.136	**0.592**	1.000	
Pb	**0.934**	**0.941**	**0.921**	**-0.669**	**0.942**	**0.943**	**0.848**	0.304	0.428	1.000

Table 6 Principle component analysis for soil and sediment samples

Parameter	PC1	PC2	PC3	PC4	PC5
%N	**-0.364**	0.001	0.004	**-0.313**	0.005
$\%P_2O_5$	**-0.364**	0.043	-0.080	-0.152	0.076
%OM	**-0.361**	-0.026	0.056	**-0.420**	**-0.387**
Fe	0.230	**-0.526**	**-0.392**	**-0.458**	**-0.387**
Cu	**-0.364**	0.036	-0.070	-0.162	0.024
Zn	**-0.364**	0.037	-0.075	-0.152	0.034
Mn	**-0.332**	0.016	**-0.464**	**0.367**	0.282
Ni	-0.154	**-0.672**	-0.257	**0.377**	**-0.508**
Cr	-0.157	**-0.511**	**0.725**	0.027	0.237
Pb	**-0.357**	0.067	0.141	**0.407**	**0.432**
Eigenvalue	7.46	1.66	0.72	0.13	0.02
Variability (%)	74.60	16.60	7.20	1.30	0.20
Cumulative (%)	74.60	91.30	98.50	99.80	100.0

PC3, which could explain 7.20% of the variation in data, has an eigenvalue of only 0.72, which is less than 1, and should therefore be ignored. However, PC3 is useful because of the presence of Cr (classified as a carcinogen) at a loading of 0.725, which is higher than that in PC1 and PC2 (0.157 and 0.511, respectively). The presence of Cr in both PC2 and PC3 indicates that at least two significant sources of Cr exists, which may be agricultural production and landfill operations. However, landfill activities that release Cr require more careful attention. Pollution loading is high if the absolute value is >0.75, moderate if the absolute value is in the range of 0.75-0.50, and weak if absolute values are between 0.50 and 0.30 [25]. As shown before, PC1 can explain 74.6% of soil and sediment pollution in terms of OM, nutrients, and heavy metals. The relative contributions of OM, TN, TP, Cu, Mn, Zn, and Pb (with loadings in the range of 0.332 to 0.364) to variations in environmental quality of the surveyed sites are equal. PC2 could explain 16.60% of the variations in the initial data set, which are primarily attributable to Fe, Ni, and Cr, with loadings in the range of 0.511 to 0.672. For PC3 (which explains 7.20% of the change in data), Fe and Mn loading is weak (0.392-0.464) while that of Cr is moderate (0.725). PCA results showed that pollution of soil and bottom sediment by OM and heavy metals is attributable to at least two main sources (PC1 and PC2), which may be agricultural activities and landfill operation. In this case, landfill operation is likely to be the primary cause of environmental pollution because untreated leachate is discharged into the surrounding environment. Heavy metals originated mainly from landfill operation, while nutrients and OM could have originated from both agricultural activities and landfill operation.

Conclusion

The results of this study show that the tested leachate sample is highly contaminated with OM (BOD and COD), nutrients (NH_4^+-N, NO_3-N, and PO_4^{3-}-P), and heavy metals (Mn, Fe, Cu, Zn, Cr, and Ni). Further, surface water samples were contaminated with COD, TSS, NH_4^+-N, Mn, and Fe. Seven heavy metals (Zn, Cu, Mn, Cr, Ni, Pb, and Fe) were detected in sediment from the leachate collection pond. All heavy metals found in leachate sediments were also detected in canal sediments and rice field soil. Therefore, we can conclude that pollutants can disperse into the surrounding environment.

Correlation analyses revealed that concentrations of OM and nutrients in soil and bottom sediment ranged from medium to high, and correlated well with Cu, Zn, Mn, and Pb concentrations. Further, PCA showed that 91.3% of the variations in soil and sediment quality data could be explained by two principal components PC1 and PC2. These two components represent the main sources of pollution, agricultural production and landfill operation.Therefore, to prevent any ill effects on human and environmental health, the landfill should be covered properly, and the leachate should be treated appropriately before it is discharged into the surrounding media.

Conflict of interest: There is no conflict of interest.

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